

Supplementary Information

AgenticDfAM: An agentic workflow automates design for additive manufacturing through traceable adaptive assessment and multicriteria redesigns

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Supplementary Table S1. Computational benchmarks and case studies of AgenticDfAM.

Study	Evaluation	Supplementary evidence
Feature recognition on NIST geometry	Recognition and measurements against the drawing and STEP reference key	Note 1.1, Table S2
Geometric measurement verification	24 dimensions and angles against a separate STEP parser	Note 1.2, Figs. S1 and S3
Feature-based manufacturability assessment	18 features and 38 findings under the reference rule catalog	Note 1.2, Tables S3 and S4
Recognition from faceted CAD	Reconstruction of 5,038 STL triangles and recognition of 53 bracket features	Notes 2.3 and 6.4, Fig. S13
Facet and feature assessment comparison	Facet screening compared with feature-based rule checking	Note 1.3, Fig. S4, Table S5
Comparison with BRepNet	NIST face segmentation and feature recognition, with inference checked on 25 example models	Note 1.4, Table S6
Build orientation screening	Geometric assessment in six axis-aligned build directions	Note 1.5, Fig. S5
Wall-rule applicability analysis	W1 and W2 assignments across 6,000 virtual wall records at four thicknesses	Note 3.1, Fig. S7
Guideline interpretation sensitivity	Manufacturability judgments under four policies on six unchanged geometries	Note 4, Tables S9 and S11
Inter-agent communication validation	Fault injection, recovery and numerical consistency using scripted agent messages	Note 5.1, main Fig. 5a, Table S13
Geometric redesign comparison	Rule compliance and material volume in three redesign strategies	Note 6.1, Tables S14 and S15
Mechanical simulation of analytic redesigns	Predicted distortion of the original analytical artifact and three redesigns	Note 6.2, Fig. S10, Table S17
Process-informed bracket redesign	Stress, distortion and temperature in mechanical and thermal design alternatives	Notes 6.4 and 7, Tables S19 and S20
Predicted dimensional deviations	Surface-normal displacement, envelope changes, bore dimensions and flatness	Notes 6.3 and 6.4, Figs. S11 and S17
Agentic support investigation	Diagnosis and correction of a support defect, followed by four runs on one clamp	Notes 8.1 to 8.3, Tables S21 and S22

S1 Geometric benchmarks and measurement verification

S1.1 NIST additive manufacturing test artifact

Feature recognition was evaluated on the National Institute of Standards and Technology (NIST) test artifact [1], containing 271 faces. A reference key was prepared from the published drawing and STEP geometry, separately from the recognizer. Seventy-one features specified in the NIST drawing were included in the recognition benchmark: 16 pins, four vertical holes, one central bore, two central cylinders, eight lateral holes, 30 rectangular fine features and ten fine pins and holes. Eighteen further features were included in the reference key from the STEP geometry: 17 walls, gaps and thin skins in the first fine-feature set and one contact region between the base and build plate. These features were not separately specified in the drawing. Five drawing entries outside the implemented feature classes were recorded separately. Seventy of the 71 drawing features and all 18 additional reference features were recognized, giving 88 matches among 89 reference features. The central through bore, 10 mm in diameter and 17 mm long, was the only benchmark feature that was not recognized separately. Its cylindrical surface was paired with a coaxial outer surface as a 3 mm-high tube, leaving the full bore without its own feature record. No binding vertical-hole rule was assigned in this catalog, so no verdict was lost through the omission.

Agreement was obtained for all 226 compared quantities at resolutions of 0.001 mm, 0.001° and 0.001 mm², with a largest area difference of 0.0003 mm². Twenty-four additional geometric readings were recorded beyond the reference matches. These comprised 12 readings across other opposed faces of slots or bosses and 12 within the lateral holes. No violation or warning was assigned to those readings. Six wall-end classifications differed because the probe crossed the 1 mm outer skin, but the same 0.3 mm thickness limit was applied under either classification. A many-to-many correspondence was used for faces and features, so precision and F1 were not inferred from these counts. Reference entries and verdicts are shown in Supplementary Table S2 and main Fig. 3.

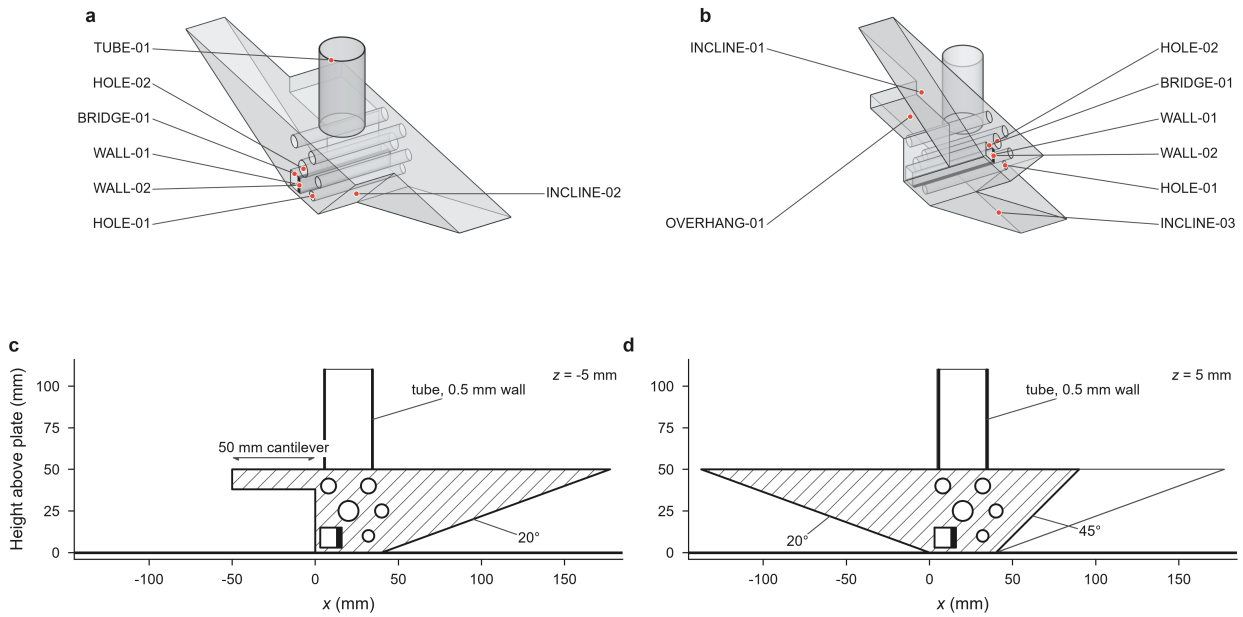
Supplementary Table S2. NIST reference correspondence. Reference counts are given as features specified in the NIST drawing and additional features identified in the STEP geometry. The 18 additional features comprise 17 walls, gaps and thin skins in the first fine-feature set and one contact region between the base and build plate. Five drawing entries outside the implemented feature classes are listed separately. V/W/P/N denote violation, warning, pass and no applicable rule. Verdicts are counted per matched reference entry. The five drawing entries outside the implemented classes were expected to produce no feature record and are included only in the final outcome-agreement column. Several findings can be issued for a feature by the complete checker, in which eight violations and seven warnings were recorded.

Group	Reference features (drawing / additional)	Reference features recognized	Verdicts V / W / P / N	Expected outcomes matched
Centre hole	1 / 0	0	not detected	0
4 mm pins	16 / 0	16	0 / 0 / 16 / 0	16
4 mm holes	4 / 0	4	0 / 0 / 0 / 4	4
Central cylinders	2 / 0	2	0 / 0 / 1 / 1	2
Lateral features	8 / 0	8	3 / 4 / 1 / 0	8
Fine features, set 1	30 / 17	47	3 / 0 / 25 / 19	47
Fine features, set 2	10 / 0	10	2 / 0 / 3 / 5	10
Base on the plate	0 / 1	1	0 / 0 / 0 / 1	1
Top surface, outer edges, staircases and ramp	5 outside feature classes	No feature record expected or returned	n/a	5
Total	71 / 18, plus 5 outside feature classes	88 of 89	8 / 4 / 46 / 30	93 of 94

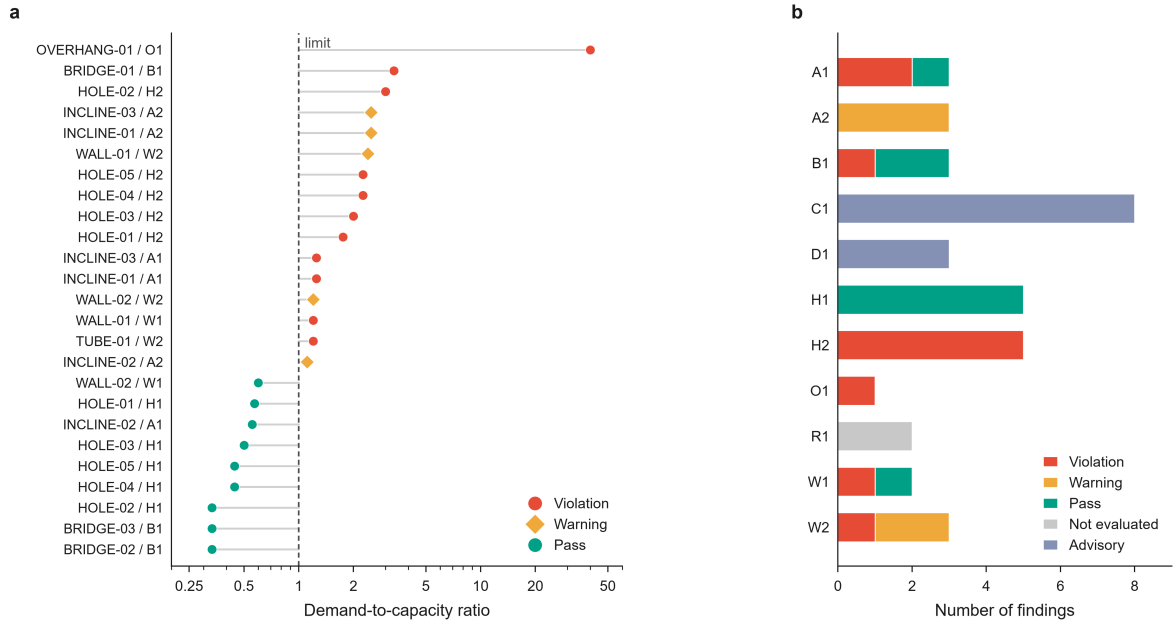
S1.2 Purpose-designed analytical artifact

A purpose-designed analytical artifact was used to test dimensions, angles and support conditions on known geometry. Holes, thin walls, narrow gaps, bridges, inclined downskins, a cantilever and a tube were included in its 40 analytic faces. Eighteen features were recognized. The envelope was $314.7 \times 110 \times 70$ mm and the volume was 411.7 cm^3 . All 24 dimensional and angular comparisons were matched to values obtained with a separate STEP-entity parser at resolutions of 0.001 mm and 0.001° . With the positive CAD Y axis used as the build direction, 38 findings were produced: 11 violations, five warnings, nine passes, 11 advisories and two unevaluated conditions. The cantilever was supported along two adjacent edges, so its governing reach was measured as 40 mm to the nearest supported edge. A reach of 50 mm would have been obtained from one edge alone. Two 1 mm slot ceilings were accepted under the strict bridge condition $b < 3$ mm. The adjacent 0.25 and 0.5 mm walls were both 12 mm high and 70 mm long, so small-wall limits and the additional large-wall warning were applied. Geometry, sections and findings are given in Supplementary Figs. S1 to S3 and Tables S3 and S4.

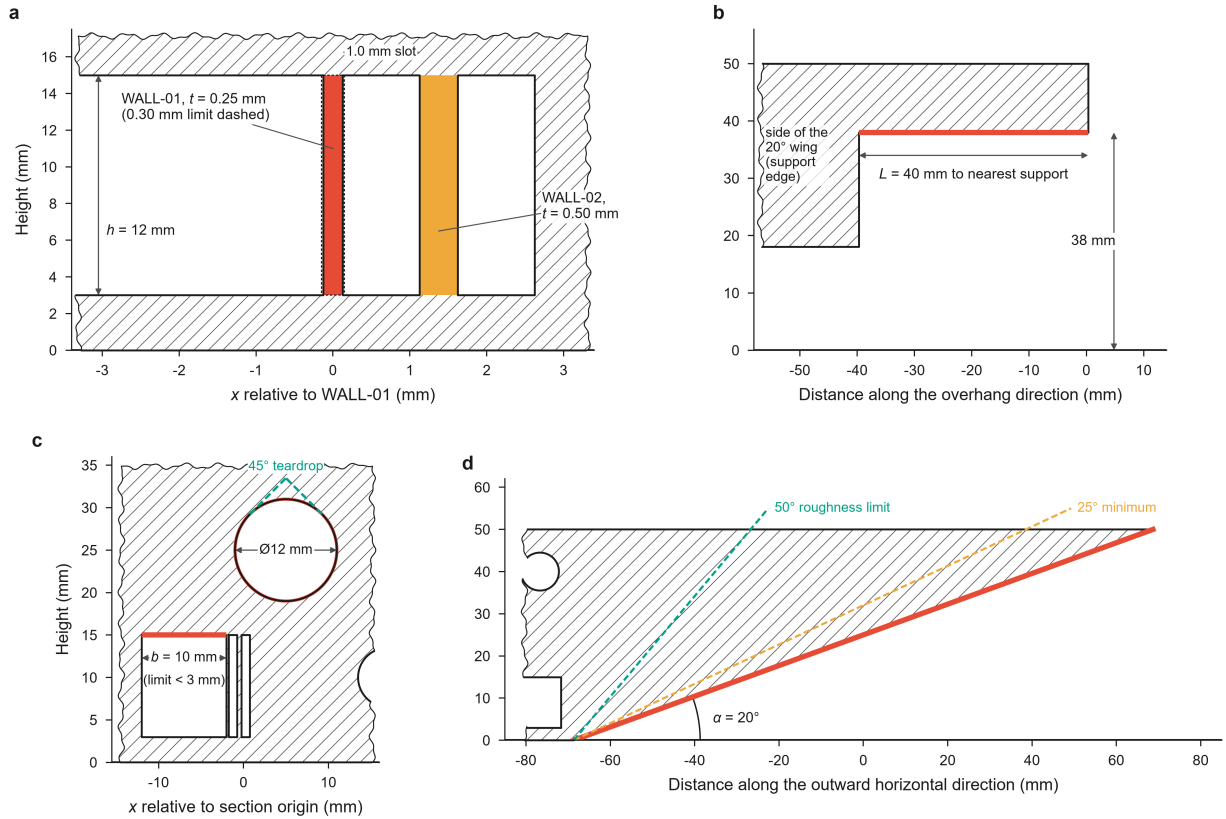
Two wall-orientation checks relative to recoater travel (R1) could not be evaluated because the recoater direction was not specified. Three advisories were issued for the two walls and the tube under the 1 mm wall-thickness guidance used for the guideline's demonstrator part (D1). Eight advisories were issued for the five holes and three bridges under the guidance on teardrop-shaped flow channels (C1). D1 and C1 were retained as recommendations rather than binding requirements (Supplementary Fig. S2b and Table S8).



Supplementary Fig. S1. Analytical test artifact. Upper and lower views locate selected features. Sections expose thin walls, slots, holes, bridges and downskins. The model contains 40 faces and 18 recognized features. Build direction is indicated by the plate and view axes.



Supplementary Fig. S2. Artifact compliance under the reference catalog. (a) Numerical demand ratios on a logarithmic scale. Each ratio orders findings within its own rule and is not a common scale of manufacturing difficulty across rules. Non-strict rules fail above one and strict rules at or above one. (b) Findings by rule and status. The complete check contains 11 violations, five warnings, nine passes, 11 advisories and two unevaluated conditions.



Supplementary Fig. S3. Sections through the artifact findings. Wall/slot, bridge/hole and unsupported-surface sections expose the geometry behind the reported measurements. Hatching denotes cut material and the build direction points upward. The multi-edge cantilever reach is distinct from its one-edge projection.

