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PRONTO Final Submission
Group 22

PRIVATE DISTRIBUTION: PRONTO Module

3D Model Reconstruction of an Object from a Video

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Date d'édition : October 8, 2025
Version : 2.0

IMT Atlantique
Bretagne-Pays de la Loire
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1. Introduction

Our PRONTO project, “3D Model Reconstruction of an Object from a Video,” focuses on researching the optimal parameters, methods, and environment for reconstructing small-object 3D models using the COLMAP software [1]. This project addresses a key challenge: making COLMAP more accessible and user-friendly for modeling from videos.

Although powerful, COLMAP is complex, offering a vast array of parameters and programs. Renault approached us to overcome these challenges and standardize COLMAP usage for their needs. Functional requirements (see “Functional Specifications”) will detail constraints, but the standardized setup aims at object sizes around ten centimeters. While we experimented with a custom backdrop (cf. 4.3), our solution must also be portable across environments. This preserves COLMAP’s strength—Structure from Motion (SfM)—in reconstructing 3D models from independent images (even sourced from different devices online).

This report incorporates adjustments highlighted in the initial requirements, including a clear outline, figure usage, and expanded discussion. Sections 3 to 5 then detail our step-by-step approach. Finally, we provide a brief plan of the report: objectives, system design and development, integration and validation, project management retrospective, individual reflections, and a bibliography.

2. Functional Specifications

2.1. Overview

The Functional Specifications document gathers all needs, expectations, requirements, and constraints defined by stakeholders for the Structure from Motion solution in the PRONTO module of the FISE A1 program at IMT Atlantique.

2.1.1. Terminology

Term	Abbreviation	Definition
Structure from Motion	SfM	3D reconstruction technique from 2D images estimating camera poses and common points.
Multi-View Stereo	MVS	3D reconstruction technique using multiple views to generate a dense model by matching correspondences.
COLMAP	—	Open-source photogrammetry software performing SfM and MVS for 3D reconstruction from images.
Mesher	—	Algorithms reconstructing surfaces from point clouds.
Computer Aided Design	CAD	Software for designing volumes from surfaces, used here to convert models into printable volumes.

Table 1: Terminology Used

2.2. System Description

2.2.1. Purpose, Mission, Objectives

Purpose: Generate a 3D model of an object from images.

Mission: The pipeline accepts images (or a video, from which images are extracted), runs COLMAP to produce a point cloud, creates a surface in Meshlab, and converts that surface into a volume in Fusion 360. The final `.stl` model is ready for 3D printing.

Objectives: - Understand and execute all steps required for high-quality 3D reconstruction. - Simplify software workflows and interfaces. - Optimize parameters that affect model quality to produce the best possible 3D model.

2.2.2. Stakeholders

Members	Roles
Lucia BERGANTIN	Reference Professor
Anne-Lise PELLETIER	Project Coordinator
Achile PINSARD	3D Reconstruction Lead
Pierre-Antoine HIGNARD	GitLab Manager
Samuel VATON	Photography Lead

Table 2: Team Roles

2.2.3. Context of Use

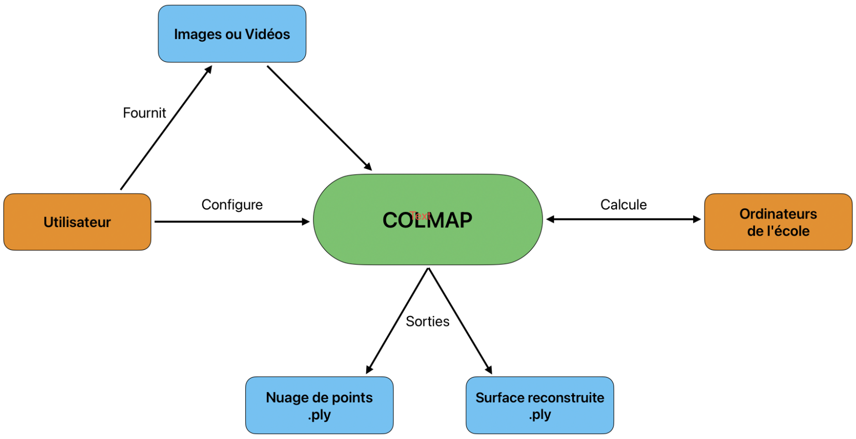


Figure 1: System Diagram in Its Environment

Figure 1 shows COLMAP's interactions with users and hardware. The user configures COLMAP and supplies source images. COLMAP leverages the CPU and GPU to compute a point cloud and reconstructed surface (two `.ply` files). In practice, further refinement often starts from the point cloud.

2.3. Functional Requirements

2.3.1. Service Functions and Constraints

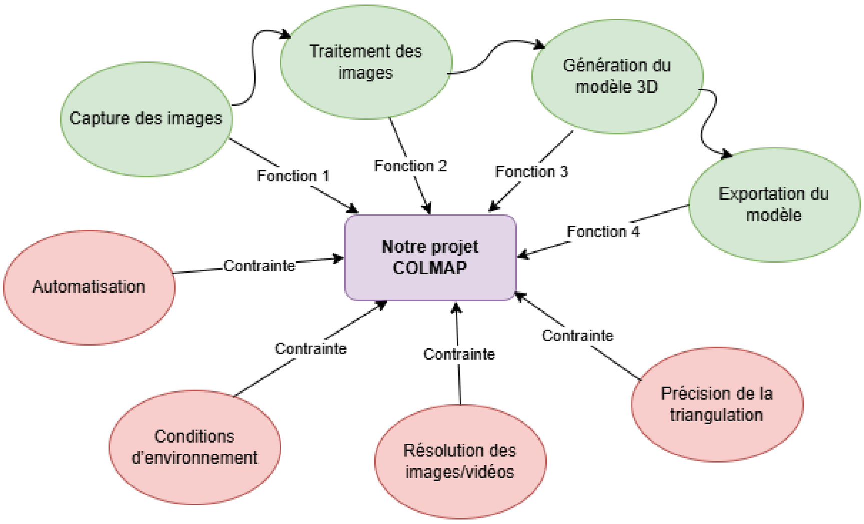


Figure 2: Main Service Functions (green) and Constraints (red)

