CANSU ERSOY

P5

THESIS PRESENTATION

SYLVA

CANSU ERSOY

01 WHAT

01

WHAT

IS THE PROBLEM

- The construction industry is increasingly exploring sustainable alternatives, yet fabrication workflows for biobased materials like lignin-cellulose composites are still in early stages of development, particularly for hot extrusion applications.
- These materials present challenges related to mechanical strength, thermal behavior, and printability-characteristics that vary significantly with changes in binder-to-fiber ratios.
- There is limited research on how these material characteristics influence extrusion performance and toolpath generation. In strength-graded systems, where different material formulations are assigned to specific structural zones, the placement of components may relate to their mechanical performance.
- It remains unclear to what extent slicing workflows can or should be adjusted to reflect these differences, and how parameters like speed, extrusion width, or cooling time might be tailored to suit varying material behaviors.

01

WHAT

IS THE PROBLEM

fabrication workflows

for biobased materials lignin-cellulose composites

hot extrusion applications.

mechanical strength, thermal behavior, and printability-

characteristics binder-to-fiber ratios.

extrusion performance

toolpath generation. strength-graded systems,

slicing workflows

parameters

material behaviors.

01

WHAT

IS THE QUESTION

“What are the challenges and opportunities of lignin-cellulose biocomposites as feedstock for hot extrusion-based robotic additive manufacturing, and how can different material ratios be optimized to ensure mechanical performance, printability, and structural viability through computational slicing strategies for architectural applications?”

fabrication workflows

for biobased materials

lignin-cellulose composites

hot extrusion applications.

mechanical strength, thermal behavior, and printability-

characteristics

binder-to-fiber ratios.

extrusion performance

toolpath generation.

strength-graded systems.

slicing workflows

parameters

material behaviors.

01

WHAT

ARE THE OBJECTIVES

MATERIAL RESEARCH

- Formulate and test lignin-cellulose-PHA composite blends to identify three strength-graded material ratios suitable for robotic hot extrusion.
- Evaluate the mechanical, thermal, and flow properties of each ratio to balance printability and structural performance.
- Investigate the influence of binder-to-fiber ratios on extrusion behavior and final brick quality.

01

WHAT

ARE THE OBJECTIVES

STRUCTURAL TESTING

- Conduct tensile tests for each composite blend.
- Validate the suitability of each material ratio for its assigned structural role within a partition wall system.
- Use simplified mechanical tests to assess the feasibility of strength-graded assemblies for modular applications in office spaces.

01

WHAT

ARE THE OBJECTIVES

COMPUTATIONAL WORKFLOW

- Develop a parametric design and fabrication workflow that connects material performance with robotic toolpath generation.
- Pre-assign material ratios to specific brick types based on structural zone requirements, enabling strength-graded fabrication.
- Adjust printing parameters such as speed, cooling time, and extrusion behavior according to predefined material characteristics.

01

WHAT

ARE THE OBJECTIVES

DESIGN AND ASSEMBLY

- Ensure the modular bricks support architectural needs such as stackability, reusability, and integration of optional functional channels.
- Maintain geometric consistency across all bricks, embedding performance adaptation solely through material assignment and slicing control.

01

WHAT

ARE THE OBJECTIVES

PROTOTYPING

- Use robotic extrusion to prototype selected brick types with placeholder materials (e.g., PETG, clay) to validate design logic and assembly sequence.
- Assess how computational design decisions translate into physical prototypes, including print accuracy and interlayer adhesion.
- Refine process parameters iteratively to improve print fidelity and material efficiency in fabrication.

02

WHY

02

WHY

THESE MATTER

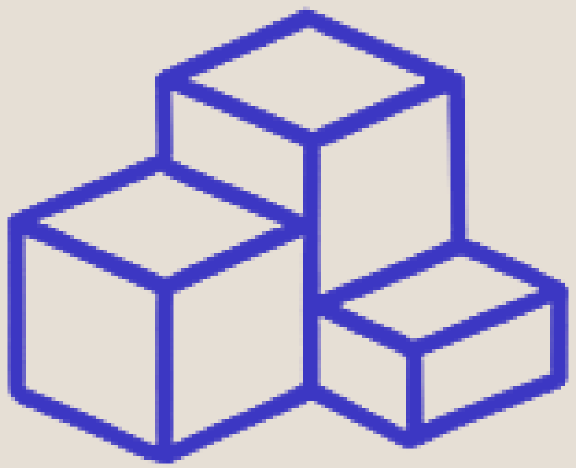
- Without reliable fabrication workflows, biobased composites cannot transition from experimental use to scalable, real-world construction applications-limiting their impact on material sustainability in the built environment.
- Understanding how material properties shift with composition is essential for ensuring structural safety, print consistency, and material efficiency during fabrication.
- A lack of insight into this relationship makes it difficult to optimize extrusion settings or predict fabrication outcomes-especially with non-standard or variable-performance materials.
- Material-to-zone assignment offers an opportunity for performance-based design, enabling more efficient use of resources and tailoring of structural behavior to architectural needs.
- Clarifying how and when to adjust printing parameters can improve fabrication quality, reduce failure rates, and expand the capabilities of robotic extrusion with bio-based composites.

02

WHY

LIGNIN AND CELLULOSE

- Lignin and cellulose are abundant byproducts of agriculture and forestry, suitable for robotic hot extrusion.
- Cellulose offers high tensile strength, while lignin contributes UV resistance and thermal stability, together forming a promising composite base.
- Their properties can be modified by adjusting binder-to-fiber ratios, making them ideal candidates for strength-graded component production.
- They are underutilized in extrusion-based additive manufacturing, providing a valuable scientific and application gap for exploration.

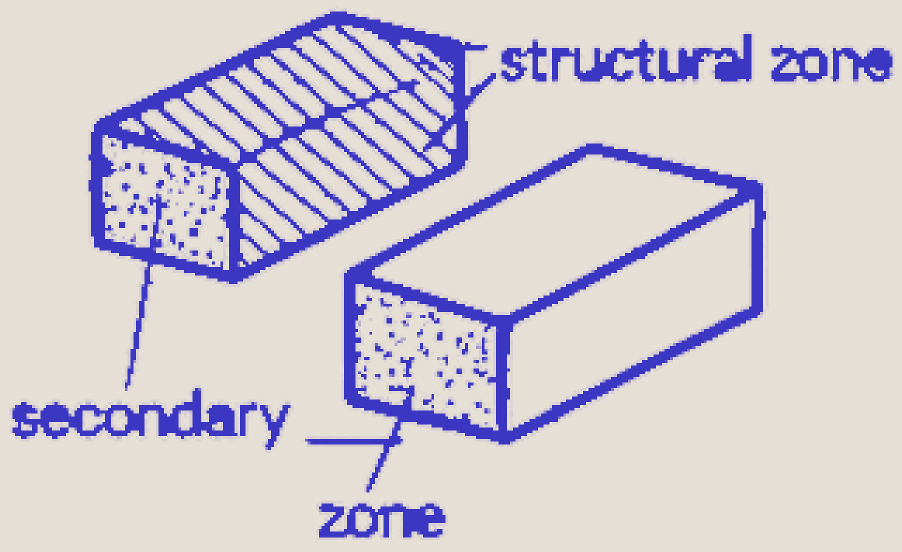


02

WHY

MODULAR BRICKS

- Modular bricks are geometrically repeatable yet functionally customizable, making them ideal for experimental prototyping and parametric design strategies.
- Their block-based nature simplifies robotic toolpath planning while allowing strategic material placement based on performance zones.
- They support circular construction through disassembly, reuse, and reconfiguration in architectural contexts like partition systems.
- Provide a scalable testbed for integrating material science with digital fabrication in a controlled manner.



02

WHY
STRENGTH GRADING

- Strength grading allows each brick to be matched to structural demands, optimizing material performance and minimizing waste.
- It introduces a performance-based logic to material placement, aligning with principles of efficiency, modularity, and circular design.
- This method supports the use of biobased materials with variable strengths, ensuring they are used appropriately rather than uniformly.
- Enables structural zoning within architectural assemblies, offering potential for lightweight wall systems.

02

WHY
ADDITIVE MANUFACTURING

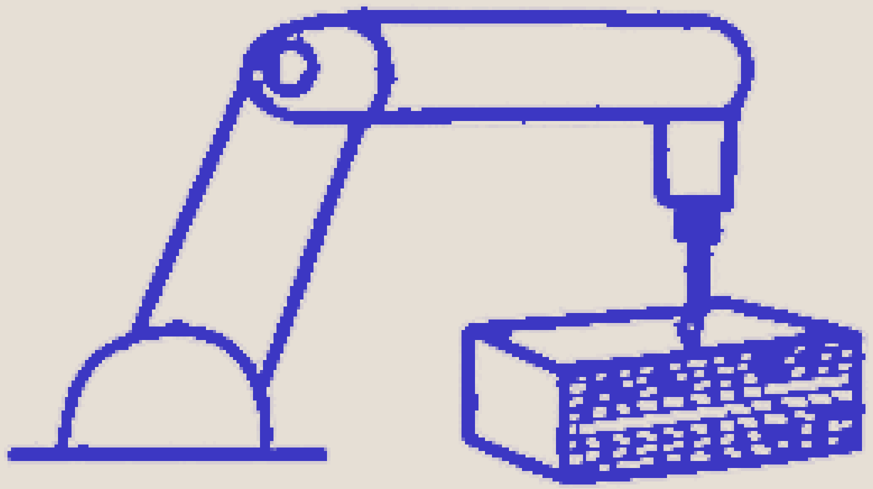
- AM allows for precise, geometry-driven fabrication of complex components without the need for molds or subtractive tooling.
- It supports low-volume, iterative experimentation, essential when testing evolving biocomposite formulations.
- Material extrusion AM methods are compatible with the pellet-based robotic systems used in architectural-scale fabrication.
- AM minimizes waste and enables on-demand production, aligning with sustainability goals in both material and production strategy.

02

WHY

COMPUTATIONAL WORKFLOW

- A computational workflow enables integration of material performance data into early-stage design and fabrication logic.
- It allows the pre-assignment of material-specific fabrication parameters (e.g., speed, extrusion width) in response to mechanical test results.
- This workflow supports parametric adaptability, making it possible to design, analyze, and fabricate strength-graded bricks in a unified pipeline.
- It provides a scalable framework for combining material variability with digital toolpath control.



02

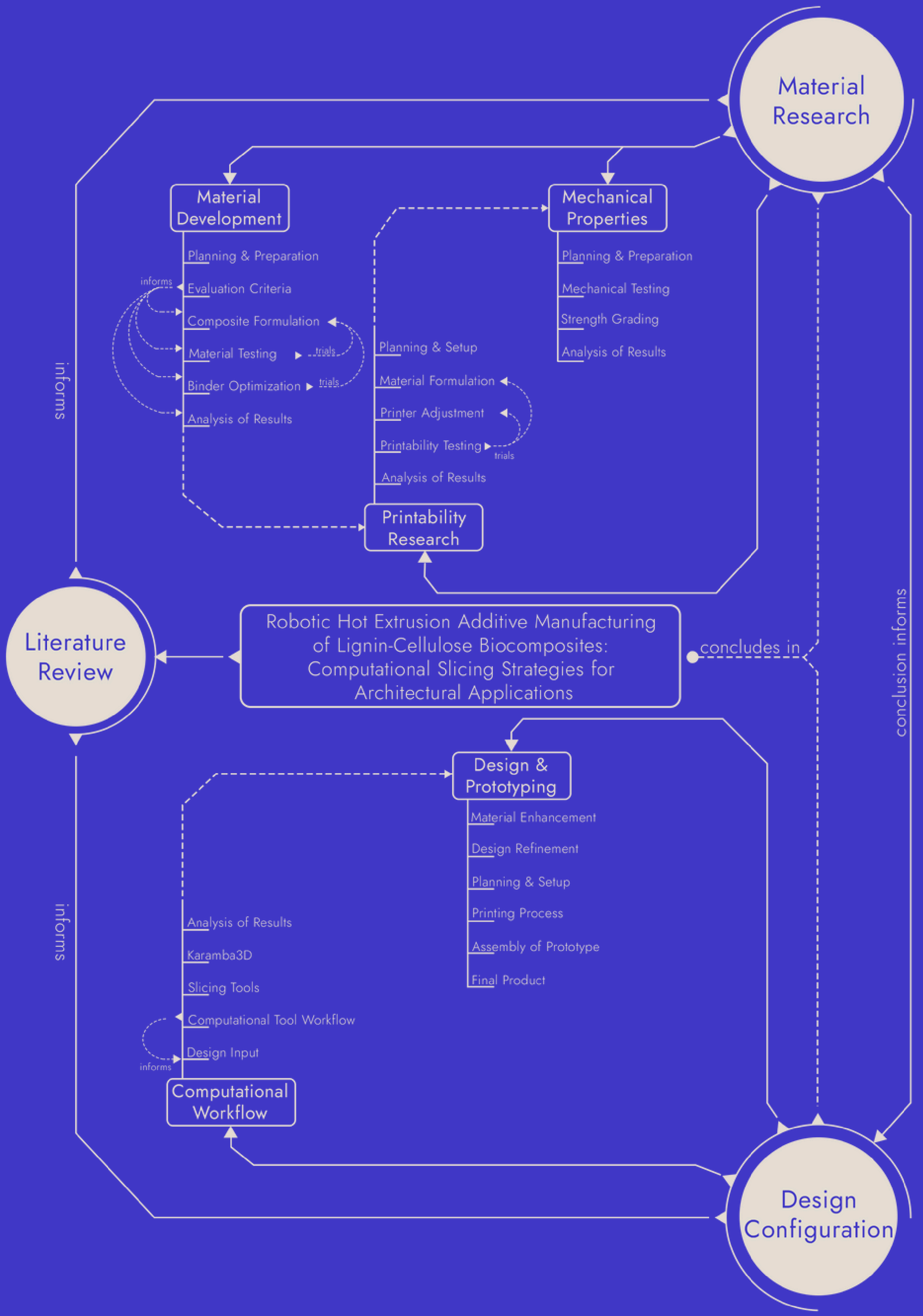
WHY

SLICERS AND ROBOTIC EXTRUSION

- Custom slicers allow for fine-tuned control over print parameters to accommodate the challenges of printing with bio-based composites.
- Robotic extrusion systems support large-scale, precise deposition of composite materials, ideal for producing architectural components.
- Integrating slicing logic into robotic workflows bridges the gap between digital design and real-world fabrication with non-standard materials.

03

HOW



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WAS IT DONE

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03 HOW

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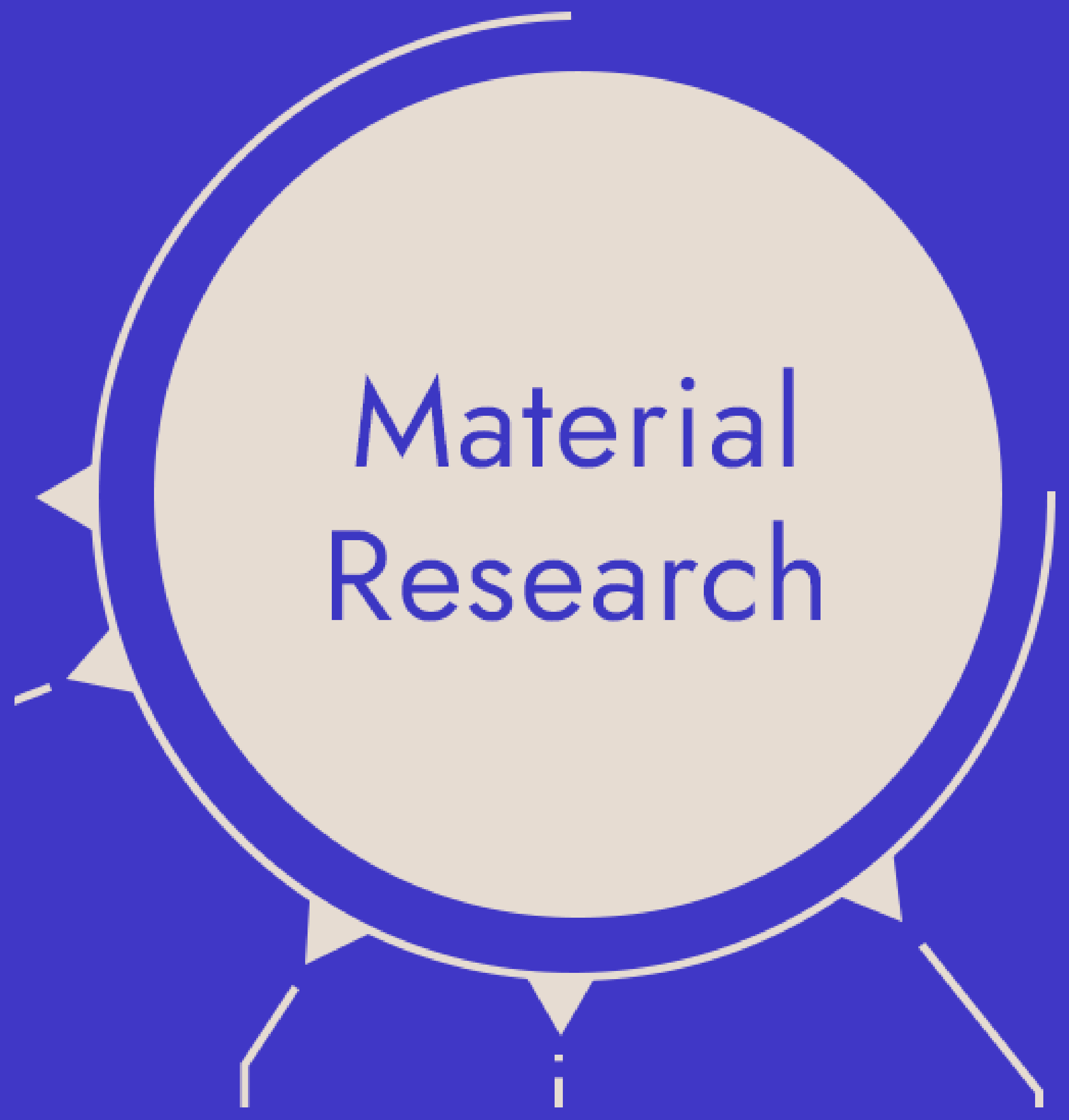

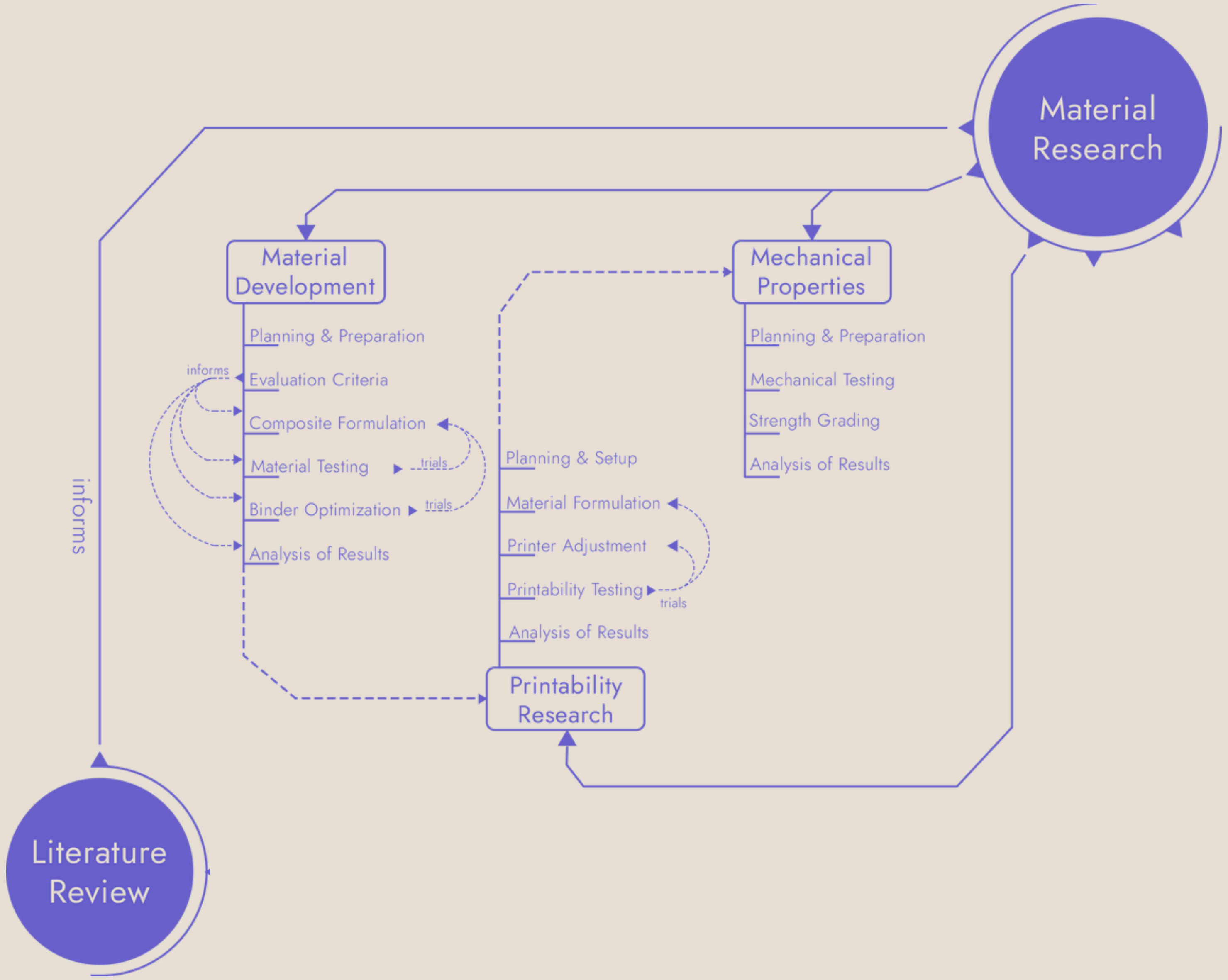

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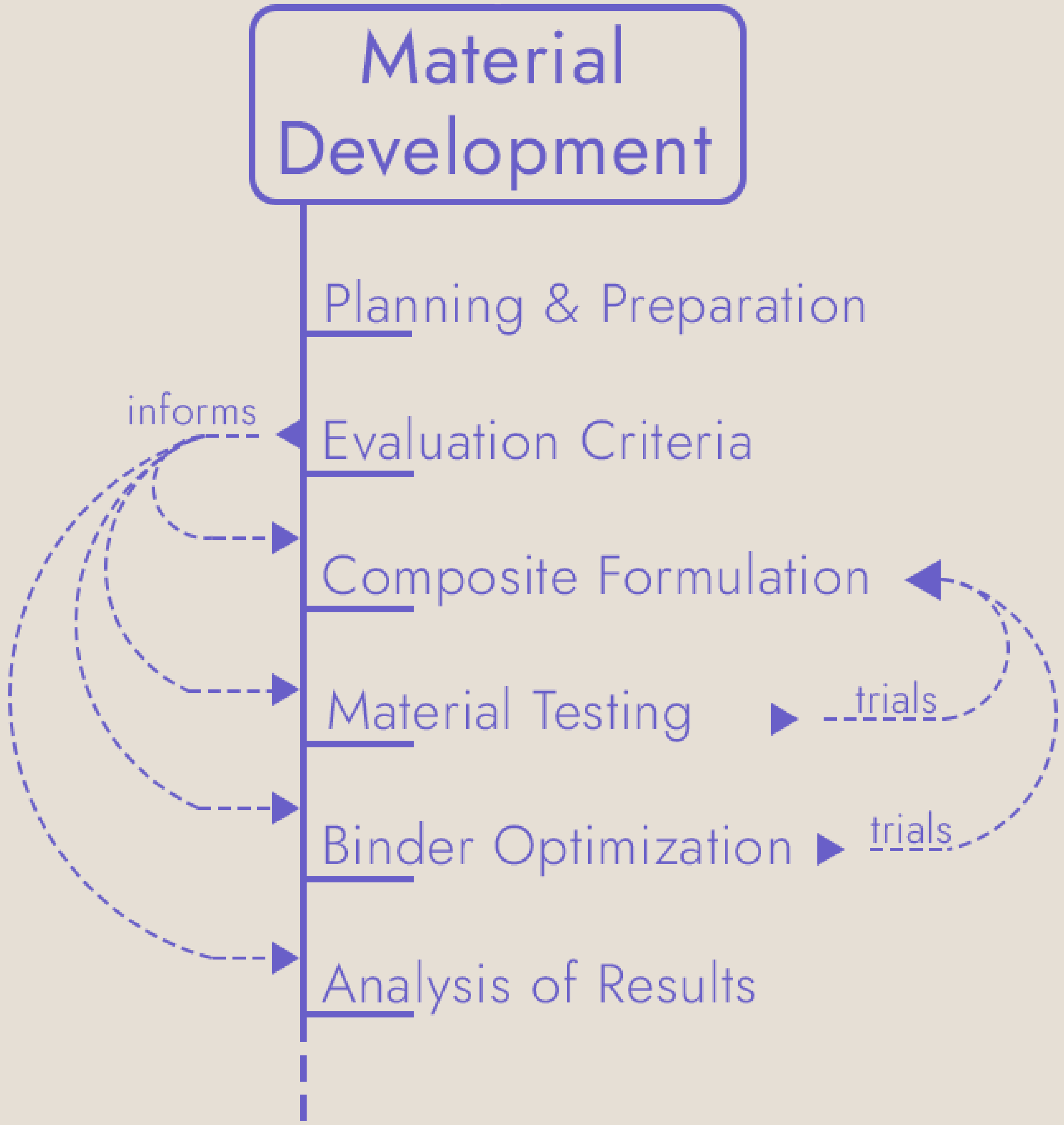
HOW

WAS IT DONE

MATERIAL RESEARCH



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HOW

WAS IT DONE

MATERIAL DEVELOPMENT

- Reviewed prior studies (e.g. Bierarch & Coelho) to understand lignin-cellulose processing in extrusion.
- Selected materials (soda lignin, kraft cellulose, PHA, PLA, TPS) based on sustainability, thermal behavior, and compatibility.
- Sourced lab equipment and materials from TU Delft facilities, online retailers, and local suppliers.
- Established lab safety, drying, and mixing protocols to ensure repeatability and minimize variability.
- Anticipated key challenges: thermal degradation, clumping, brittleness, and viscosity management.

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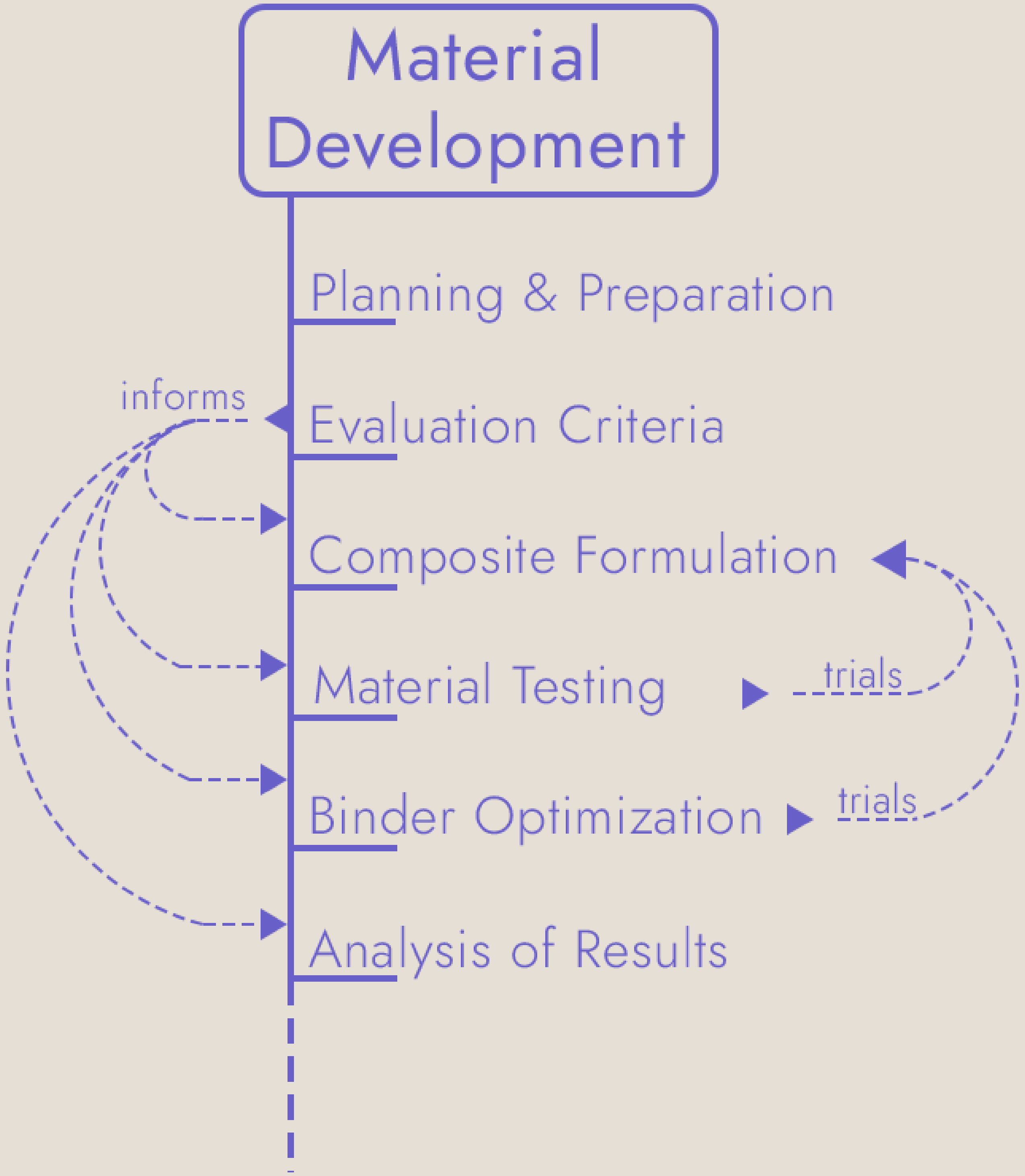
HOW

WAS IT DONE

MATERIAL DEVELOPMENT



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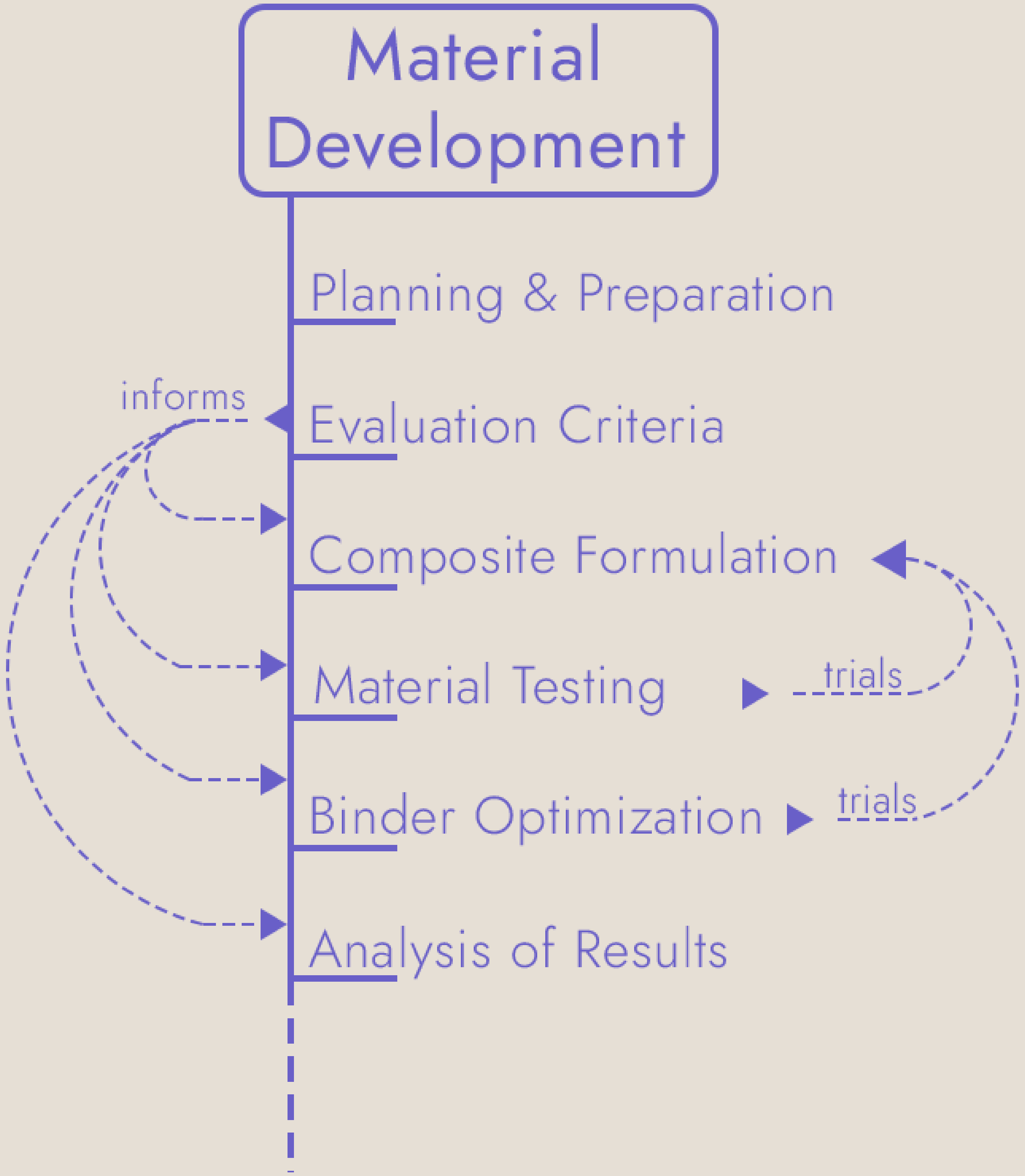
MATERIAL DEVELOPMENT