Supplementary Table S3. All 18 recognized features of the analytical artifact. Angles are measured from the build plate. Face identifiers refer to the source model.

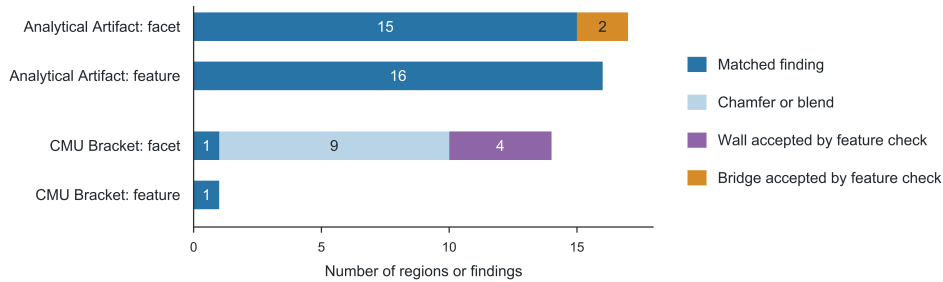
ID	Feature	Main dimensions	Angle	Faces
BASE-01	Build plate contact	40 mm $\times$ 70 mm, 2800 mm ²	On plate	10
BRIDGE-01	Channel ceiling	Span 10.0 mm, length 70 mm, clear height 12 mm	$\alpha = 0^\circ$	26
BRIDGE-02	Slot ceiling	Span 1.0 mm, length 70 mm	$\alpha = 0^\circ$	22
BRIDGE-03	Slot ceiling	Span 1.0 mm, length 70 mm	$\alpha = 0^\circ$	29
GAP-01	Slot	Width 1.0 mm, depth 12 mm, length 70 mm	Vertical	19, 21
GAP-02	Slot	Width 1.0 mm, depth 12 mm, length 70 mm	Vertical	28, 30
HOLE-01	Horizontal hole	$\varnothing 7$ mm $\times$ 70 mm, ligament 6.50 mm	Axis 0°	5, 16
HOLE-02	Horizontal hole	$\varnothing 12$ mm $\times$ 70 mm, ligament 4.87 mm	Axis 0°	6, 15
HOLE-03	Horizontal hole	$\varnothing 8$ mm $\times$ 70 mm, ligament 8.50 mm	Axis 0°	4, 17
HOLE-04	Horizontal hole	$\varnothing 9$ mm $\times$ 70 mm, ligament 3.75 mm	Axis 0°	7, 14
HOLE-05	Horizontal hole	$\varnothing 9$ mm $\times$ 70 mm, ligament 5.50 mm	Axis 0°	3, 18
INCLINE-01	Wing underside	Slope 146.2 mm, width 30 mm, reach 137.4 mm	$\alpha = 20.0^\circ$	13
INCLINE-02	Wing underside	Slope 70.7 mm, width 30 mm, reach 50.0 mm	$\alpha = 45.0^\circ$	11
INCLINE-03	Wing underside	Slope 146.2 mm, width 40 mm, reach 137.4 mm	$\alpha = 20.0^\circ$	33
OVERHANG-01	Cantilever underside	Governing reach L = 40.0 mm, one-edge projection 50.0 mm, 38 mm above the plate	$\alpha = 0^\circ$	35
TUBE-01	Thin-walled tube	$\varnothing 31$ mm and $\varnothing 30$ mm, wall 0.50 mm, height 60 mm	Axis 90°	1, 2, 37, 38, 39
WALL-01	Thin wall	t = 0.25 mm, h = 12 mm, length 70 mm	90°	19, 25
WALL-02	Thin wall	t = 0.50 mm, h = 12 mm, length 70 mm	90°	21, 30

Supplementary Table S4. Artifact violations and warnings. Grouped rows contain multiple features. Corrective operator families are given in Table S14. D is defined in equation (1).

Feature	Rule	Measured	Limit	D	Status
OVERHANG-01	O1	40.0 mm	≤ 1.0 mm	40.0	Violation
BRIDGE-01	B1	10.0 mm	< 3.0 mm	3.33	Violation
HOLE-02	H2	12 mm	≤ 4 mm	3.00	Violation
HOLE-04, HOLE-05	H2	9 mm	≤ 4 mm unsupported	2.25	Violation
HOLE-03	H2	8 mm	≤ 4 mm unsupported	2.00	Violation
HOLE-01	H2	7 mm	≤ 4 mm unsupported	1.75	Violation
INCLINE-01, INCLINE-03	A1	20.0°	$\geq 25^\circ$	1.25	Violation
WALL-01	W1	0.25 mm	≥ 0.30 mm	1.20	Violation
TUBE-01	W2	0.50 mm	≥ 0.60 mm	1.20	Violation
INCLINE-01, INCLINE-03	A2	20.0°	$\geq 50^\circ$	2.50	Warning
WALL-01	W2	0.25 mm	≥ 0.60 mm	2.40	Warning
WALL-02	W2	0.50 mm	≥ 0.60 mm	1.20	Warning
INCLINE-02	A2	45.0°	$\geq 50^\circ$	1.11	Warning

S1.3 Comparison of facet screening and feature-based assessment

A reimplemented facet screen was compared with the feature-based assessment on the analytical artifact and CMU bracket [2] in STL format. The bracket consists of a base, a central web with four openings and a cylindrical boss, as shown in Supplementary Fig. S13 and Supplementary Note 6.4. Facet angles and inward-ray thicknesses were used to identify connected regions, which were then matched to feature-level findings of the same concern. On the analytical artifact, 17 regions were flagged, of which 15 were matched to 16 feature-level findings. Different feature findings could be grouped within one connected facet region. The two unmatched regions were the 1 mm bridges accepted by the span rule. On the bracket, 14 regions were flagged, but only one was matched to its single feature-level warning. The 13 unmatched regions were associated with six chamfers, three blends, and four wall regions accepted or excluded under the feature policy. Unmatched regions were not classified as experimentally demonstrated false positives. The comparison was used to examine the consequences of geometric context and rule assignment (Table S5).



Supplementary Fig. S4. Facet-screen and feature-check correspondence under the same rule catalog. Stacked bars distinguish matched findings from regions accepted or excluded by the feature policy. The unmatched regions are policy differences, rather than experimentally established physical false positives. Complete counts and geometric contexts are given in Supplementary Note 1.3.

Supplementary Table S5. Facet-screen correspondence under a shared rule catalog. Unmatched regions are disagreements with the reference feature policy, not measured physical false positives.

Part	Method	Regions / findings	Matched	Unmatched	Unmatched context
analytical artifact	Facet analysis	17	15	2	Two 1.0 mm bridges
analytical artifact	Feature-based check	16	16	0	None
CMU Bracket	Facet analysis	14	1	13	6 chamfers, 3 blends, 4 on 0.5 mm walls
CMU Bracket	Feature-based check	1	1	0	None

S1.4 Comparison with BRepNet face segmentation

A pretrained BRepNet model [3] was evaluated on the same NIST artifact used in S1.1. Before the NIST artifact was evaluated, the BRepNet installation was checked using the 25 example CAD models and reference face labels distributed with the official BRepNet repository. An accuracy of 90.0% was obtained across their 2,769 labeled faces. On the NIST geometry, all 271 CAD faces were assigned a label and four of the eight Fusion 360 Gallery modeling-operation classes were used. Labels were assigned to individual CAD faces, rather than to separate hole, pin, or wall instances. The operation labels obtained for the feature groups specified in the NIST drawing are compared with AgenticDfAM recognition in Supplementary Table S6. Reference counts are given as faces / features. The group rows cover the 71 features specified in the NIST drawing and included in the benchmark. The total also includes 18 features identified from the STEP geometry but not separately specified in the drawing: 17 walls, gaps and thin skins in the first fine-feature set and one

contact region between the base and build plate. Of the 89 reference features, 88 were recognized, comprising 70 drawing features and all 18 additional features. Face counts for the listed groups sum to 220, whereas all 271 CAD faces are included in the total. Reference face counts were taken from the STEP geometry and reference feature counts from Supplementary Table S2. BRepNet counts are face assignments. ExtrudeSide and ExtrudeEnd denote side and end faces assigned to an extrusion operation. CutSide and CutEnd denote side and end faces assigned to a cutting operation. Times were obtained on the same workstation, from a single run for BRepNet and as means of three runs for AgenticDfAM. Different outputs and timing boundaries were used, so recognition accuracy and speed were not ranked.

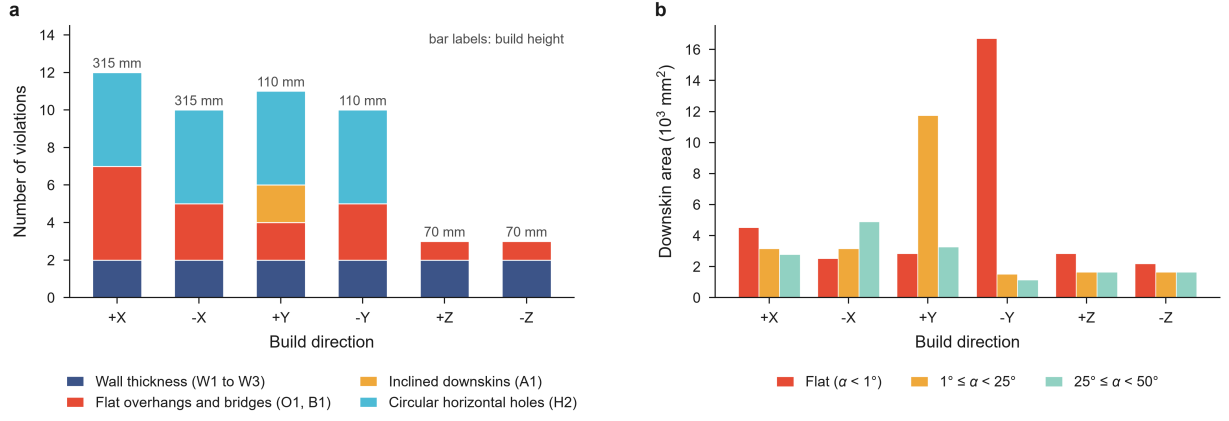
BRepNet operates on the boundary representation of faces, edges and vertices stored in a STEP file. Information is passed between neighboring faces and edges to assign one of eight Fusion 360 Gallery modeling-operation classes, such as extrude side, cut end, fillet or chamfer. These labels describe CAD construction history. Faces are not grouped into DfAM feature instances, and build direction is not represented. An equivalent feature-instance accuracy was therefore not obtained. Learned labels and kernel-derived dimensions are combined in hybrid feature-recognition work [4].

Supplementary Table S6. Reference counts, BRepNet face assignments, AgenticDfAM feature recognition and processing times on the NIST artifact.

Feature group or measure	Reference (faces / features)	BRepNet (faces)	AgenticDfAM (features)
4 mm pins	48 / 16	ExtrudeSide 32, ExtrudeEnd 16	16, vertical bars
4 mm holes	8 / 4	ExtrudeSide 8	4, vertical holes
Centre hole	2 / 1	ExtrudeSide 2	0, through bore not recognized separately. Its surface was included in a thin-walled tube.
Central cylinders	6 / 2	ExtrudeSide 4, ExtrudeEnd 2	2
Lateral features	36 / 8	CutSide 26, CutEnd 10	8
Fine features, set 1	100 / 30	ExtrudeSide 42, CutSide 38, ExtrudeEnd 10, CutEnd 10	30
Fine features, set 2	20 / 10	CutSide 10, ExtrudeSide 10	10
Artifact totals	271 / 89	271 CAD faces labeled	88, including 70 specified in the drawing and 18 additional reference features
Processing time	Not applicable	Input extraction: 4.46 s. Inference: 0.33 s. End-to-end: 9.2 s. One run.	NIST artifact, 271 CAD faces. Recognition and measurement: 7.3 s. Rule checking: 0.002 s. Mean of three runs.

S1.5 Effect of build orientation on geometric assessment

The analytical artifact was screened in all six axis-aligned build directions (Supplementary Fig. S5) using the rule checker. In the reference +Y direction, 11 violations, 110 mm height and 2,800 mm² plate contact were recorded. In +Z and -Z, three violations were recorded at 70 mm height, with contact areas of 5,561 and 6,211 mm². Ten and 12 violations were recorded for -X and +X, respectively, at approximately 315 mm height. In -Y, contact was restricted to the tube rim, with an area of 48 mm². The downward-facing area below 25° was reduced from 11,755 mm² in +Y to approximately 1,642 mm² in either Z direction. The feature-rule and geometric quantities were used for screening. The screening was limited to geometric assessment.



Supplementary Fig. S5. Six-axis orientation experiment. (a) Violations by rule and build height. (b) Downskin area by angle range, excluding plate contact. The same geometry is re-recognized and rechecked in each direction.

S2 Geometry and feature recognition

The geometric tools were developed in Python for this study. CAD models in STEP format were read as single solids by the geometric tools through OCP [5]. Faces and edges were indexed, and adjacency, analytic surface parameters and oriented normals were retained. Views and selected ray measurements were produced from triangulations. Analytic dimensions were queried from the boundary representation, with the distinction between analytic and sampled measurements retained.

The build frame and geometric measurements are defined in equations (2) to (7) of the main article. Redesign operators are defined in equations (8) to (10). Downward-facing surfaces were identified by $n \cdot b < 0$. A 1° tolerance was used for horizontal and vertical surface classification. Ray origins were offset by 10^{-4} mm to avoid self-intersection.

S2.1 Cylinders and holes

Cylindrical faces were grouped by axis, radius and convexity, with at least 359° coverage required for a complete cylinder. Radial normal direction was used to distinguish an internal bore from an external cylinder. Horizontal and vertical axes were classified at angles to the plate of at most 5° and at least 85° , respectively. Through and blind ends were distinguished by point probes 0.25 mm beyond each end.

The minimum ligament was obtained from distances to nonadjacent faces. Material was required at nine points along the connecting segment. The material above a horizontal hole was measured with a crown ray. A teardrop was identified from an incomplete bore closed by two downward-facing tangent planes, with roof angle and apex height recorded. Coaxial inner and outer cylinders with overlapping axial intervals and $0 < R_o - R_i \leq 3$ mm were examined as a tube, and wall thickness was confirmed by rays.

S2.2 Walls and unsupported surfaces

Planar face pairs were retained when their outward normals satisfied $n_i \cdot n_j < -0.99999$. A wall or gap was identified from the signed separation, $n_i \cdot (c_j - c_i)$. Candidate wall thicknesses up to 2 mm and gap widths up to 5 mm were confirmed by rays cast from a 1.5 mm grid on the smaller face, with distance agreement within 0.001 mm. Attachment was characterized with end, top and bottom probes. These values were used to control geometric recognition. Manufacturing limits were applied separately through the rule catalog.

Supported edges of a flat downskin were identified from adjacent faces extending below the region and facing the space beneath it. Only straight edges were tested. This local condition did

not establish a continuous connection to the build plate. A bridge was assigned when supported edges were opposed. For other configurations, cantilever reach was measured as the largest distance to the nearest supported edge. A downskin without a supported edge was assessed by its largest in-plane dimension. For Eq. (7), faces were sampled on a grid in their surface parameters using a nominal spacing of 1.5 mm, reduced to 0.75 mm for faces smaller than 200 mm². The grid was limited to 40 points in each parameter direction, and every triangulation vertex was additionally included. Clear height beneath a downskin was obtained from downward rays.

Sensitivity of the neighboring-face orientation filter in Eq. (5) was checked at thresholds of 0.3, 0.5, 0.7 and 0.866. Identical results were obtained on the analytic artifact in +Y at every threshold, with 11 violations, five warnings, a 40.0 mm O1 reach and a 10.0 mm B1 span. For the clamp in +Z, five O1 violations with unchanged reaches were obtained from 0.3 to 0.7. At 0.866, five O1 violations remained, but the boss surface below one lug edge, inclined 58.7° to the plate, was no longer counted as support. The 35.65 mm overhang under that lug was therefore reclassified as a flat downskin and assessed at its 40.0 mm largest dimension, while the other overhangs kept their reaches of 34.09 and 12.45 mm.