Four main functions are identified: - Image capture - Image processing - 3D model generation - Model export

Key technical constraints include: - Process automation - Environmental conditions (lighting, stability) - Image/video resolution - Triangulation precision

2.4. Usage Scenarios

The optimized COLMAP system addresses three client expectations: - Reduced modeling time - High model quality - Accessible software

Two nominal scenarios:

1. User provides images: system reconstructs 3D via COLMAP and exports `.stl`.
2. User provides a video: frames are extracted, then processed as above.

Additional flows handle low-quality images, unstable videos, and incorrect inputs with alerts or documentation.

2.4.1. Nominal Use

A typical session (<30 min compute, visually accurate):

- Object preparation (lighting, background).
- Data acquisition (photos/video).
- Import into COLMAP.
- SfM reconstruction (e.g. 60 images, High quality, 1 h on RTX A4500 + AMD EPYC 7543P).
- Export point cloud (`.ply`).

2.4.2. Edge Cases

- Acquisition issues (blur, exposure, insufficient coverage).
- Computation delays (>2 h), insufficient images, poor lighting.
- Calibration and brightness variations.
- User errors (unsupported files, wrong parameters).

2.5. Validation Plan

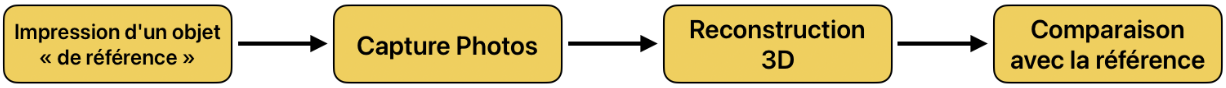


Figure 3: Validation Workflow

Tests against reference 3D models:

- Print reference models (e.g. a chair).
- Capture 60 photos under ideal lighting.
- Reconstruct with COLMAP.
- Compare visually and via Hausdorff distance.

Evaluation criteria:

- Visual quality
- Geometric fidelity
- Time constraints (<2 h)

2.6. Conclusion of Specifications

Next steps:

- Build a first model using default COLMAP parameters.
- Systematically study parameter influence.
- Optimize for our use cases.

3. Component and System Design

3.1. COLMAP

COLMAP is open source software that reconstructs 3D point clouds from sets of photos.

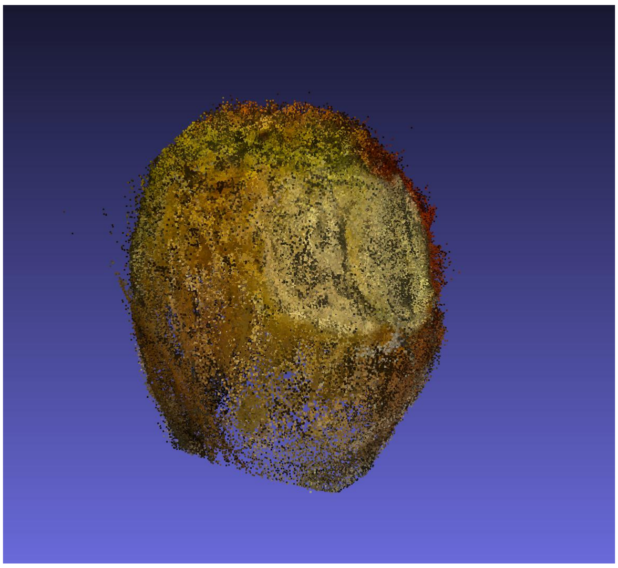


Figure 4: Point Cloud of an Apple Reconstructed by COLMAP

Key steps:

- Feature extraction (SIFT).
- Feature matching (exhaustive or sequential).
- Camera pose estimation (initial pair, then PnP).
- Triangulation to form the 3D point cloud.

3.2. Hardware Requirements

High-performance PCs with GPU are needed. Initial attempts on underpowered machines caused COLMAP crashes. We resolved this by using remote Shadow PCs and a dedicated Fablab workstation.

3.3. Meshlab

Meshlab is an open source mesh editor:

- Cleans and repairs point clouds.
- Generates surfaces (Screened Poisson, Ball Pivoting).
- Prepares meshes for 3D printing.

3.4. Fusion 360

Fusion 360 (CAD) converts closed meshes into printable volumes.

3.5. Reference Object: 3D Chair

We printed a chair model, captured photos, reconstructed the point cloud in COLMAP, created a surface in Meshlab, converted to volume in Fusion 360, and compared original vs. reconstructed mesh.

3.6. 3D Printer

We used Ultimaker 2+ and Creality K1 with PLA, printing a 5 cm tall chair in two halves (2 h total).

4. Development

We wrote Python scripts for:

- Extracting frames from video (OpenCV).
- Automatic image preprocessing (resize, CLAHE contrast, sharpening, denoising).
- Batch reconstruction via pycolmap.

4.1. Video to Images

Using OpenCV's `VideoCapture` and `imwrite`, we sample frames at regular intervals.

4.2. Image Processing and Reconstruction

4.2.1. Image Processing

The `process_images()` function:

1. Resize to (1600,1200).
2. Apply CLAHE in LAB space.
3. Sharpen via Gaussian blur and `addWeighted`.
4. Denoise with `fastNlMeansDenoisingColored`.