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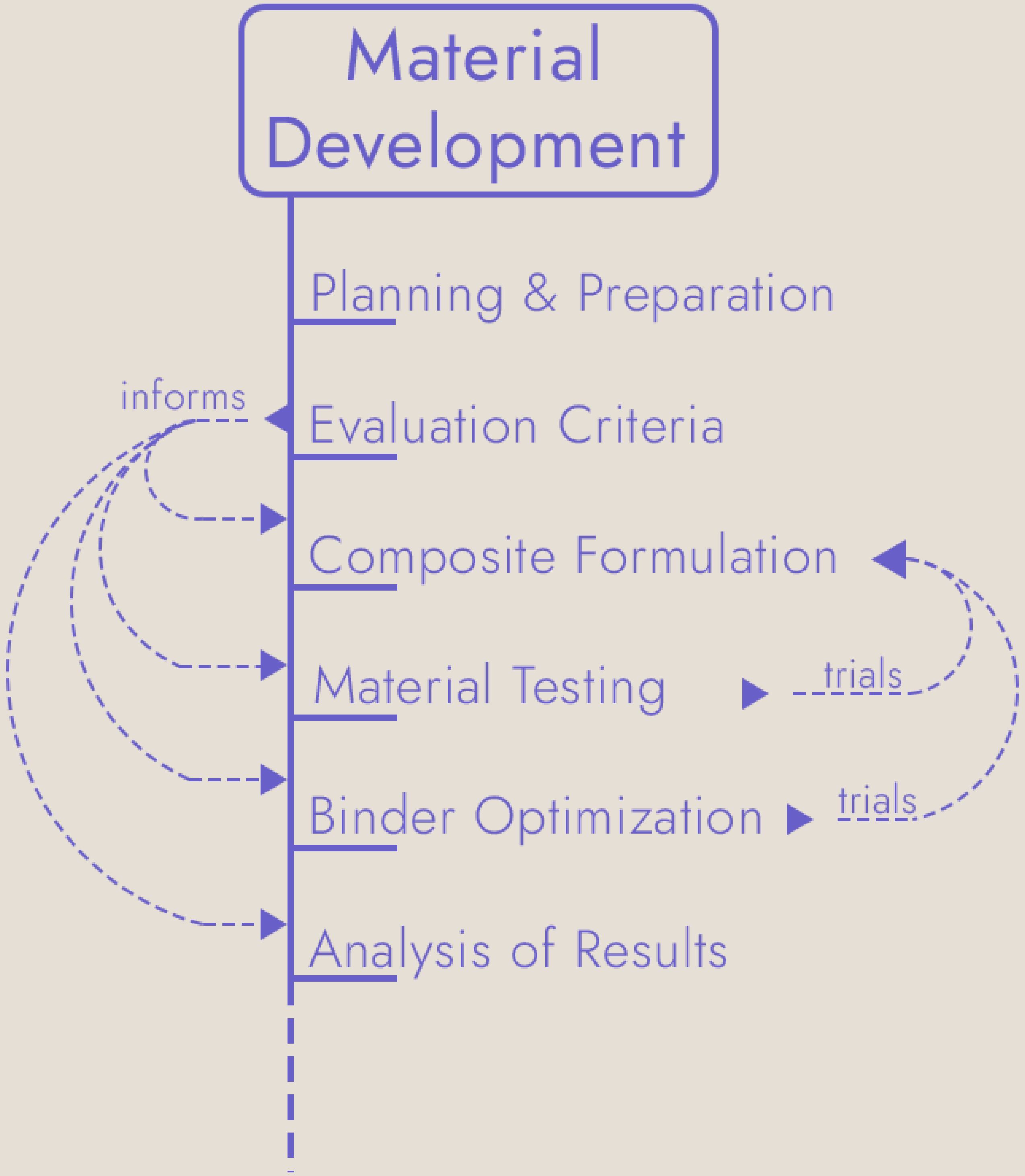

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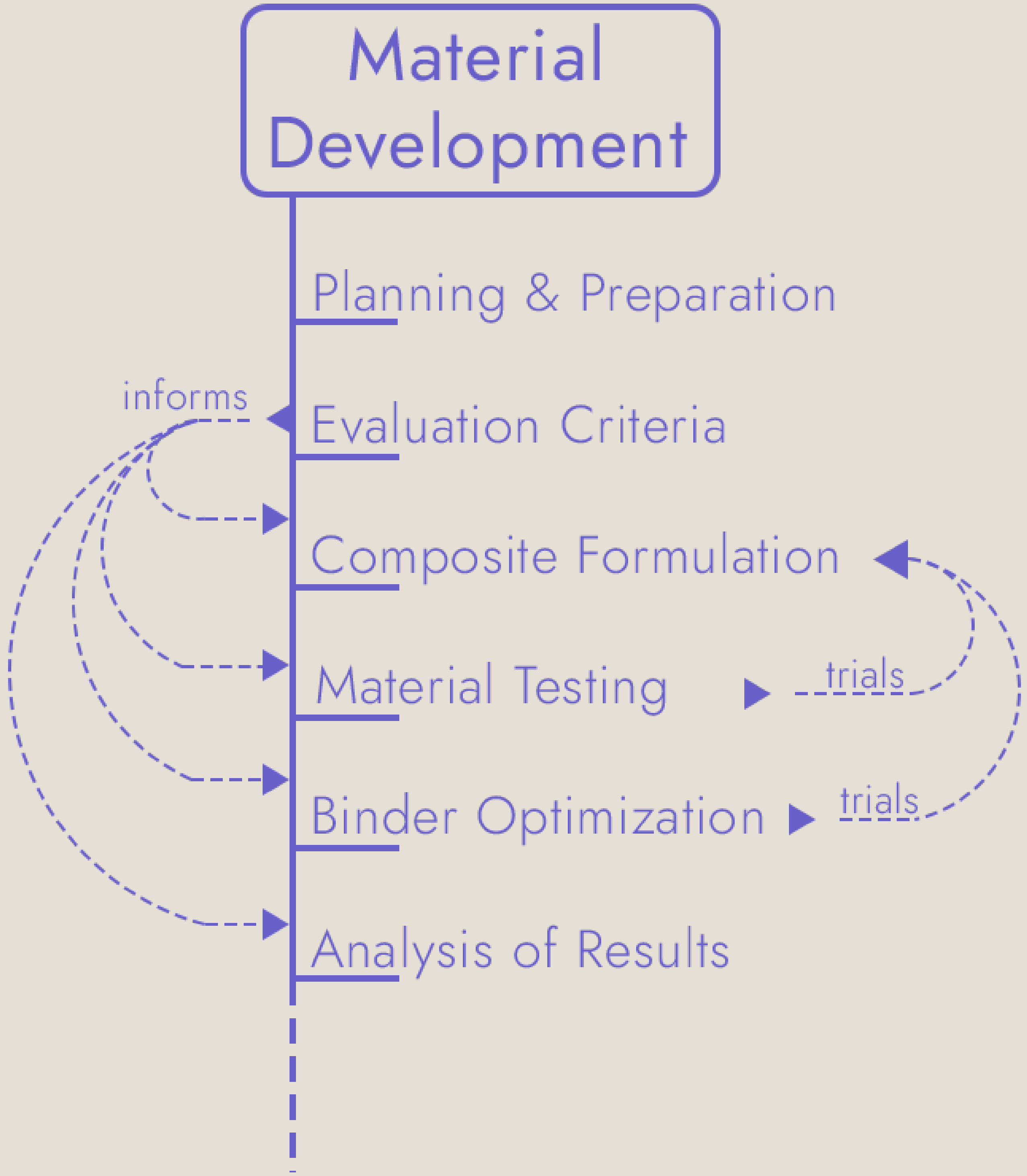

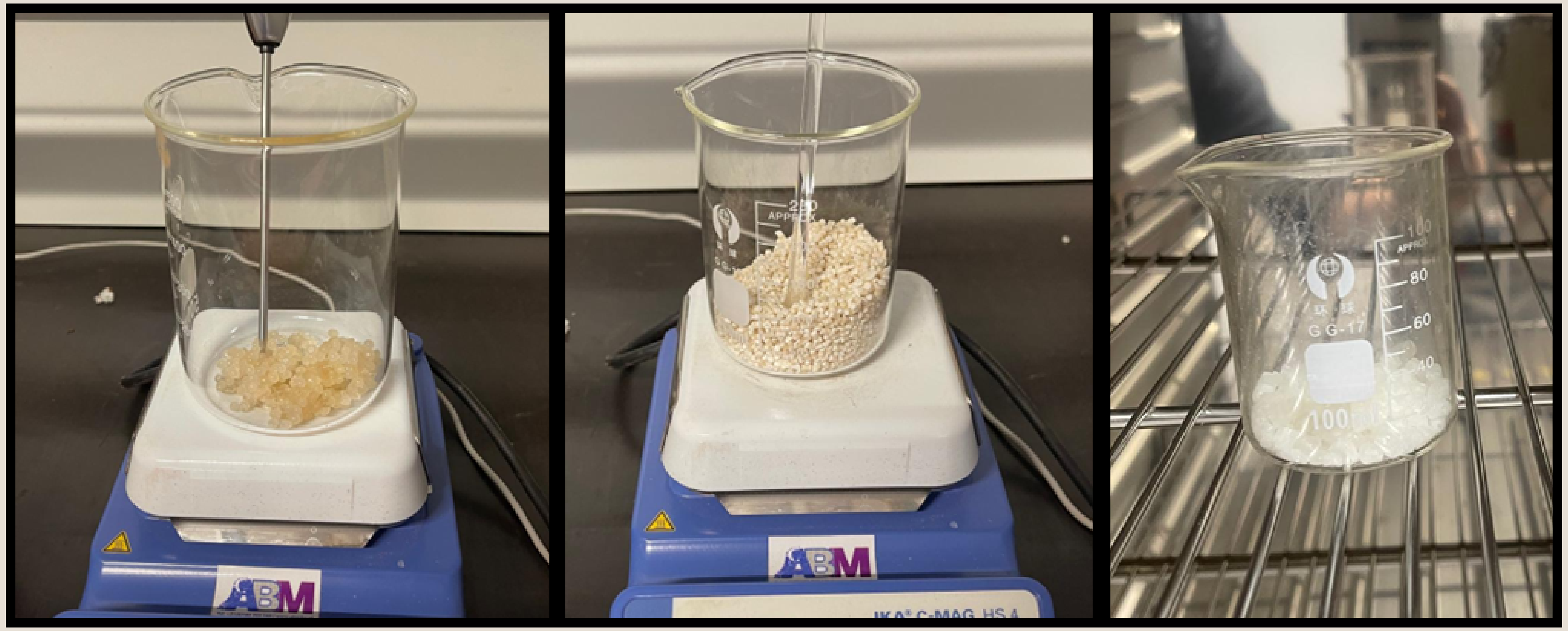

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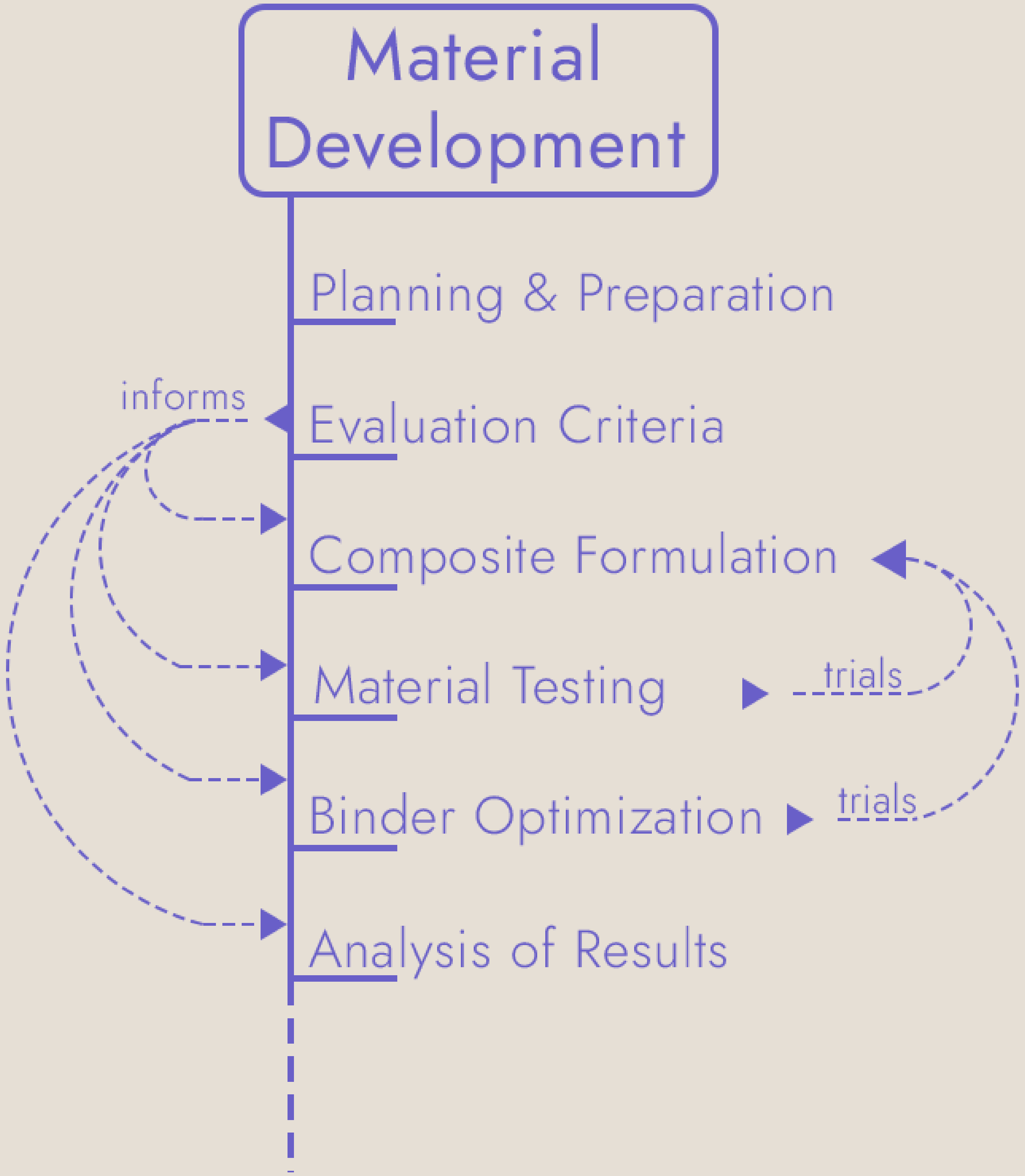

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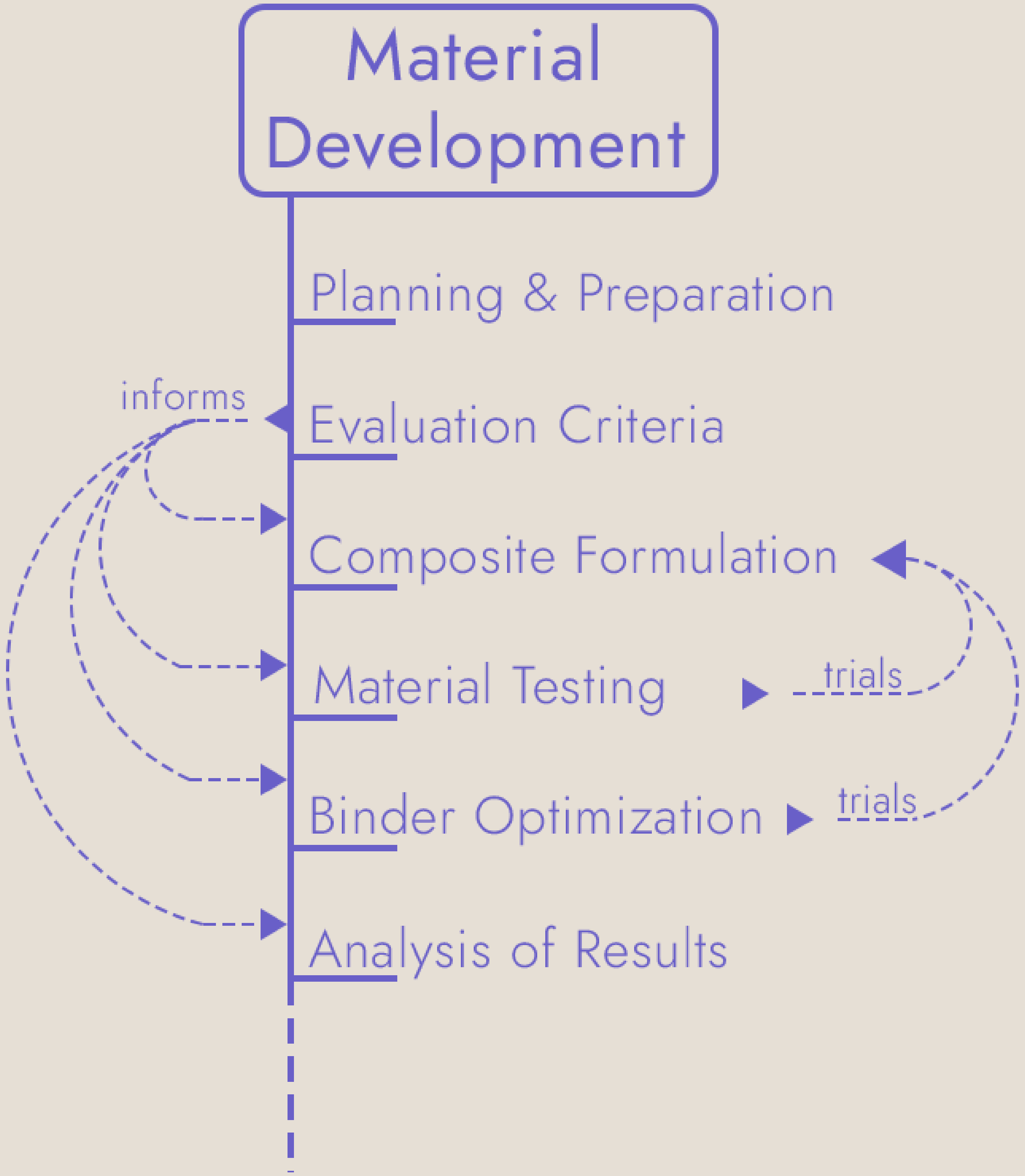

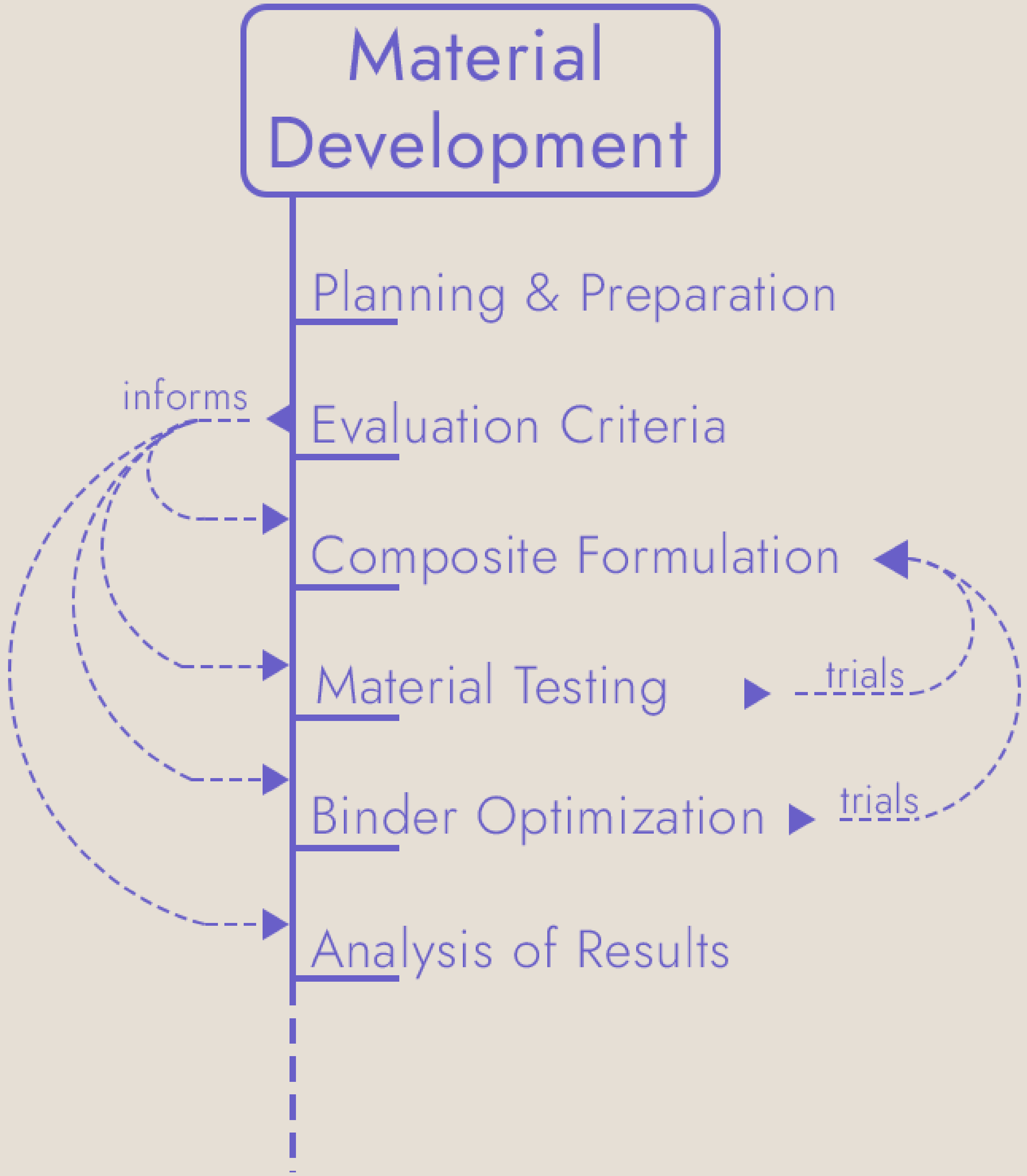

03 HOW

WAS IT DONE

MATERIAL DEVELOPMENT

- Developed three distinct formulations tailored to different structural zones (low, medium, high strength).
- Maintained fixed levels of binder (60% PHA) while varying lignin and cellulose ratios.
- Pre-blended citric acid with glycerol to act as a primer, improving fiber dispersion and adhesion.
- Pre-treated and dried fiber blend before gradual incorporation into molten binder.
- Standardized pellet formation using silicone trays to prepare extrusion-ready test material.

03 HOW

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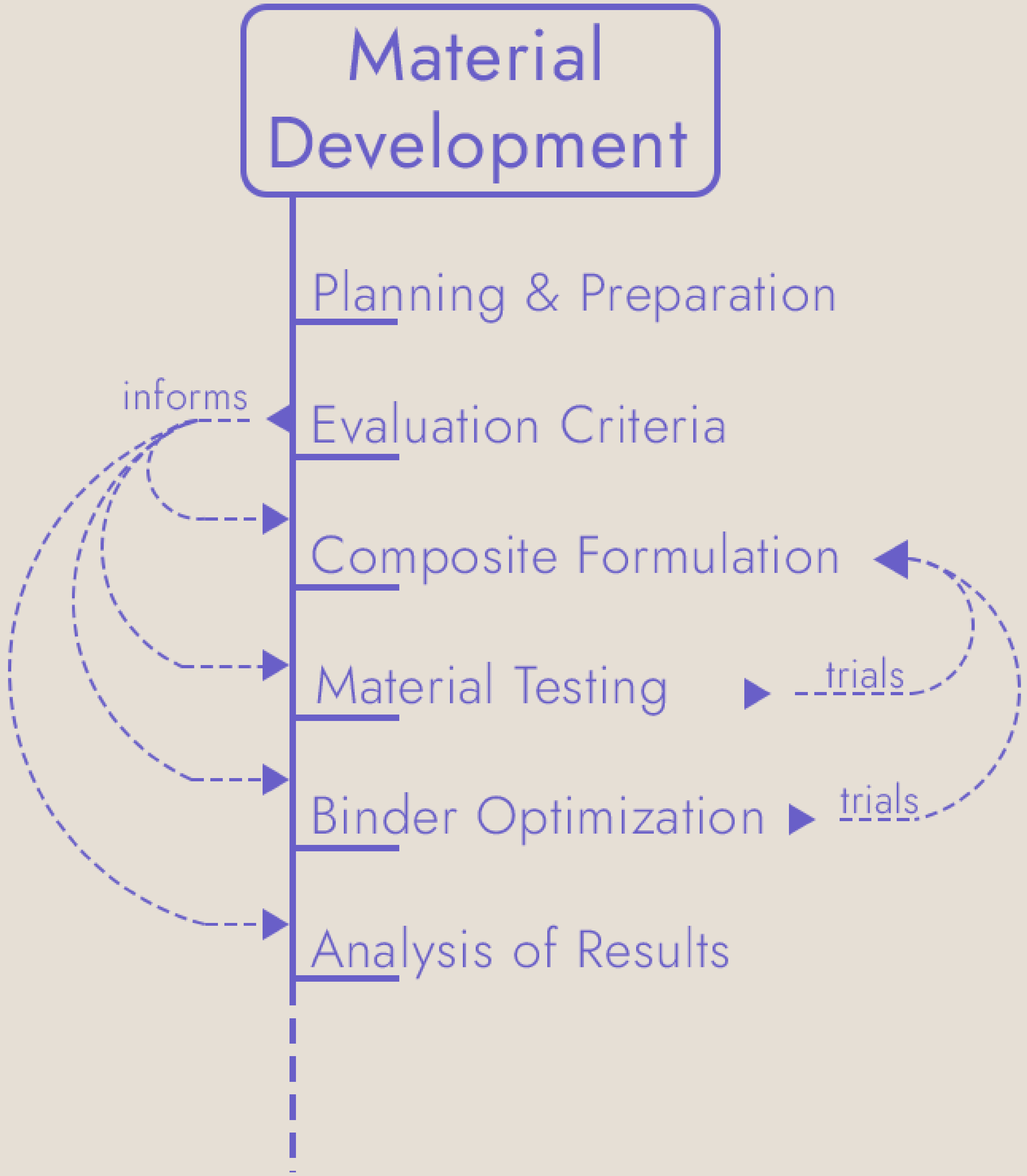
MATERIAL DEVELOPMENT



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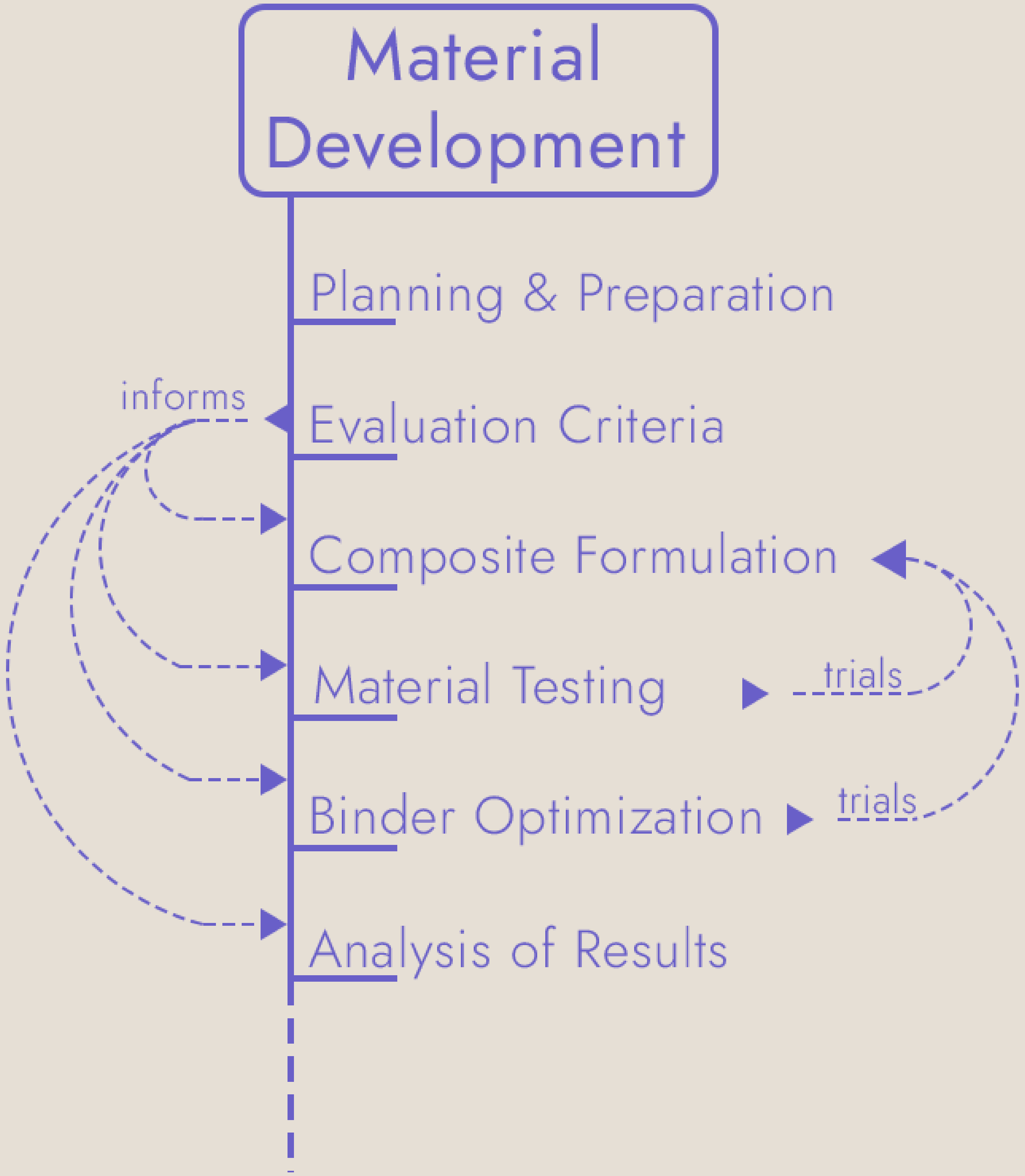