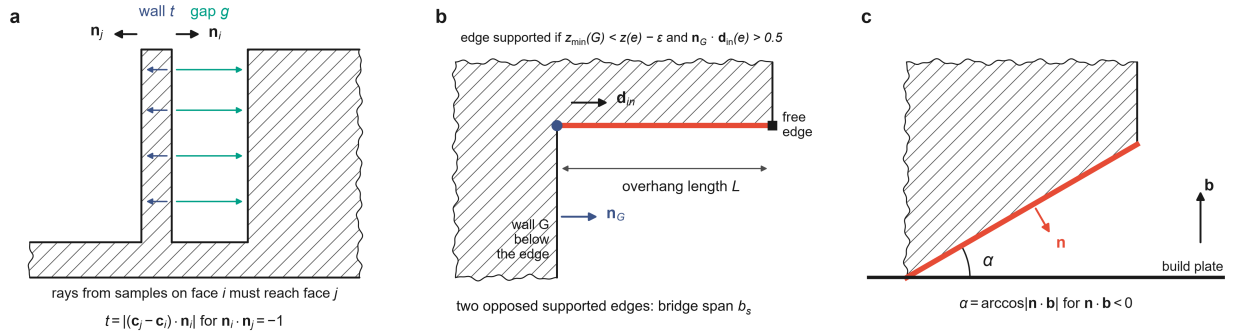
Wall limits were assigned using end support, height and length. The supported-wall class W3 was applied to walls held at both ends. For free-standing walls, a minimum thickness of 0.30 mm was specified by the small-wall rule W1 for the 15 mm-high, 10 mm-long sample. A minimum of 0.60 mm was specified by the large-wall rule W2 for the 30 mm-high, 25 mm-long sample (Supplementary Table S8). The small-wall limit was used when both dimensions lay within the small specimen. When height remained within 15 mm but length exceeded 10 mm, W1 was retained and W2 was added with warning severity. For heights above 15 mm, W2 was assigned. Extrapolation was recorded above 30 mm. A failed thickness check was retained as a violation even when the rule was extrapolated. A passing check outside the tested height was downgraded to a warning. A closed tube wall was treated as free-standing because a ring was not represented by the source samples.

The analytical-artifact walls were 12 mm high and 70 mm long. Their actual thicknesses were 0.25 and 0.50 mm. A W1 violation and W2 warning were therefore assigned to the first, while a W1 pass and W2 warning were assigned to the second. The 60 mm-high tube was assigned W2 with height extrapolation.

S2.3 Reconstruction of faceted CAD geometry

The CMU bracket in STL format was stitched into a closed solid with a tolerance of 10⁻⁴ mm. Coplanar faces were merged at 10⁻³ mm tolerance. Neighboring facets were grouped into curved regions using normal changes of 0.2 to 35°, width ratios below six and local bend radii below 30 mm. Normal consistency within 0.5°, circle-fit residuals within 0.1% of radius and appropriate angular coverage were required for cylinder candidates. Shared edges were required to follow the cylinder axis within 0.25°, with an exception provided for offset end-ring triangulations.

For a remaining curved downskin region above 10 mm², the angle was assigned from the flattest facet carrying at least 1% of its area. Planar downskin facets below 0.1 mm² were excluded. A planar chamfer was identified from a width of at most 3 mm, neighboring faces and an approximately bisecting normal. Conical end rings of at most 3 mm width and height were classified as chamfers. Cylindrical blends were classified at coverage of at most a semicircle and radius of at most 10 mm. Faceted blends were identified by radius of at most 1 mm, or by width of at most 2 mm with a surface turn of at least 30°. These details were excluded from the initial feature rules. Their manufacturability was not established by that exclusion, and independent surface checks were retained for the clamp. The measurement geometry is illustrated in Supplementary Fig. S6.



Supplementary Fig. S6. Geometric definitions. (a) Antiparallel faces and ray confirmation distinguish walls from gaps. (b) Neighboring geometry determines local edge support, with $\varepsilon = 0.05$ mm. Opposed supported edges define a bridge of span b_s , and the nearest supported edge governs cantilever reach. (c) Downskin angle is measured from the build plate for downward-facing surfaces.

S2.4 Geometric measurement capabilities and evaluation scope

Coverage of the implemented geometric assessment is summarized in Supplementary Table S7. Wall, bar, hole, tube, downskin, overhang, bridge, teardrop, recoater and advisory conditions were represented in the initial feature assessment. Empty-space operators were reported but were not benchmarked for powder removal. Lattice and freeform recognition and recoater-collision assessment were not demonstrated. Support removability was left unevaluated because its measurement operator was absent from the reported runs.

Supplementary Table S7. Coverage of the implemented geometric assessment. A catalog entry, an implemented operator and a validated measurement are distinguished.

Quantity or condition	Geometric basis	Implementation and evidence
Wall, bar, hole and tube dimensions	Analytic parameters, distances and confirmation rays	Measured on the analytic, faceted and NIST geometries
Downskin angle, bridge span, overhang reach	Normals, supported edges and sampled nearest-edge distance	Measured and exercised across orientations
Recoater angle	Wall/build-frame directions	Evaluated only with recoater direction
Powder-facing downward area	Surface/ray classification against part, support and plate	Added surface assessment.
Direct plate contact	Part faces lying on the plate	Direct contact was measured. Connectivity through support structures was not assessed by this quantity.
Unsupported surface span	Queries of separate part and support bodies	Measured on constructed and exported geometry (Supplementary Note 8.3).
Support above the intended contact surface	Sampled support points with no part intersection above	Examined through agentic investigation and code correction (Supplementary Note 8.2).
Cavities and enclosed empty space	Connectivity of empty space	Implementation described, without quantitative validation of powder removal.
Support accessibility for removal	Required tool-path reachability	Unevaluated

S3 Manufacturing criteria and agent review rules

The guideline paper was located and interpreted by the Rules Librarian and reviewed by the author. The primary catalog was prepared as an interpretation of the IN718 experiments reported by Herzog et al. [6]. Fifteen entries and ten check types, including an advisory type, were represented. Source

statements and their executable interpretations are recorded in Supplementary Table S9, and agent contracts are given in Supplementary Table S12. An identifier, feature classes, measured quantity, limit, strictness, units, severity, rationale, recommendation, source location, supporting passage and tested envelope were stored for each rule. Numerical limits and sample dimensions are reproduced in Supplementary Table S8.

Supplementary Table S8. Reference IN718 rules [6] . Published statements are distinguished from their executable interpretation in Table S9. D1 was encoded numerically as advisory demonstrator practice. C1 and L1 retain numerical source recommendations as advisory text rather than evaluated criteria.

Rule	Quantity or feature	Reference limit	Status	Tested condition or interpretation
W1	Unsupported small wall	$t \geq 0.3 \text{ mm}$	Violation	Walls 10 mm wide and 15 mm high
W2	Unsupported large wall	$t \geq 0.6 \text{ mm}$	Violation	Walls 25 mm wide and 30 mm high
W3	Supported wall	$t \geq 0.3 \text{ mm}$	Violation	Box specimen of 30 mm $\times$ 30 mm
A1	Inclined wall	$\alpha \geq 25^\circ$	Violation	Angles from 25° to 80° tested
A2	Downskin roughness	$\alpha \geq 50^\circ$	Warning	Downskin roughness rises steeply below 50°
O1	Horizontal overhang	$a \leq 1.0 \text{ mm}$	Violation	Overhangs of 0.5 to 3.0 mm tested
B1	Horizontal bridge	$b < 3.0 \text{ mm}$	Violation	Spans of 1 to 5 mm tested
P1	Unsupported bar	$d \geq 0.8 \text{ mm}$	Violation	Thinner bars tend to bend
H1	Horizontal bore hole	$D \geq 4 \text{ mm}$	Warning	Larger deviation below 4 mm
H2	Circular horizontal hole	$D \leq 4 \text{ mm}$	Violation	Support recommendation encoded as a limit for circular horizontal holes
T1	Teardrop hole	Roof angle $\geq 45^\circ$	Violation	Diameters of 5 to 15 mm tested
R1	Wall orientation	Wall angle $\geq 15^\circ$	Warning	Requires the recoater direction
D1	Demonstrator practice	$t \geq 1.0 \text{ mm}$	Advisory	Used for the demonstrator part
C1	Flow channels	Teardrop roof of at least 30°	Advisory	Flow-channel recommendation retained as advisory text
L1	Lattice struts	At least 0.4 to 0.6 mm	Advisory	Lattice recommendation retained as advisory text

Supplementary Table S9. Interpretation decisions linking source guidance [6] to executable rules. Wording is condensed. The archived catalog retains exact source passages and locations.

Rules	Statement in the guideline	Interpretation required
W1, W2	Minimum thickness of 0.3 mm for small and 0.6 mm for large free-standing walls	Classification of walls with untested dimensions and treatment beyond the specimen sizes
W3	Minimum thickness of 0.3 mm for walls held at their ends	Geometric identification of support at both wall ends
A1	Overhang angles between 25° and 80° were tested and built	Interpretation of the tested angle range as a lower limit measured from the build plate
A2	Roughness of downskins rises rapidly below 50°	Selection of a roughness threshold and its warning severity
O1	Overhang length a of at most 1.0 mm	Use of the largest distance to the nearest supported edge. Application of the single-edge overhang limit to configurations with multiple supporting edges was an interpretation.
B1	Bridge span b below 3.0 mm	Definition of the span between supports and retention of the strict inequality
P1	Bar diameter of at least 0.8 mm	Restriction to free-standing vertical bars within the tested height range
H1	Hole diameters of at least 4 mm preferred	Treatment of the preferred diameter as a warning

Rules	Statement in the guideline	Interpretation required
H2	Support always recommended for holes of 4 mm and more	Treatment of the support recommendation as a binding check for unsupported holes larger than 4 mm
T1	No support needed for a teardrop roof at 45°	Extension of the tested 45° roof angle to a minimum-angle criterion
R1	Walls at least 15° to the recoater direction	Deferral of the check when the recoater direction is unknown
D1, C1, L1	Wall thickness of the demonstrator, teardrop channels at 30° and more, lattice struts of 0.4 to 0.6 mm	Treatment of guidance outside the tested scope as advisory

Demand ratios were calculated using Eq. (1) of the main article. Verdicts were assigned from the recorded inequalities, with the ratio retained for reporting. A criterion was not met at $D > 1$ for a non-strict limit or $D \geq 1$ for a strict limit. Ratios were used for ranking within a rule, not as a common scale of manufacturing difficulty across rules. For lower limits, $D = \infty$ was returned when $x \leq 0$. A1 was restricted to inclined downskins, while flat downward-facing surfaces at $\alpha = 0^\circ$ were assessed by O1 or B1. Under the bridge policy, a span strictly below 3 mm was required. Under the reference support policy, unsupported circular holes up to and including 4 mm in diameter were allowed. Support was recommended from 4 mm in the source guideline (Supplementary Table S9), so the treatment of the boundary value was an explicit interpretation choice. The recommendation was encoded as a rule, and its severity was varied in the sensitivity analysis (Supplementary Note 4).

Six orientation, six redesign, eight support and five simulation criteria were provided in four stage-reviewer catalogs (Supplementary Table S10). The 25% support-volume warning threshold, 10% footprint allowance, 15% redesign-volume warning threshold and three-voxel resolution screen were designated as study choices. Associated concerns were informed by published studies, while the thresholds and severities were recorded separately. Under ORI-S1 and SUP-V1, support volume above 25% of part volume was assigned a warning, so an alternative could be retained with that material-use warning. An exceedance of an applicable flat-overhang limit was assigned a violation requiring rejection or correction.

Supplementary Table S10. The 25 stage-review criteria in their final interpretation. Study thresholds, process transfers and unevaluated conditions are explicit. SUP-G1 uses measured span. SUP-P1 concerns hatching, separately from wall thickness. The four SUP-T1 dimensions are tooth height, top length, base length and spacing, respectively. Severity is retained from the original catalogs. SUP-V1 and ORI-S1 use a warning threshold for material use. SUP-R1 remains unevaluated where its measurement is absent. ORI-A1 concerns the unsupported part. Its recorded scope allows a failing direction to be built with support reaching the plate.

Rule	Quantity or condition	Criterion	Severity and basis
ORI-A1	Direct part-to-plate contact	$\geq 1 \text{ mm}^2$	Violation. Support concern from Beuerlein et al. (2025) [7]. The 1 mm^2 threshold was a study choice. Direct part contact only.
ORI-S1	Support / part volume	$\leq 25\%$	Warning. Study threshold
ORI-P1	Downskin area on powder	Report	Advisory. Process concern. Angle from reference catalog
ORI-H1	Build extent	Report	Advisory. Geometric quantity
ORI-C1	Dominating alternative directions	None	Violation. Study comparison condition
ORI-R1	Wall angle to recoater	$\geq 15^\circ$	Warning. Guideline. Needs recoater direction
RED-F1	Original features removed	None	Violation. Study admissibility policy
RED-I1	Chamfers or fillets changed	None	Violation. Study admissibility policy

Rule	Quantity or condition	Criterion	Severity and basis
RED-V1	Target violations remaining	None	Violation. Recheck condition
RED-N1	New violations	Report warning	Warning. Same catalog reapplied
RED-M1	Part-volume change	$\leq 15\%$	Warning. Study threshold
RED-R1	Refusals with geometric reason	100%	Warning. Study reporting condition
SUP-N1	Unnecessary projected footprint	$\leq 10\%$	Violation. Study threshold. Not a volumetric test
SUP-A1	Support pieces without foundation	None	Violation. Connectivity condition
SUP-G1	Measured unsupported span	≤ 1 mm	Violation for flat spans. Flat-overhang limit transferred to supports. Curved-span exceedances were assessed with applicability warnings
SUP-P1	Grid hatching	0.5 to 2 mm	Warning. Tested range. Wall thickness remains 0.2 mm
SUP-T1	Contact tooth dimensions	0.4 / 0.7 / 1.0 / 0.3 mm	Warning. IN625 parameters transferred to IN718
SUP-R1	Contact reachable for removal	100% intended	Warning. Operator absent. Unevaluated
SUP-V1	Support / part volume	$\leq 25\%$	Warning. Study threshold
SUP-H1	Support height	Report	Advisory. Geometric quantity
SIM-D1	Minimum member / voxel size	≥ 3	Warning. Study resolution screen
SIM-P1	Departure from specified process	None	Violation. Reference parameter comparison
SIM-R1	Released / on-plate displacement	≤ 20	Warning. Study screening ratio
SIM-V1	Simulated / checked volume difference	$\leq 1\%$	Violation. Study consistency threshold
SIM-C1	Sample spacing recorded	Required	Warning. Study reproducibility condition

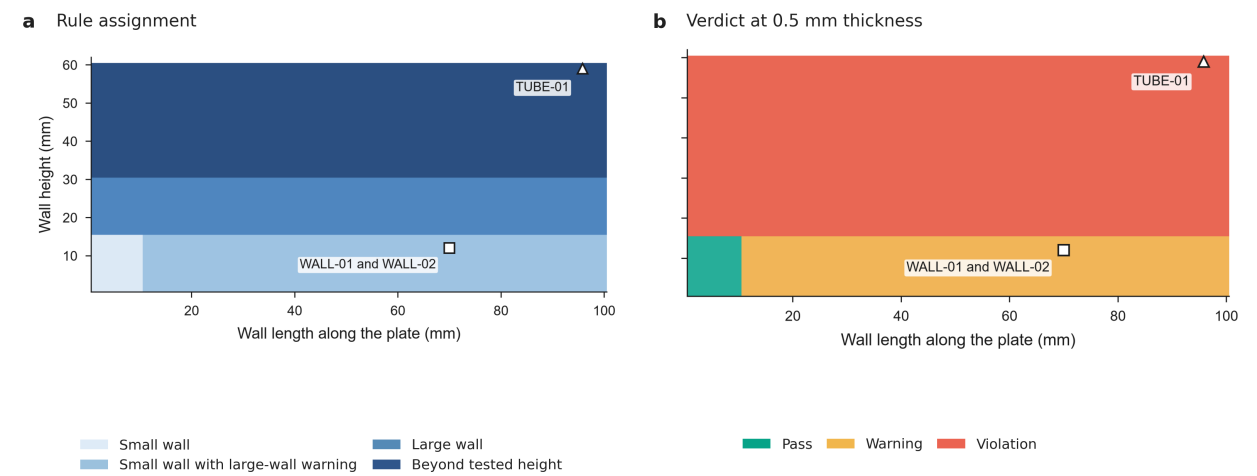
Two support measurements were distinguished. Under SUP-G1, the unsupported span was measured on the generated geometry at 0.15 mm spacing, both during construction and on the exported design. These support-grid measurements were separate from the face sampling in Eq. (7). Nominal grid spacing minus wall thickness did not describe the unsupported span on inclined or curved surfaces. Under SUP-P1, the 0.2 mm grid wall was distinguished from the hatching interval of 0.5 to 2 mm evaluated by Dimopoulos et al. [8]. The tooth parameters recommended for IN625 [9] were used as the closest found material resource to IN718. Support removal under SUP-R1 was reported as unevaluated because no measurement operator was used in the reported runs.