`process_folder()` applies this to all images in a directory.

4.2.2. Reconstruction

Using `pycolmap`, we automate feature extraction, matching, and sparse/dense reconstruction from the processed images.

4.3. Photo Booth Platform

We built a simple white-turntable backdrop from cardboard and paper to reduce background features and allow inverting the object without background interference (Figures 5–6).

Figure 5: Overall View of the Backdrop

Figure 6: Camera's View of the Backdrop

5. Integration and Validation

5.1. Reconstruction Steps

5.1.1. Image/Video Capture

Guidelines:

- Avoid mixed sunlight indoors.
- Preserve EXIF metadata.
- Do not crop—use masking instead.
- Capture 60 images from diverse angles and distances.

5.1.2. Automatic Reconstruction in COLMAP

We used the "Automatic Reconstruction" GUI with GPU and High quality settings (Figure 7).

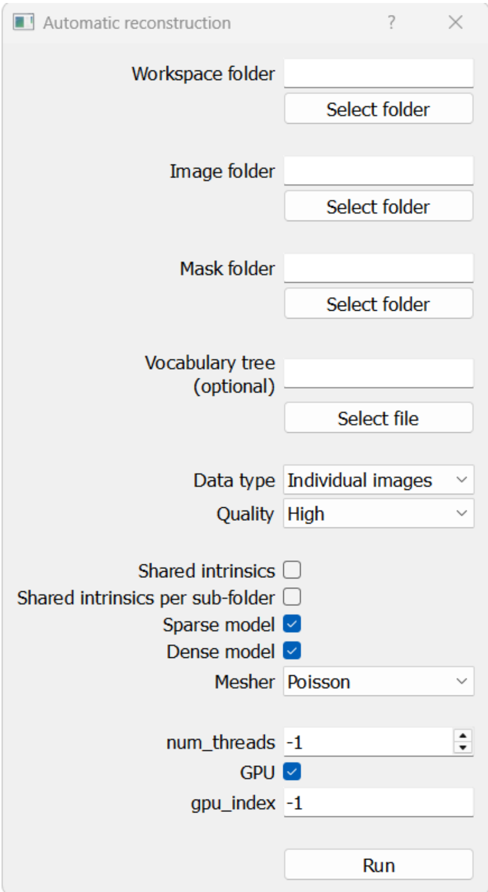


Figure 7: COLMAP Automatic Reconstruction Window

5.1.3. Point Cloud Cleanup in Meshlab

We remove outliers using Select Vertices and Select Faces by Color (Figures 8, 9).

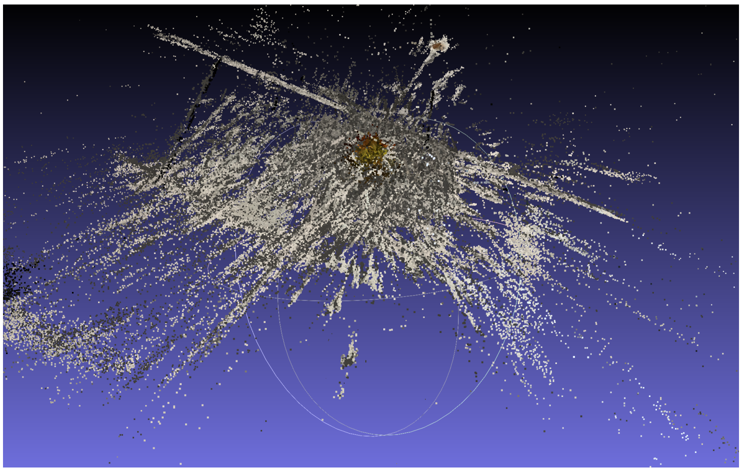


Figure 8: Spurious "Ghost" Points

Figure 9: Edge Background Points

5.1.4. Surface Reconstruction

We primarily use Screened Poisson for watertight meshes (Figures 10–12), despite "skirt" artifacts.