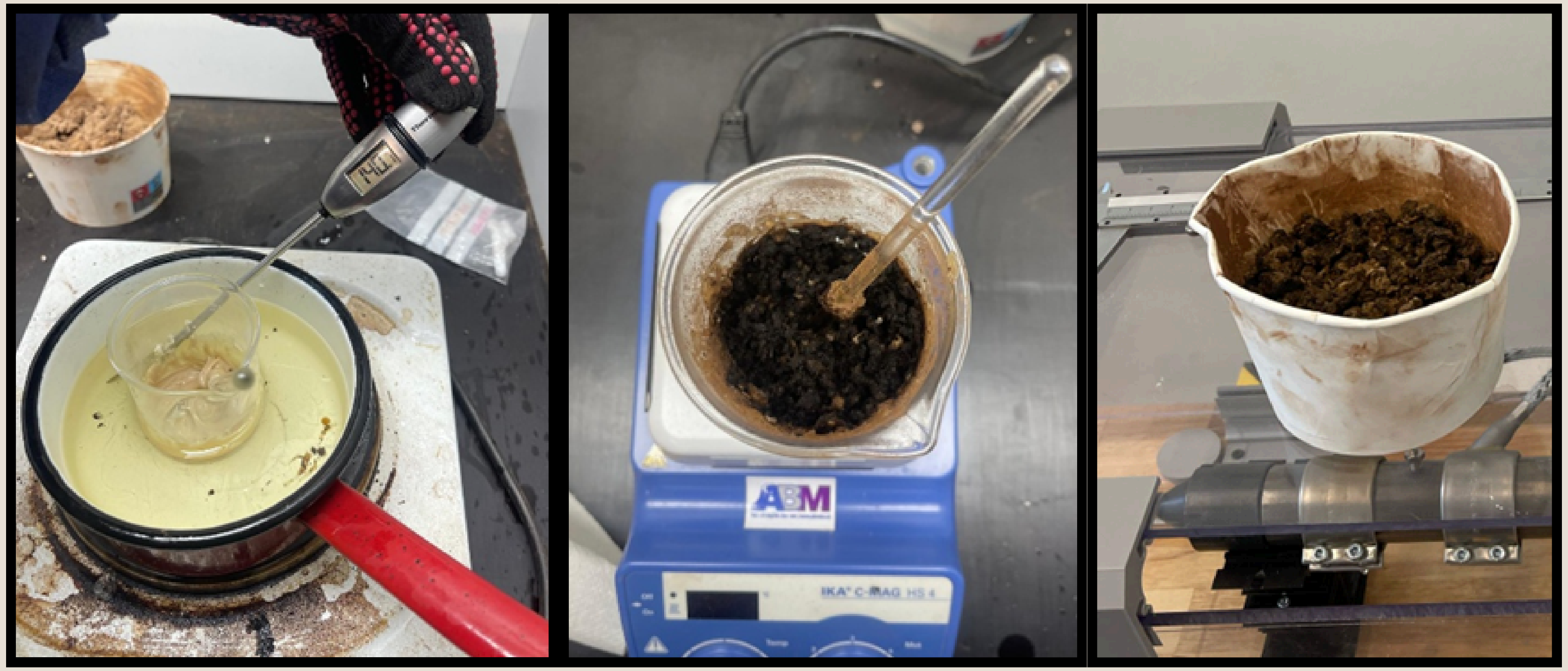

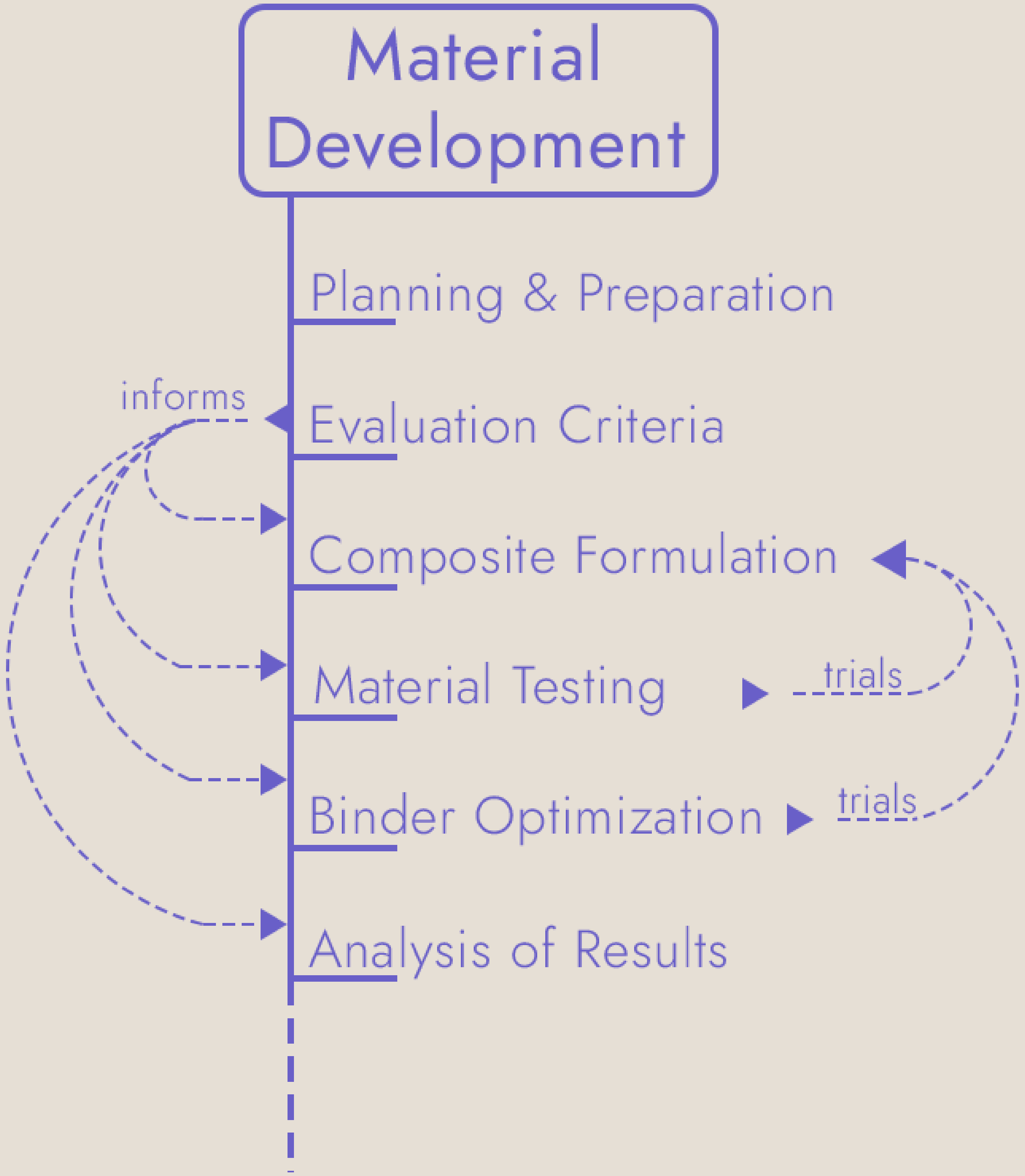

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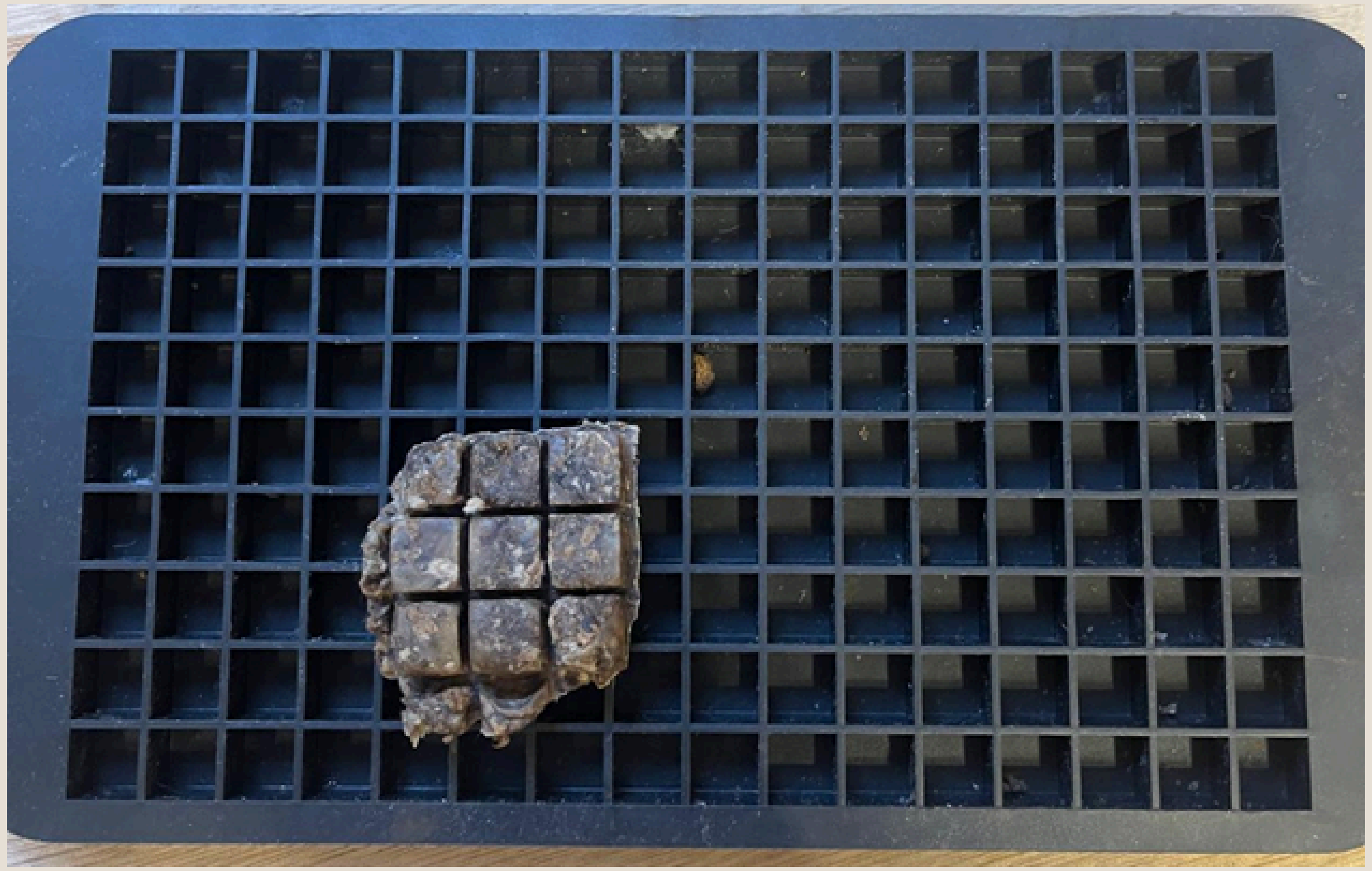

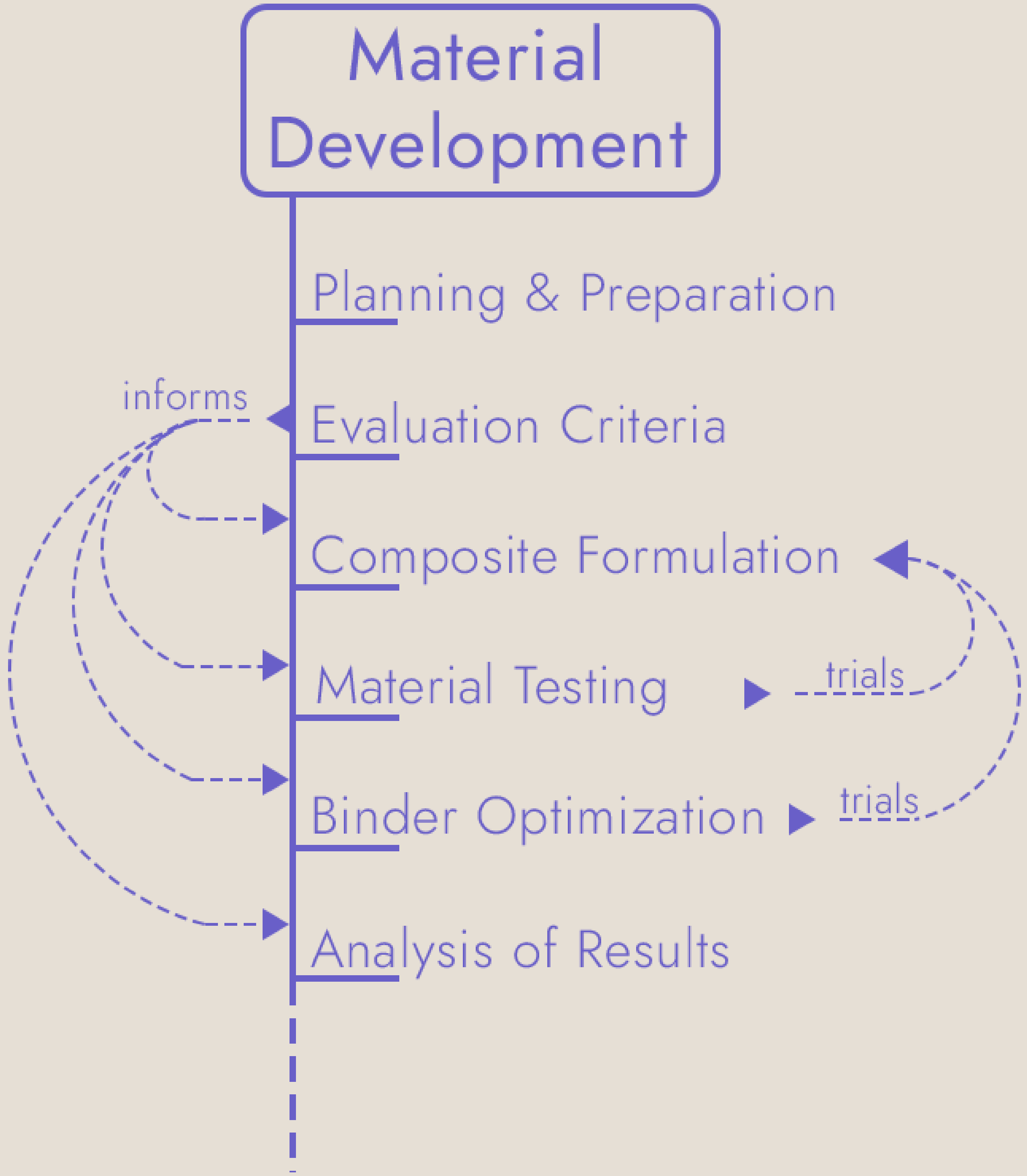

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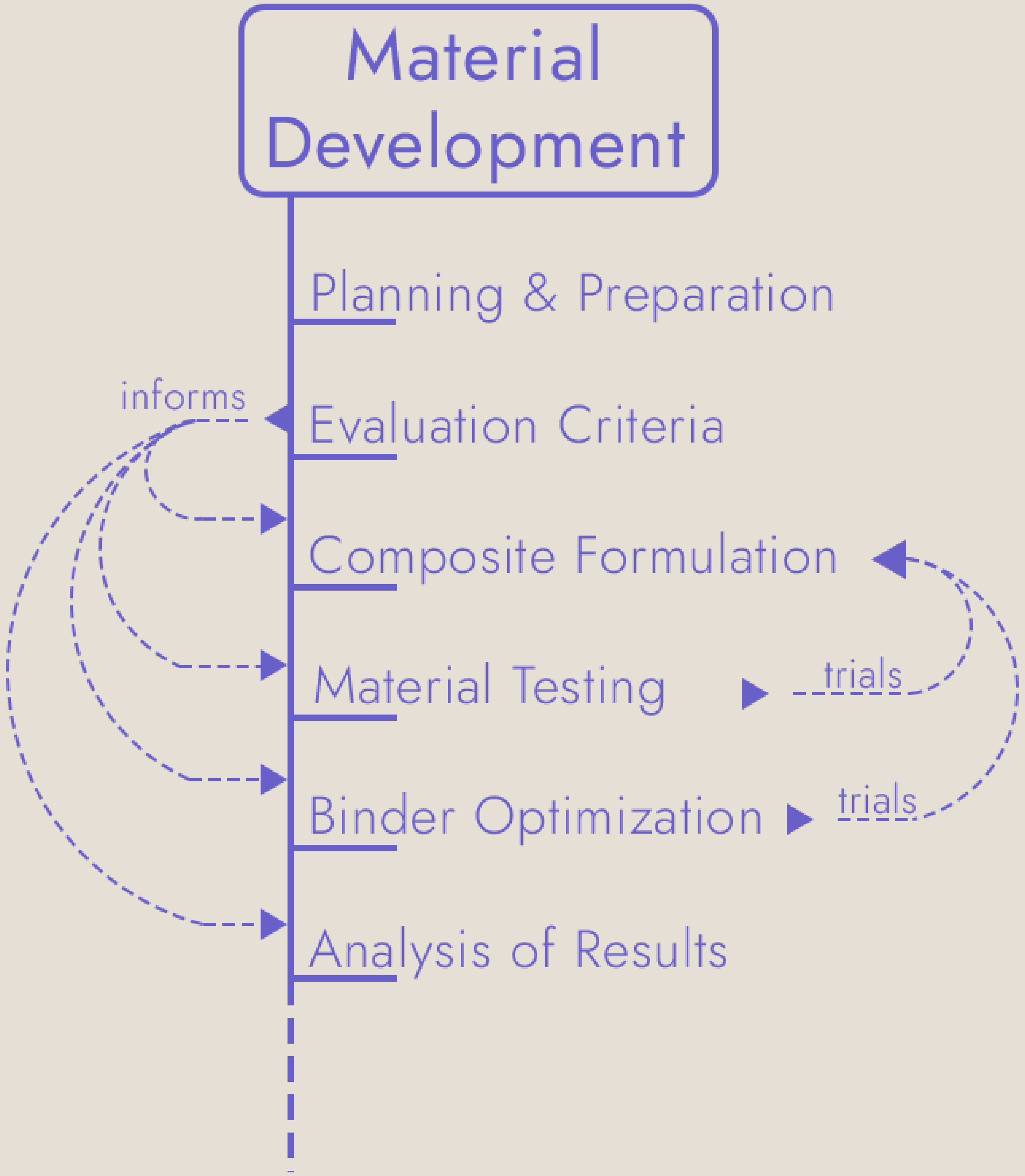
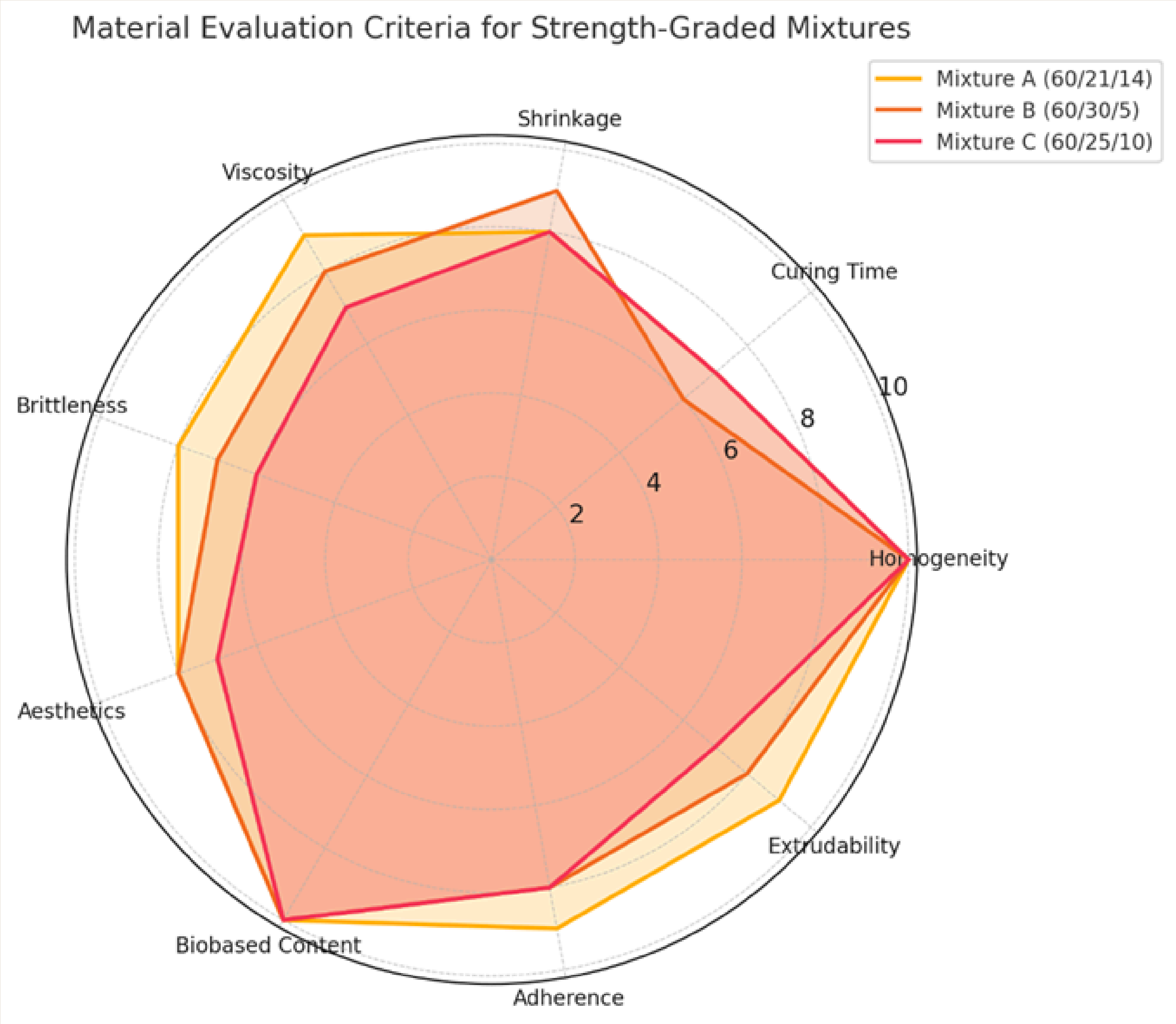
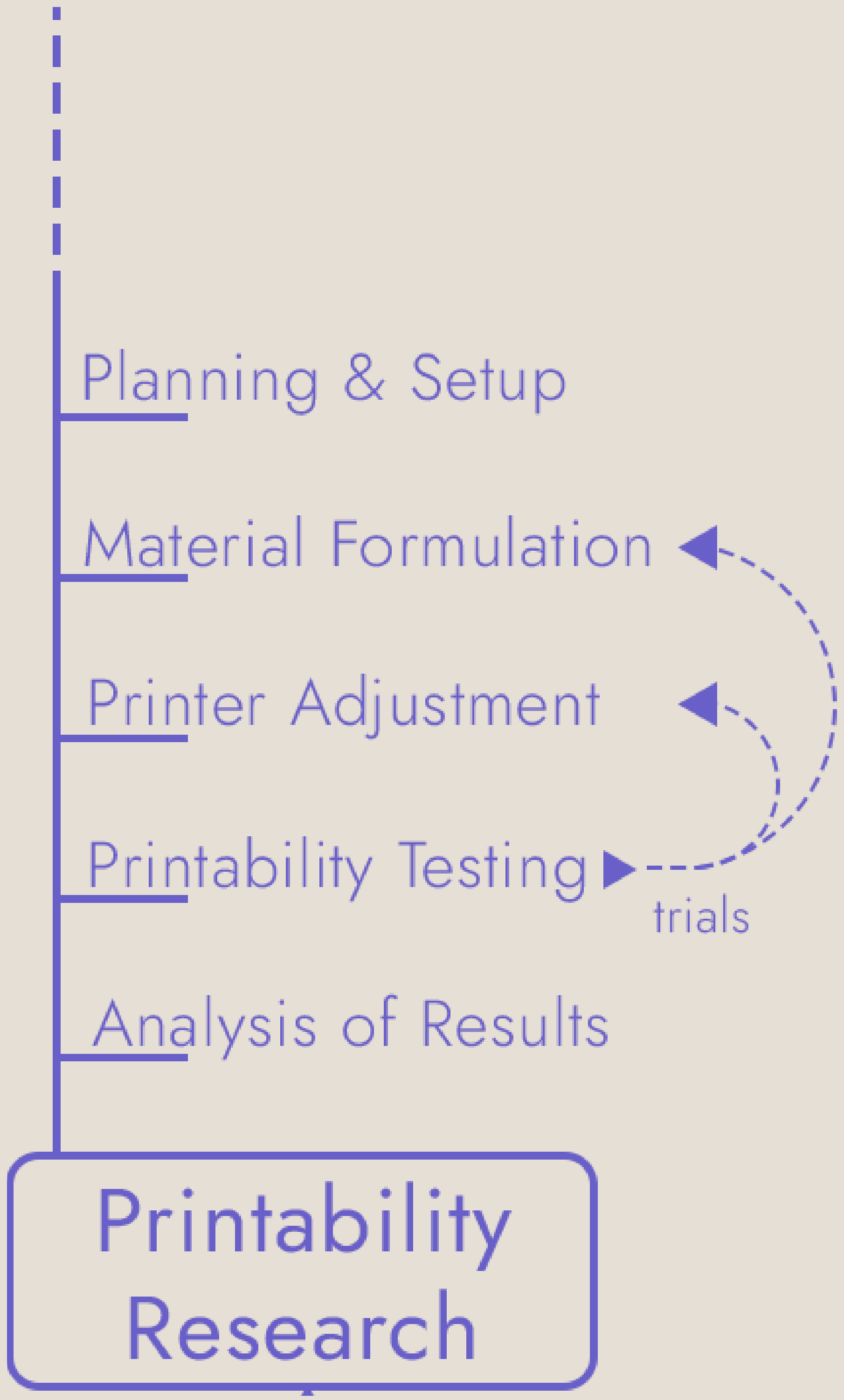






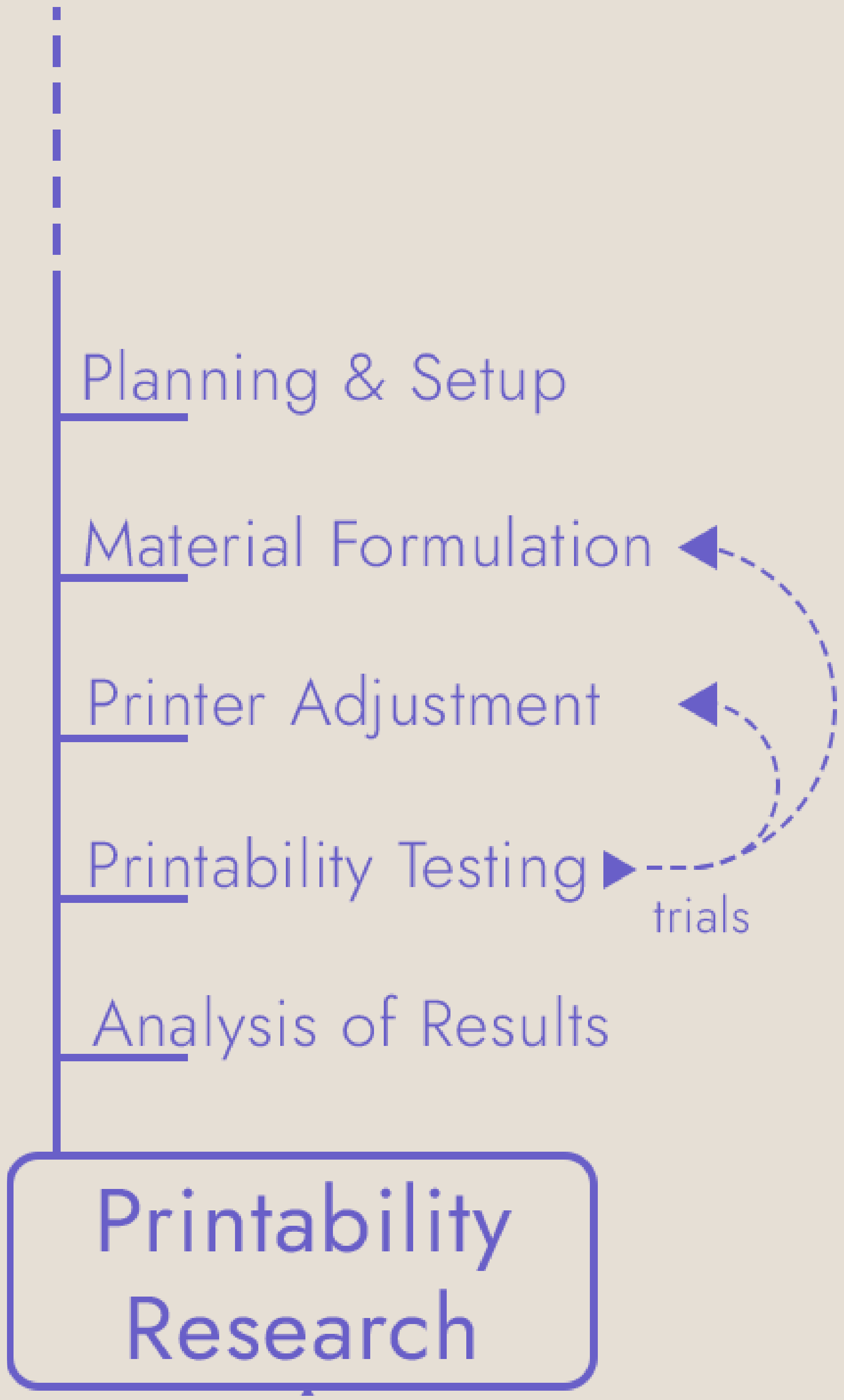
03

HOW

WAS IT DONE

PRINTABILITY RESEARCH

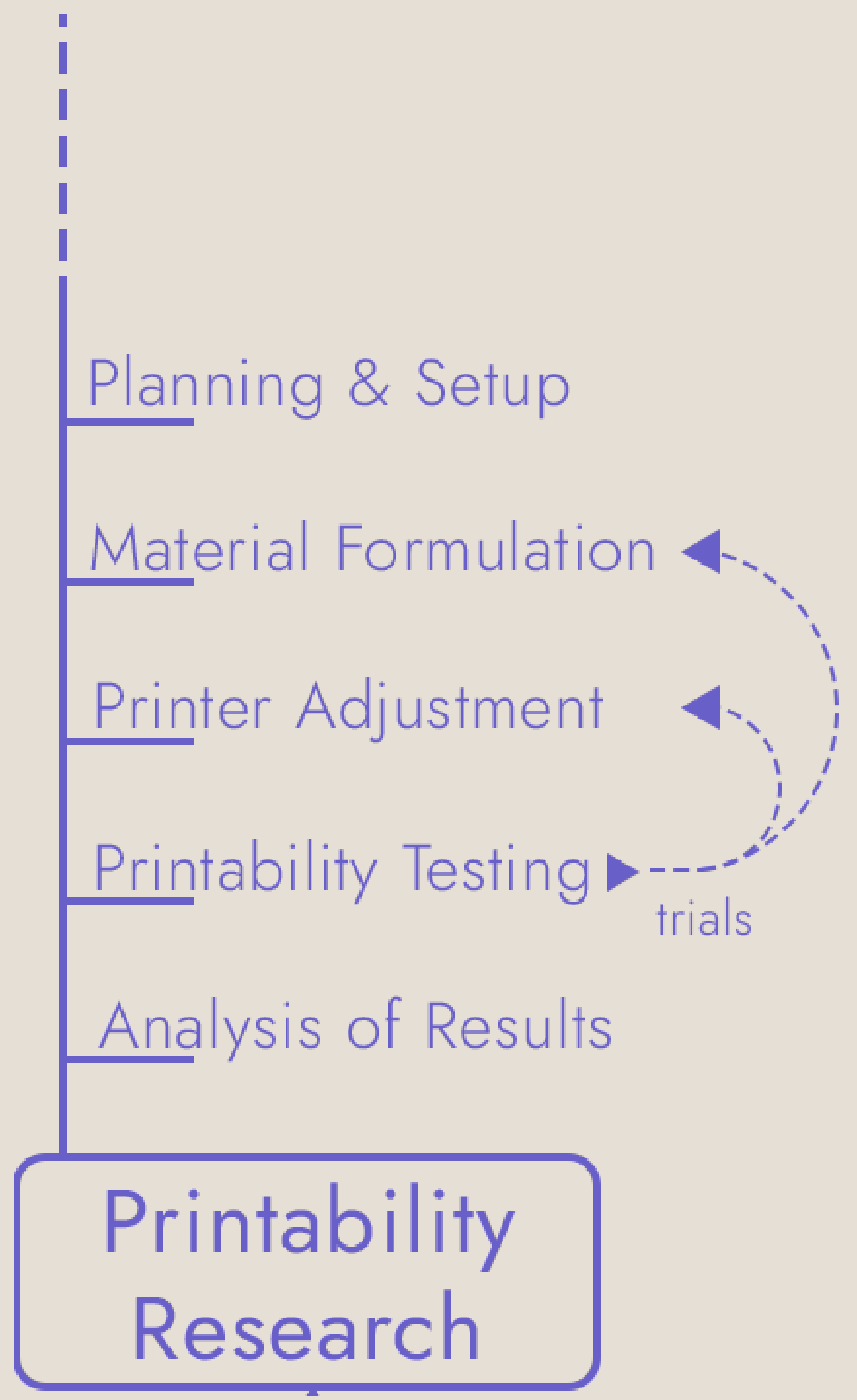
- Initial printability experiments conducted using a manually operated homemade pellet extruder at the LAMA Lab.
- Aimed to observe early strand formation behavior and evaluate flow consistency before robotic trials.
- Materials were pre-melted on a hotplate or oil bath, then manually extruded through a nozzle into simple test paths.
- Early tests helped identify visible defects like clumping, nozzle blockage, and premature stiffening.
- Observations from LAMA trials guided the refinement of material moisture control, pellet shape, and thermal tuning.