Direct part-to-plate contact was measured during orientation screening. Connectivity of the part to the plate through generated support structures was not established by this measurement.

S3.1 Test of wall-rule applicability

The minimum thicknesses of free-standing walls reported by Herzog et al. were established using specimens of specific heights and lengths, so the assignment of these limits to walls of other dimensions was examined. The assignment to the small-wall rule W1 and large-wall rule W2 was tested independently of geometric recognition. A set of 6,000 virtual wall records was generated from all combinations of height from 1 to 60 mm and length along the plate from 1 to 100 mm, at 1 mm intervals. Each record was evaluated at thicknesses of 0.25, 0.40, 0.50 and 0.70 mm, giving 24,000 checks. Height, length, thickness, unsupported ends and vertical orientation were passed directly to the rule checker. No CAD geometry was generated. The implemented classification policy was thereby tested without including recognition or measurement errors. W1 and W2 were assigned as specified to all 6,000 records, with boundary values assigned to the lower class (Supplementary Fig. S7a). At 0.50 mm thickness, 150 records were assigned a pass, 1,350 a warning and 4,500 a violation (Supplementary Fig. S7b). Only 150 records, or 2.5% of the set, lay within the dimensions of the tested small-wall specimen. Height extrapolation was flagged for the 3,000 records above 30

mm. A further 1,125 records were above 15 mm and up to 30 mm high and longer than the 25 mm large-wall specimen. Their excess length was not flagged, because extrapolation was recorded in height only.



Supplementary Fig. S7. Test of wall-rule applicability. (a) Assignment to wall classes and identification of height extrapolation across 6,000 height-length combinations. (b) Findings at a uniform thickness of 0.5 mm. Markers indicate the height and length of the analytical-artifact walls and tube. Panel b uses the same trial thickness for every record, irrespective of the actual thickness of a marked feature. Classification and rule scope were tested. Physical printability was not evaluated.

S4 Evaluating Sensitivity to guideline interpretation

Interpretation sensitivity was evaluated by changing the rule catalog while the geometry, recognizer and measured quantities were held fixed. Reference, strict, permissive and envelope policies are defined as predefined alternatives. Documented choices were combined within each policy, so sensitivity to those combined interpretations was evaluated, rather than the isolated effect of one choice.

Under the strict policy, the roughness trend A2, preferred hole size H1 and demonstrator wall thickness D1 were treated as binding requirements. Under the permissive policy, A2 and H1 were retained as advisories, the unsupported-hole recommendation H2 was assigned a warning, the bridge boundary value was admitted and recoater guidance was made advisory. Under the envelope policy, the large-wall thickness was applied as a violation when wall length exceeded the small specimen, instead of the reference warning.

Six geometries were assessed: the original analytical artifact, CMU bracket, NIST artifact and three analytical-artifact redesigns. V1 was prepared for envelope retention, V2 for warning treatment and V3 for material removal, as documented in S6.1. Violations and warnings are reported in Supplementary Table S11 and main Fig. 4. Between six and 17 violations were obtained for the original analytical artifact, and between six and 23 for the NIST artifact. No violation was obtained for the bracket under the reference, permissive or envelope policy, whereas three were obtained under the strict policy. V2 was retained without a violation under three policies, compared with two for V1 and V3. Sensitivity to the selected interpretations was quantified.

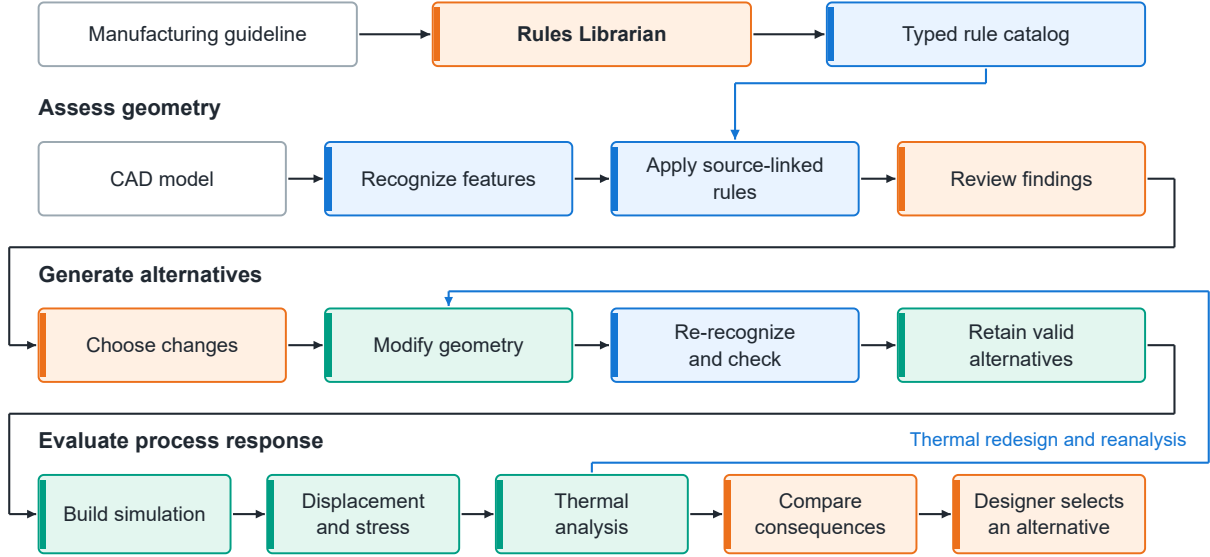
Supplementary Table S11. Interpretation sensitivity. Entries are violations / warnings on unchanged geometry. Each policy changes the documented set of interpretation choices.

Geometry	Reference	Strict	Permissive	Envelope
analytical artifact	11 / 5	17 / 2	6 / 7	13 / 3
Bracket	0 / 1	3 / 0	0 / 0	0 / 1

Geometry	Reference	Strict	Permissive	Envelope
NIST artifact	8 / 7	23 / 0	6 / 1	8 / 7
Artifact variant V1	0 / 9	9 / 3	0 / 3	2 / 7
Artifact variant V2	0 / 1	3 / 1	0 / 1	0 / 1
Artifact variant V3	0 / 9	9 / 3	0 / 3	2 / 7

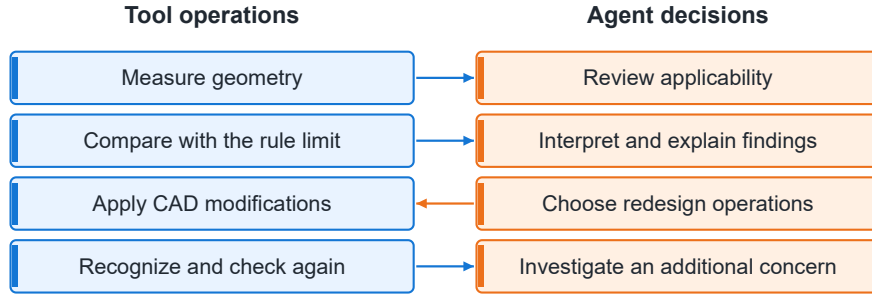
S5 Inter-agent communication and execution provenance

The inter-agent interfaces were validated for both record structure and semantic consistency. Pydantic schemas were used to enforce record structure, and semantic checks were applied to rule and geometry identifiers, required limits and units, review coverage and permitted applicability changes. Typed catalogs, feature observations, adjudicated findings and executable alternatives were submitted through the four primary interfaces (Supplementary Fig. S8).



Supplementary Fig. S8. AgenticDfAM workflow from source-linked assessment to executable redesign and process analysis. The alternative geometries are recognized and checked again before their simulated responses are compared. Thermal findings can prompt geometric revision and reanalysis. The designer selects among the alternatives. Tool measurements, source applicability and review reasons remain in the decision record. Stage reviews and the complete support workflow are shown in main Fig. 2.

Measurement, numerical comparison, and applicability interpretation were separated in the submitted records (Supplementary Fig. S9). The first two were reserved for tools. Applicability reasons were permitted for feature reclassification, support from existing geometry and a recognized design detail. An extrapolated limit could be treated as a warning, with the original measured value and reason retained. Compliance within an untested regime was not established by that warning. Valid solids were required from redesign, followed by reassessment with the same catalog.



Supplementary Fig. S9. Authority of tools and agents. Tools supply geometric measurements, numerical comparisons, CAD modifications and final rechecking. Agents select investigations, interpret applicability and propose actions. A permitted applicability change retains the measured value and demand ratio. Numerical alterations and unsupported overrides are rejected by the validation contract.

Supplementary Table S12. Agent roles, evidence access and submission contracts. The four stage-reviewer interfaces are included. During the complete clamp runs, only support-catalog review returned work. The orientation, redesign and simulation catalogs were applied after each run for reporting. The saved support designs were subsequently assessed by the Support Reviewer through geometric queries and applicability judgments. Measurements and submission checks were performed by the developed tools.

Agent	Input	Tools	Output	Checks on submission
Rules Librarian	Guideline PDF	Submit rule catalog	Typed rule catalog with sources and quotes	Schema, unique identifiers, required limits, wall classes
Feature Analyst	Part summary and candidate features	Ten geometry tools, submit feature report	Reviewed features with dimensions, angles and descriptions	Schema, unique identifiers, existing face identifiers, required measurements per kind
Compliance Reviewer	Rule catalog, features and checker findings	Ten geometry tools, get rule, evaluate rule, submit compliance review	Verdict, summary, adjudicated findings with rationale and fix, orientation advice	Schema, known identifiers, every violation and warning reviewed
Design Reviser	Rule catalog, features, violations and warnings	Ten geometry tools, get rule, preview variant, submit design variants	Two to four design variants with fixes, strategy and trade-offs	Schema, parameter ranges, one fix per feature, distinct variants, no violation left after the check
Orientation Reviewer	Orientation catalog, the measured directions and the one selected	Ten geometric queries, rendering, get rule. Uncatalogued-concern record	Verdict on the selected direction, and the changes the stage must make	Every cited rule must have been measured. Acceptance is forbidden with a retained violation. A required change must be stated when the stage is not accepted.
Redesign Reviewer	Redesign catalog, the variants produced and the refusals recorded	Ten geometric queries, rendering, get rule. Uncatalogued-concern record	Verdict on the variants and the refusals	As above
Support Reviewer	Support catalog, parameters and measurements of the exported support geometry	Ten geometric queries, rendering, get rule. Uncatalogued-concern record	Judgment on support geometry and material use, with recorded concerns	As above. Measured values may not be changed.

Agent	Input	Tools	Output	Checks on submission
Simulation Reviewer	Simulation catalog, the settings and the finished result	Ten geometric queries, rendering, get rule. Uncatalogued-concern record	Judgment on whether the simulation supports the comparison	As above

S5.1 Validation with scripted inter-agent messages

A scripted protocol test was performed on the analytical artifact described in Supplementary Note 1.2, using the IN718 guideline and geometry retained from the redesign study (main Fig. 5a). Two faults were injected at each of the four primary agent interfaces (Supplementary Table S13).

Supplementary Table S13. Faults injected in the scripted protocol test. Each invalid call or submission was returned as an error by the receiving tool or validator, and the corrected response supplied by the script was then accepted.

Agent	Injected fault	Property tested
Rules Librarian	Rule submitted with an unsupported check type	Rule definition
Rules Librarian	Rule submitted without its required limit	Rule definition
Feature Analyst	Request for a feature identifier that does not exist	Feature reference
Feature Analyst	Feature submitted with a face identifier that does not exist	Face reference
Compliance Reviewer	Request for a rule identifier that does not exist	Rule reference
Compliance Reviewer	Review submitted without one required finding	Review coverage
Design Reviser	Teardrop hole with a roof angle of 30°, outside the permitted 45° to 70°	Redesign parameter
Design Reviser	Variant submitted with the targeted overhang still violating rule O1	Retention of a targeted violation

Controls for preservation of numerical evidence were constructed using a bridge measured at 10 mm against a 3 mm limit. One message assigned a pass without a permitted applicability reason, while another substituted a span of 20 mm. After an admissible review was accepted, the original 38 checker values and demand ratios were retained when the findings were combined.

S5.2 Execution times of tools

An end-to-end duration of 30.9 s was recorded for the scripted protocol. This included tool computation, coordination and report generation, with model latency excluded by construction (main Fig. 5b). On the 40-face analytical artifact, recognition was completed in 348 ± 3 ms and rule checking in 0.26 ± 0.01 ms over ten repetitions.

S5.3 Agent execution and human involvement

A reference catalog, rule checker and redesign planner were used for the early geometric benchmarks, catalog comparisons and initial artifact redesigns. Scripted model replies were used in the S5.1 protocol controls. Mechanical and thermal redesigns of the bracket were generated by the agent from simulation feedback. The guideline was retrieved and its rules were extracted by the Rules Librarian.

The support investigation and operator correction were performed by the agent without author guidance during those steps. After local verification, the correction was reused in four autonomous clamp runs through Claude Code, from STEP input to simulated alternatives, with no human intervention during execution. Only support-catalog review returned work during the runs. The

orientation, redesign and simulation catalogs were applied once after each run and reported findings without returning work to those stages. LLM review was subsequently applied to the saved support designs by the Support Reviewer, with geometric queries and rendered views available and judgments submitted with reasons. Limits were distinguished from extrapolated guidance. Measurements, numerical comparisons, CAD operations and submission validation were performed by the developed tools.

Request budgets of 8, 40, 40 and 40 were assigned to the Rules Librarian, Feature Analyst, Compliance Reviewer and Design Reviser, respectively. Twelve requests were allowed for each stage reviewer, and three retries were allowed for stream-parsing failure. Request and fault counts in S5.1 were obtained from scripted controls.

S6 Geometric redesign and mechanical simulation

Six operator families were implemented: teardrop cuts for horizontal holes, pitched bridge roofs, ribs, downskin steepening by addition or removal, wall thickening, and tube thickening. Geometric preconditions were enforced, including roof clearance and an attachment surface continuing below the proposed lower rib-wall intersection. A valid single solid was required after each operation. Before another target was selected, the current solid was recognized again, because identifiers could be changed by Boolean operations.

S6.1 Geometric redesign strategies of analytical artifact

Three strategies were applied to the analytical artifact: the principal envelope was retained in V1, additional warnings were addressed in V2, and material was removed in V3. Operators, targets, parameters and rule relations are given in Supplementary Table S14. At least 0.5 mm clearance above roof cuts and 0.2 mm beside wall thickening were required. Feasible carrier geometry was required for downskin filling. Wall and tube changes were applied first, followed by ribs, downskins, bridge roofs and hole roofs. Recognition was repeated after each Boolean operation. Valid single solids were obtained for all three final variants and were rechecked with the reference catalog (main Fig. 6).