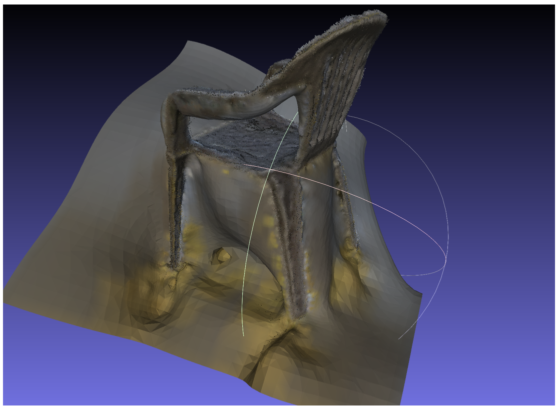


Figure 10: “Skirt” Artifact

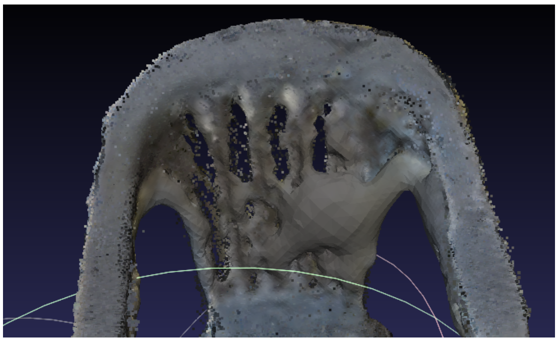


Figure 11: Holes in Complex Objects

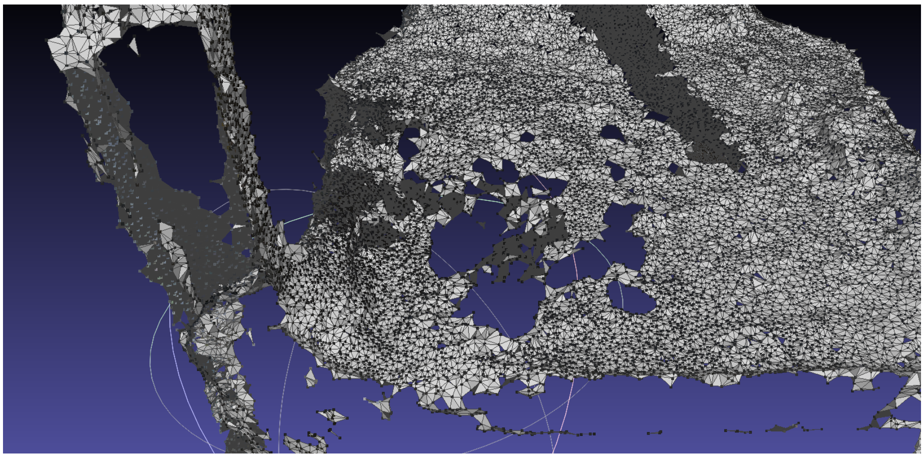


Figure 12: Ball Pivoting Reconstruction

5.1.5. Volume Conversion

In Meshlab, we close holes and ensure watertightness (`Close Holes`, `Re-Orient all faces coherently`). We simplify to 10 000 faces and repair non-manifold edges. Export as `.obj`, import into Fusion 360, generate face groups, then use `Convert Mesh` to produce a solid and export STL with “3D Print” (ASCII, centimeters) (Figures 13–16).

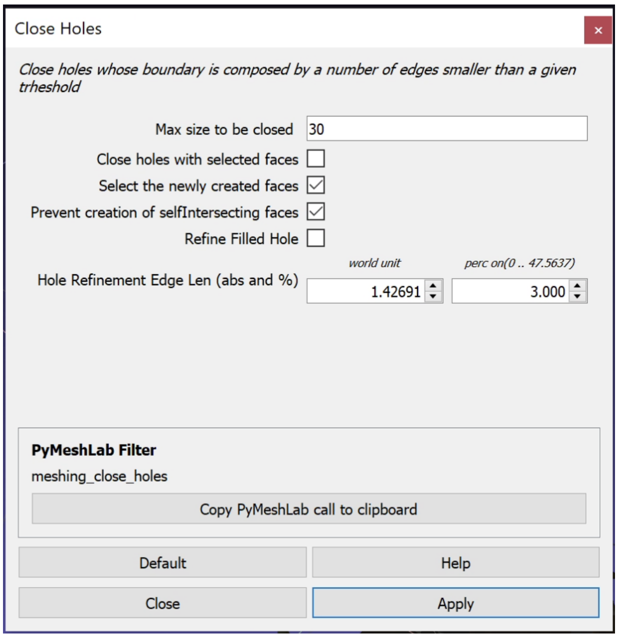


Figure 13: Meshlab "Close Holes" Tool

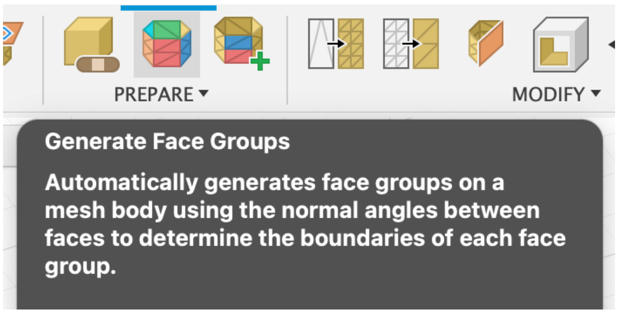


Figure 14: Fusion 360 Face Groups and Cleanup

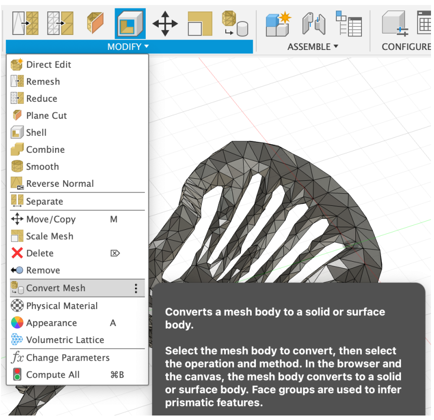


Figure 15: Convert Mesh Button

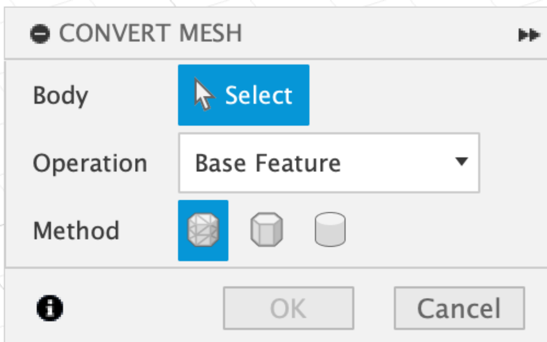


Figure 16: Conversion Parameters

5.2. Photo vs. Video Comparison

Point clouds and surfaces from single-shot photos outperform those from evenly sampled video frames, due to motion blur. We tested a Laplacian-based sharpness filter (`video_to_images_quality.py`) with no significant improvement. We therefore recommend direct photo capture.

5.3. Processed vs. Raw Image Comparison

We applied our processing to chair and glue-bottle images (Figures 17–**??**). Processed images show enhanced detail and contrast, though some blurring in flat regions. Lack of time prevented full COLMAP comparison.