03 **HOW**

WAS IT DONE

PRINTABILITY RESEARCH



03

HOW

WAS IT DONE

PRINTABILITY RESEARCH

- Ensured fiber-to-binder ratios matched final mechanical testing set: A (21:14), B (30:5), C (25:10).
- Verified pellet surface quality, residual moisture, and mechanical consistency before trials.
- Performed oven-drying pre-tests at 60°C to improve strand consistency during robotic feeding.
- Manually pre-mixed batches using primer blend (glycerol + citric acid) to enhance adhesion during print.

03

HOW

WAS IT DONE

PRINTABILITY RESEARCH

Planning & Setup

Material Formulation

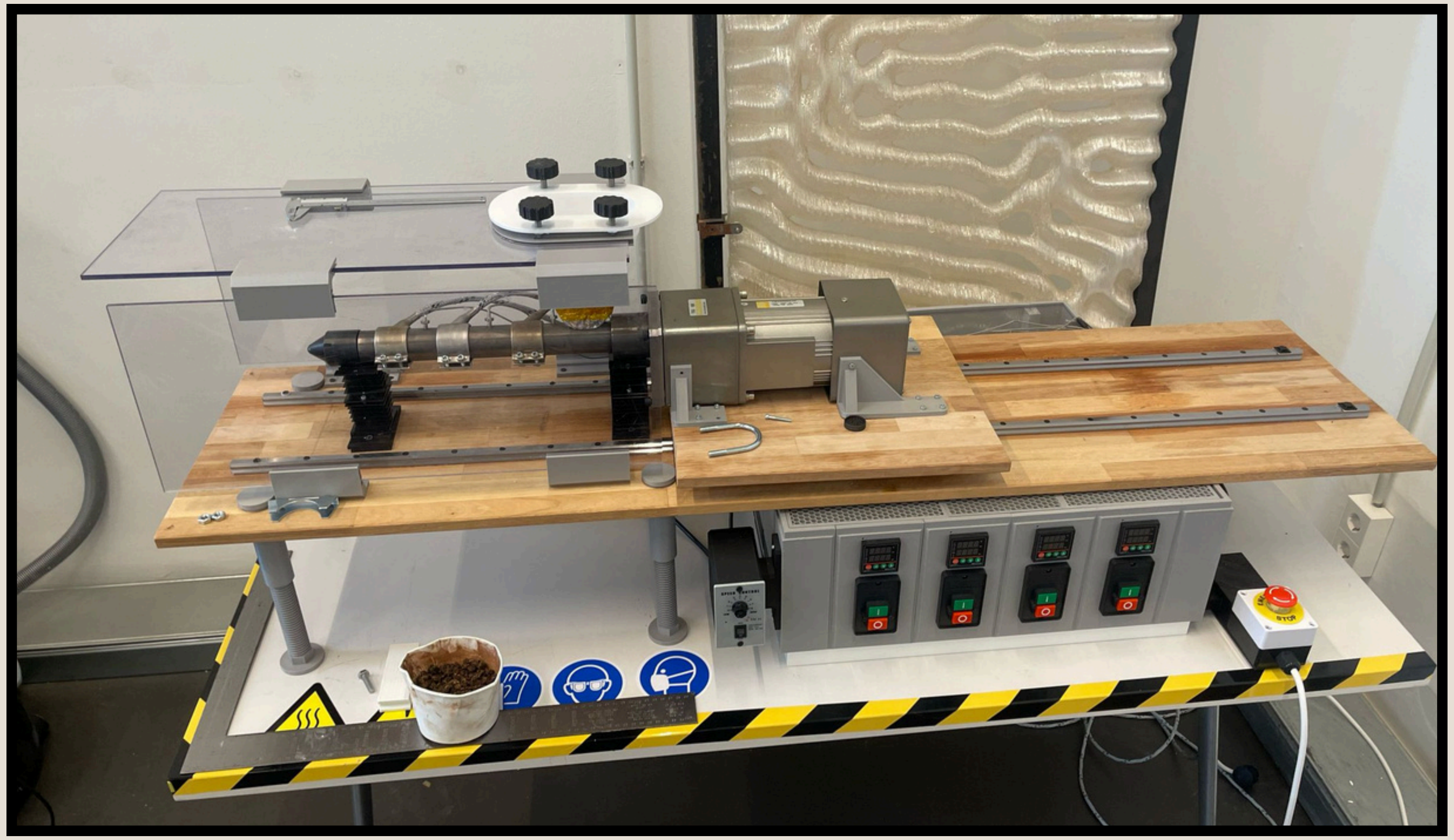
Printer Adjustment

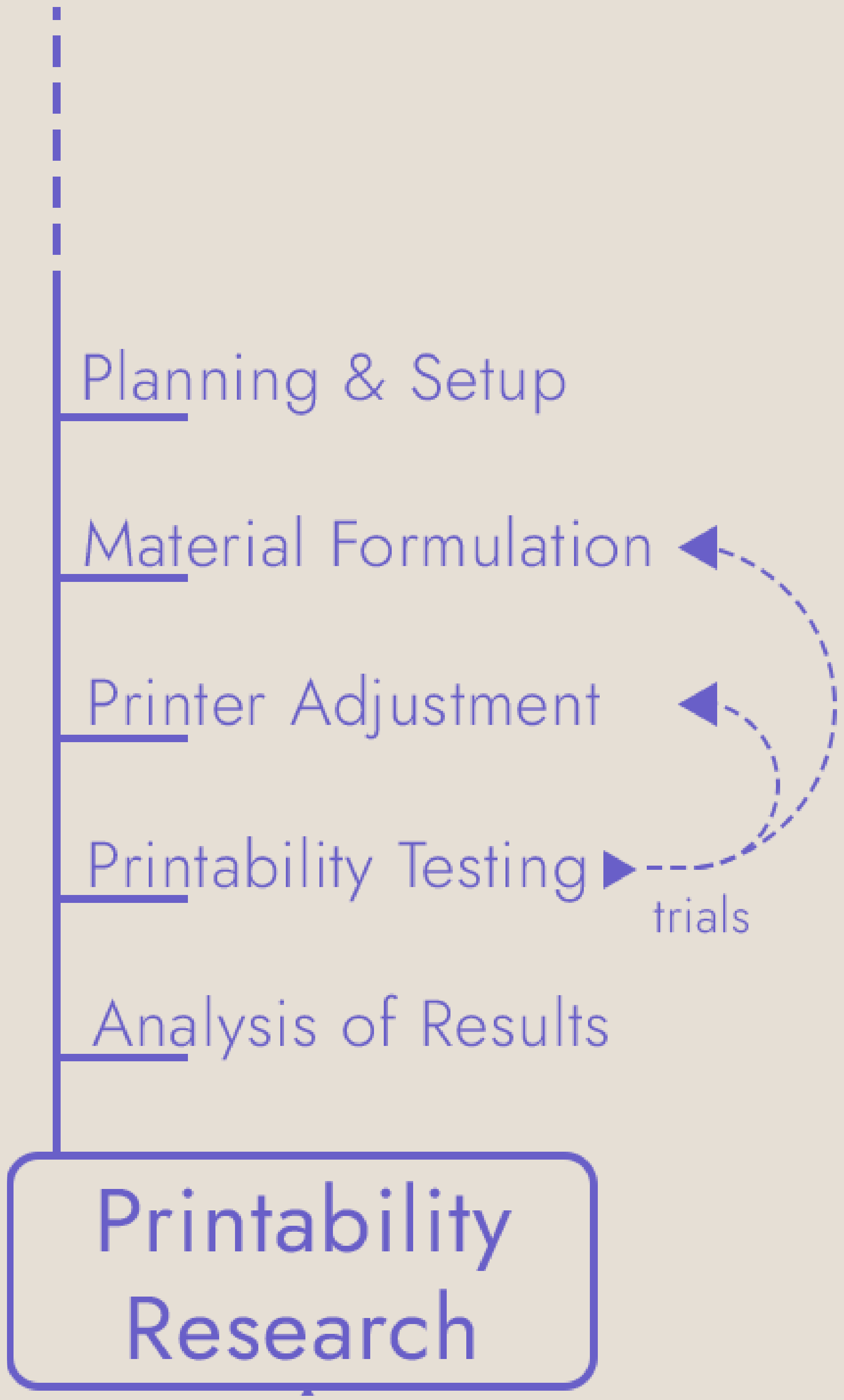
Printability Testing

trials

Analysis of Results

Printability Research





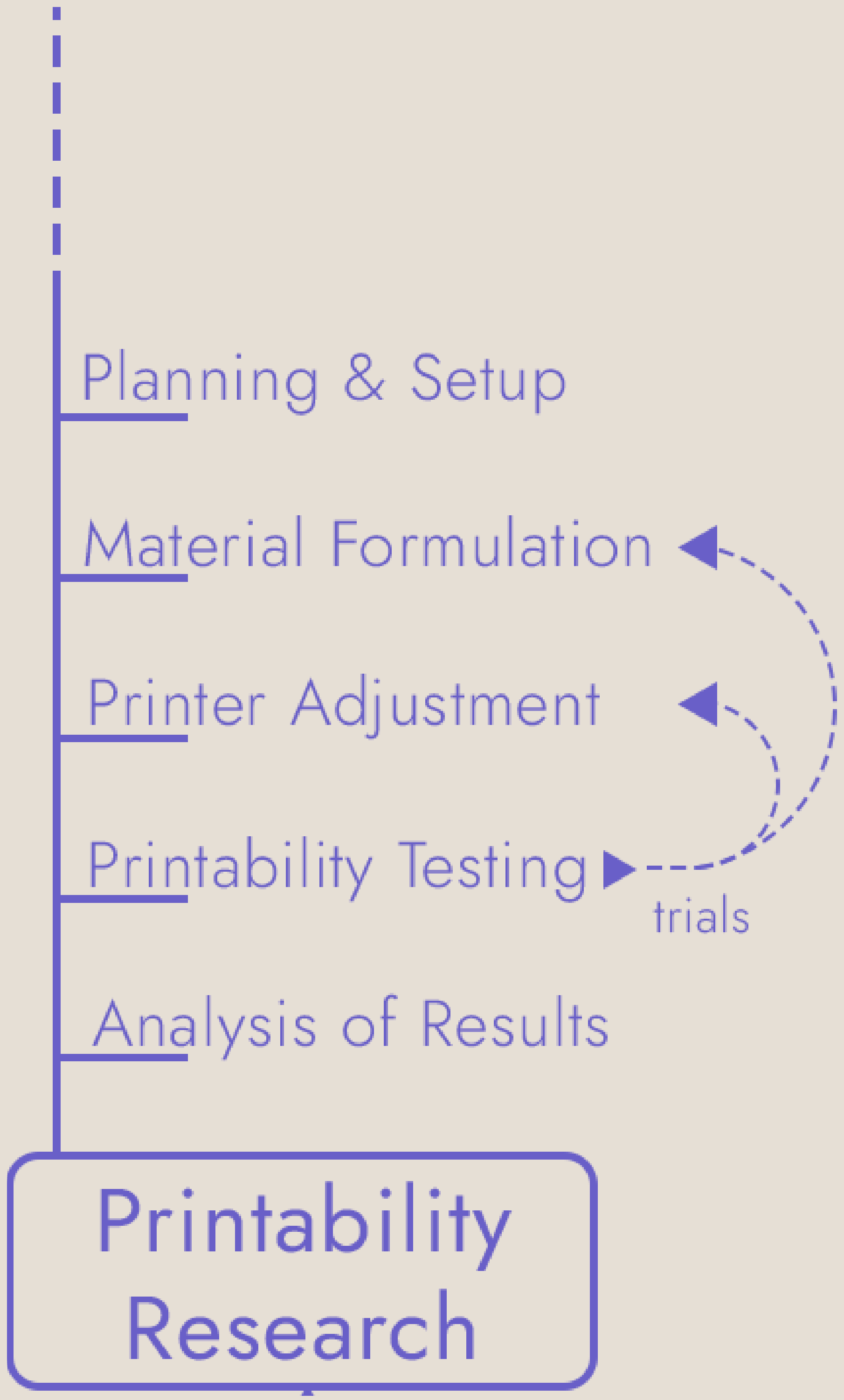
03

HOW

WAS IT DONE

PRINTABILITY RESEARCH

- Calibrated print head temperature and extrusion rate to match the melting range of PHA (~145-160°C).
- Modified robotic speed and nozzle distance to account for differences in material flow per mix.
- Adjusted feeder pressure and timing to minimize strand thinning and snapping.
- Maintained consistent substrate conditions (surface temperature, material, and flatness).



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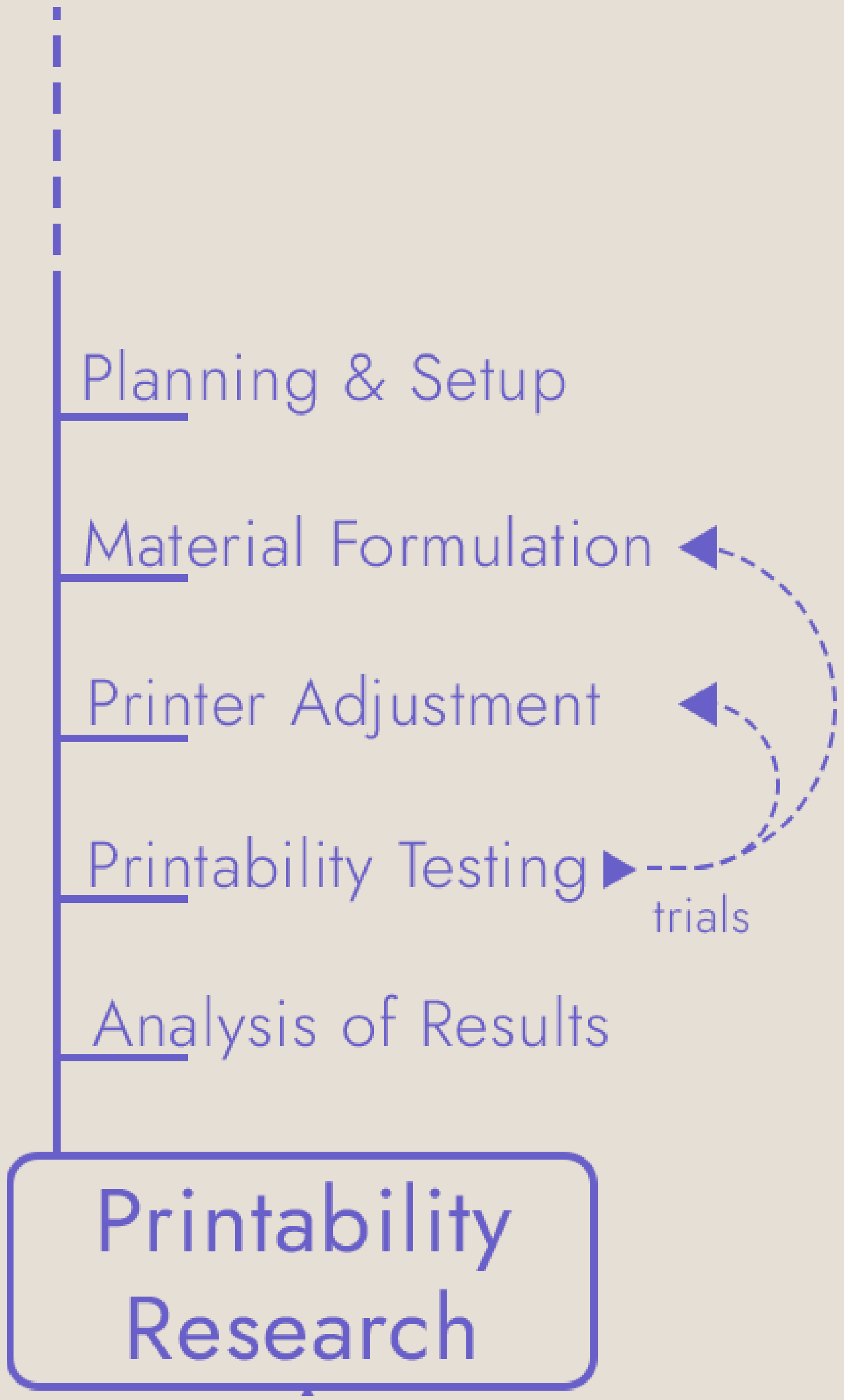
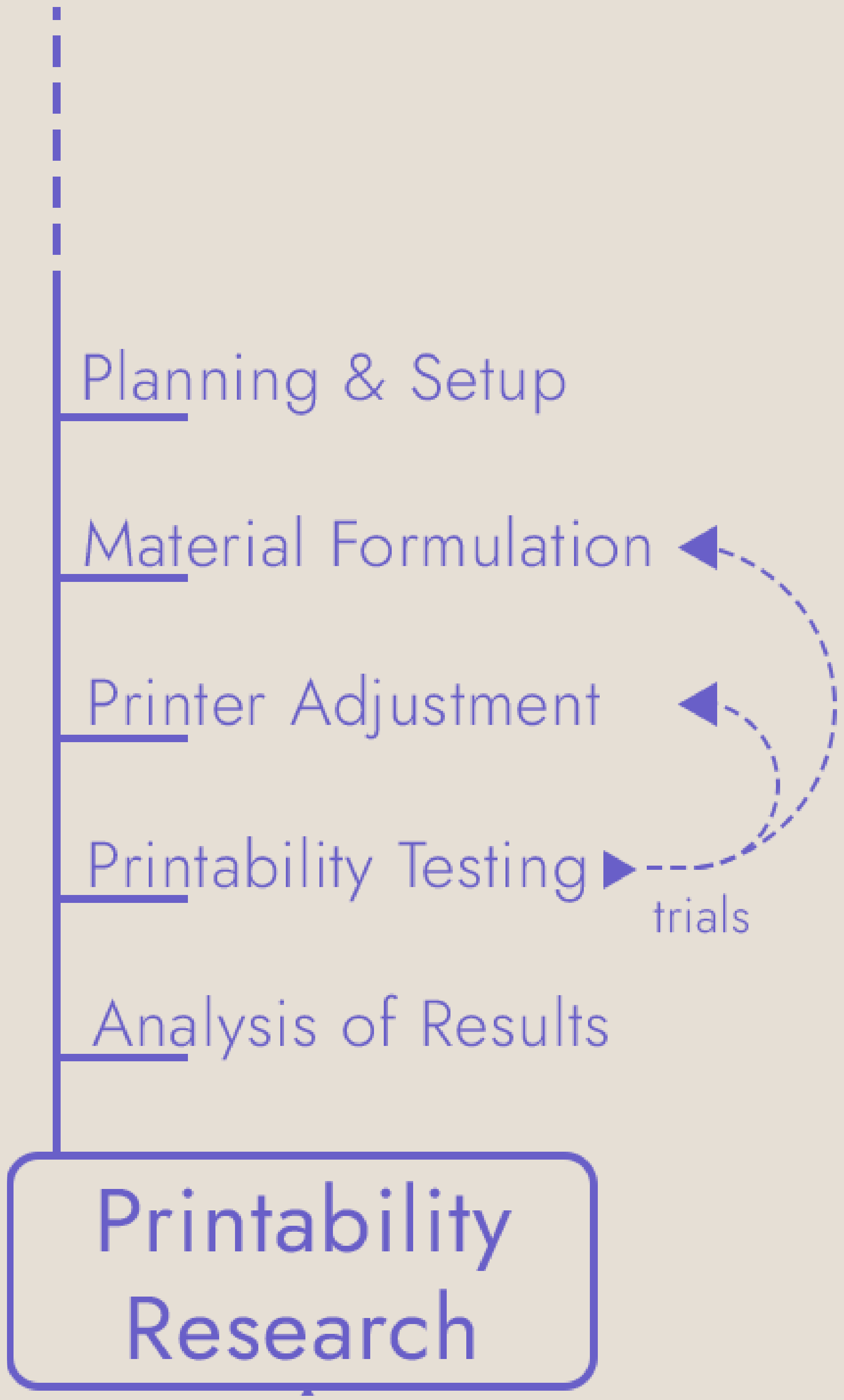




03

HOW

WAS IT DONE

PRINTABILITY RESEARCH

- Conducted controlled robotic extrusion trials using CEAD E25 nozzle and standardized test path.
- Observed strand continuity, start/stop behavior, adherence to substrate, and curling or detachment.

03

HOW

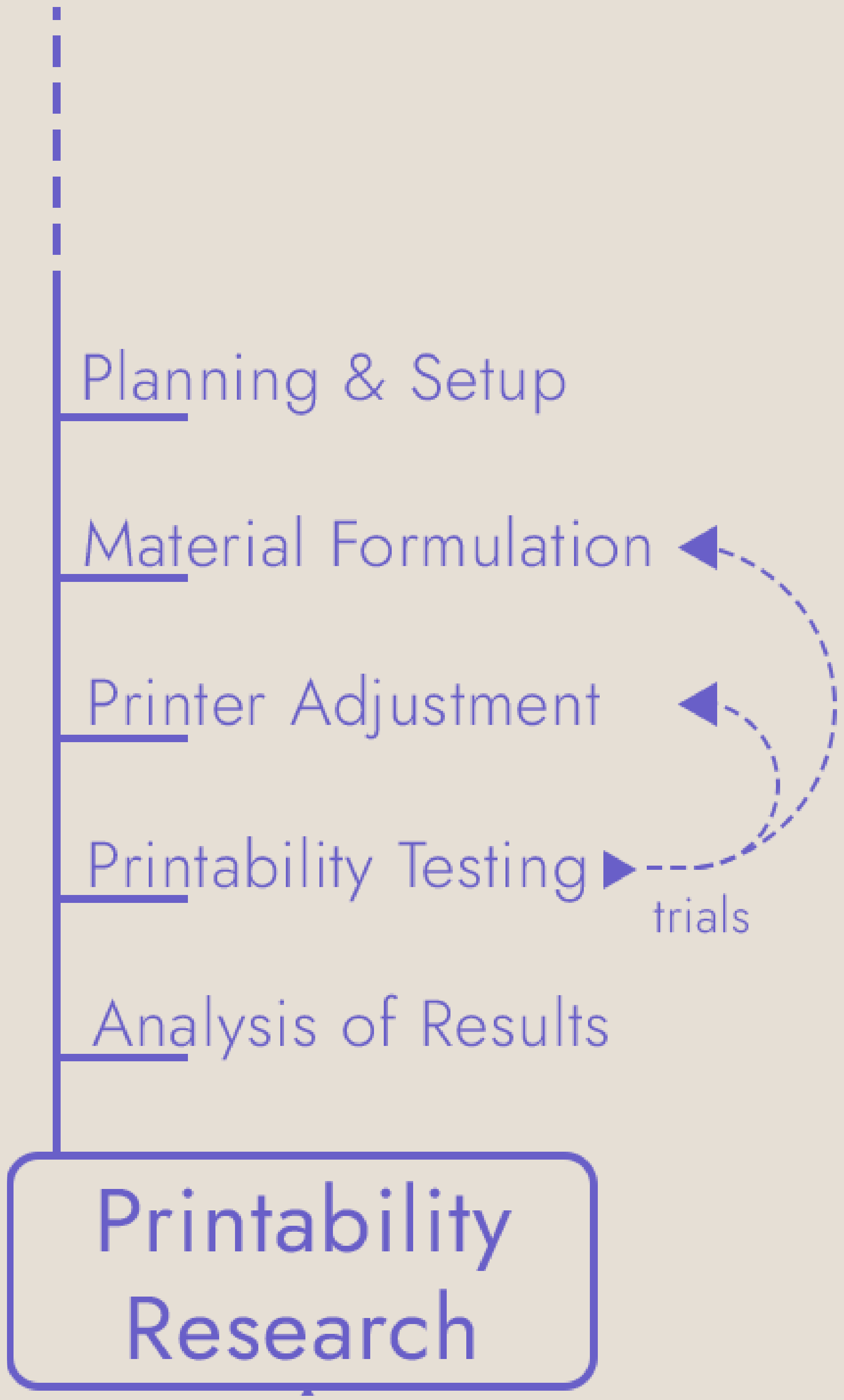
WAS IT DONE

PRINTABILITY RESEARCH

- Planning & Setup
- Material Formulation
- Printer Adjustment
- Printability Testing
- Analysis of Results

trials

Printability Research



03 HOW

WAS IT DONE

PRINTABILITY RESEARCH

- Mixture A showed the best print performance: smooth, continuous flow and strong layer bonding.
- Mixture B printed well but showed slight edge curling, indicating higher shrinkage or lower flow.
- Mixture C had increased stiffness and higher viscosity, leading to nozzle blockage risks in long runs.
- Results inform slicing parameter decisions (speed, cooling, extrusion width) for strength-zoned printing.

Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES

- Defined the goal: validate mechanical behavior across three composite ratios reflecting low, medium, and high structural performance.
- Selected tensile testing as primary method, with complementary compression tests for architectural relevance.
- Produced standardized filaments using homemade pellet extruder at LAMA Lab (160-180°C).
- Specimen length fixed at 95 mm; diameter measured at 5-8 locations per sample (excluding ends) to calculate accurate cross-sectional area.

Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES

Mechanical Properties

- Planning & Preparation
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- Strength Grading
- Analysis of Results

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WAS IT DONE

MECHANICAL PROPERTIES

Mechanical Properties

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03

HOW

WAS IT DONE

MECHANICAL PROPERTIES

- Conducted tensile tests using a 10 kN load cell at the Mechanical Engineering Faculty (Fred Veer’s lab).
- Followed ISO 527 (adapted for bio-based filaments); gauge length set to 18.10 mm; crosshead speed ~0.19 mm/min.
- Strain measured via displacement transducer, with each formulation tested across multiple replicates.
- Material preparation and extrusion conditions were controlled but inherently variable due to experimental setup.

Mechanical Properties

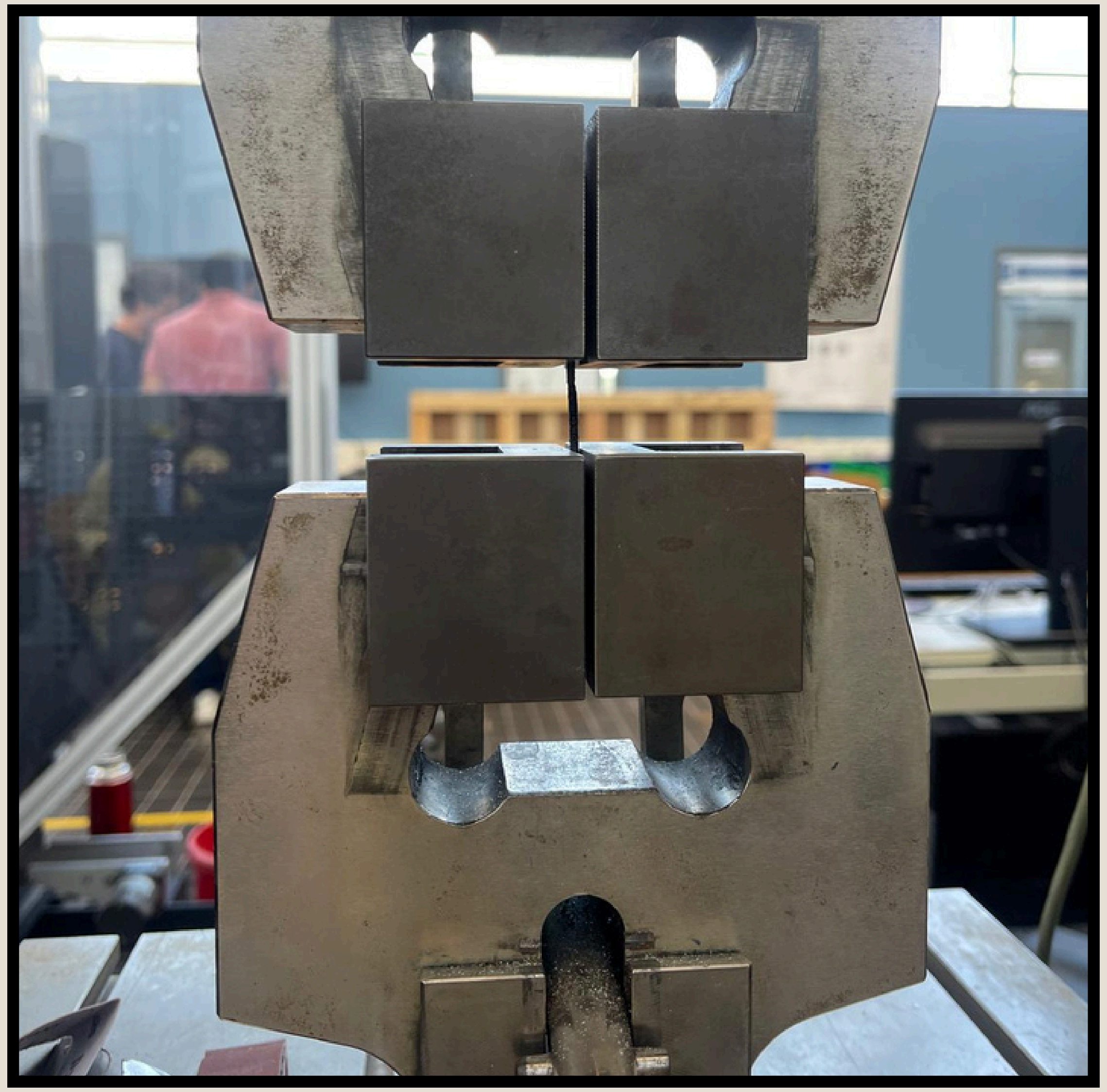
- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES



Mechanical Properties

- Planning & Preparation
- Mechanical Testing
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- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES

Group	Diameter (mm)	Area (mm²)	Max Force (N)	UTS (MPa)	Young's Modulus (MPa)	Strength Grade
A (14% L / 21% C)	2.3	4.15	41.52	9.99	6.55	Low
B (25% L / 10% C)	2.5	4.91	52.81	10.76	13.19	Medium
C (5% L / 30% C)	2.6	5.31	55.64	10.48	5.9	High

Mechanical Properties

- Planning & Preparation
- Mechanical Testing
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03

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MECHANICAL PROPERTIES

Mechanical Properties

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HOW

WAS IT DONE

MECHANICAL PROPERTIES

Group A (14% L / 21% C)

- Despite having a higher cellulose content than Group B, Group A recorded the lowest average UTS (9.99 MPa) and a moderate Young's modulus (6.55 MPa). Its strain at break (6.61) was relatively high, but the stress-strain curves exhibited significant variability in failure modes. The inconsistency between specimens suggests that Group A's printability or fiber dispersion may have been suboptimal, leading to unreliable performance across samples.