Supplementary Table S14. Parametric CAD operations for geometric redesign. Geometric feasibility was checked using equations (8) to (10) of the main article and the clearance and solid-validity checks in Supplementary Note 6.1.

Fix	Target feature	Parameters	Operation	Rules addressed
Teardrop hole	Circular horizontal hole	Roof angle θ	A prism was cut to form roof faces tangent to the bore and meeting above the crown.	H2, T1
Pitched roof	Horizontal bridge	Roof angle	A triangular prism was cut above the span to form a pitched roof.	B1, A1, A2
Rib	Horizontal overhang	Underside angle φ	A triangular rib was added beneath the overhang and joined to the supporting wall.	O1, A1, A2
Steepen downskin	Inclined downskin, planar or conical	Angle θ , fill or trim	Material was added below a plane or cone through the upper edge, or removed above one through the lower edge.	A1, A2
Thicken wall	Thin wall	Thickness	The face adjacent to the larger free-space region was extruded.	W1 to W3
Thicken tube	Thin-walled tube	Thickness, side	A cylindrical shell was added to the inner or outer surface.	W1 to W3

In V1, the redesigned hole and bridge roofs were inclined at 45° to the build plate, while rib undersides and downskin surfaces were inclined at 30°. Walls were thickened to exceed the applicable minimum thickness by 0.05 mm. The principal envelope was retained. In V2, 50° surfaces and 0.6 mm walls were used to address additional roughness and wall warnings. In V3, selected shallow

downskins were trimmed to 30°. Eleven, 13 and 11 individual operations were applied, with nine, one and nine warnings retained, respectively. All 11 reference violations were removed. Volumes of 526.8, 633.9 and 349.1 cm³ were obtained, compared with 411.7 cm³ initially. In V3, the length was reduced from 314.7 to 213.2 mm. Plate-contact areas of 6,354, 10,445 and 2,800 mm² were recorded. Geometry and dimensional consequences are reported in Supplementary Tables S15 and S17. Under common process settings, maximum displacement after release was predicted as 4.84 mm for the original and 3.02, 2.01 and 2.67 mm for V1 to V3.

Supplementary Table S15. Geometric and material outcomes of analytical-artifact redesign. V and W denote violation and warning counts. The principal envelope was retained in V1, additional warnings were addressed in V2, and material was removed in V3.

Design	Operations	V	W	Volume (cm ³)	Change (%)	Plate contact (mm ²)	Length (mm)
Original	0	11	5	411.7	0	2800	314.7
V1 envelope retention	11	0	9	526.8	+28.0	6354	314.7
V2 warning treatment	13	0	1	633.9	+54.0	10,445	314.7
V3 material removal	11	0	9	349.1	-15.2	2800	213.2

S6.2 Process mechanical simulations

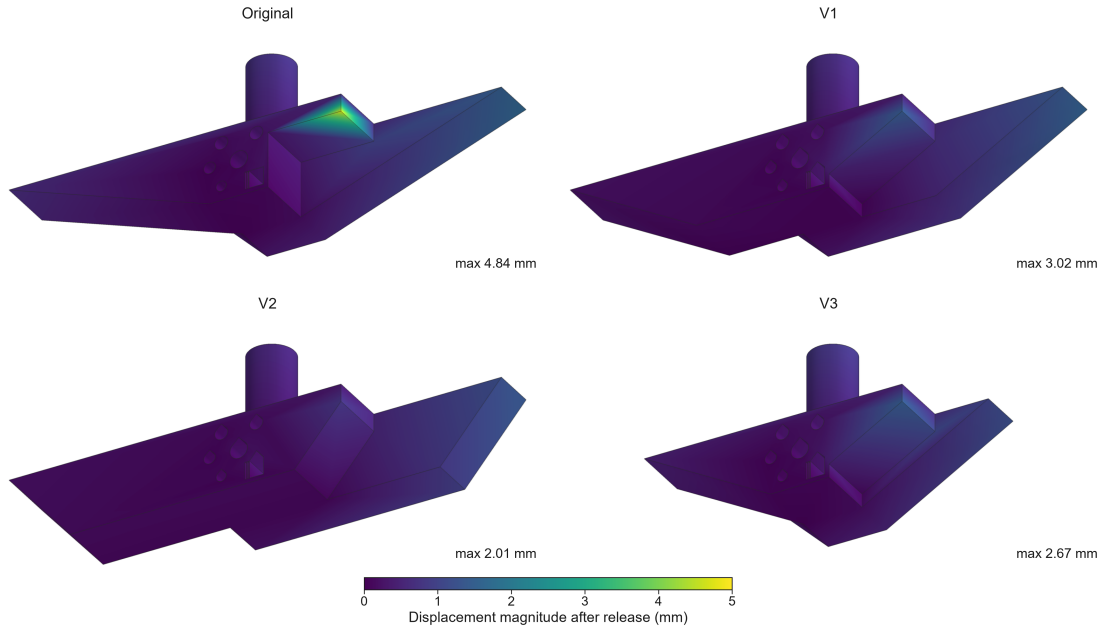
Mechanical build simulations were performed in Ansys Additive and Mechanical APDL 2025 R2 with the machine-learning thermal-strain model and layerwise elastic-plastic mechanics using bilinear isotropic hardening. IN718 process settings were taken from the guideline where specified [6], with documented defaults for beam and stripe settings (Supplementary Table S16). A generic machine definition was used for the analytical artifact because its approximately 315 mm envelope exceeded the build area of the guideline machine. Voxel sizes of 1.5, 0.5 and 1 mm were used for the analytical artifact, bracket and clamp, respectively. Thin features in the analytical artifact were represented by partially filled voxels, so their local stresses were not resolved. The clamp support wall thickness was one-fifth of the 1 mm voxel size, and clamp displacements were treated as exploratory predictions. The support correction was assessed separately on CAD geometry using volume and the fraction with no part surface above it. The settings and process parameters were determined entirely by the agent without any author intervention.

Supplementary Table S16. Mechanical and thermal simulation settings. Parameters taken from the guideline, and software defaults.

Parameter	Value	Source
Laser power	280 W	[6]
Scan speed	1000 mm/s	[6]
Hatch distance	95 µm	[6]
Deposited layer thickness	60 µm	[6]
Plate and initial powder temperature	20 °C	[6]
Beam diameter	100 µm	
Scan strategy	Stripe width, 10 mm. Initial scan angle, 57°. Rotation between layers, 67°.	
Material	IN718	Ansys Additive 2025 R2
Mechanical law	J2 plasticity, bilinear isotropic hardening	Ansys Additive 2025 R2

Parameter	Value	Source
Mechanical voxels	analytical artifact, 1.5 mm. CMU bracket, 0.5 mm. Clamp, 1 mm.	
Plate geometry	20 mm margin and 25 mm thickness	
Build plate treatment	Plate ties deactivated, 3-2-1 rigid-body constraints	
Thermal grid	1 mm voxels and 40 numerical deposition layers	
Absorptivity	Reference, 0.5. Sensitivity analyses, 0.3 and 0.7	[10]
Convection coefficient	12.5 W/(m ² K)	Model setting
Recoating time	10s per deposited layer	Thermal model setting

Release displacements were calculated by MAPDL after the final layer, deactivating plate ties and applying 3-2-1 constraints to remove rigid-body motion. Fields were read from solver result files, transformed to model coordinates and sampled on the CAD surface. Maximum displacement, the 95th percentile of absolute normal deviation, envelope change, bore dimensions and underside flatness were evaluated. For the original and V1 to V3, 140,030, 174,535, 205,639 and 119,378 elements were used, and build calculations were completed in 90, 95, 118 and 65 min. Maximum displacements of 4.63, 2.03, 0.98 and 1.98 mm were predicted on the plate, followed by 4.84, 3.02, 2.01 and 2.67 mm after release (Supplementary Fig. S10). Common settings were used for these comparisons. The simulations were not validated against manufactured specimens, and mesh convergence was not established.



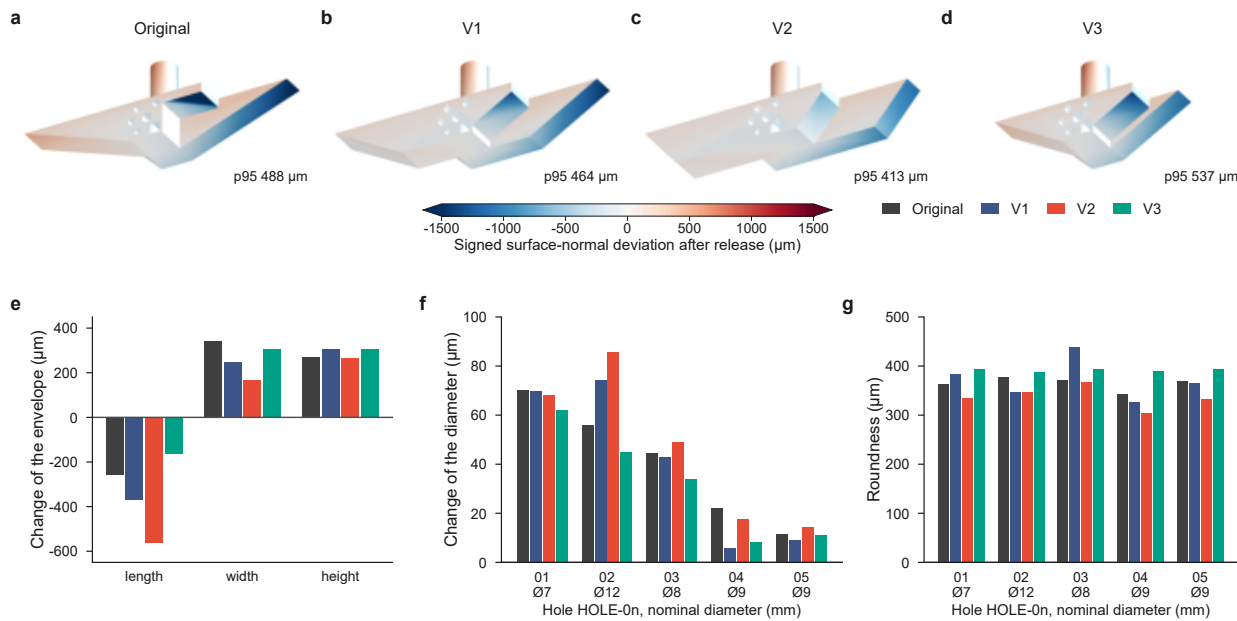
Supplementary Fig. S10. Artifact displacement fields after release from the plate. Original and V1-V3 use a shared color scale and common process settings. Results are mapped from the voxel simulation to each CAD surface.

Supplementary Table S17. Mechanical simulation and dimensional deviations of the analytical artifact and its redesigns. The dimensional deviation is the 95th percentile of absolute surface-normal deviation after release.

Design	Elements	Run time (min)	Largest displacement (mm)	Dimensional deviation, p95 (μm)	Length change (μm)	Height change (μm)
Original	140,030	90	4.63 / 4.84	488	-259	+268
V1 envelope retention	174,535	95	2.03 / 3.02	464	-368	+305
V2 warning treatment	205,639	118	0.98 / 2.01	413	-561	+267
V3 material removal	119,378	65	1.98 / 2.67	537	-162	+307

S6.3 Predicted dimensional deviations

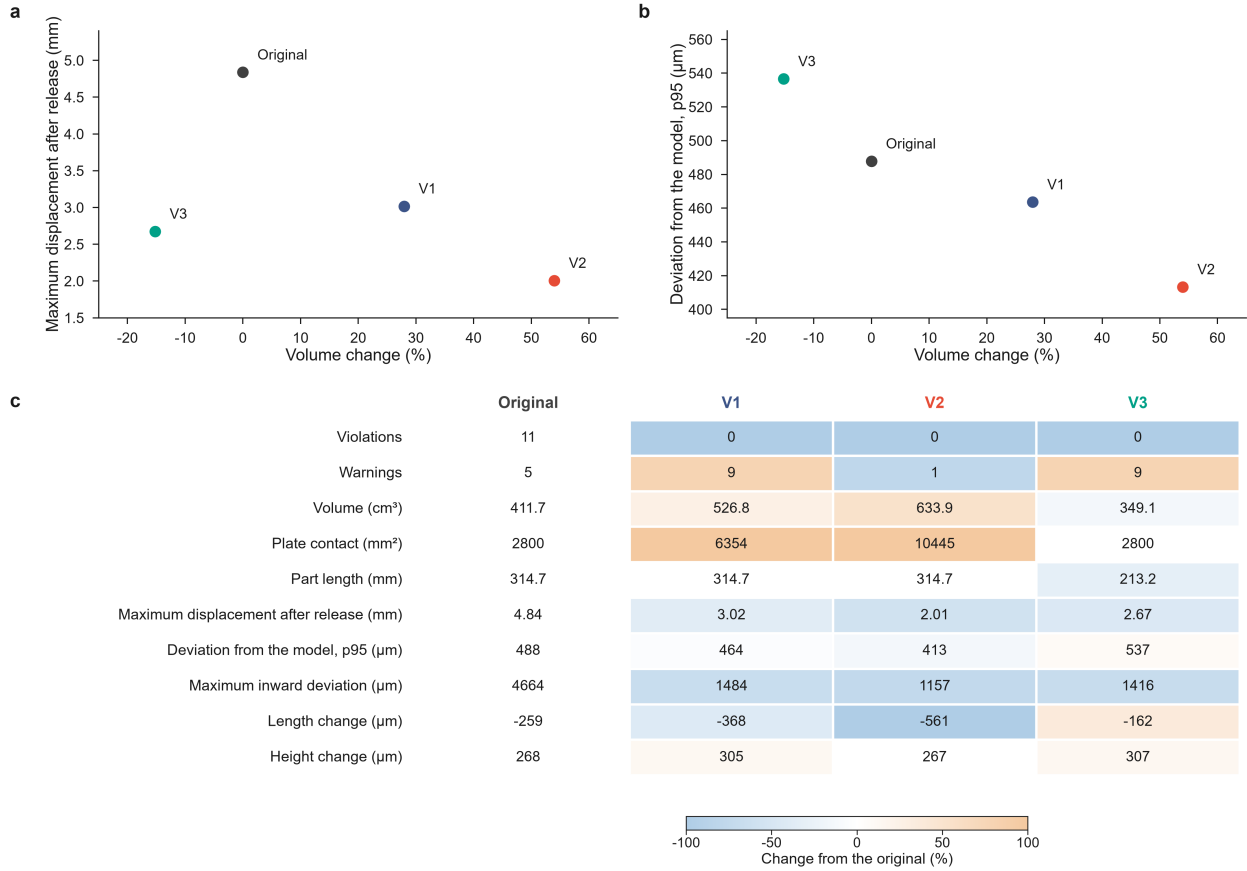
Surface-normal deviation was obtained by projecting sampled displacement onto the outward unit normal of each design's undeformed CAD surface. Absolute values were summarized by the 95th percentile and complete distributions (Supplementary Fig. S11 and main Fig. 7). Envelope changes were evaluated in model coordinates. Hole diameter and roundness were fitted to deformed bore samples. Underside flatness was obtained from the residual height range after a best-fit plane had been removed, so rigid tilt was excluded from that measure.



Supplementary Fig. S11. Predicted dimensional deviations of the analytical artifact after release. (a-d) Signed surface-normal deviation of the original design and V1 to V3, sampled on each undeformed CAD surface. Positive values denote outward displacement of the surface. A common colour scale of $\pm 1,500 \mu\text{m}$ is used, and values beyond it are shown in the end colours. The original reaches $-4,664 \mu\text{m}$, whereas the largest deviation in V1 to V3 is about 1.5 mm . The 95th percentile of the absolute deviation is given in each panel. (e) Change of the envelope in length, width and height, evaluated in model coordinates. (f) Change of the diameter and (g) roundness of the five holes, HOLE-01 to HOLE-05 (Supplementary Table S3), fitted to the deformed bore samples. Nominal diameters are given below each hole number, and bar colours identify the designs.