Figure 17: Chair Before Processing

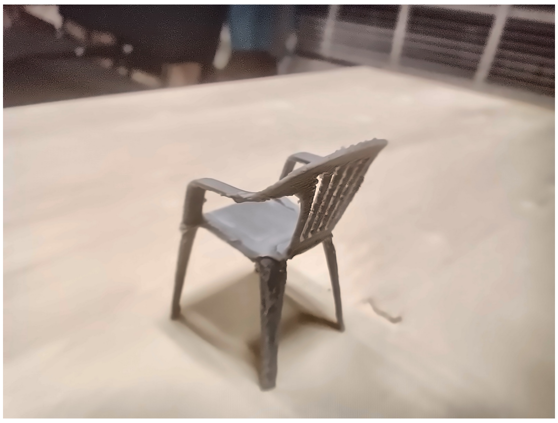


Figure 18: Chair After Processing

6. Project Closure

6.1. Point Cloud Creation (Chair)

Using our backdrop and 60 photos, COLMAP auto-reconstruction (High, GPU) yielded the point cloud in Figure 19.

Figure 19: Initial Chair Point Cloud

6.2. Surface Creation (Chair)

After removing white background points (Figure 20), we ran Screened Poisson (Figure 21). A large hole in the seat remains, but we proceed for demonstration.

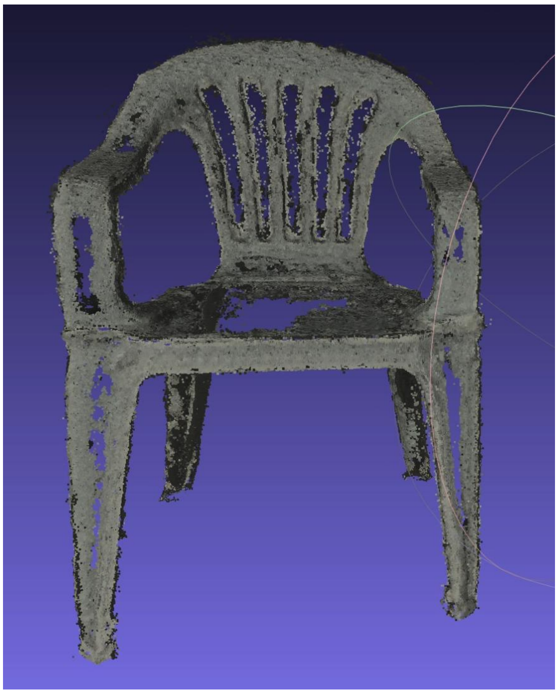


Figure 20: Cleaned Chair Point Cloud

Figure 21: Chair Surface from Meshlab

We observe persistent artifacts on the seat and rear left leg due to reflective glue and print-support imperfections (Figures 22, 23).

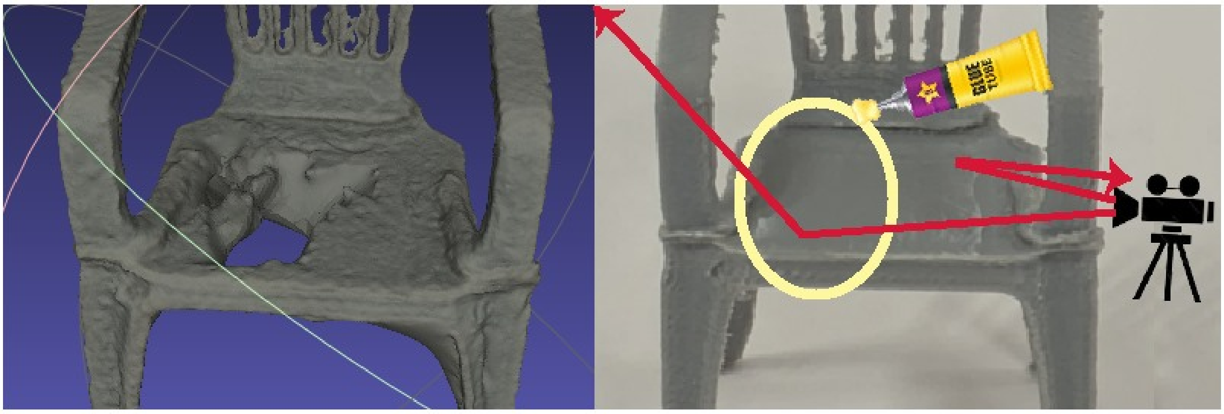


Figure 22: Schema: Seat Reflection Issue

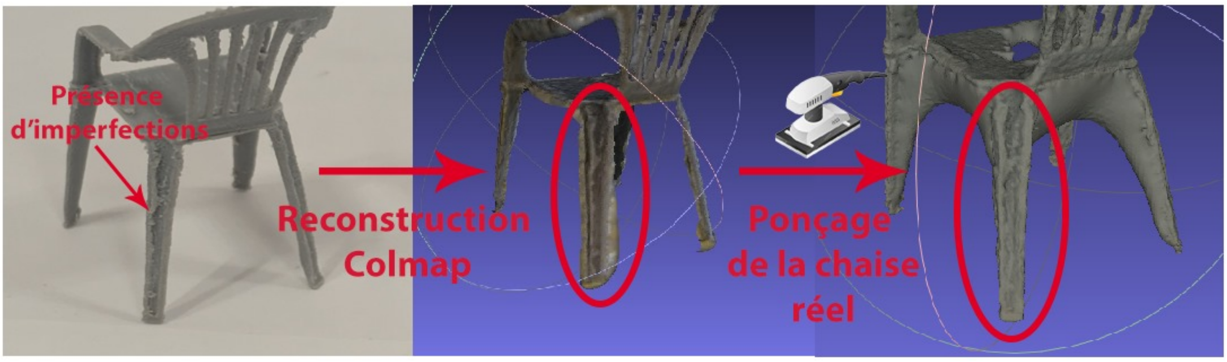


Figure 23: Schema: Rear Leg Modeling Issue

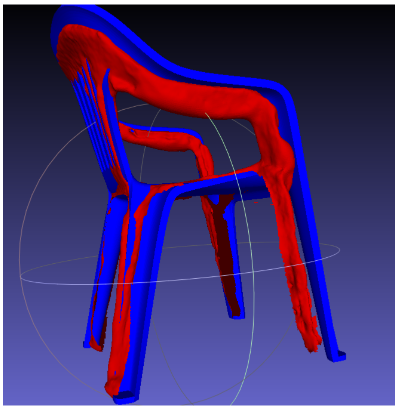
6.3. Volume Conversion (Chair)

After converting to a solid in Fusion 360, we exported the final STL (Figure 24).