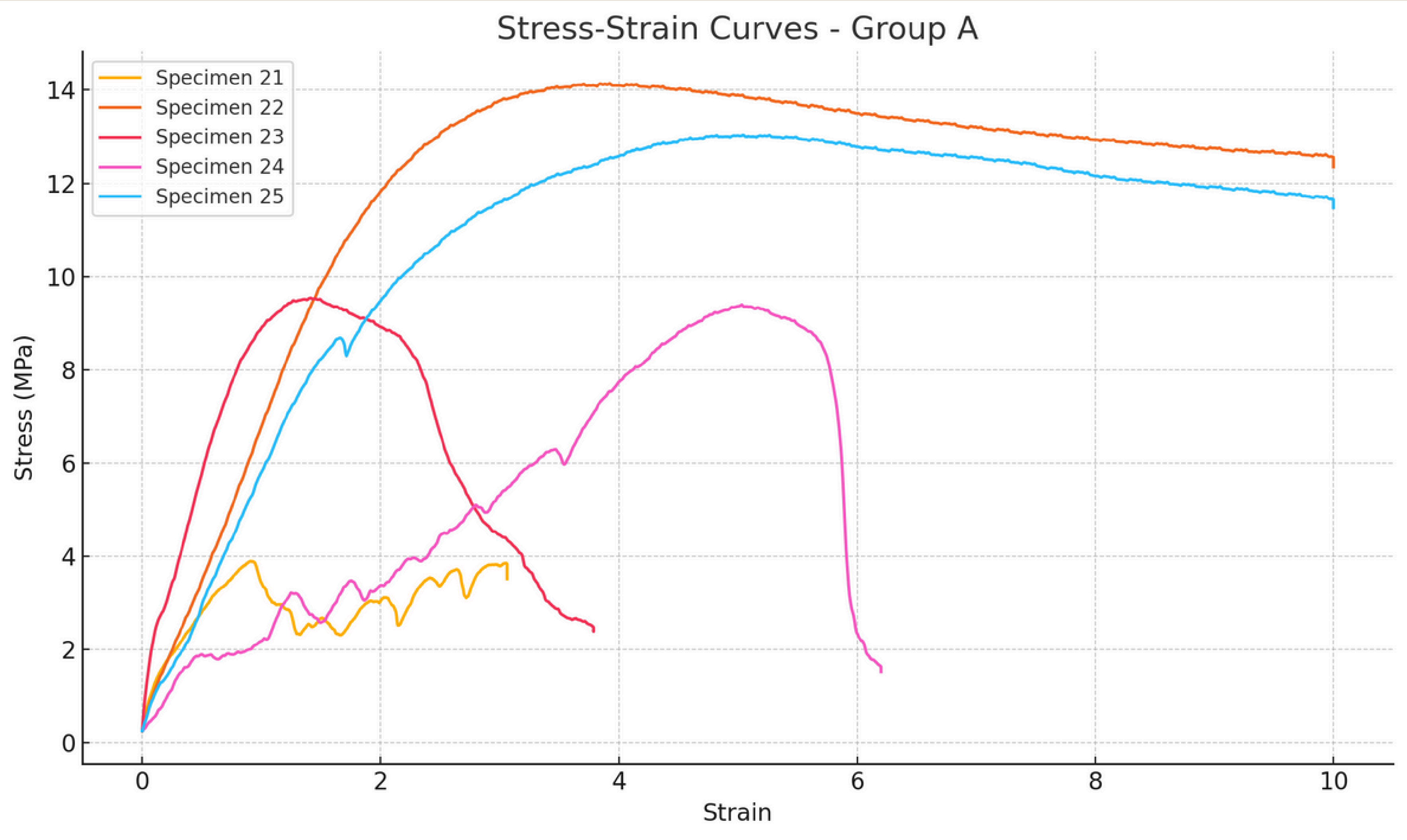
03 HOW

WAS IT DONE

MECHANICAL PROPERTIES

Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results



Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES

Group B (25% L / 10% C)

- Demonstrated the highest average UTS (10.76 MPa) and the stiffest response (Young's modulus: 13.19 MPa), but it also had the lowest strain at break (4.26). The stress-strain curves indicate predominantly brittle behavior, with several specimens failing suddenly after short elongation. The high lignin content may have contributed to stronger interfacial bonding during extrusion, it also reduced ductility and increased variability. Overall, appears strong but brittle.

Mechanical Properties

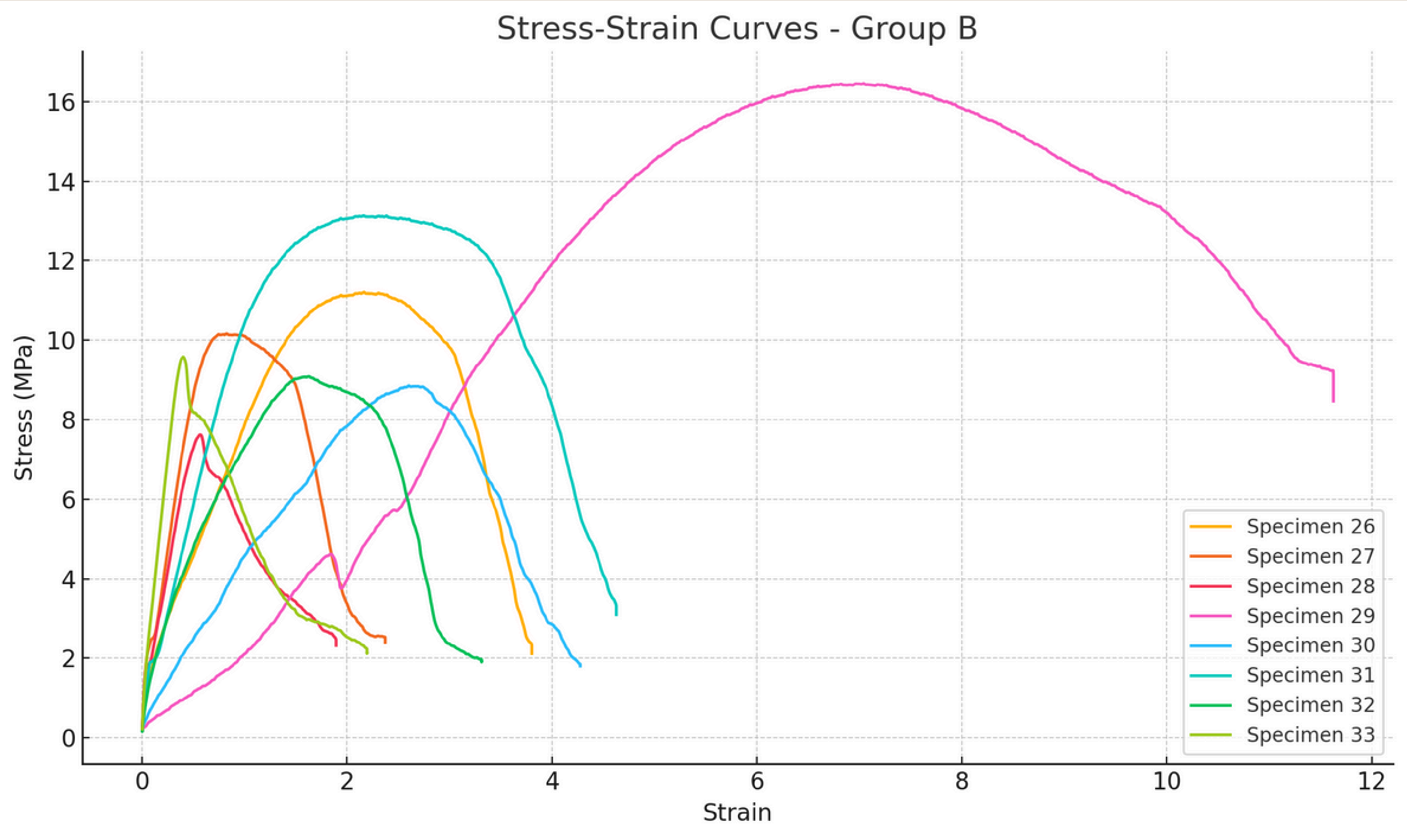
- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03

HOW

WAS IT DONE

MECHANICAL PROPERTIES



Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03 HOW

WAS IT DONE

MECHANICAL PROPERTIES

Group C (5% L / 30% C)

- Although it did not reach the highest UTS (10.48 MPa), it demonstrated the highest strain at break (6.73%) and the most consistent mechanical behavior among all groups. Its Young's modulus (5.90 MPa) indicates a more flexible material, and the stress-strain curves show smooth yielding and ductile failure across specimens. The high cellulose content likely contributed to better energy absorption and strain tolerance. Group C provides the best balance between strength and ductility, making it the most application-suitable formulation for modular or deformation-sensitive architectural components.

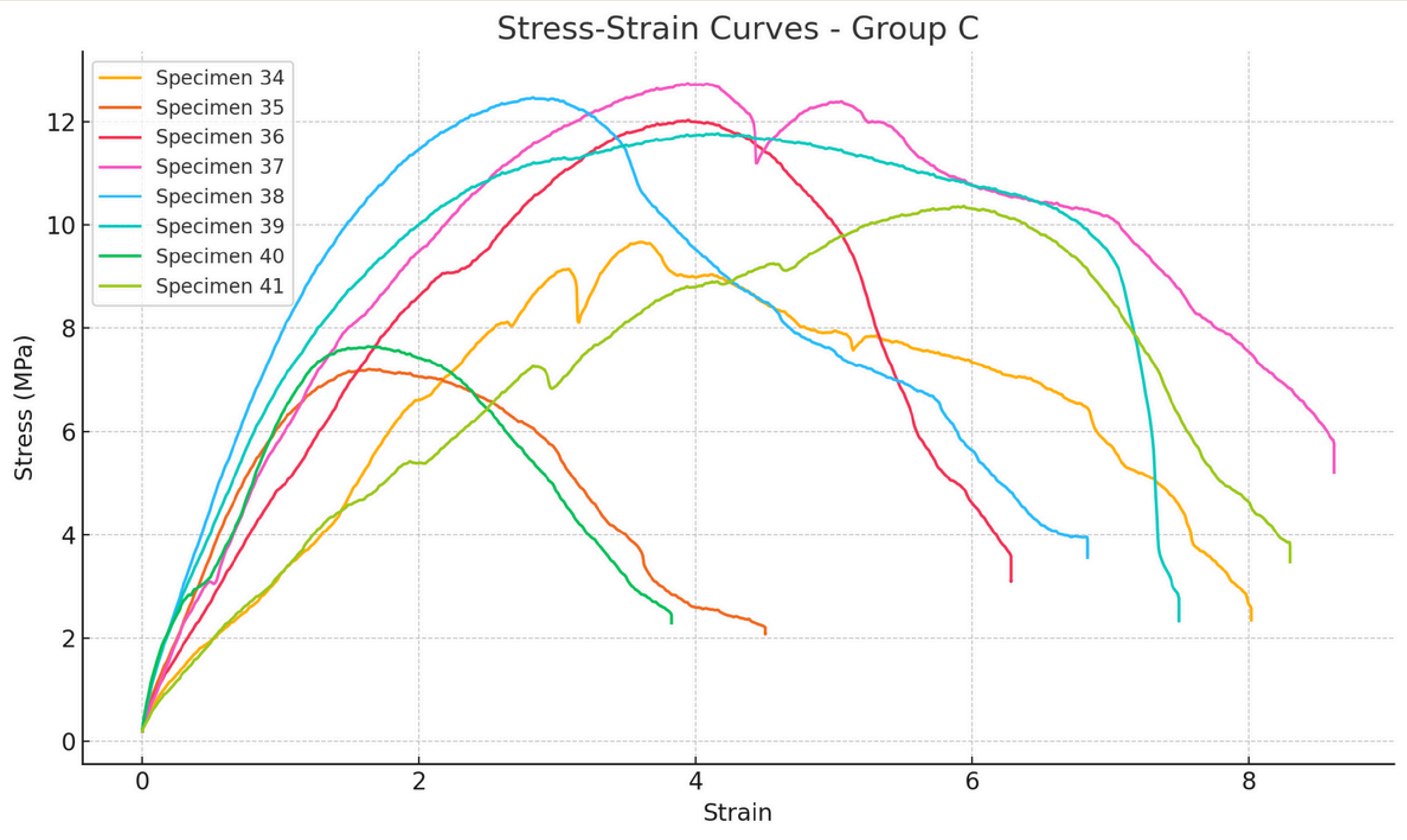
Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

03 HOW

WAS IT DONE

MECHANICAL PROPERTIES



03

HOW

WAS IT DONE

Mechanical Properties

- Planning & Preparation
- Mechanical Testing
- Strength Grading
- Analysis of Results

Material Type	Feedstock /Filler	Matrix /Binder	Tensile Strength (MPa)	Young's Modulus (MPa)
Group A	14% Lignin / 21% Cellulose	PHA + glycerol/citric	9.9	6.5
Group B	25% Lignin / 10% Cellulose	PHA + glycerol/citric	10.7	13.1
Group C	5% Lignin / 30% Cellulose	PHA + glycerol/citric	10.4	6
PLA	Corn/ sugarcane starch	Thermoplastic	50–70	3000–3500
Wood–PLA (WPC)	Wood flour	PLA	20–40	1500–3000
Lignin–PLA	10–30% Lignin	PLA	25–35	1200–2500
Cellulose–PLA	Nano/micro cellulose	PLA	70–100	6000–10000
PHA	Bacterial fermentation	Thermoplastic	25–40	1000–1500

03 HOW

WAS IT DONE

MECHANICAL PROPERTIES

This comparative analysis highlights the mechanical performance of lignin-cellulose composites (Groups A-C) against established bioplastics like PLA, PHA, and their wood/cellulose-based hybrids.

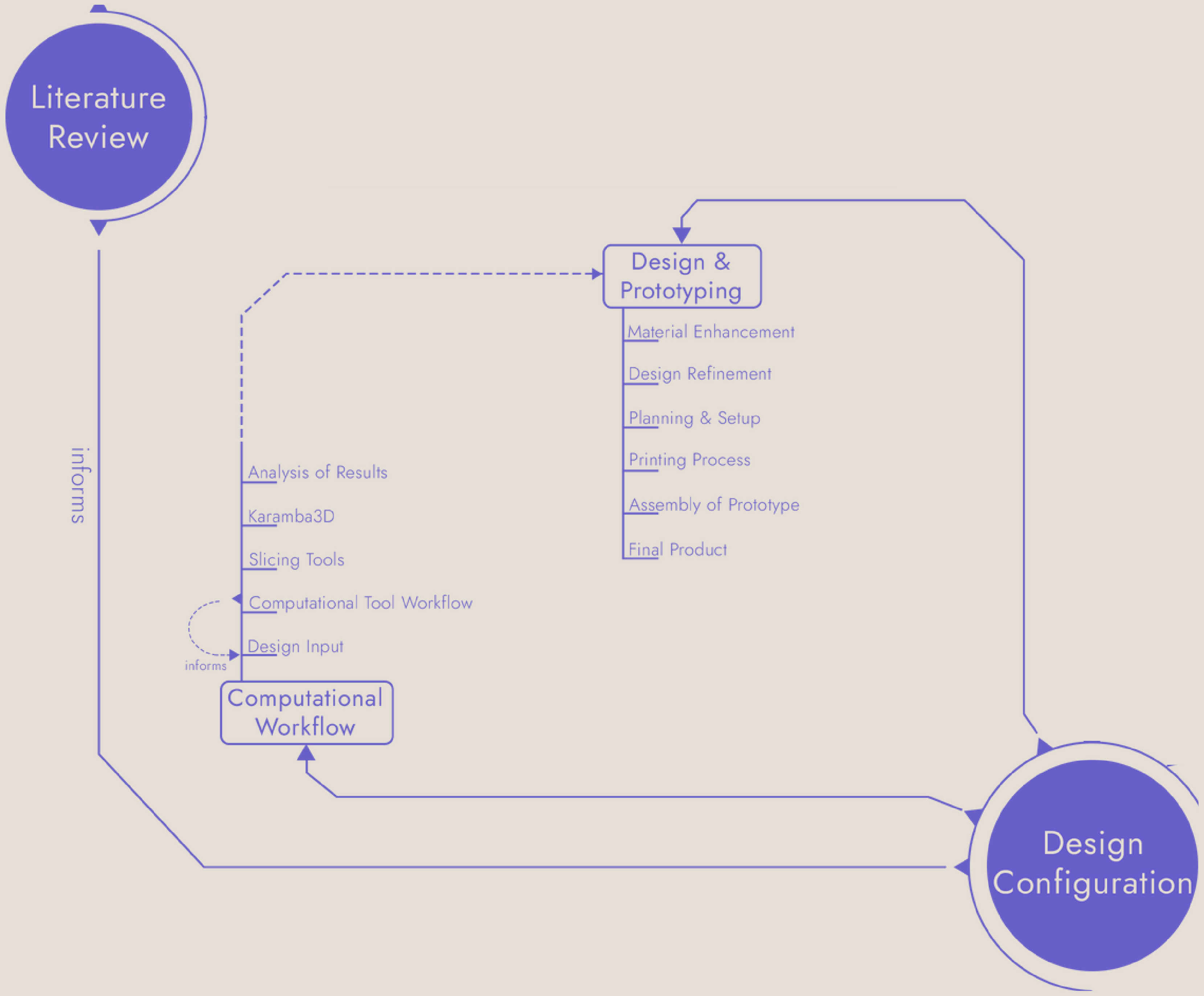
- Tensile Strength: The custom-developed biocomposites (9.9-10.7 MPa) fall well below PLA (60 MPa) or Cellulose-PLA (85 MPa). Despite this, they remain within range of commonly used WPCs and Lignin-PLA mixes (25-35 MPa), making them promising candidates for non-load-bearing architectural elements.
- Young's Modulus: With modulus values under 15 MPa, the lignin-cellulose composites are significantly more flexible than PLA-based materials (PLA: ~3250 MPa, Cellulose-PLA: up to 8000 MPa). This flexibility supports energy dissipation and crack resistance in modular components but limits their applicability in high-stiffness applications.

03

HOW

WAS IT DONE

Design Configuration

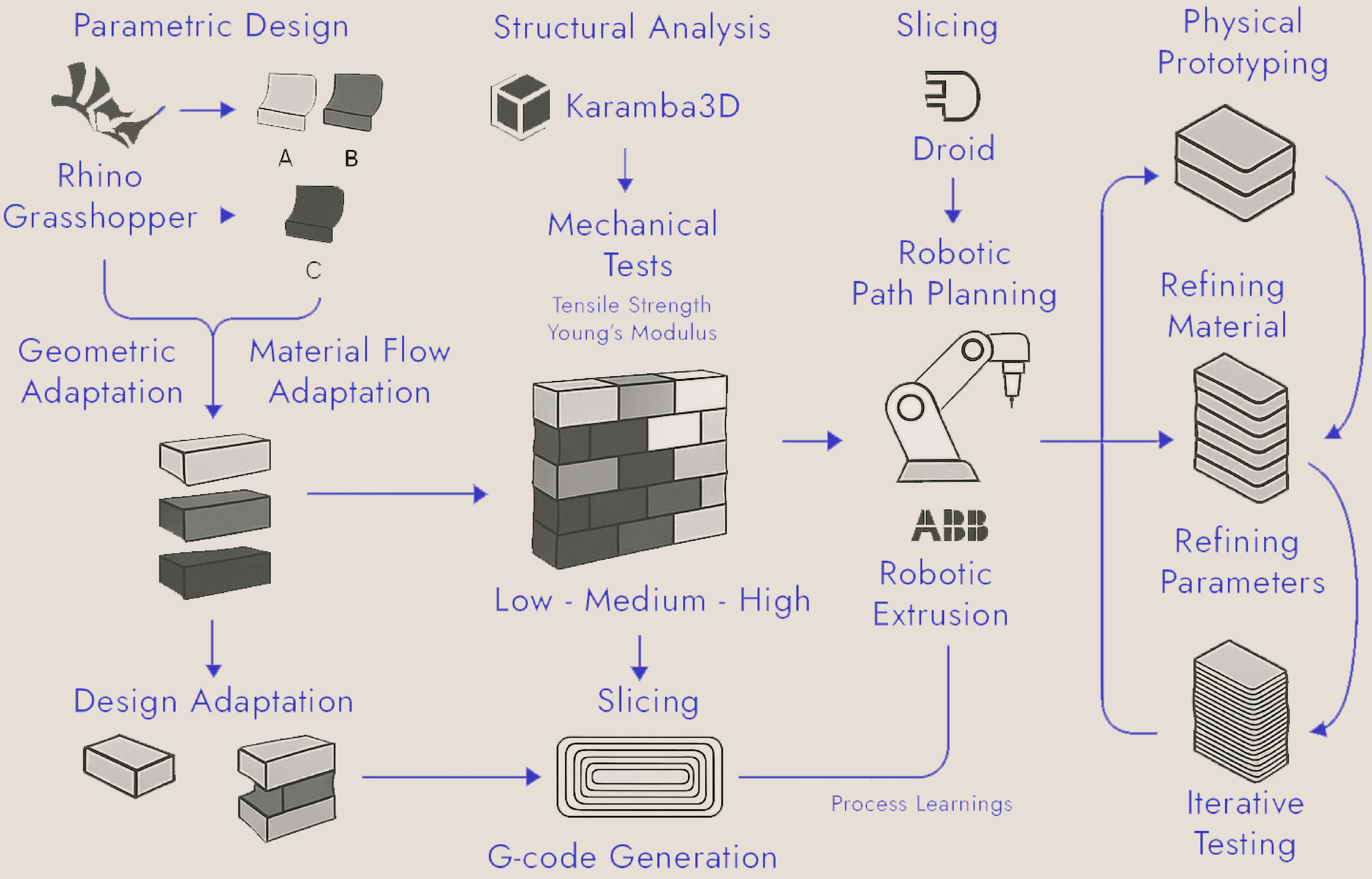


03

HOW

WAS IT DONE

DESIGN CONFIGURATION

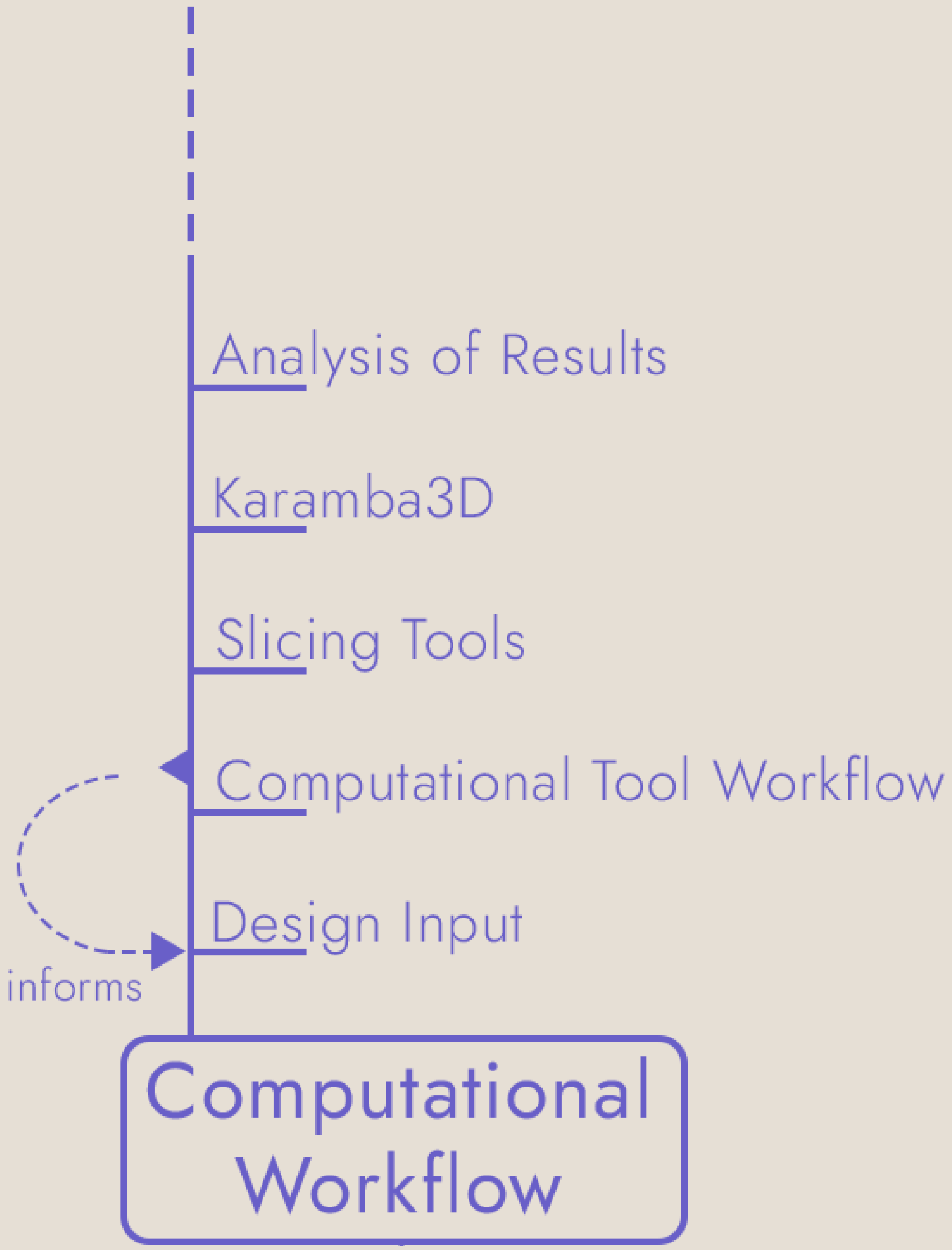

Parametric Design
Rhino
Grasshopper
A
B
C
Geometric Adaptation
Material Flow Adaptation
Design Adaptation
Structural Analysis
Karamba3D
Mechanical Tests
Tensile Strength
Young's Modulus
Low - Medium - High
Slicing
G-code Generation
Slicing
Droid
Robotic Path Planning
ABB
Robotic Extrusion
Process Learnings
Physical Prototyping
Refining Material
Refining Parameters
Iterative Testing