For the original and V1 to V3, 95th-percentile absolute normal deviations of 488, 464, 413 and 537 μm were obtained. Length changes of -259 , -368 , -561 and $-162 \mu\text{m}$ and height changes of $+268$, $+305$, $+267$ and $+307 \mu\text{m}$ were recorded (Supplementary Table S17). For the original, signed normal deviations from -4.66 to $+1.58 \text{ mm}$ were predicted. The largest deviations were

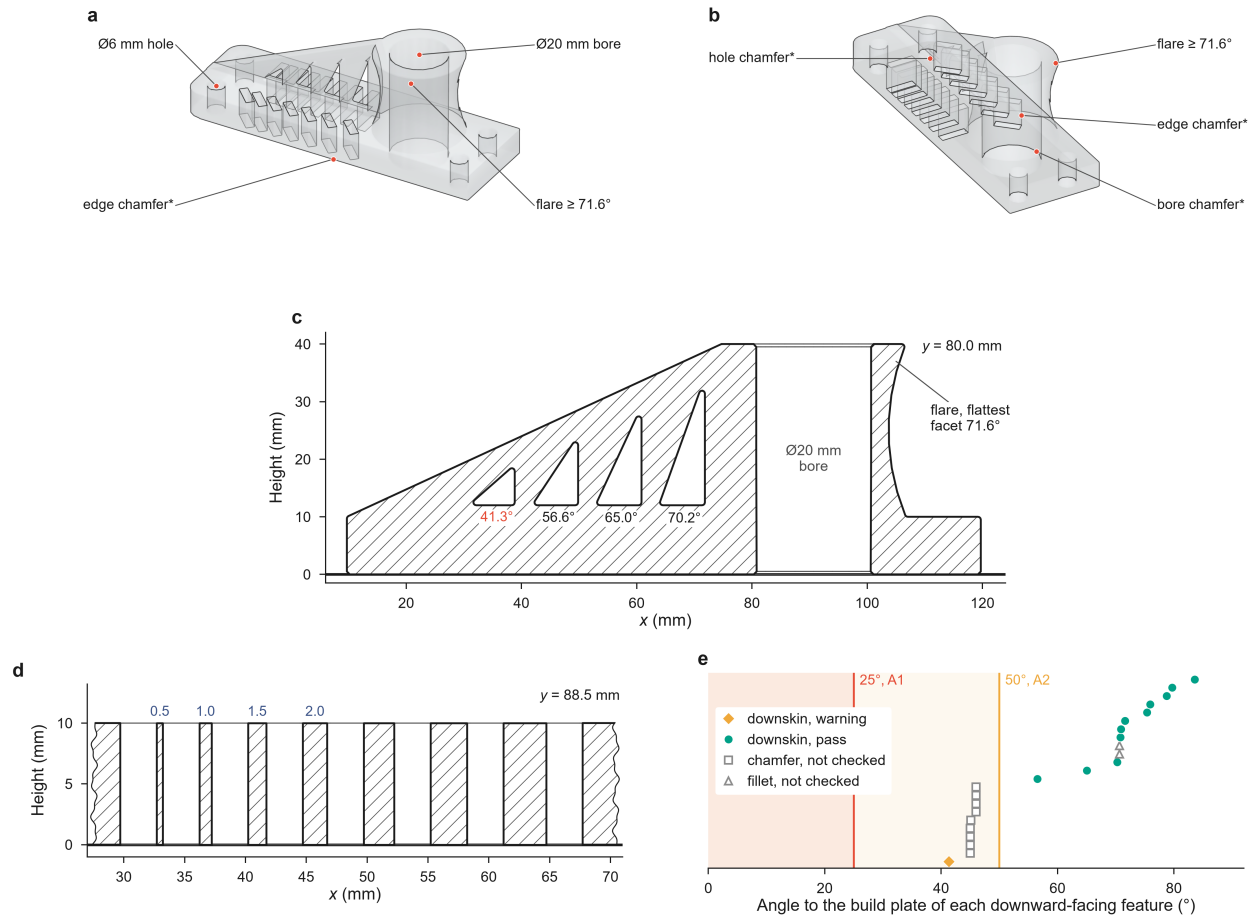
reduced to approximately 1.5 mm in the modified designs. Hole-diameter changes from 6 to 86 μm and roundness deviations from 300 to 440 μm were obtained. Maximum displacement was reduced in the material-saving V3, while its 95th-percentile normal deviation was increased. The smallest displacement was obtained in V2, with the greatest material addition. Material, contact area, length and dimensional consequences are compared in Supplementary Fig. S12.



Supplementary Fig. S12. Consequences of analytical-artifact redesign. (a,b) Volume change compared with released displacement and the 95th percentile of absolute surface-normal deviation. (c) Numerical results for the original design and V1 to V3. Cell colour encodes the signed percentage change from the original within each row and is capped at $\pm 100\%$. Colour does not designate a preferred design.

S6.4 Feature recognition and mechanical redesign of the CMU bracket

The CMU bracket was provided in STL format. It has a 110×35 mm base, 10 mm thickness, approximately 40 mm overall height, a central web with four openings and a cylindrical boss. A 20 mm bore, four 6 mm holes, 3 mm slots and walls of 0.5, 1, 1.5 and 2 mm were included. Its volume is $42,127 \text{ mm}^3$ and direct plate-contact area is $2,776 \text{ mm}^2$. After stitching and coplanar merging of 5,038 triangles, 2,172 faces were obtained, including 2,065 curved facets. From these, 292 cylindrical patches and 29 curved regions were reconstructed, and 53 features were recognized. Loading and recognition were completed in 1.8 and 13.5 s. Overhang angles of 41.3° , 56.6° , 65.0° and 70.2° were measured for the four web openings. Twelve downskin features were assessed, with one A2 roughness warning and no violation. Chamfers and blends were retained outside the initial rule catalog (Supplementary Fig. S13 and Table S18).



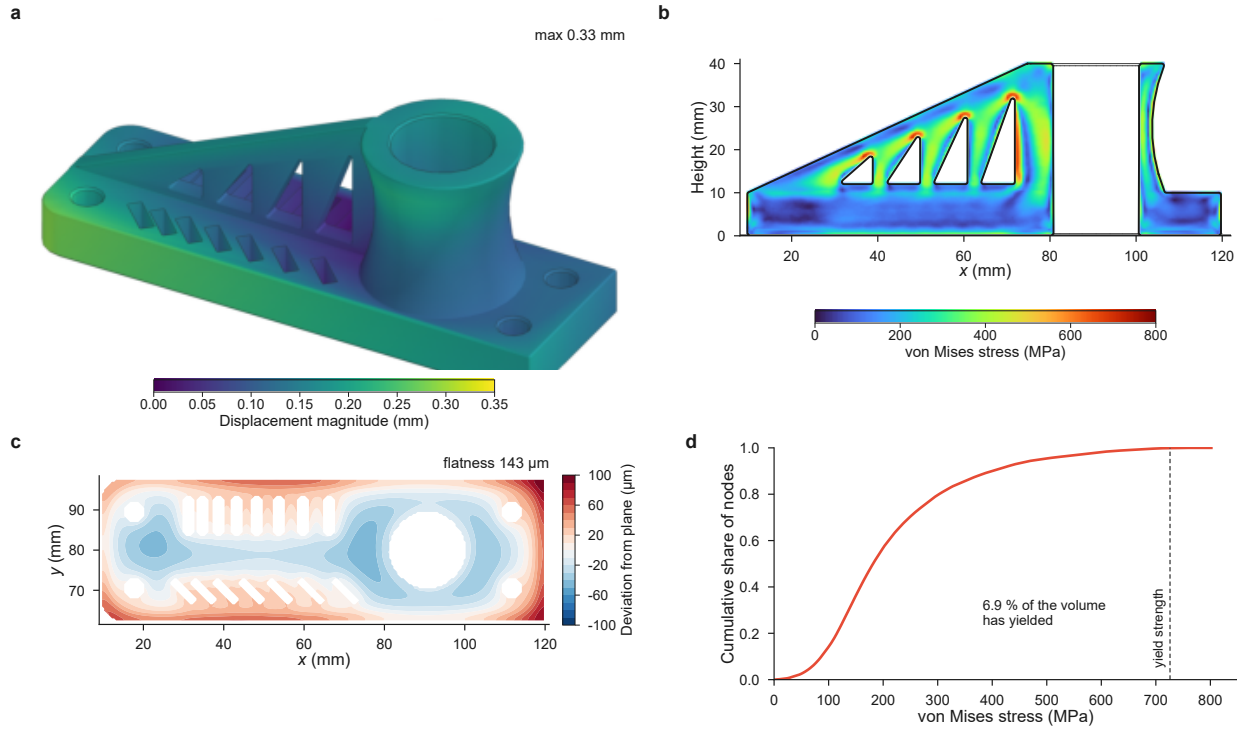
Supplementary Fig. S13. CMU bracket reconstruction and geometric assessment. (a,b) Oblique views showing the 6 mm holes, 20 mm bore, flared boss and chamfers. (c) Section through the central web and bore showing the overhang angles of the four web openings, measured from the build plate. (d) Section through the base showing wall thicknesses of 0.5, 1.0, 1.5 and 2.0 mm. (e) Inclinations of downward-facing surfaces compared with the minimum overhang angle of 25° (A1) and the roughness threshold of 50° (A2). Filled circles indicate passing downskins, the diamond indicates a roughness warning, and open markers indicate chamfers and fillets outside the rule catalog. Hatching denotes cut material, and asterisks identify details outside the reference feature rules. From 5,038 input triangles, 53 features were recognized, with no violations and one roughness warning under the reference rule catalog.

Supplementary Table S18. Bracket downskin and detail assessment. Details with no catalog rule remain outside that feature assessment.

Features	Count	Angle to the plate (°)	Area (mm ²)	Result
Opening overhangs	4	41.3, 56.6, 65.0, 70.2	24.7 to 60.2	1 warning (A2), 3 pass
Flare of the boss	1	71.6 (flattest facet)	1054	Pass
Facets between web and boss	7	70.8 to 83.6	0.2 to 3.4	Pass
Chamfers of the holes	5	45.1 and 46.0	14.0 and 45.0	Not checked
Chamfers of the plate edges	4	45.0	16.3 to 73.2	Not checked
Blends along the fourth opening	2	70.6	15.9	Not checked

The bracket was simulated with 0.5 mm voxels and 360,628 elements. The build calculation was completed in 123 min and release in 4 min. On the plate, a maximum displacement of 0.10 mm, median stress of 452 MPa and 99th-percentile stress of 728 MPa were predicted. Yielding was recorded in 6.7% of the volume. Stress concentrations were located with a 700 MPa threshold and

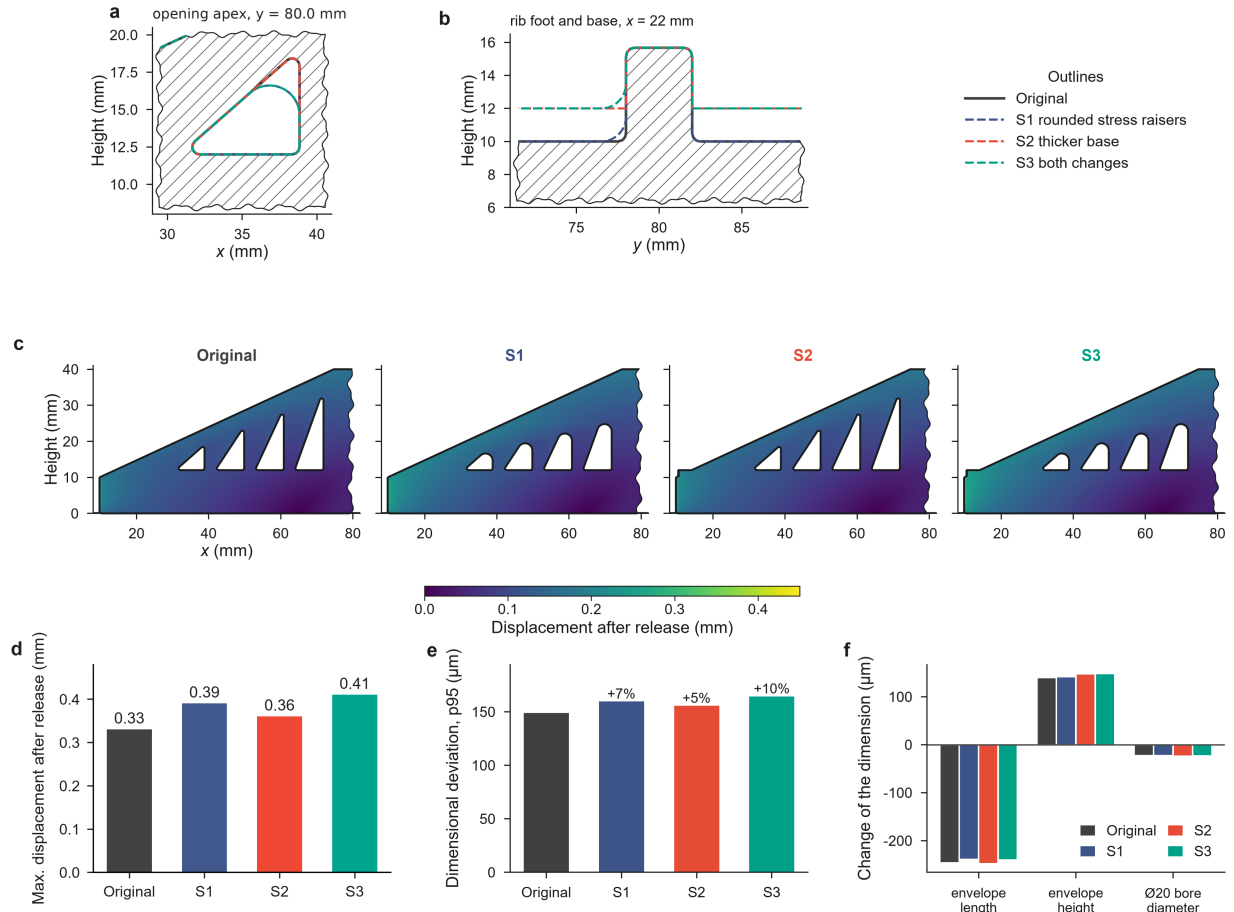
4 mm clustering. A 28,189-node region was identified near the web foot, where the web joins the base, with a peak of 787 MPa. After release, maximum displacement of 0.33 mm, median stress of 181 MPa and yielded volume of 6.9% were obtained. Maximum equivalent plastic strain of 6.87% was recorded. A 1,042-node web-foot cluster reached 773 MPa, and a 117-node underside cluster reached 802 MPa. Base tilts of 1.4 and 4.4 $\mu\text{m}/\text{mm}$ were removed before an underside flatness of 143 μm was calculated (Supplementary Fig. S14). Mesh analysis and simulation verification were not performed as they are outside the scope of this study.



Supplementary Fig. S14. Bracket stress and displacement fields after release from the plate. (a) Displacement magnitude. (b) Section through the mid-plane of the web showing von Mises stress. (c) Underside flatness after tilt removal. (d) Cumulative distribution of von Mises stress, with the yield strength and the yielded volume. Concentrations at the apexes of the web openings and the web foot motivate S1-S3 redesigns.

Three redesign alternatives were prepared from these findings (Supplementary Fig. S15). In S1, the four opening apexes were rounded with a radius of 2 mm and fillets of 1.5 mm were added on both sides of the web foot over a length of 61 mm, with 0.4% volume added. In S2, the exposed top face of the base (1,962 mm^2) was extruded by 2 mm, and the grooves along the web and around the foot of the boss were filled to the same height. The web, boss and underside were unchanged. The Boolean addition formed a single connected region between 10 and 12 mm above the plate with a volume of 4,189 mm^3 , equivalent to 9.9% of the original part. No material was removed. Both changes were combined in S3, with 10.4% added.