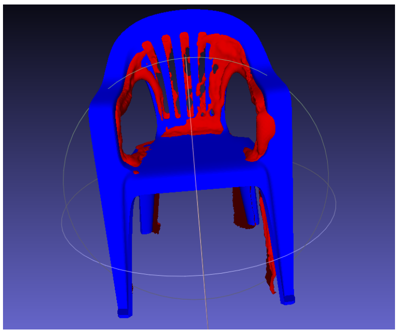
Figure 24: Chair Ready for 3D Printing (STL)

6.4. Comparison with Original Mesh

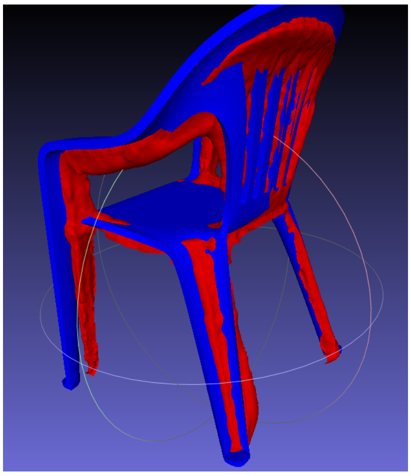
In Meshlab, we overlaid the original STL (blue) and reconstructed mesh (red) (Figure 25). Qualitatively, the backrest and rear legs align well; some scale adjustment remains.



Right Side Comparison



Front View Comparison



Third View

Figure 25: Overlay of Original vs. Reconstructed Chair

6.5. Physical Print Comparison

Figure 26: Original Printed Chair

Figure 27: Reconstructed Chair Print

Figure 28: Print Comparison: Before and After Reconstruction

The reconstructed print shows good detail but minor asymmetries in the armrests and a hollow seat.

6.6. Deliverables

ID	Deliverable	Description	Date	Delivery
L1	Scoping Document	Requirements, team organization, risk register	27/02	Moodle & Email
L2	First Chair Test	Visualization with 3D-printed chair model	11/03	Meeting
L3	Additional Model Tests	Default COLMAP tests on other models	25/03	Meeting
L4	Encountered Issues	List of issues	08/04	Meeting
L5	Parameter Tests	Full parameter testing on chosen model	22/04	Meeting
L6	Synthesis	Summary of L5 and improvement tests	29/04	Meeting
L7	Bonus	Image processing and parameter optimization	13/05	Meeting
L8	Final Report	Project summary + final prototype	29/05	Moodle & Email
L9	Future Deliverable	Real-time reconstruction demo	–	Demonstration

Table 3: Project Deliverables

6.7. Conclusion

We developed multiple testing processes and tools, demonstrating that input image quality is the most critical factor. Our photo booth and processing scripts reduce manual cleanup. With a good GPU, High-quality mode is feasible. Future work could automate mesh cleanup and selection of reconstruction algorithms via AI based on object characteristics.

Remaining challenges:

- Reflective or absorptive materials cause sparse reconstructions.
- Surface-to-volume conversion still requires manual refinement.
- Semi-automatic pipelines may need 5 % human intervention.

7. Project Management Retrospective

We under-utilized GitLab, opting for Google Drive and WhatsApp. Our Gantt charts evolved to reflect longer test phases and removed obsolete tasks, leading to better workload distribution. Future projects will anticipate test durations more accurately.

8. Teamwork and Individual Reflections

8.1. Pierre-Antoine HIGNARD – Leadership

Early access to a Shadow PC let me drive initial experiments, allocate tasks, and maintain global project oversight once Fablab access was obtained.

8.2. Samuel VATON – Technical Decisions

I weighed using `pycolmap` vs. direct INI file automation for reconstruction. I chose `pycolmap` due to its intended purpose and GPU support.