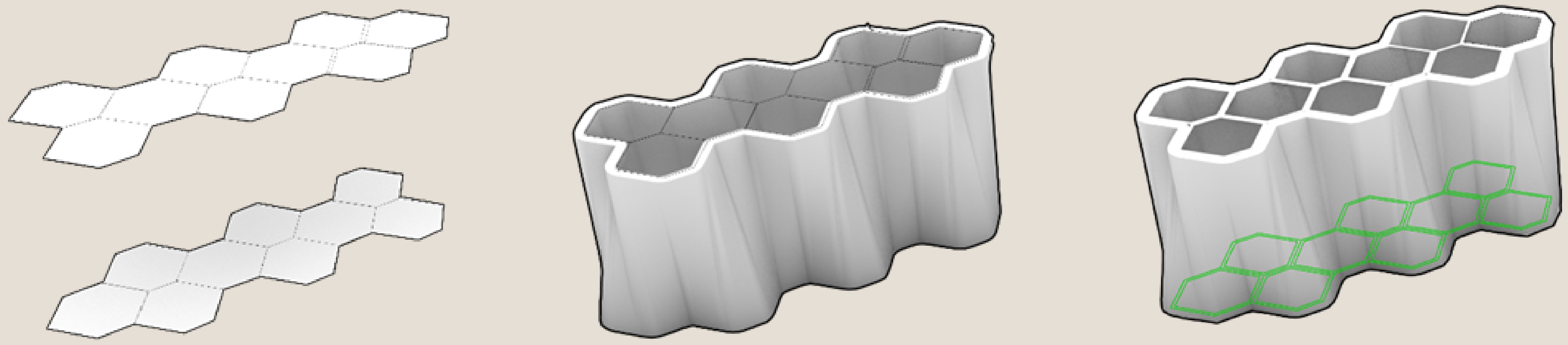
03

HOW

WAS IT DONE

DESIGN INPUT

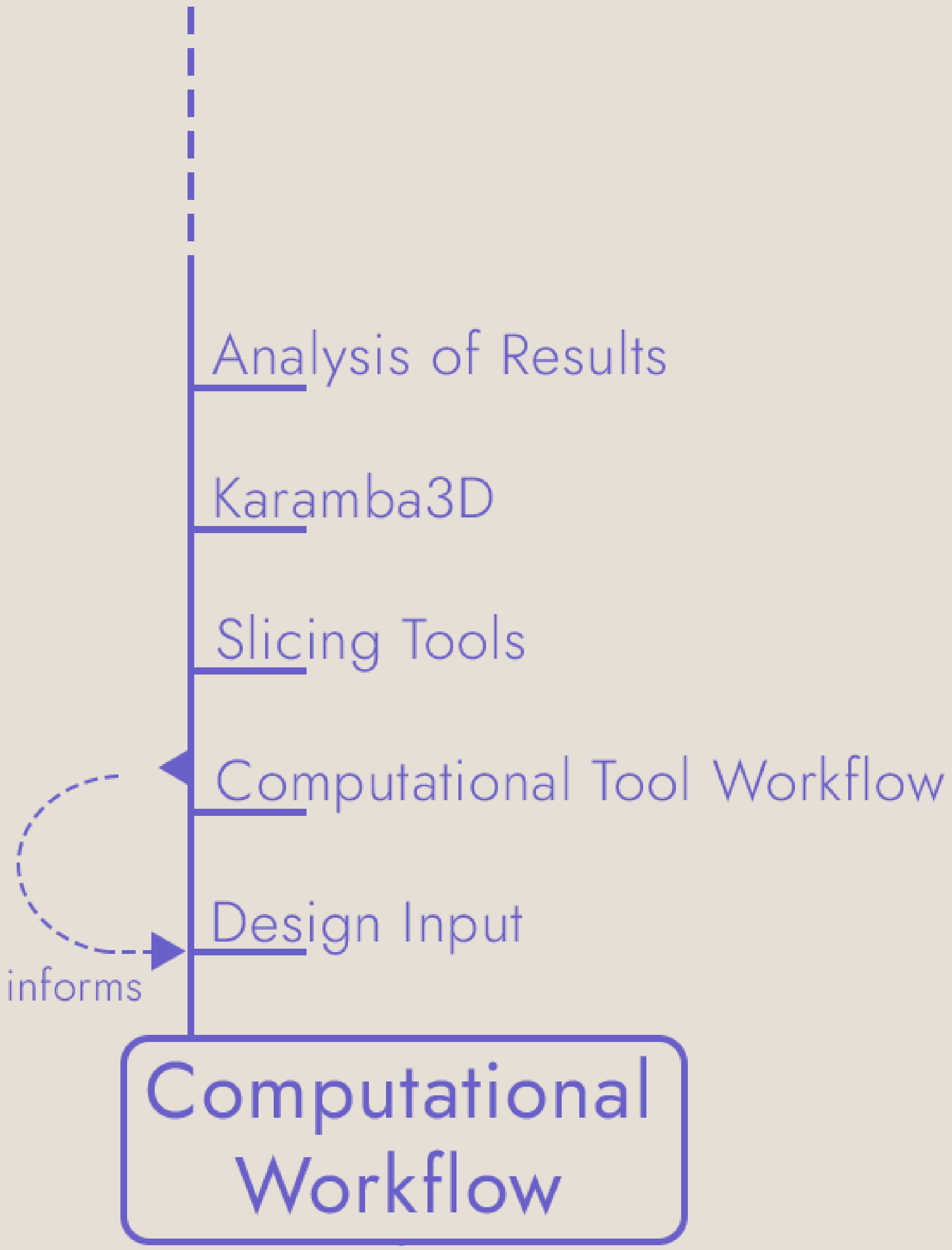


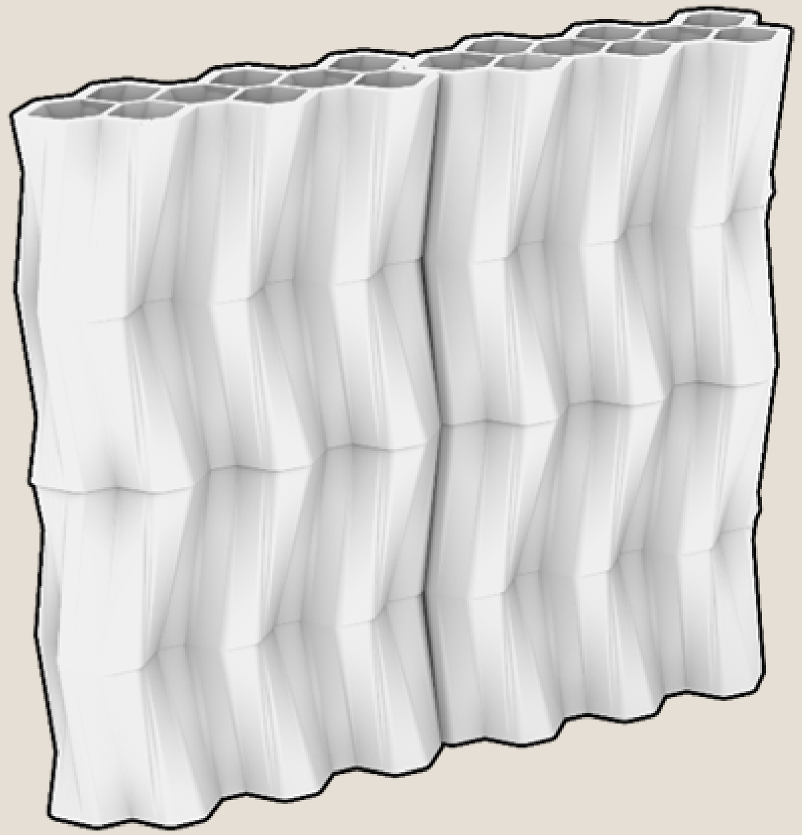


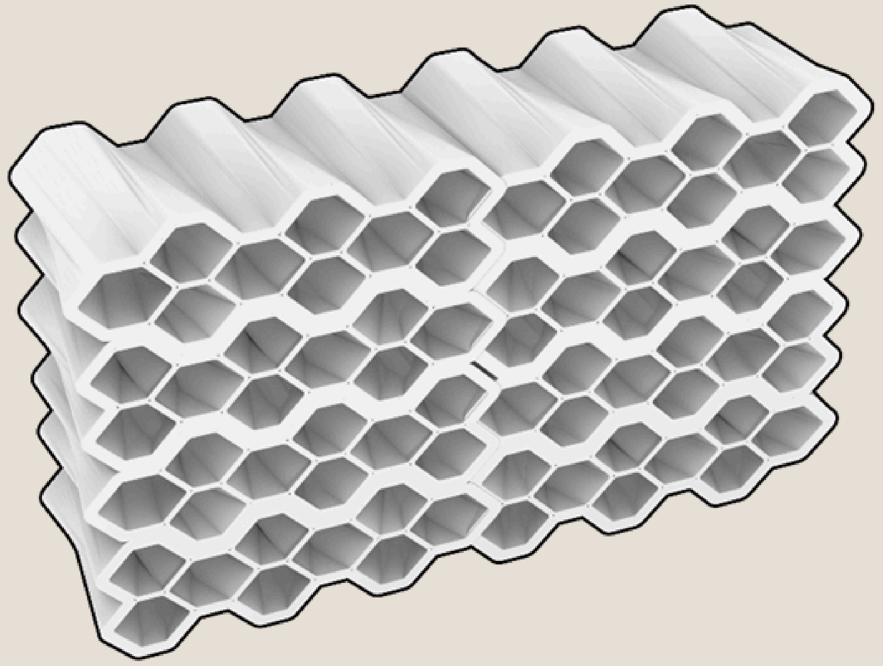
03 HOW

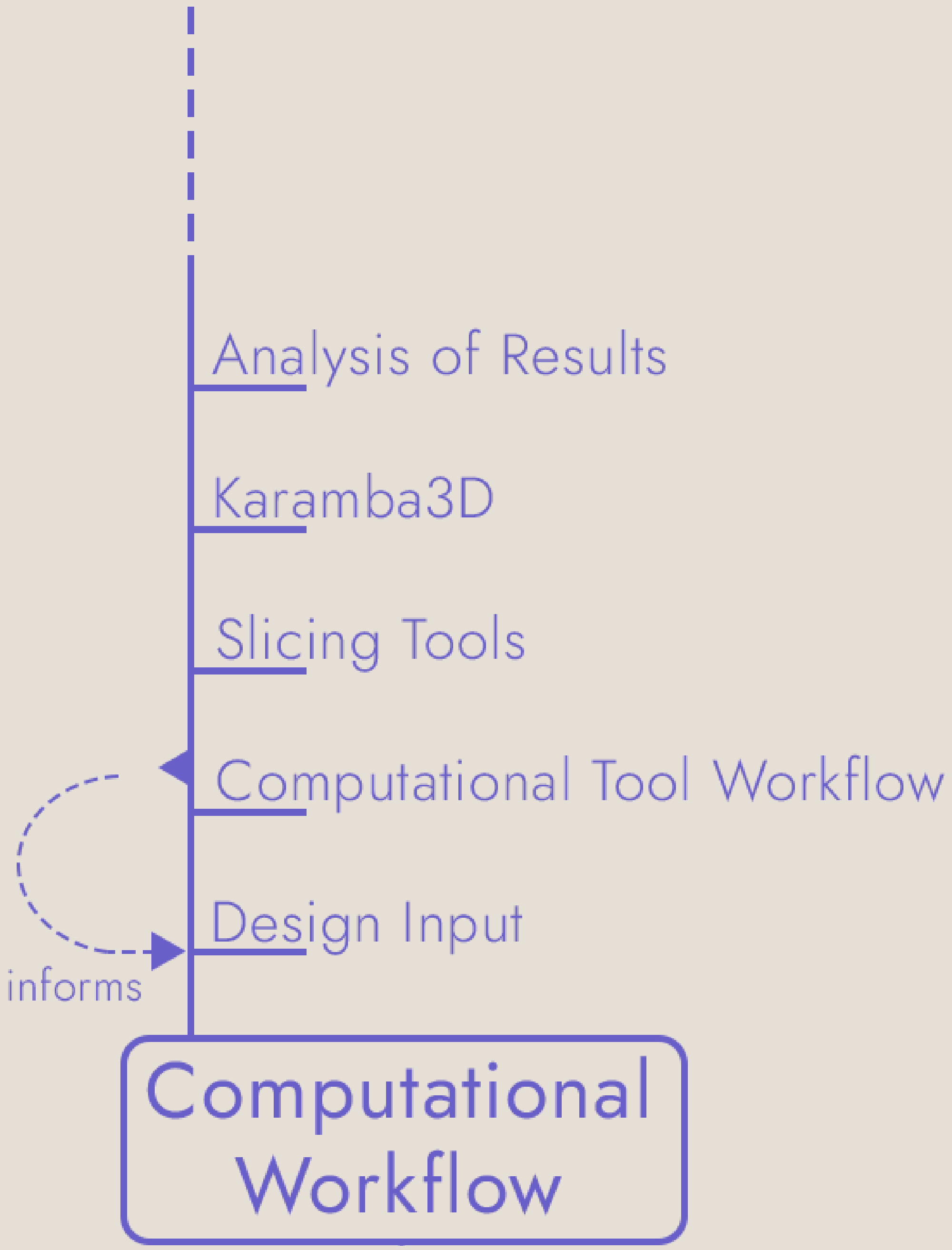
WAS IT DONE

DESIGN INPUT









03

HOW

WAS IT DONE

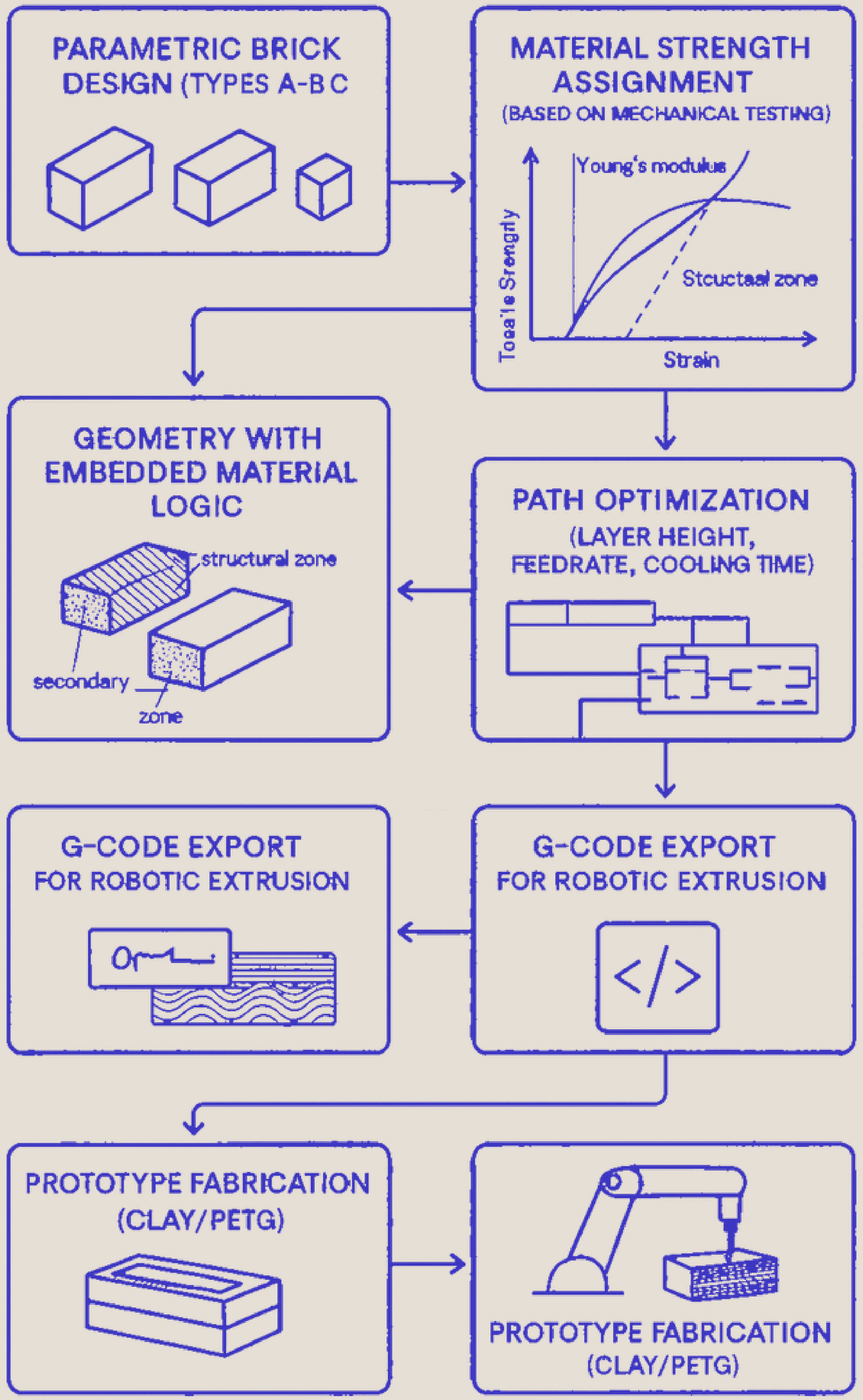
COMPUTATIONAL WORKFLOW

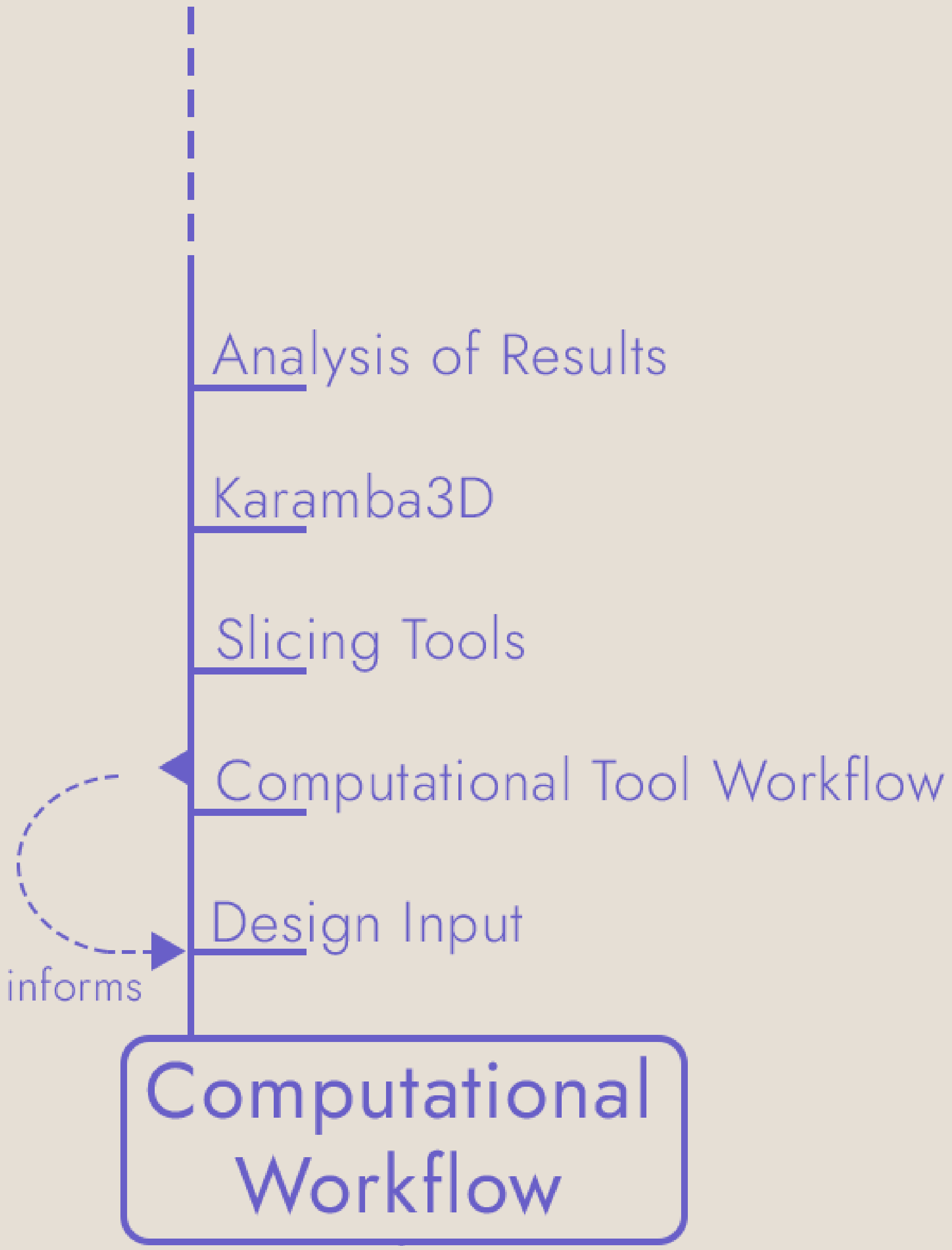
- Built a custom Grasshopper workflow integrating design geometry, strength assignment, slicing, and robot path logic.
- Used structured data trees to assign material labels (A, B, C) to each brick instance based on its spatial location.
- Included adjustable parameters for robotic constraints like orientation, reachability, and base placement.
- Ensured full integration from parametric layout to robot-ready toolpaths.

03 HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW





03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

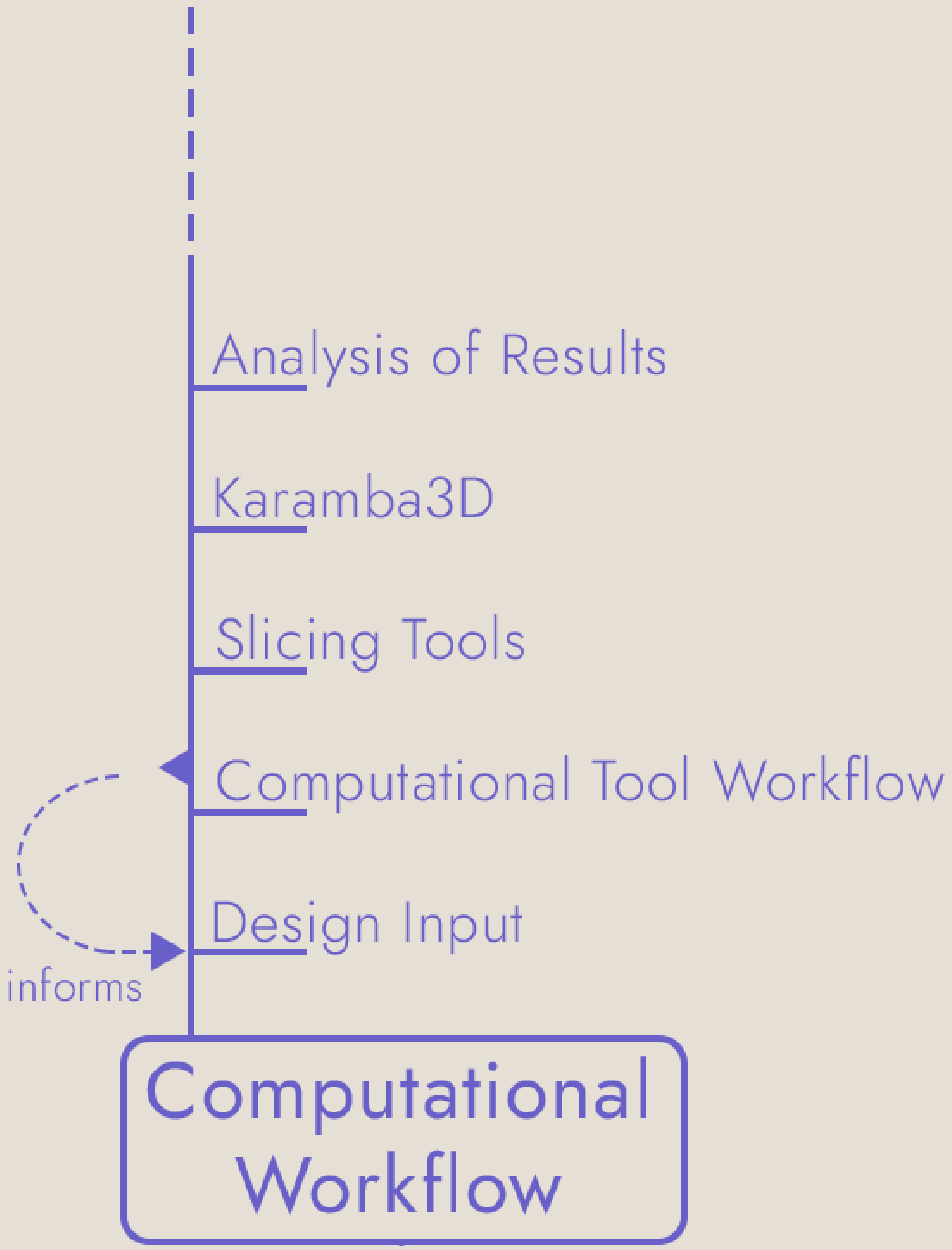
- Four slicing tools assessed: Droid, Termite, Silkworm, and COMPAS.
- Purpose: convert digital brick geometries into extrusion-ready robotic toolpaths.
- Selection criteria included:
  - Compatibility with pellet extrusion
  - Control over layer height, speed, toolpath continuity
  - Ability to generate robot-compatible G-code or curve paths
  - Seamless use within the Grasshopper environment

03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW



Parameter	Droid	Termite	Silkworm	COMPAS
Layer Height	Yes	Yes	Yes	Yes
Extrusion Speed	Yes	Yes	Yes	Yes
Travel Speed	Yes	Yes	Yes	Yes
Nozzle Diameter Setting	Yes	No	No	Custom
Infill Pattern Generation	Yes	Yes	No	Custom
Wall Thickness / Perimeters	Yes	Yes	No	Custom
Path Offsets (for width control)	Yes	Yes	Limited	Yes
Overhang Support Control	Limited	Limited	No	Custom
Tool Orientation Control	Yes	No	No	Yes
Post-processing / Custom Code	Yes	Yes	Yes	Yes

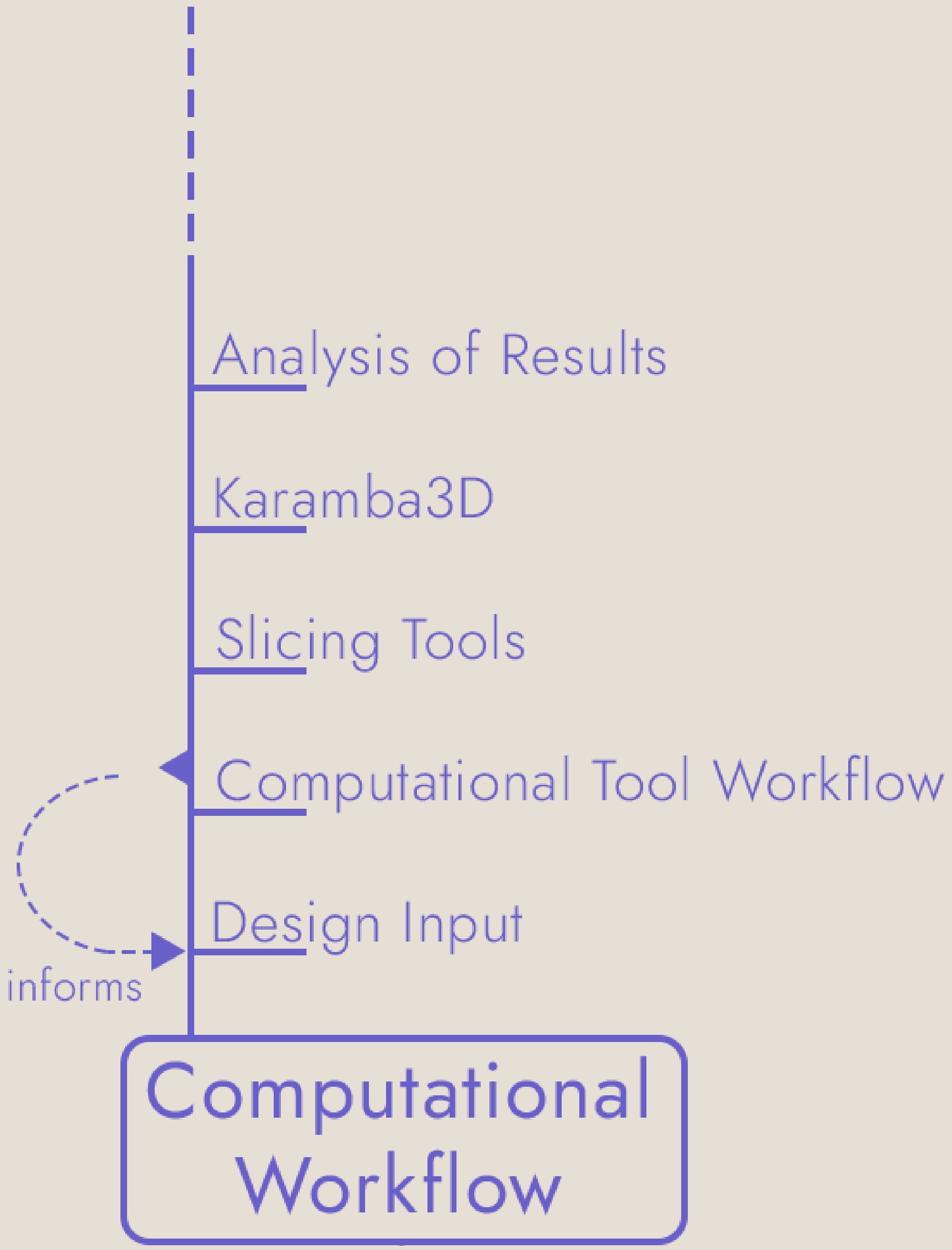
03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

Feature	Droid	Termite	Silkworm	COMPAS
Slicing Capability	Planar slicing with per-layer control	Parametric slicing & non-planar	Basic planar slicing	Fully custom slicing via Python workflows
Infill Generation	Simple 2D infills (grid, lines)	No infill support	No infill (shell-only slicing)	No built-in infill — user must script it
Path Optimization	Basic path optimization	More advanced path planning	Minimal optimization	Fully scriptable optimization
G-code Output	No native G-code (curve paths only)	No native G-code (curve paths only)	Native G-code output (FDM)	No native G-code — export via scripts
G-code Usable for Robotics	Yes (post-processing via RoboDK/KUKA prc)	Yes (post-processing via RoboDK/KUKA prc)	Yes, but requires manual adaptation	Yes (custom Python export to G-code)
Robot Compatibility	KUKA, ABB (after post-processing)	KUKA, ABB (after post-processing)	Limited — requires manual adaptation	Any robot, via custom script definitions
Tool Compatibility	Pellet & filament extruders	Pellet & filament extruders	Filament extruders (FDM only)	Any extrusion tool — fully scriptable
End Product	Curve paths → post-process to G-code	Curve paths → post-process to G-code	Direct G-code output → conversion needed	Curve paths, JSON, or G-code via scripting



03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

Feature	Droid	Termite	Silkworm	COMPAS
Slicing Capability	1	1	0	1
Infill Generation	1	-1	-1	-1
Path Optimization	0	1	-1	1
G-code Output	-1	-1	1	-1
G-code Usable for Robotics	1	1	-1	1
Robot Compatibility	1	1	-1	1
Tool Compatibility	1	1	-1	1
Ease of Use	1	1	0	-1
Total Score	3	3	-3	1

03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

- Droid: Best for continuous toolpaths across closed meshes. Easy Grasshopper integration but lacks non-planar slicing.
- Termite: Offers non-planar slicing, but limited to single-surface workflows with fragmented paths.
- Silkworm: FDM-focused. Produces G-code but lacks robotic and pellet extrusion support.
- COMPAS: Fully customizable but requires advanced scripting and CPython integration. Not feasible within project constraints.

03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

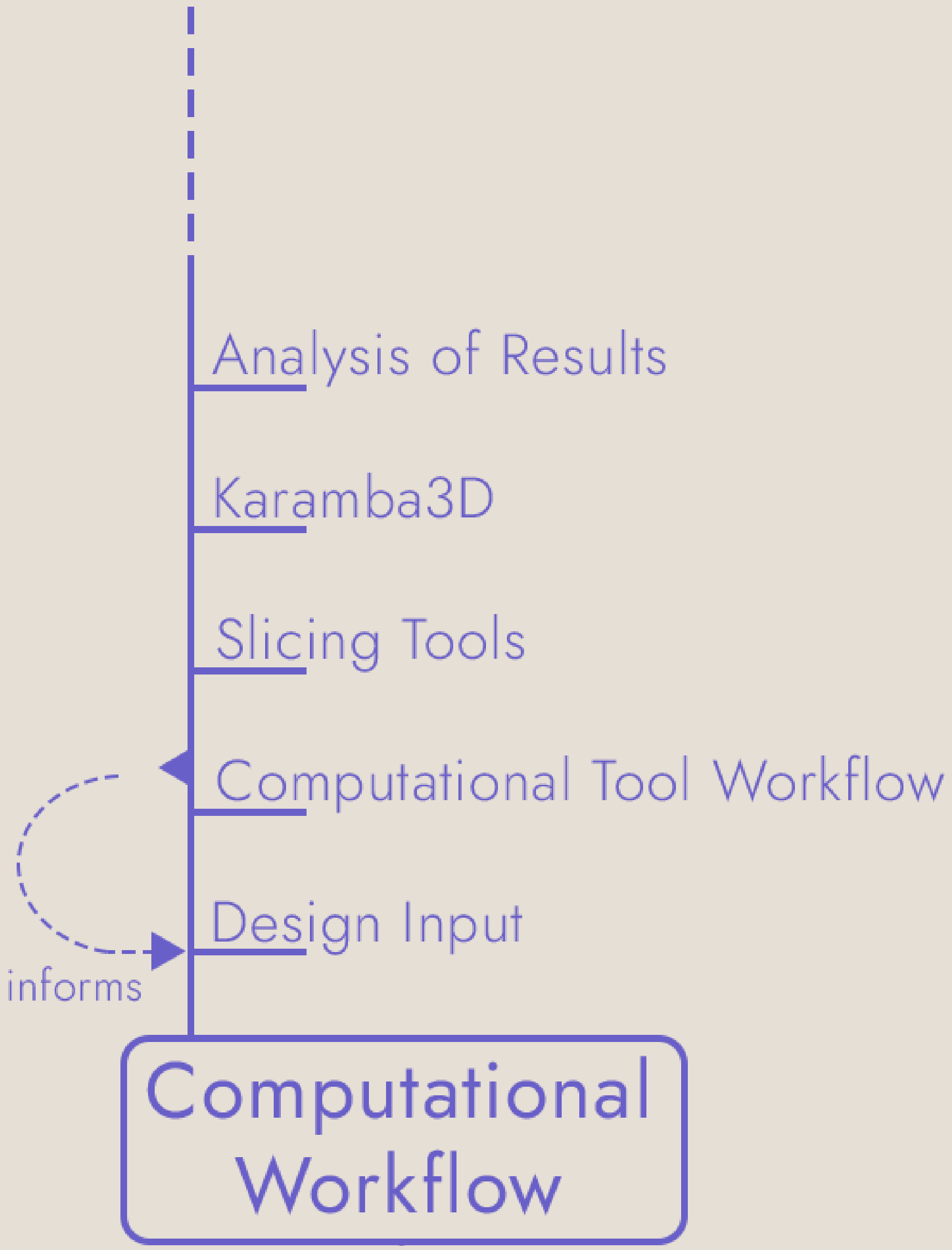
- Initial tests with Droid helped explore extrusion continuity and volume slicing.
- Termite was later chosen for final slicing due to:
- Better support for manual parameter adjustments per brick type
- Clearer control over path spacing, speed, and geometry-specific logic
- Integration flexibility with robotic workflows via post-processing
- While Termite requires slicing surface-by-surface, this also allowed tailored slicing logic for different material types (A, B, C).