On the plate, the apex yielded fraction was reduced from 2.5% to 0.5% in S1 and S3. Peak apex plastic strain was reduced from 2.65% to 0.94% and 0.83%, respectively. After release, apex yielding was reduced from 5.6% to 1.6%, peak apex strain from 3.96% to 1.78% and 1.70%, and whole-part peak stress from 802 to 765 and 770 MPa. Web-foot yielded fractions of 4.8%, 8.8% and 8.2% were obtained for S1 to S3. Whole-part maximum plastic strains of 7.75% and 7.76% were obtained for S2 and S3. Local relief was therefore not equated with whole-part improvement. Maximum displacements after plate release of 0.39, 0.36 and 0.41 mm and underside flatness values of 169, 142 and 166 μm were predicted for S1 to S3, respectively. Local reductions in yielding were accompanied by greater released displacement in S1 and S3, while the thicker plate in S2 provided little change in underside flatness. Mechanical and dimensional comparisons are given in Supplementary Table S20 and Fig. S17. Thermal alternatives T1 to T4 are defined in Supplementary Note 7.

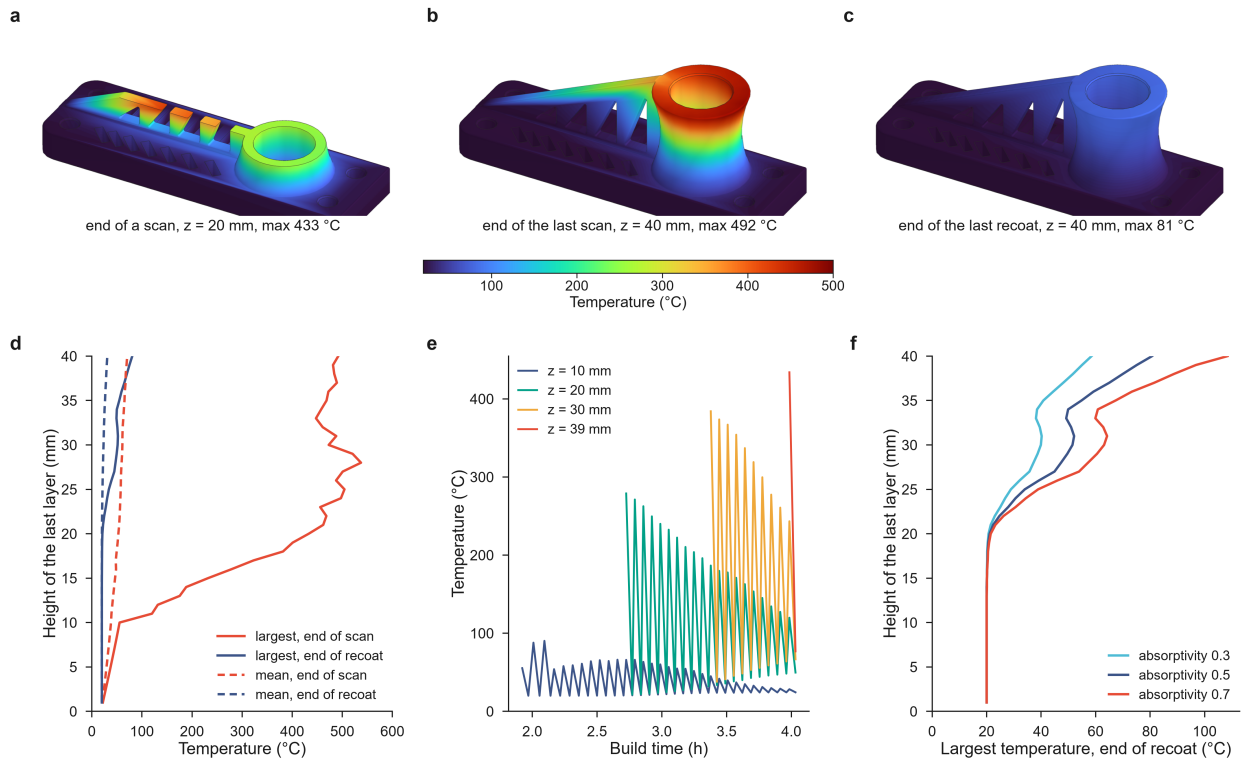


Supplementary Fig. S15. Mechanical bracket alternatives. (a,b) Sections show apex/foot rounding and plate thickening. (c-f) Released displacement, normal-deviation statistics, envelope changes and bore-diameter change. S1 and S3 relieve apex concentrations while increasing maximum released displacement. S2 changes the load path without eliminating the web-foot concentration.

S7 Thermal analysis and process-informed bracket redesign

A separate transient thermal analysis was performed by the agent in Mechanical APDL using 1 mm voxels and 40 lumped deposition layers. Approximately 17 deposited 60 μm layers were grouped in each 1 mm numerical layer. Ten seconds of recoating time were assigned per deposited layer. Absorbed power was distributed through each newly activated numerical layer during its scan time, calculated from layer area divided by scan speed and hatch distance. Approximately 4 h of physical build time were represented by 40 layers, with computation completed in 4.3 min. The plate was held at 20 $^{\circ}\text{C}$, a convection coefficient of 12.5 $\text{W}/(\text{m}^2\text{K})$ was applied, and temperature-dependent IN718 properties were taken from the software library. Absorptivity was set to 0.5 and varied to 0.3 and 0.7 in sensitivity calculations [10].

Heat accumulation was observed in the computed fields from approximately 20 mm build height. A maximum of 537 $^{\circ}\text{C}$ was predicted at 28 mm and a peak of 81 $^{\circ}\text{C}$ after the final recoat (Supplementary Fig. S16). At absorptivities of 0.3 and 0.7, last-scan peaks of 330 and 650 $^{\circ}\text{C}$ and last-recoat peaks of 58 and 108 $^{\circ}\text{C}$ were obtained. Little change was observed in the height at which accumulation began. Persistence of the geometric bottleneck was assessed through this sensitivity calculation, while the dependence of absolute temperature on absorptivity was retained.



Supplementary Fig. S16. Transient thermal response of the CMU bracket and sensitivity to absorptivity. (a) Predicted temperature field at the end of scanning at a build height of 20 mm. (b,c) Temperature fields at the end of the final scan and after the final recoating step, respectively, at a build height of 40 mm. (d) Maximum and mean part temperatures at the end of each scan and recoating step, plotted against build height. (e) Temperature histories at four points within the cross-section, at heights of 10, 20, 30 and 39 mm. (f) Maximum part temperature after each recoating step for absorptivities of 0.3, 0.5 and 0.7. Simulations were performed using a part-scale Mechanical APDL model with 40 lumped deposition layers. An absorptivity of 0.5 was used in panels a to e. The onset of heat accumulation persists near 20 mm despite changes in absolute temperature.

The thermal analysis was solved in degrees Celsius, with the build plate held at 20 °C. The peak temperature reached by each node during the build was divided by the largest peak in the part, and nodes at or above 0.90 of that maximum formed the critical zone, the most severe level of the critical zone identification of Ranjan et al. [11, 12]. The threshold therefore marks where heat accumulates relative to the rest of the part, not a temperature at which the material fails. Because the Celsius scale does not start at absolute zero, the selection depends on this unit. For the original bracket, the 537 °C peak gave a threshold of 484 °C, which was exceeded by 1% of the nodes in three clusters. The same ratio taken in kelvin would have lowered the threshold to 456 °C and selected 5.8% of the nodes. The ratio of the temperature rise above the plate gave 486 °C and 0.8%, close to the Celsius result. Connected clusters were associated with the underlying geometry. Conduction paths below each cluster were examined within columns parallel to the build direction, with the projected cluster footprint expanded by one voxel. Solid cross-sectional area was evaluated at each height along these columns. Redesign was triggered when an area below the cluster was at least 10% smaller than the area at the cluster, with a reduction of at least three voxels in the cross-section. The voxel-count threshold was used to exclude small differences caused by the discretized boundary. Both thresholds were specific to this implementation.

Below the hottest web cluster, the solid conduction area narrowed from 67 mm² at the cluster to 13 mm² at the opening floors, a reduction of 81%. Narrowing of 72% and 96% was recorded along the conduction paths beneath the boss-rim clusters. Four thermal alternatives were prepared to widen these paths. In T1, the boss waist was filled to a straight cylinder of radius 15.6 mm, with 4,301 mm³ added. In T3, that change was combined with steeper opening roofs. An intermediate

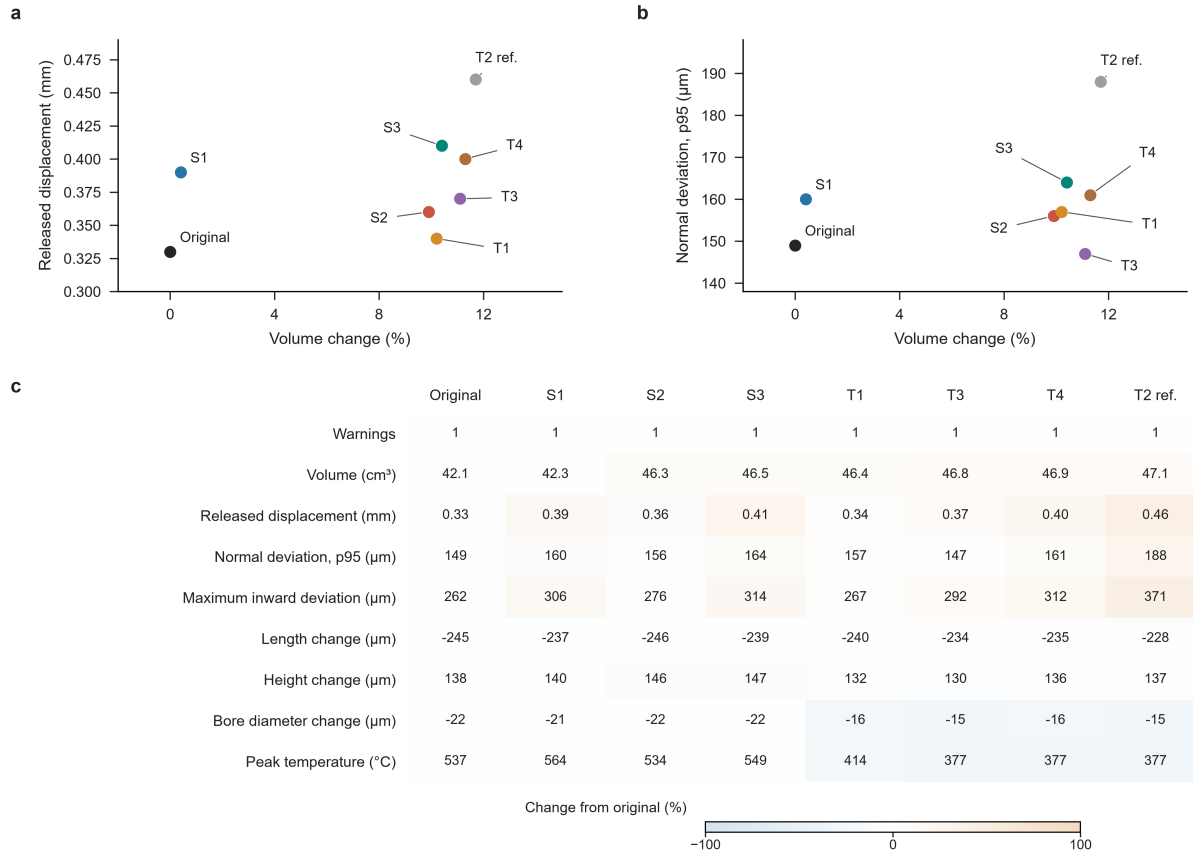
design with 75° roofs was reanalysed, and a peak of 378 °C was predicted. A concentration remained above opening 2 at 344 °C, exceeding 90% of that design's maximum. A further revision was made, with final angles of 80° for openings 3 and 4 and 60° for opening 2. A total of 4,693 mm³ was added in final T3. In T4, the boss change was combined with floors of openings 3 and 4 raised from 12 to 22 mm, with 4,783 mm³ added. In reference T2, those two openings were closed, with 4,934 mm³ added. T2 was excluded as an admissible redesign because features were removed. Changes and their rationale are given in Supplementary Table S19.

Layer-scale peaks of 537 °C for the original, 413 °C for T1 and 377 °C for T3, T4 and T2 were obtained. Released displacements of 0.33, 0.34, 0.37, 0.40 and 0.46 mm were obtained, respectively. In T3, a 160 °C peak reduction was obtained with 11.1% volume added and all four openings retained. Areas of 42, 23 and 41 mm² were retained in openings 2, 3 and 4, respectively, compared with original areas of 48, 68 and 88 mm². In T4, areas of 11 and 26 mm² were retained in openings 3 and 4, compared with 68 and 88 mm² originally. Feature retention was therefore not equated with preserved function. Thermal fields and conduction sections are shown in main Fig. 8.

Supplementary Table S19. Geometric modifications and thermal rationale for bracket redesign. The redesign rationales were informed by relevant literature retrieved online by the agent. Mechanical and dimensional outcomes are given in Supplementary Table S20, thermal peaks in Supplementary Note 7 and model settings in Supplementary Table S16.

Variant	Geometric change	Evidence and design rationale
T1	Straight boss, radius 15.6 mm	Conduction paths beneath the two boss-rim clusters were widened while the bore and openings were retained [11, 12] .
T3	T1 plus 80° overhangs at openings 3/4 and 60° at opening 2	Powder-facing overhang was reduced and the supporting rib was widened. A remaining cluster above opening 2 was identified during reanalysis of 75° overhangs [11–15].
T4	T1 plus floors of openings 3/4 raised from 12 to 22 mm	The narrow conduction section below the hot web was widened while openings, roofs and apexes were retained [11, 12].
T2 reference	T1 plus closure of openings 3/4	The largest local conduction-path increase was obtained by closing two openings. This reference was excluded as an admissible redesign because features were removed [12].

The same thermal peak was obtained in T3 and T4, but different opening geometries and released displacements were predicted (Supplementary Table S20 and Fig. S17). The steeper overhangs in T3 retained more opening area and produced less released displacement than the raised floors in T4. Selection could therefore not be based on peak temperature alone.



Supplementary Fig. S17. Consequences of bracket redesign. (a,b) Volume change against released displacement and the 95th percentile of absolute surface-normal deviation. (c) Mechanical and thermal alternatives. Thermal variants T1, T3 and T4 and the feature-removing reference T2 are defined in Note 7. Signed percentage change within each row is encoded by cell colour, capped at $\pm 100\%$. No preferred design is designated by colour.

Supplementary Table S20. Bracket mechanical and dimensional results. Displacements are reported after plate release and bore values as diameter changes. The dimensional deviation is the 95th percentile of absolute surface-normal deviation after release.