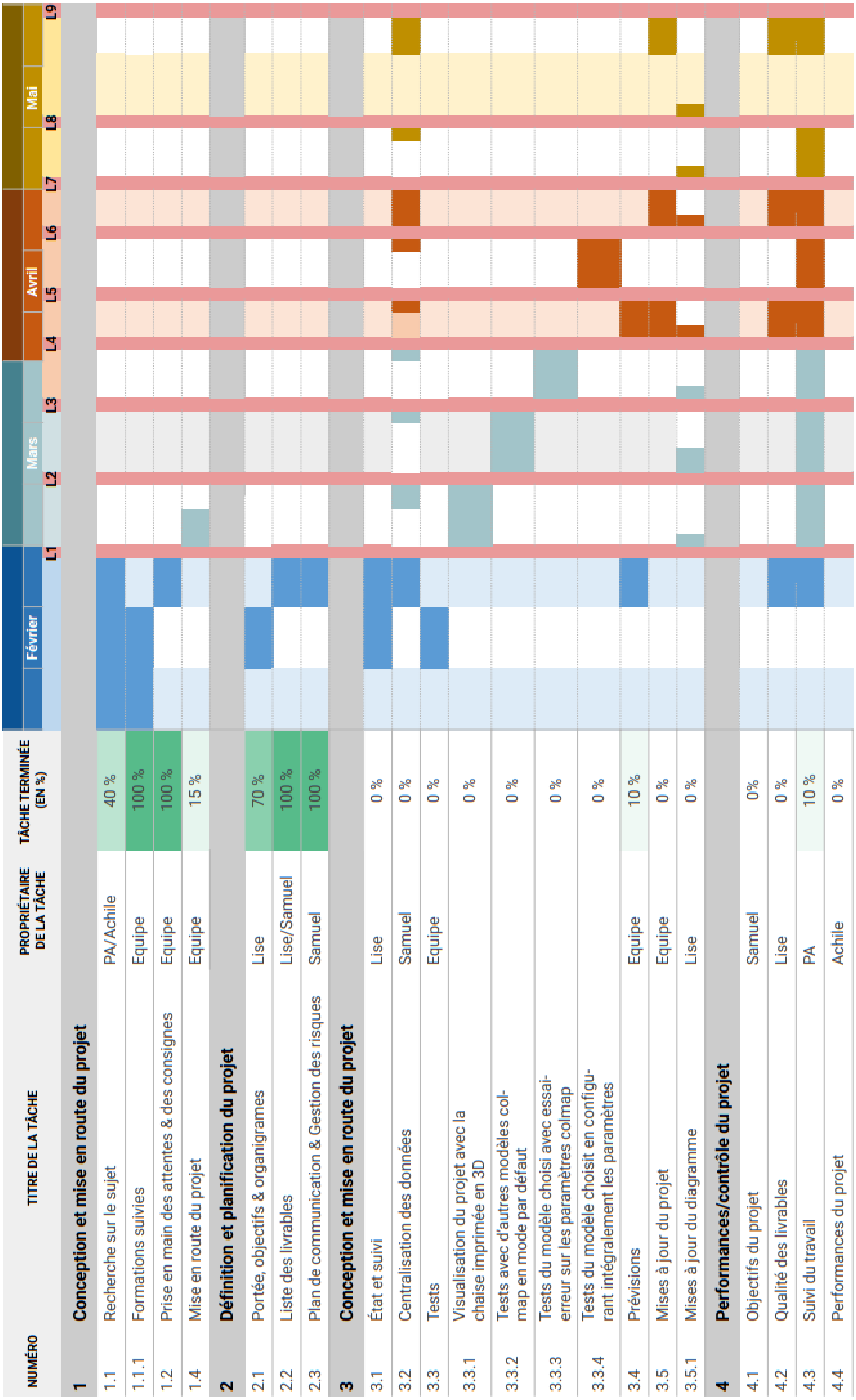


Figure 29: Initial Gantt Chart

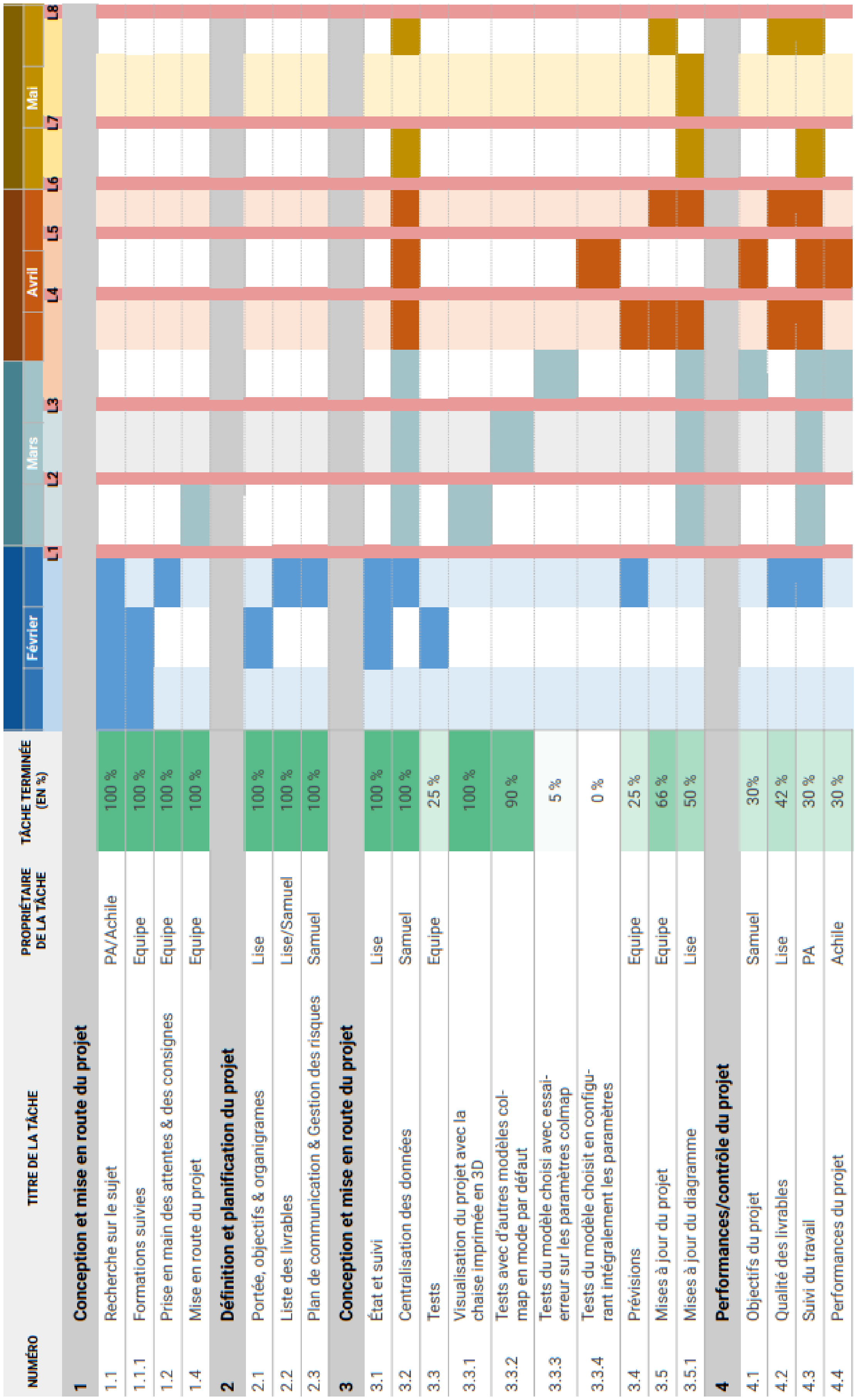


Figure 30: Mid-Project Gantt Chart

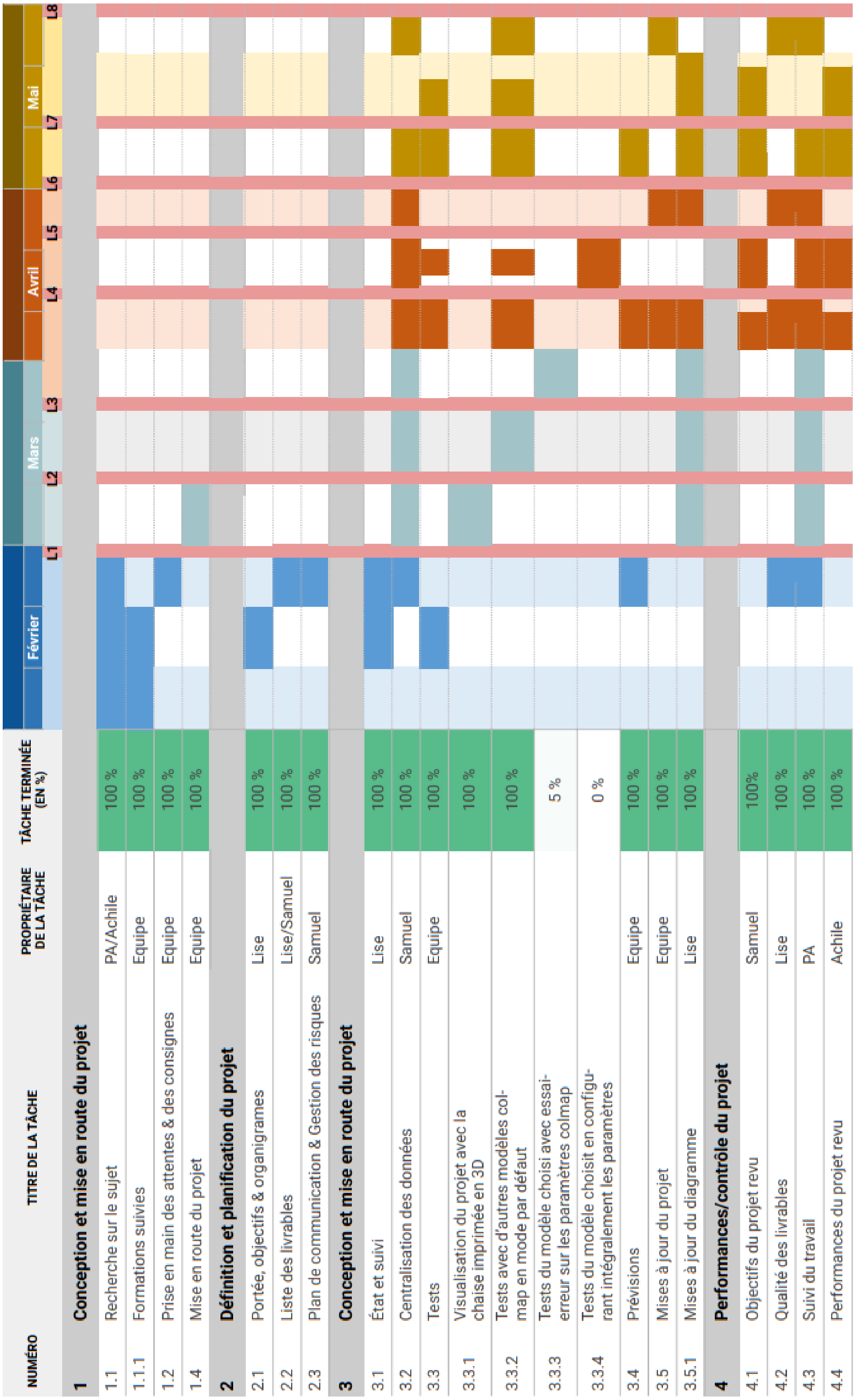


Figure 31: Final Gantt Chart

8.3. Anne-Lise PELLETIER – Error Handling

I over-cleaned the mesh in Meshlab, losing authentic object characteristics. Group feedback helped me revert to a more faithful model.

8.4. Achile PINSARD – Motivation

When only one PC worked, I reorganized tasks (photo capture, cleanup, documentation) and proposed a "fil rouge" object to maintain momentum.

8.5. Group Reflection

We adapted well to resource constraints but need stricter timelines and reduced tolerance for delays.

9. Conclusion and Future Work

The PRONTO project taught us teamwork on a complex, long-term task. While some deliverables remain incomplete, we gained deep insights into computer vision and SfM, successfully re-printing a chair from reconstruction. We conclude satisfied and believe this report reflects our sustained effort.

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OUR WORLDWIDE PARTNERS UNIVERSITIES - DOUBLE DEGREE AGREEMENTS

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