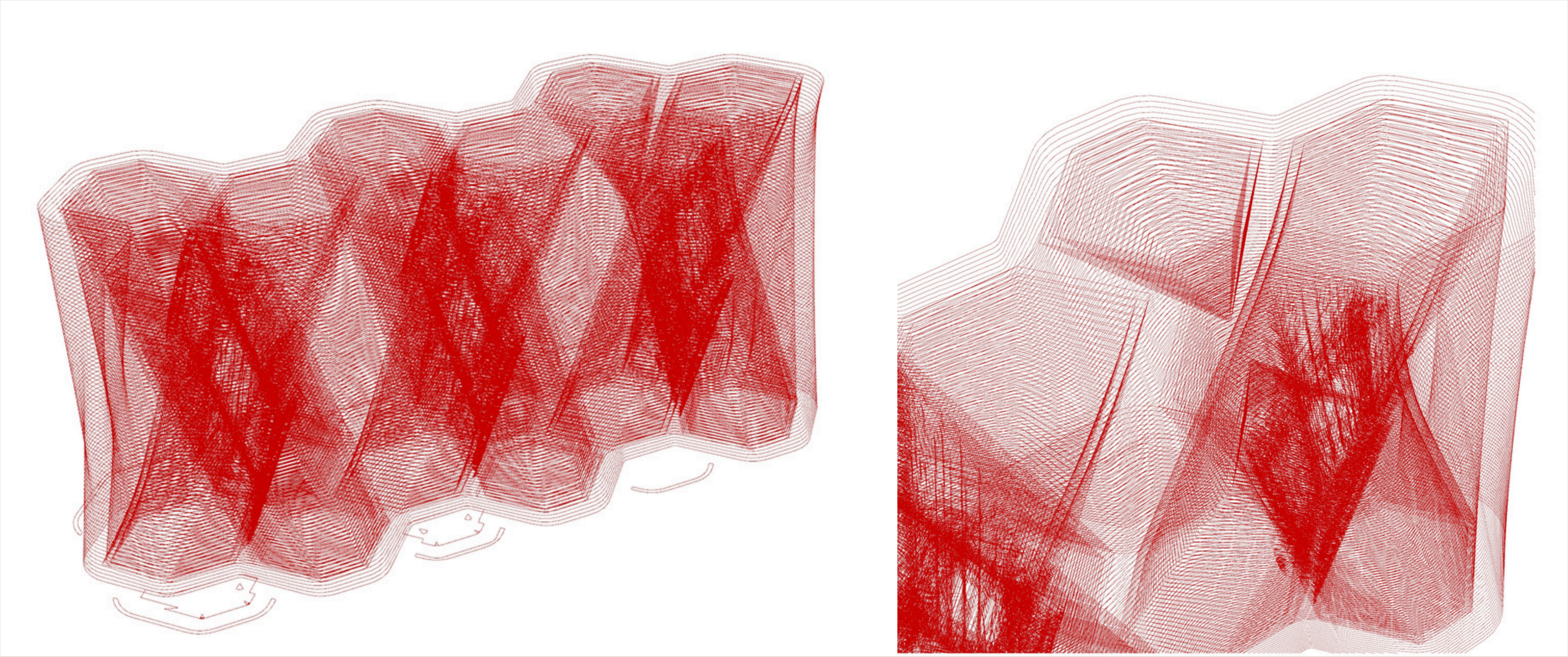
03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW





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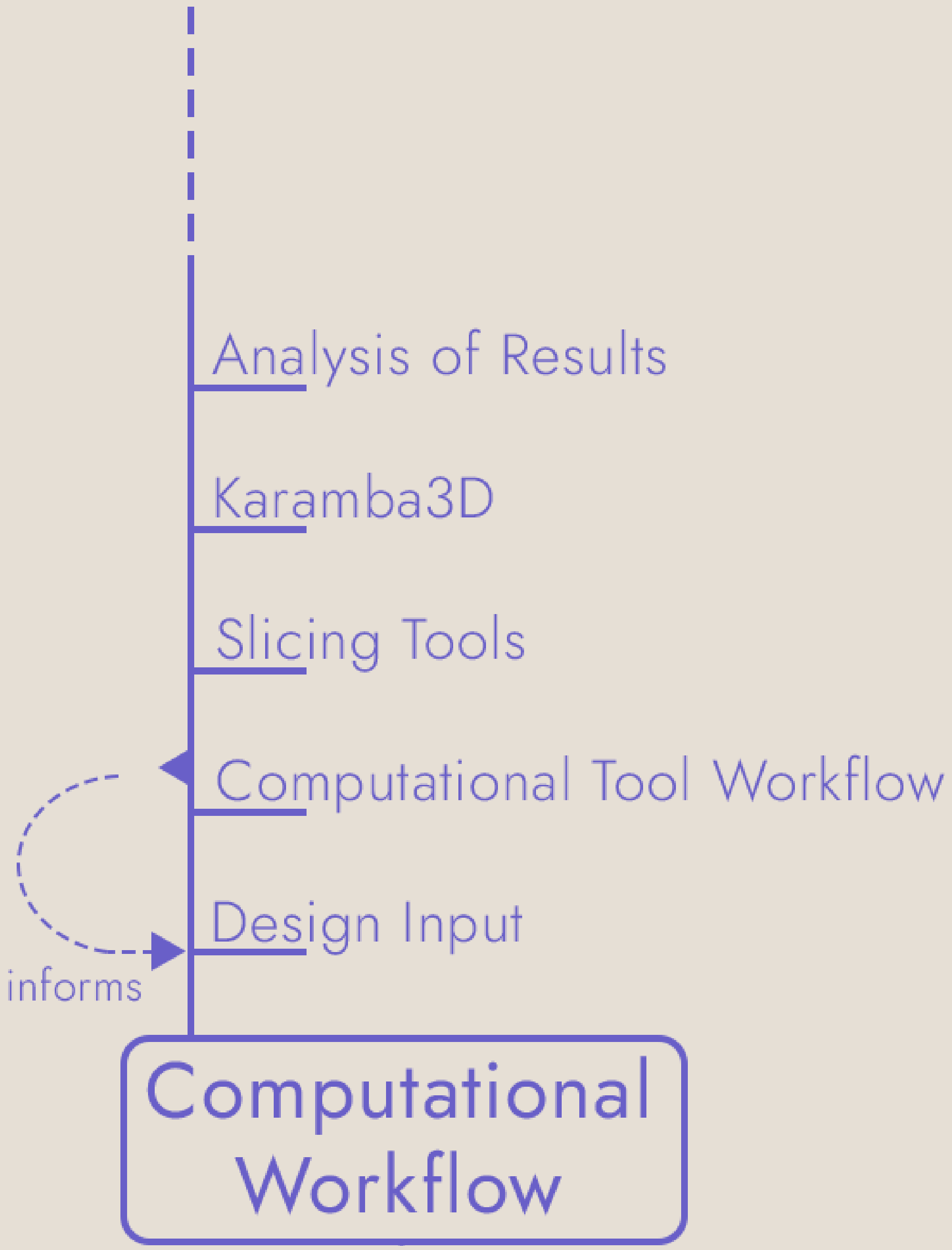
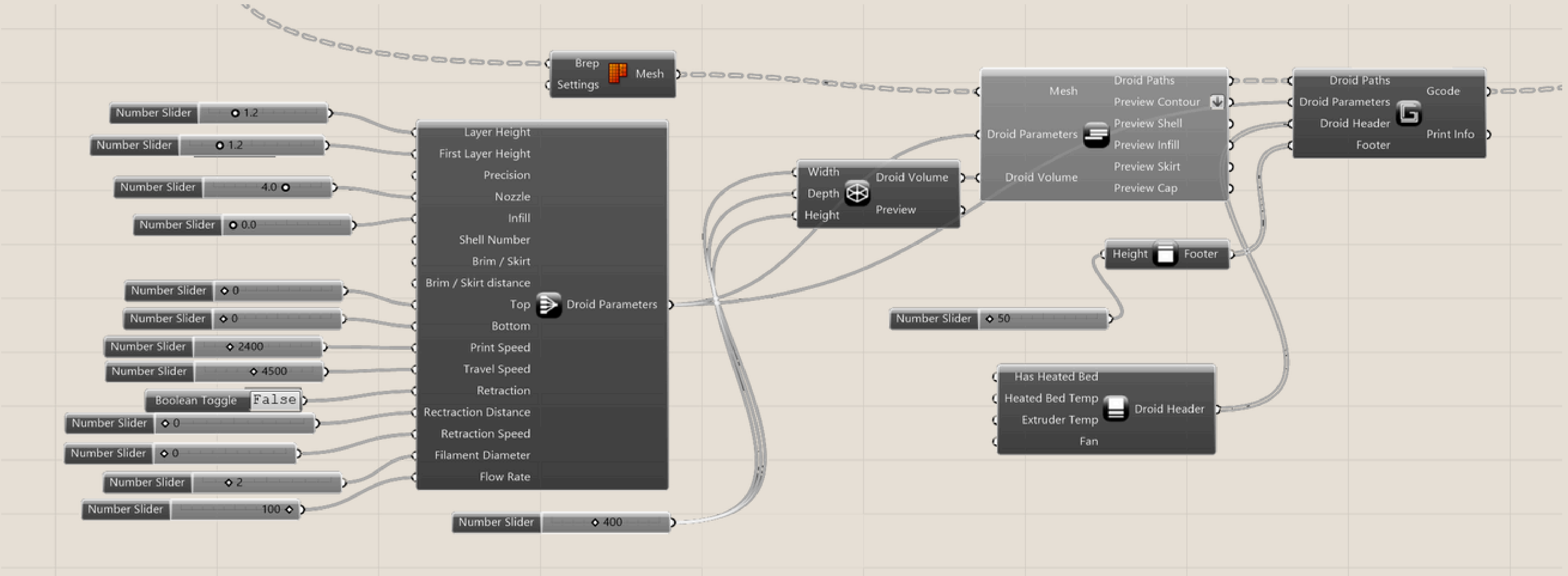
HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW





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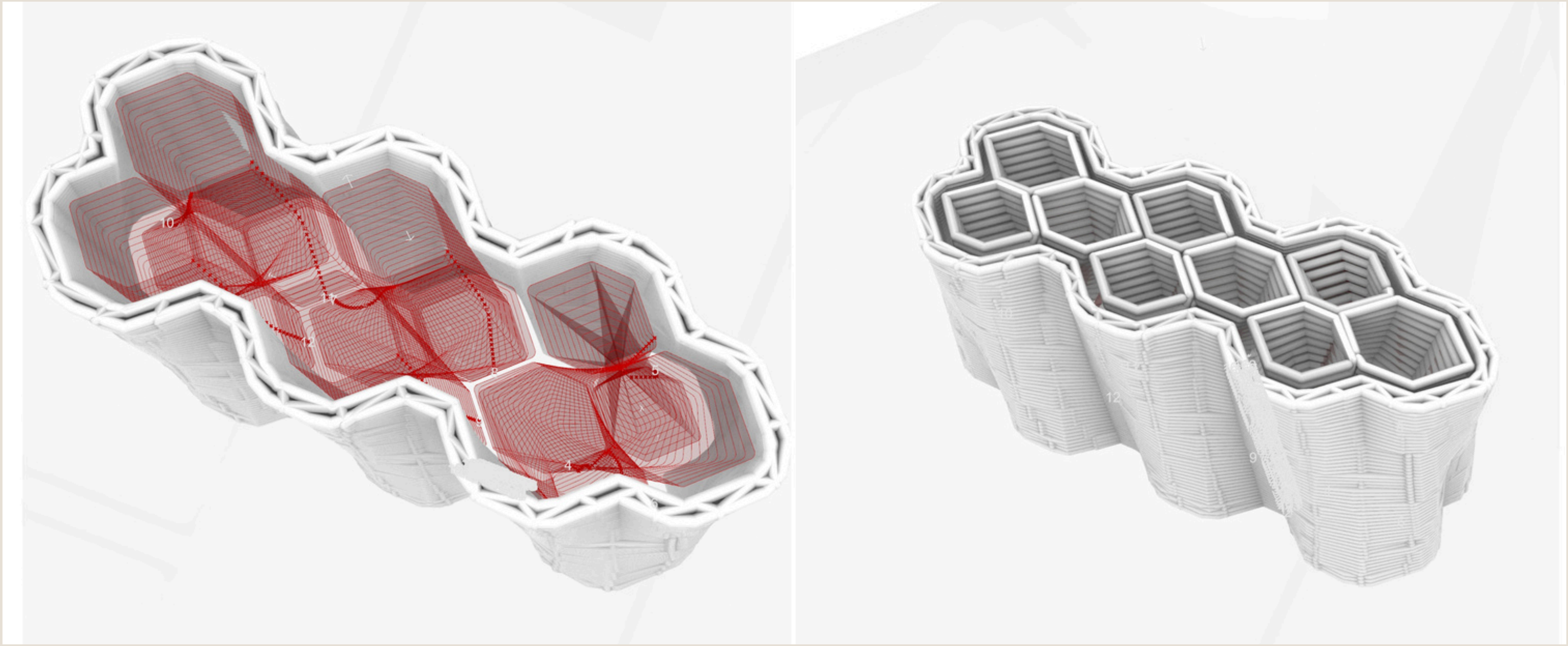
HOW

WAS IT DONE

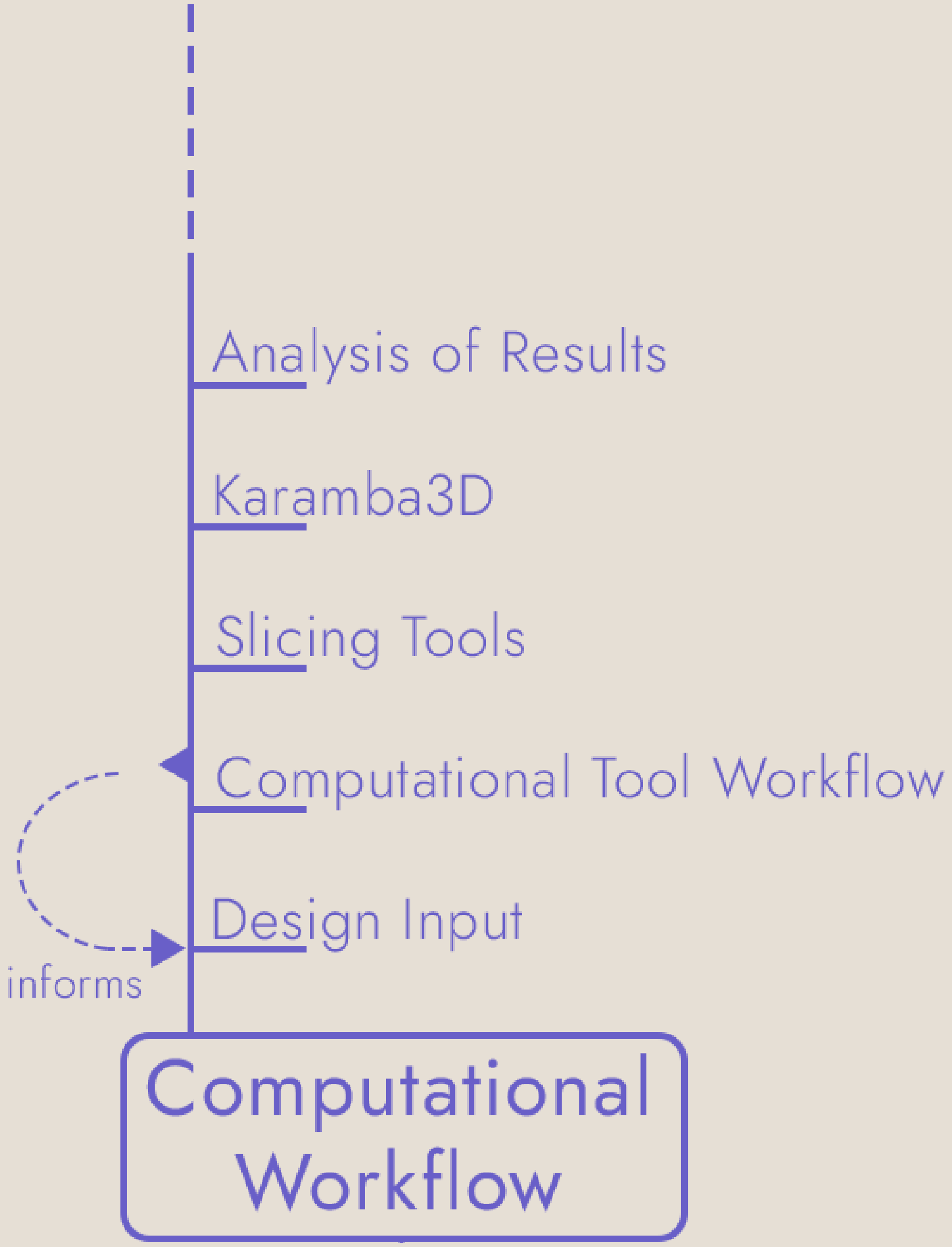
COMPUTATIONAL WORKFLOW

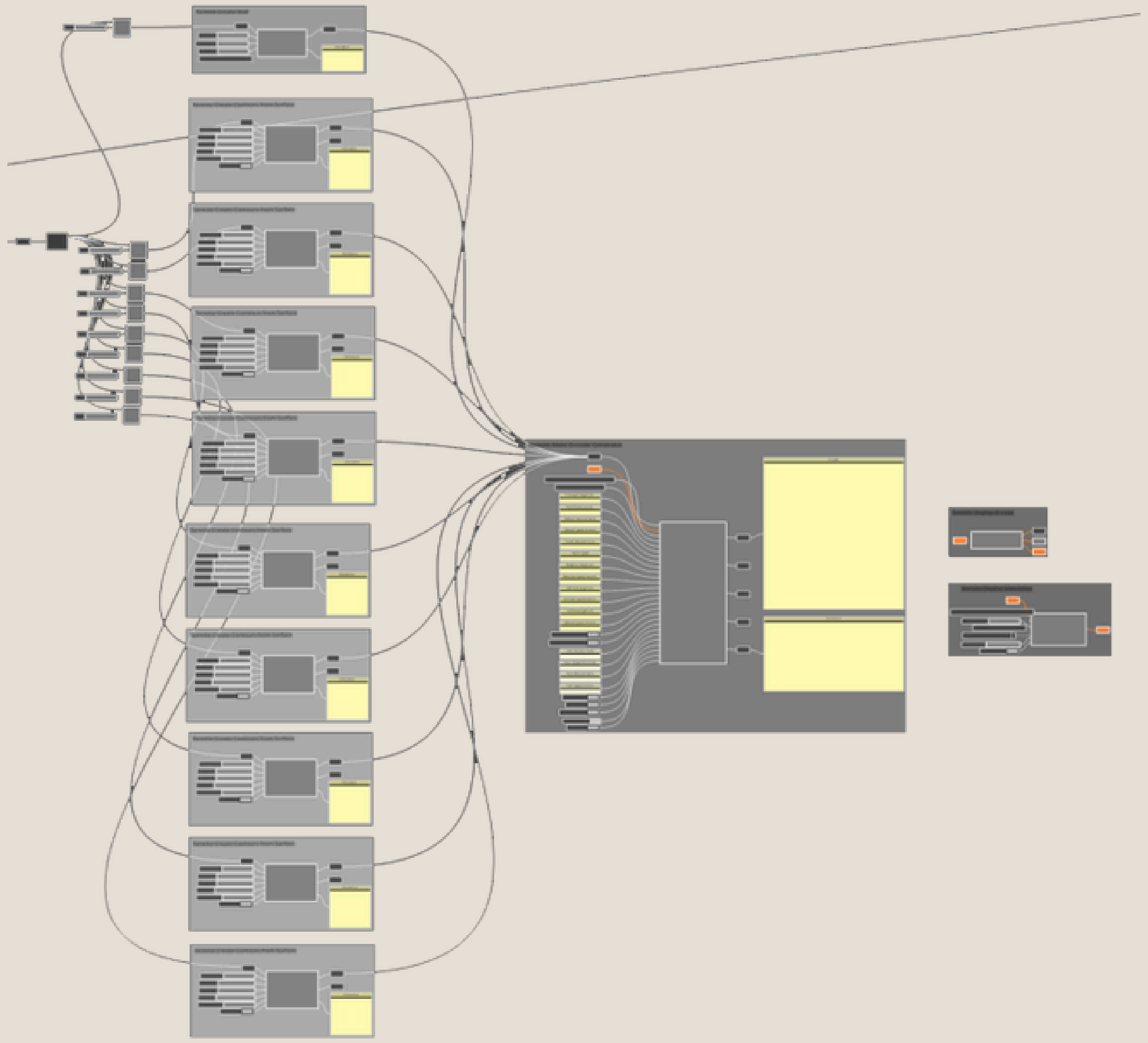


03 # HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW





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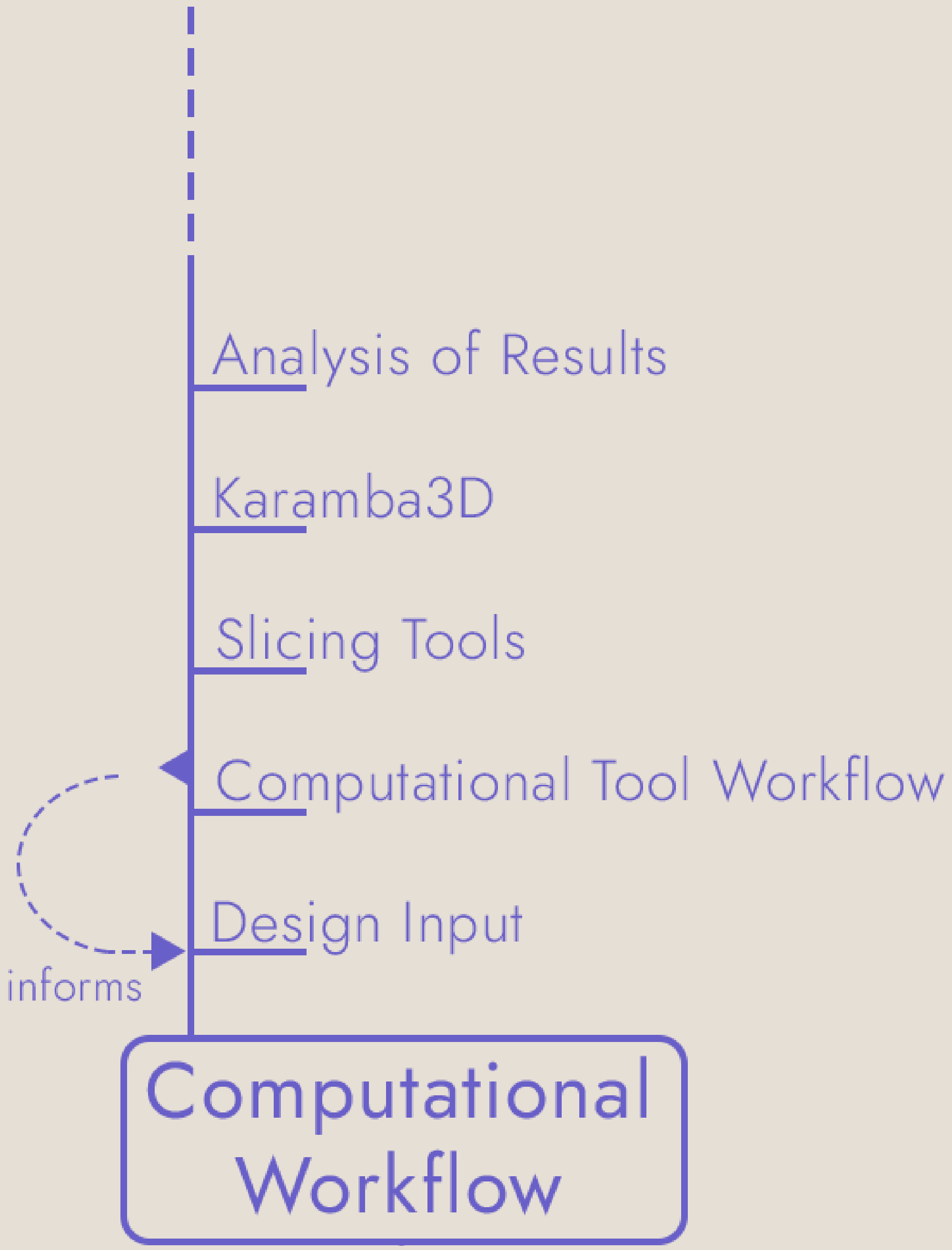
HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW



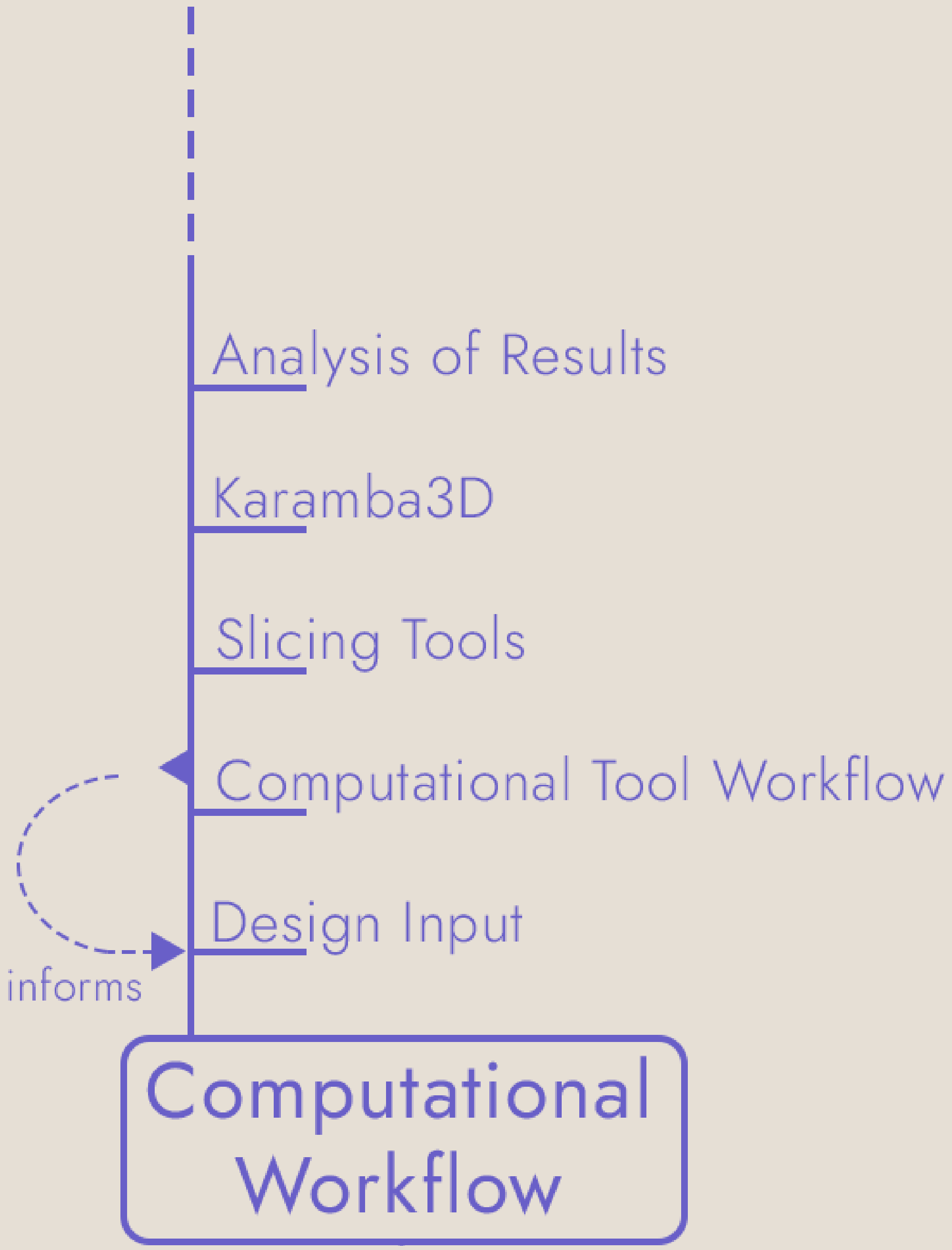
- Used Termite in Grasshopper to generate robot-compatible toolpaths per brick.
- Manually adjusted slicing parameters (extrusion speed, path width, printing order) per material strength.
- Exported curve paths post-processed with KUKA|prc for the CEAD E25 extruder and KUKA robot arm.
- Achieved clean control over robotic movement, strand flow, and path continuity for each formulation.

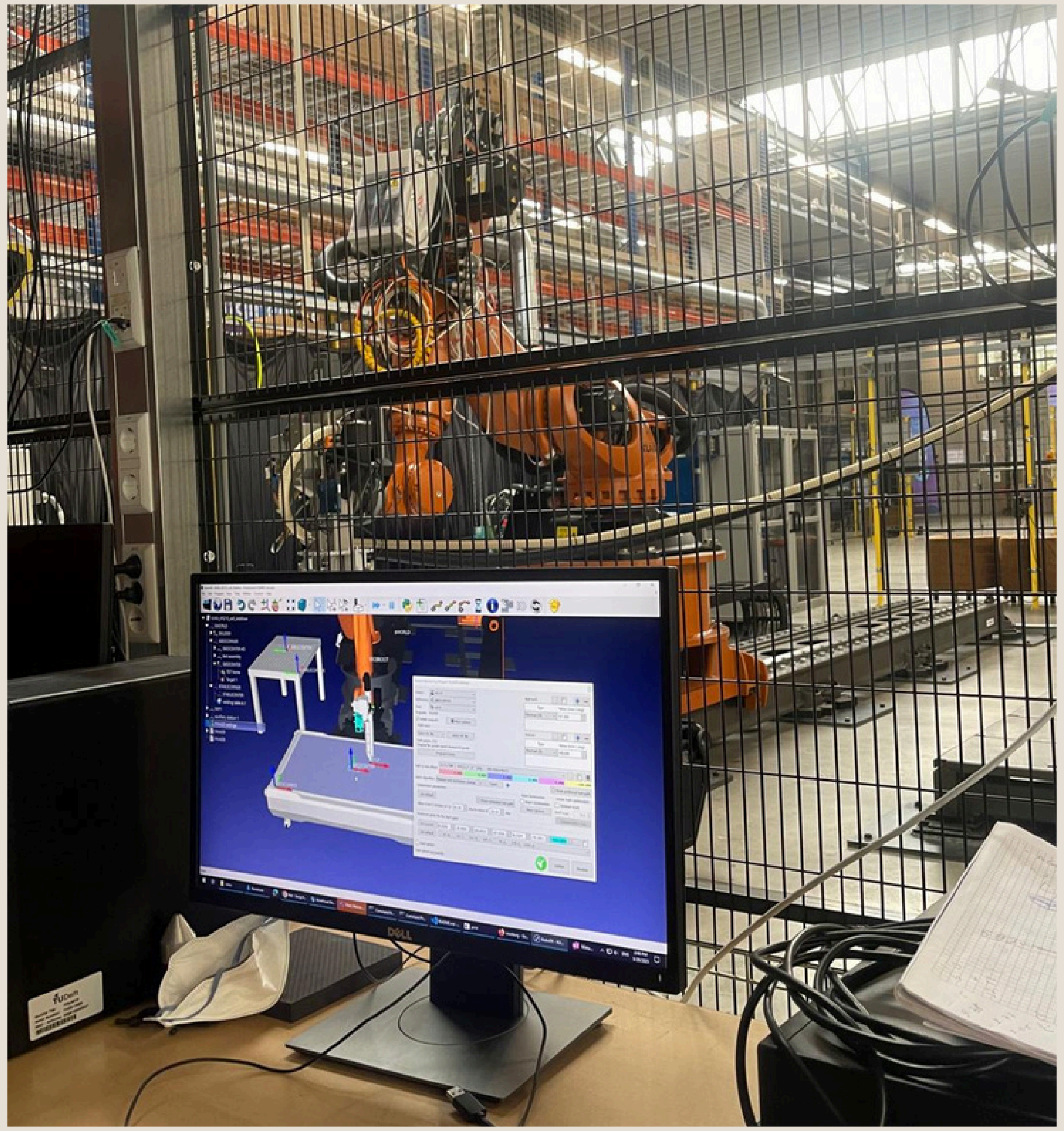
03

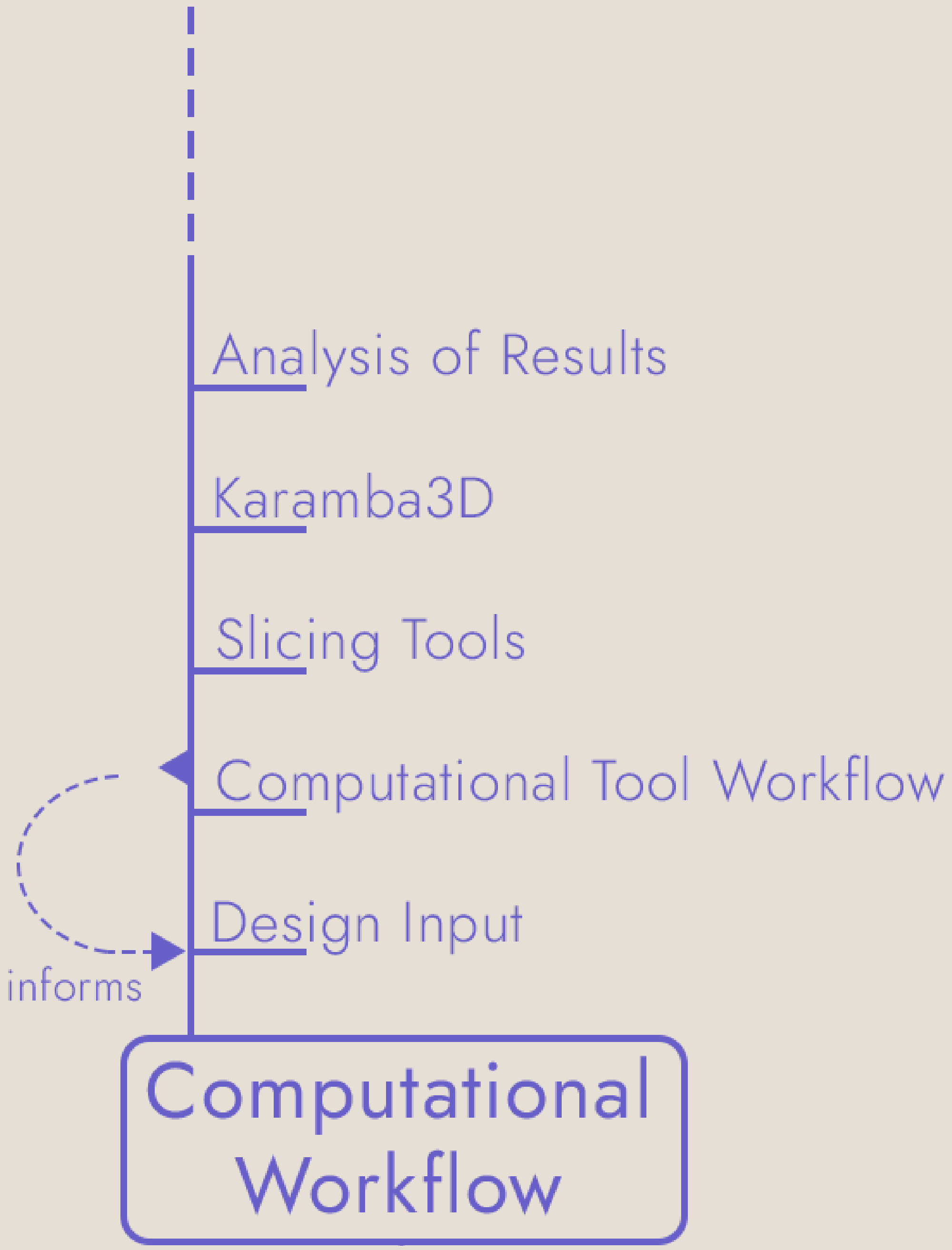
HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW







03 HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW

- Simulated full partition wall using a mirrored hexagonal brick layout
- Wall modeled as mesh-based beam elements with self-weight as the only load case
- Bottom nodes fixed to represent floor support
- Evaluated stress strength metrics:
- Simulations showed that the partition wall performs well under self-weight, with most areas staying within 1.5% stress capacity. However, overhangs reached up to 2.7%, highlighting structurally weaker zones. While suitable as a lightweight, freestanding system, some areas may need reinforcement for real-world use.