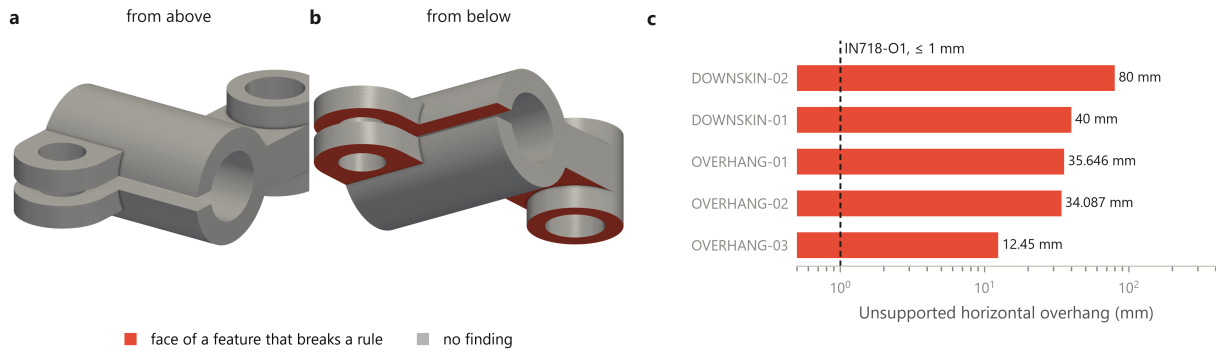
Design	Volume change (%)	Largest displacement (mm)	Dimensional deviation, p95 (μm)	Length change (μm)	Height change (μm)	Ø 20 mm bore (μm)
Original	0	0.33	149	-245	+138	-22
S1 rounded stress raisers	+0.4	0.39	160	-237	+140	-21
S2 thicker plate	+9.9	0.35	156	-246	+146	-22
S3 both changes	+10.4	0.41	164	-239	+147	-22
T1 straight boss	+10.2	0.34	157	-240	+132	-16
T3 straight boss and steeper overhangs	+11.1	0.37	147	-234	+130	-15
T4 straight boss and raised opening floors	+11.3	0.40	161	-235	+136	-16
T2 closed openings (reference)	+11.7	0.46	188	-228	+137	-15

S8 Agentic support design and verification on an additional part

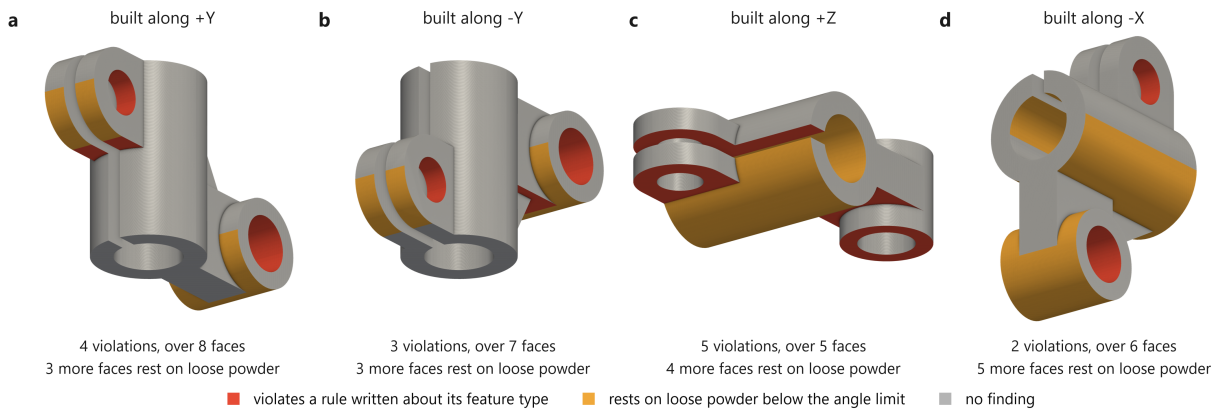
An extension to the workflow to include support design was evaluated using a CAD model of a mechanical clamp obtained from GrabCAD [16]. The clamp comprised a split clamping eye and a second boss joined by a web. Thirty-four analytic faces, a $134 \times 80 \times 50$ mm envelope and a volume of $160,575 \text{ mm}^3$ were recorded. In the initial +Z orientation, 65.9% of its downward-facing area was outside a rule-bearing feature, including part of the split eye. The coverage limitation was identified during author review. Surface checks were added to assess downward-facing regions outside the recognized feature classes.

S8.1 Surface assessment, build orientation and redesign feasibility

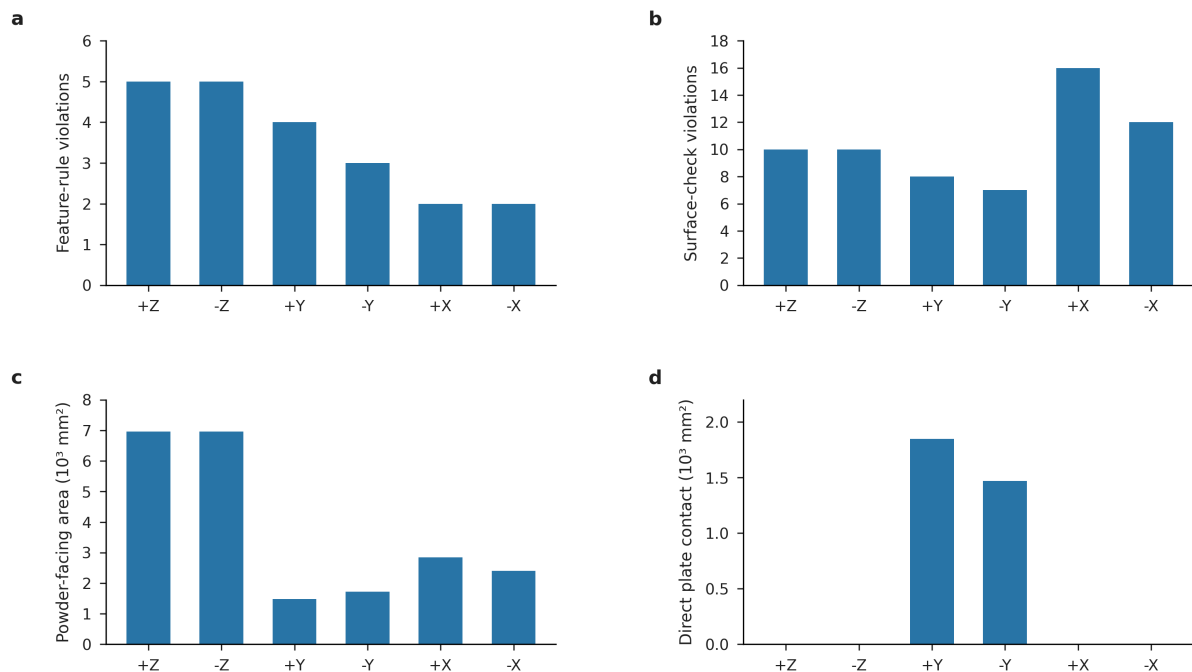
In the initial +Z direction, five unsupported reaches of 80, 40, 35.6, 34.1 and 12.45 mm were measured. Addition of triangular ribs beneath the overhangs was evaluated as a geometric remedy. Each rib was required to join existing material at its lower attachment. The adjacent walls ended 11.92, 14.89, and 15.00 mm above the plate, leaving no material at the proposed attachment locations, so rib addition was rejected. Downward-facing areas of $4,419.7 \text{ mm}^2$ inside rule-bearing features and $8,549.5 \text{ mm}^2$ outside them were recorded. Of the latter, $2,820.7 \text{ mm}^2$ was measured below 25° (Supplementary Figs. S18 and S19). Six directions were then screened. In +Y, $1,478 \text{ mm}^2$ powder-facing area and $1,850 \text{ mm}^2$ direct plate contact were recorded. Direct contact of $1,466.6 \text{ mm}^2$ was recorded in -Y. Two feature-rule violations were found in each X direction, with build height increased to 134 mm (Supplementary Fig. S20).



Supplementary Fig. S18. Initial clamp assessment in +Z. Top (a) and underside (b) views distinguish feature-rule coverage from the downward-facing surface condition (c). Five unsupported spans are detected. A substantial fraction of the split eye lies outside rule-bearing features. This coverage test motivates the separate surface checks.



Supplementary Fig. S19. Clamp surface and feature findings in four build directions (a) along +Y, (b) along -Y, (c) along +Z, and (d) along -X. Each panel uses its own build frame. Face-level maps expose downward geometry outside the feature-rule catalog and provide the targets for subsequent support assessment.

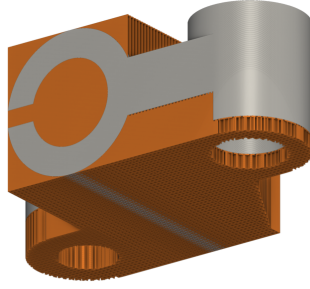


Supplementary Fig. S20. Clamp assessment before support construction for six build directions. (a) Violations of feature rules. (b) Violations from the added surface checks. (c) Downward-facing area on powder below the 25° limit. (d) Direct part contact with the build plate.

S8.2 Agentic review and correction of support geometry

After the surfaces requiring support had been identified, block support structures were constructed beneath them while the original part geometry was retained. A grid of 0.2 mm walls and contact teeth was used, with an initial grid spacing of 1.625 mm. Part material was subtracted from the generated support geometry. The construction parameters and review criteria are specified in Supplementary Table S10. The initial +Z design was produced before the support catalog existed, and no support criterion was evaluated on it (Supplementary Fig. S21). Material was placed beneath steep regions of curved faces that did not require support under the angle criterion. Across the curved targets, 53.5% to 70.6% of each projected footprint lay beneath these regions. The unnecessary material was retained in this initial output.

The coverage limitation and excess support prompted the addition of an Orientation Reviewer, Redesign Reviewer, Support Reviewer and Simulation Reviewer for the respective stage outputs. SUP-N1 was evaluated at every support attempt in the catalog-based runs. The workflow was restarted on the same clamp in +Y, -Y, +Z and -X, with only support-catalog review returning work during execution. The other three catalogs were applied after each run for reporting. Grid spacing was adjusted in response to measured unsupported spans, and disconnected support pieces were removed. A second defect remained: support extended above the curved surface it was intended to carry. The reviewer interfaces were subsequently extended with geometric queries, rendered views and a field for concerns outside the catalog. Saved outputs from the catalog-based runs were then examined by agent reviewers, so that additional measurements could be requested and corrections directed to the responsible stage (Supplementary Note 5.3 and main Fig. 2).



Supplementary Fig. S21. Initial +Z support before introducing the agent reviewer to the workflow. The part is shown in gray and support in orange. No support criterion was evaluated because the support catalog did not yet exist. Support had been placed beneath curved regions that did not require it. A support volume of $41,615 \text{ mm}^3$ was displayed for this initial output. The later catalog-based support of $52,191 \text{ mm}^3$ was used as the baseline for the operator correction and complete reruns in main Fig. 9.

The additional condition was investigated by the Support Reviewer using rendered views, point classification and rays along the build direction. A sample of 600,000 points was drawn uniformly from each support bounding box and classified against the support solid. Rays were cast from interior points to test for part material above them. Total support volume was reproduced within 0.4% using the same sample. In +Z, $1,596 \text{ mm}^3$, or 3.05% of support volume, was estimated to have no part surface above it. Part material was present below every flagged point. This volumetric condition was recorded separately from SUP-N1, the projected-footprint check. SUP-N1 was recorded as a pass at 0.0% in both support attempts of this $52,191 \text{ mm}^3$ +Z run.

Local surface height was found to be discarded by the support-envelope code. Surface triangles selected as requiring support were projected onto the plate and extruded to the maximum height of their parent face. For the outer cylindrical target in +Z, 28 of 114 triangles were selected for support. Those triangles reached only 4.7 mm above the plate, but the complete face extended to 50.0 mm. Support was consequently generated above the cylinder. The operator was revised by the agent so that each selected triangle was swept from its actual position to the plate. The revision was checked locally on this cylindrical target and a flat horizontal underside. For the flat target, all selected triangles were located at the parent face height, so the original height calculation was valid. The cylindrical-target volume was reduced from $24,854$ to $1,314 \text{ mm}^3$, or 94.7%, while the flat-target volume was retained at $1,617 \text{ mm}^3$. The intended change to the curved envelope was thus verified alongside a flat-target regression control before reuse (main Fig. 9a).

S8.3 Workflow reruns and review of the final clamp support designs

Four autonomous runs were conducted, for +Y, -Y, +Z and -X, from STEP input to simulated alternatives with no human intervention during execution (Supplementary Tables S21 and S22 and main Fig. 9). Support-catalog review was applied during the runs. The other three catalogs were applied after each run, followed by review of the saved support designs. In +Z, total support was reduced from $52,191$ to $36,719 \text{ mm}^3$, or 29.6%, and the fraction with no part above it was reduced from 3.05% to 0.02%. The +Z design was subsequently rejected because its exported flat unsupported span of 1.20 mm exceeded the 1 mm limit. The comparison baseline was the later catalog-based run, rather than the initial $41,615 \text{ mm}^3$ design in Supplementary Fig. S21. In -X, the STEP support file was reduced from 620 to 128 MB and Boolean-fusion time from 7.4 to 1.3 h. Simulation was completed in 4.8 h. Across the four directions, returns to support construction were reduced from ten to five. The supported clamp assemblies were evaluated by mechanical simulation with 1 mm voxels. Individual 0.2 mm support walls could not be resolved by this mesh, so the computed displacement fields were treated as preliminary estimates. Maximum displacement after plate release was compared across the four orientations (Supplementary Table S22 and main Fig. 9).

Supplementary Table S21. Final support construction after the operator revision. Returns count repeats after reviewer refusal. SUP-N1 passed with an unnecessary projected footprint of 0.0% in all four corrected-operator runs.

Direction	Returns	Initial → final pitch (mm)	Support (mm ³)	Support/ part volume (%)
+Y	1	1.625 → 0.956	16,299	10.2
−Y	1	1.625 → 0.956	25,576	15.9
+Z	1	1.625 → 0.914	36,719	22.9
−X	2	1.625 → 0.673	63,834	39.8

The saved designs were assessed by the review agent using measurements of the exported geometry. In +Z, a flat span of 1.20 mm was measured on the exported geometry, compared with 1.00 mm on the in-loop solid. Both SUP-G1 support-grid checks used 0.15 mm sampling. The difference was traced to a mismatch between the two geometries and changed the judgment at the 1 mm limit. The exported measurement was used for final review, and +Z was rejected. In −X, the only span exceedance was measured on curved surfaces at 1.12 mm. That alternative was retained with a warning because the flat-overhang limit had been extrapolated. Both exceedances were preserved, with different judgments recorded according to source applicability. Three alternatives were accepted with warnings and +Z was rejected in the support-stage review. Support volumes of 10.2%, 15.9%, 22.9% and 39.8% of part volume were recorded for +Y, −Y, +Z and −X. The −X value was 14.8 percentage points above the 25% warning threshold under SUP-V1 and ORI-S1 (See Supplementary Table S10). A warning was retained according to the recorded severity, without changing the exceedance. Spans, pitches and reviewer returns are given in Supplementary Tables S21 and S22.

In the separate surface assessment, a “scanning onto loose powder” violation was assigned to a face when more than 1 mm² rested on powder below the A1 angle limit of 25°. The limit field stored an angle in degrees. For +Y, −Y, +Z and −X, respectively, 8, 7, 9 and 11 faces were flagged, with summed areas below 25° of 786.1, 906.2, 2,322.5 and 1,212.8 mm². Most flagged faces belonged to bores or bosses. An additional −X face, INCLINE-01, was assigned an A2 warning for 229.6 mm² below 50°, with no area below 25°. That warning area was excluded from the below-25° totals. These surface violations remained in the checker output. Powder-facing area was treated only as an uncatalogued concern in the final support review, so the recorded support-stage acceptances did not resolve the surface findings.

ORI-A1 assessed direct contact of the unsupported part with the plate using the pre-support orientation measurements. Its catalog entry recorded that a failing direction could still be built with support reaching the plate, so the finding pointed to the support stage. ORI-A1 was applied after each run for reporting and could not stop execution. Violations were recorded and retained in +Z and −X, where the part touched the plate along a line and direct contact area was 0 mm². On the exported assemblies, part-plus-support plate-contact areas of 2,564.7 mm² in +Z and 1,345.4 mm² in −X were measured, and both anchoring checks passed. In −X, ORI-C1 recorded that +Y and −Y were at least as good on every measured orientation criterion, including area below 25°, build height and plate contact, and better on at least one. That violation remained unresolved. No ORI-C1 violation was recorded in +Z. The final saved-design reviews assessed only the support stage and recorded no ORI-A1 or ORI-C1 applicability reason. Their decisions are reported in Supplementary Table S22.

Supplementary Table S22. Measurements on the final exported clamp designs. Powder-facing area is the sum of the violating portions below 25°. The last column records the final reviewer’s support-stage decision, distinguishing the flat-span violation from extrapolation to curved surfaces. Loose-powder surface violations remained in all four designs. Removability remains unevaluated in every direction.

Direction	Flat span (mm)	Curved span (mm)	Powder-facing area below 25° (mm ²)	Max. released displacement (mm)	Recorded support-stage decision
+Y	0.67	0.95	786.1	0.830	Accepted with warnings
−Y	0.67	0.95	906.2	1.015	Accepted with warnings
+Z	1.20	1.20	2,322.5	0.779	Rejected
−X	0.00	1.12	1,212.8	0.970	Accepted with warnings

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