03 **HOW**

WAS IT DONE

COMPUTATIONAL WORKFLOW

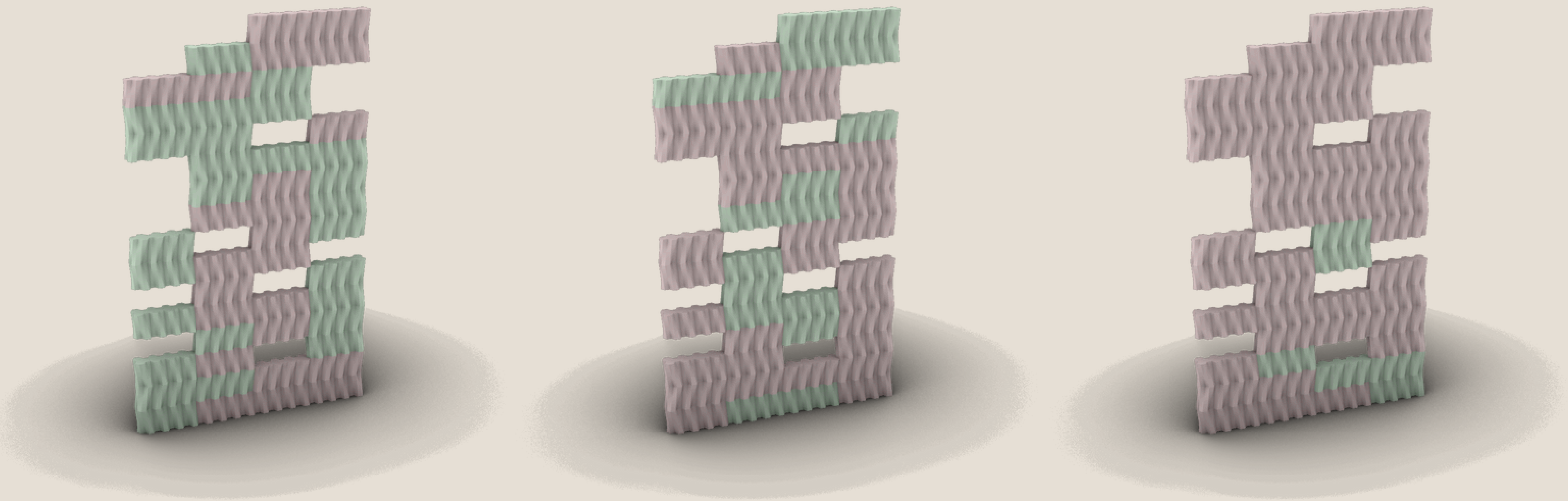
- Defined Brick Types A, B, and C based on experimental tensile strength & stiffness
- Used a gene pool with Galapagos solver to assign bricks and optimize load distribution
- Objective: Minimize deformation while matching brick strength to local structural needs
- High-strength bricks placed in high-load zones; low-strength bricks in less critical areas
- Result: a performance-based material map guiding extrusion without changing geometry

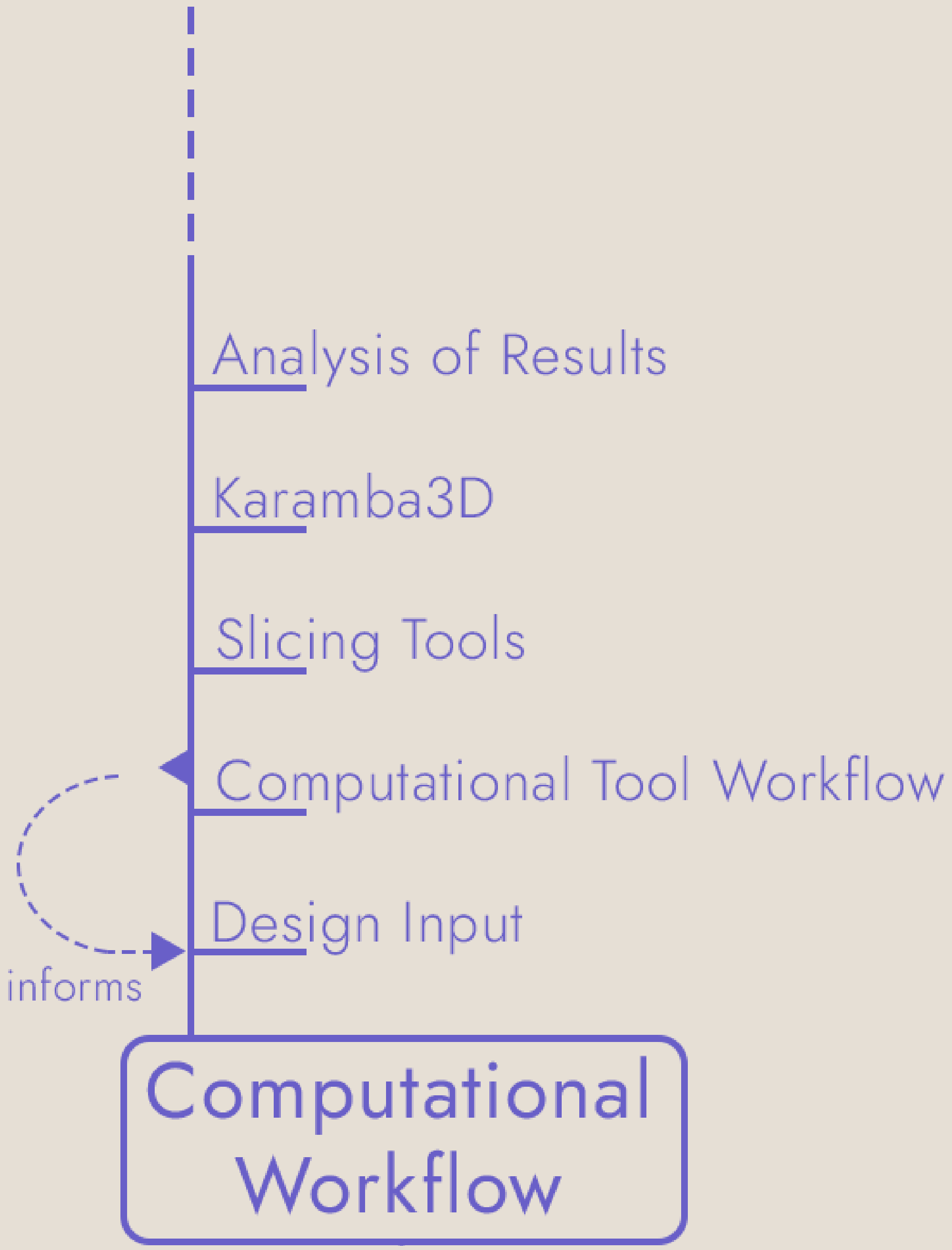
03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW



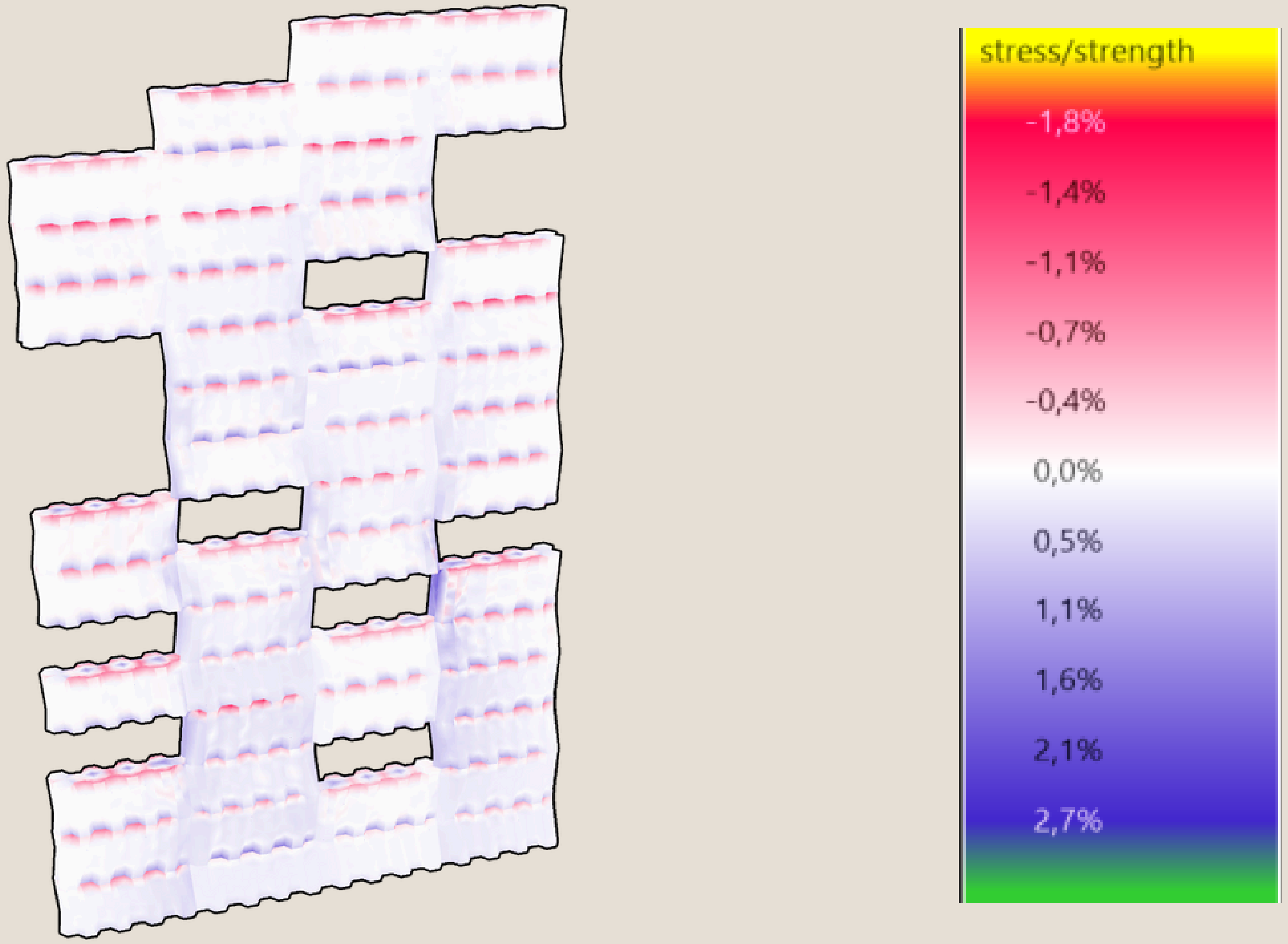


03

HOW

WAS IT DONE

COMPUTATIONAL WORKFLOW



Design & Prototyping

- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P1

Design & Prototyping

- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P1

- The PETG-glass fiber prototype allowed testing of:
    - Print speed vs. cooling time
    - Layer bonding behavior under real robotic motion
    - Behavior of single-wall perimeter paths without infill
- These insights are directly translatable to lignin-cellulose extrusion:
    - If PETG shows stringing or warping → expect amplified issues in bio-based mixes
    - If layer adhesion fails in PETG under certain speeds → adjust slicing logic for PHA-lignin-cellulose

03 HOW

WAS IT DONE

DESIGN & PROTOTYPING - P1

Design & Prototyping

- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03 HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

- Homemade biocomposite pellets-manually mixed and cast-contained air pockets, which disrupted extrusion consistency.
- To resolve this, pellets were ground using a coffee grinder, reducing their size and increasing packing density.
- Result: more consistent feed, reduced jamming, and improved strand formation during extrusion trials.
- This step not only improved mechanical consistency but also revealed how internal pellet structure can impact extrusion smoothness - critical for robotic workflows.

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

- With the new company - 10XL, more extensive testing was possible before printing.
- The moisture content of the material was tested, which turned out to be 2%, and in order to avoid air pockets and water content disrupting printing, it was dried down to 0.05%
- Result: more consistent feed, reduced pockets, and improved strand formation during extrusion trials.
- This step was essential in order to conclude the line trials with satisfactory results.

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

Design & Prototyping

- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03

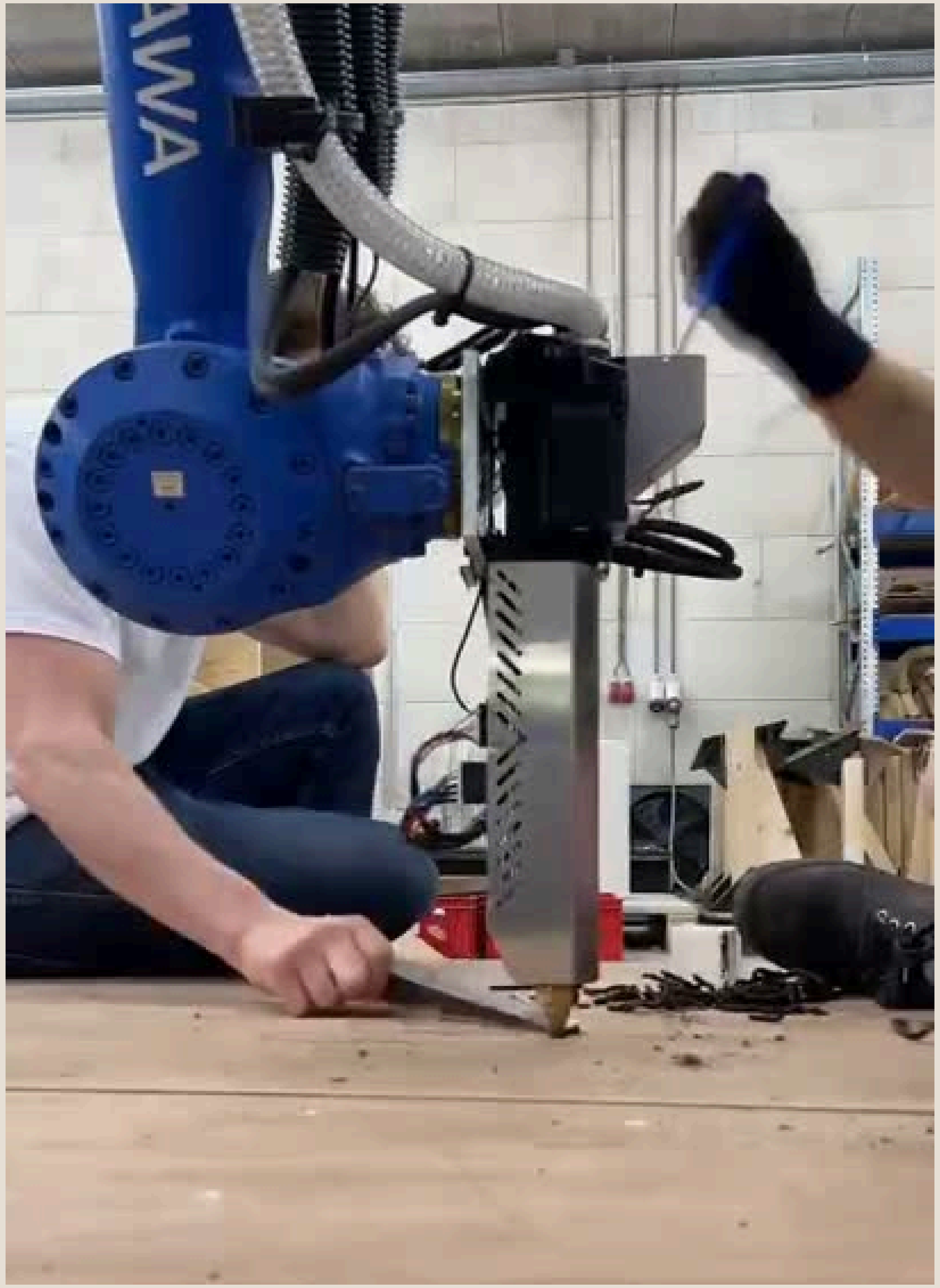
HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

- The initial brick geometry was refined to improve printability:
- Adjusted path continuity to avoid overlapping strands or redundant loops
- Ensured wall thickness aligned with nozzle diameter for cleaner deposition
- Smoothed curvature transitions to reduce toolpath retractions and layer interruptions
- These refinements were essential to match the geometry with the slicing tool's strengths (Droid) and the extruder's behavior.

TRIAL?



03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

ERROR!

Design & Prototyping

- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

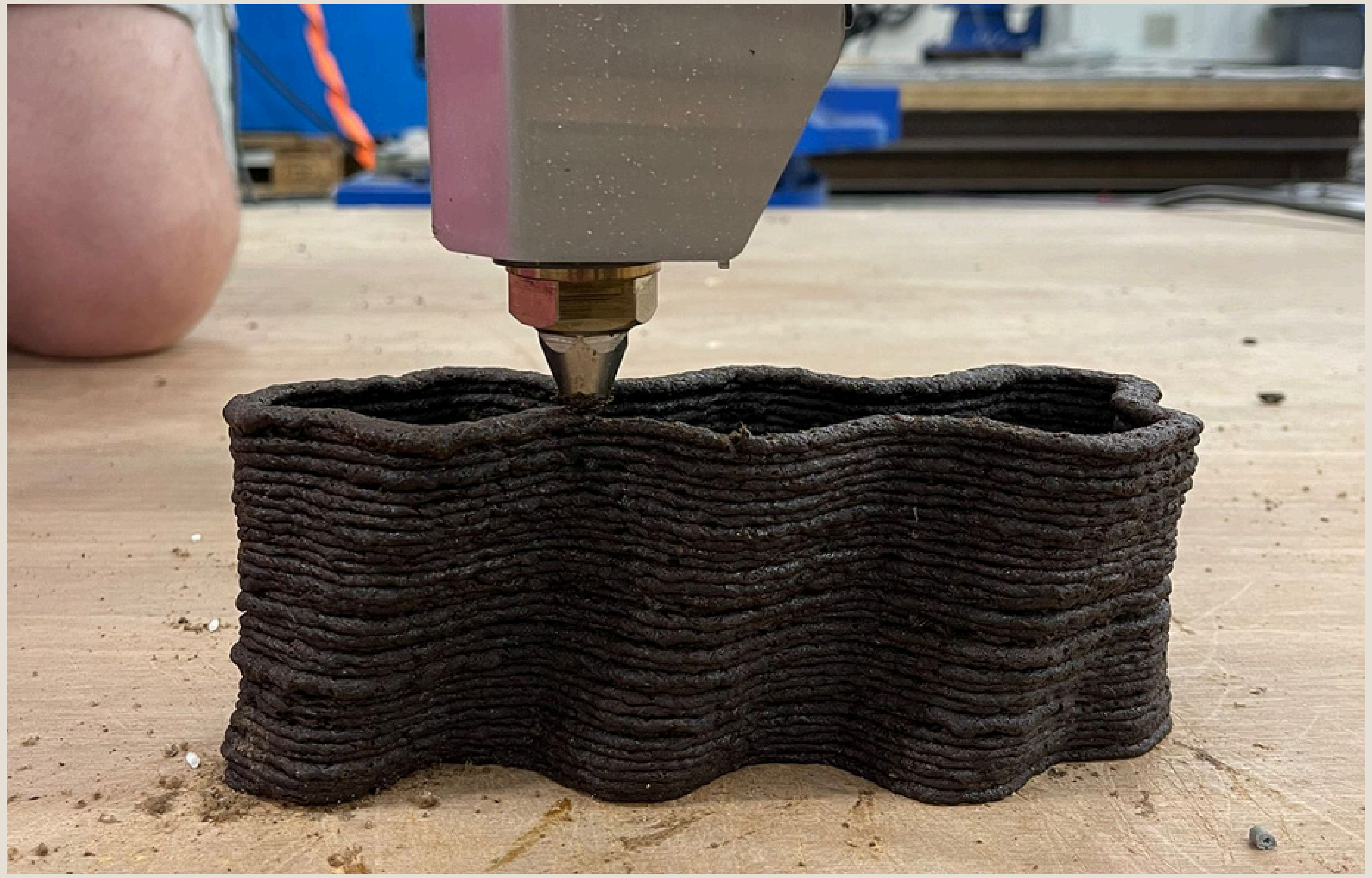
- 2 days trial and error resulted in conclusions to be made in printing process and material enhancement
- The end material fed into the extruder was in powder form, not pellet form, which made it difficult to feed properly, resulting in inconsistent printing due to human error
- By adding a 1/10 ratio of PHA pellets, the powder was connected to the pellet, which resulted in a consistent flow.
- The flow, temperature and robot speed was optimized iteratively through the g-code, which reduced the time and back-and-forth necessary for robotic translation.

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2



SUCCESS!

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2

Design & Prototyping

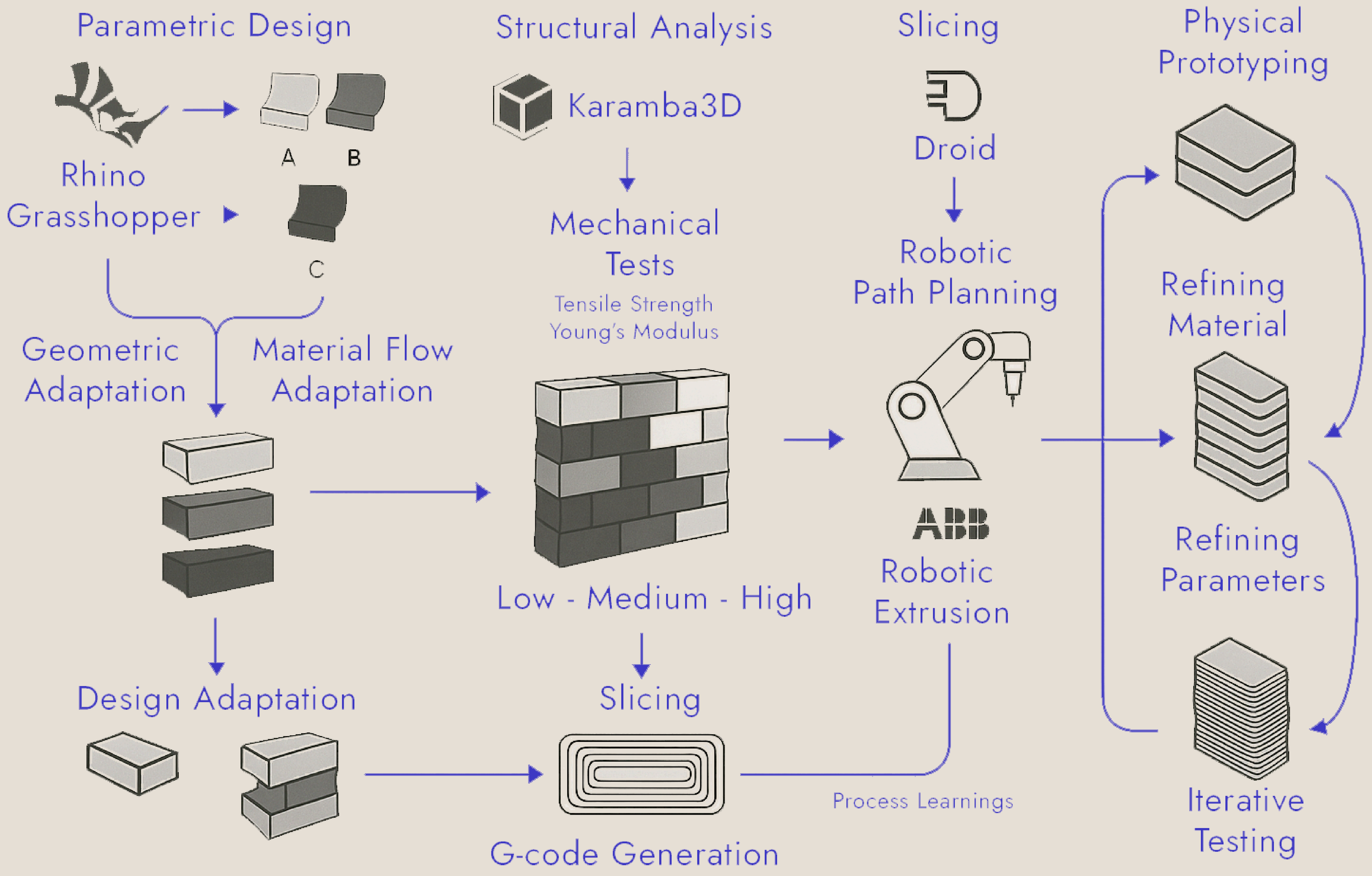
- Material Enhancement
- Design Refinement
- Planning & Setup
- Printing Process
- Assembly of Prototype
- Final Product

03

HOW

WAS IT DONE

DESIGN & PROTOTYPING - P2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Process Learnings
Physical Prototyping
Refining Material
Refining Parameters
Iterative Testing

04

WHAT

WAS DONE

Robotic Hot Extrusion Additive Manufacturing of Lignin-Cellulose Biocomposites: Computational Slicing Strategies for Architectural Applications

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04

WHAT
WAS DONE

05

WHAT IS NEXT

04

WHAT IS NEXT

🧱 Prototype All Material Ratios

Use all material ratios to 3D print the modular brick types and evaluate real-world assembly.

🏗️ Assemble Full Partition Mock-Up

Demonstrate strength-graded placement and modular assembly logic with the printed bricks.

🔍 Refine Printing Parameters

Calibrate extrusion speeds, cooling times, and toolpaths per material mix for final fabrication trials.

🧪 Mechanical Retesting

Conduct standardized mechanical testing with Fred Veer on full-scale extruded bricks.

🧠 Enhance Structural Tool

Link Karamba3D further with slicing logic to automate material placement based on load distribution.

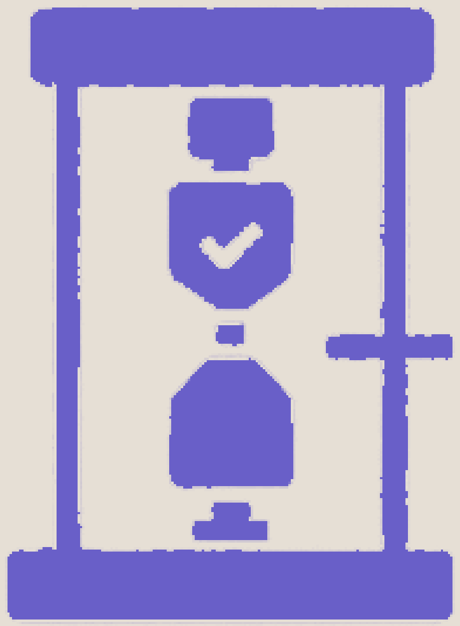
📈 mprove Computational Workflow

Document the full design-to-fabrication pipeline and streamline for future applications.

05

HOW

COULD IT BE BETTER

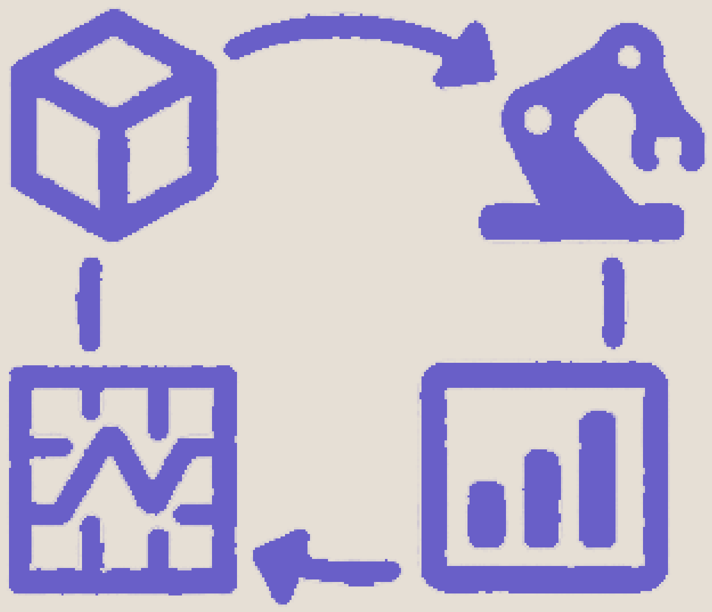


05 HOW

COULD IT BE BETTER

TECHNICAL ACCURACY

- Strength values can be recalculated based on maximum force and cross-sectional area for increased consistency, after real life testing and more detailed structural tests
- Stress-strain graphs can be used more systematically to cross-reference mechanical performance data.
- Comparative benchmarks (e.g., PLA, PETG) can be introduced to contextualize the results within AM standards.



05

HOW

COULD IT BE BETTER

COMPUTATIONAL WORKFLOW

- The slicer comparison will emphasize understanding gained from each tool, not just performance, and iterative testing with a robot can be done in order to asses real life implementation of different material ratios with parameters
- The Karamba3D simulation can be revised or contextualized further, as current results may not yet fully reflect material behavior.

06

WHY

IT WASN’T PERFECT

06

WHY

IT WASN'T PERFECT

TIME CONSTRAINTS

- The ambitious scope of integrating material science, robotic extrusion, and structural optimization proved difficult to fully execute within the graduation timeline.
- Material development took longer than anticipated, impacting the depth of testing and limiting time for design integration.

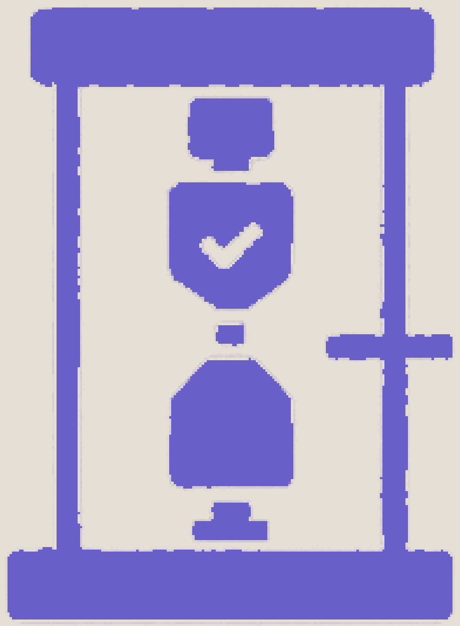
06

WHY

IT WASN'T PERFECT

FABRICATION

- Limited access to industrial-scale pellet extruders (e.g. CEAD at SAM|XL) delayed consistent print trials.
- The homemade extruder setup, while extremely valuable to the research process, introduced variation in specimen quality, particularly in tensile test samples.



06

WHY

IT WASN’T PERFECT

MECHANICAL TESTING

- Testing data was affected by irregular filament dimensions due to manual extrusion.
- Some inconsistencies arose between calculated and visual stress-strain results, requiring further refinement of analysis methods.
- Compression testing on full bricks was limited due to lab access and time constraints.

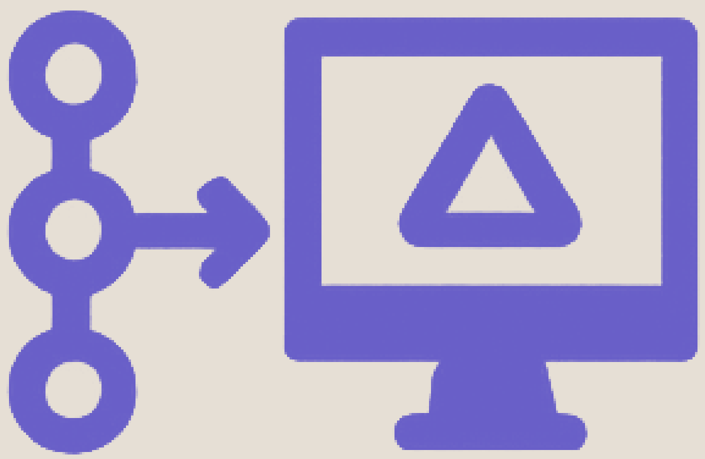
06

WHY

IT WASN'T PERFECT

MATERIAL DEVELOPMENT

- Initial underestimation of the complexity of working with lignin-cellulose composites, especially the sensitivity to heat and mixing behavior.
- Extra time was needed to refine binder compatibility and extrusion behavior, especially when working without conventional compounding tools.
- Compressive testing and rheological testing would be needed in order to fully determine the properties of materials, which would improve the workflow significantly.



06

WHY

IT WASN'T PERFECT

COMPUTATIONAL WORKFLOW

- Karamba3D results may not fully reflect the real mechanical behavior of the materials; further calibration is needed.
- While four slicers were tested, the integration into a seamless pipeline needs more development time and post-processing refinement to ensure real-world readiness.
- Design informatics and data feedback loops (e.g., performance-driven slicing) were not yet fully implemented.

06

WHY

IT WASN'T PERFECT

SETBACKS

- Earlier prioritization of structural design and robotic toolpath generation could have improved cohesion between physical and computational tracks.
- Testing and design iterations were sequential rather than integrated-more overlap between material trials and design simulations would benefit future phases.
- Personal health issues and lab access limitations affected continuity, especially during critical testing periods and formulation sprints.
- Delays in sourcing and verifying suitable bio-based binders temporarily paused material development.

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and a very special thanks to Sevil Sarıyıldız, although not with us, I will always carry her legacy with me...

She was truly a role model

Thank you for the journey!

Questions?