Project in Visual Computing
3D Printing of Cardiac Ultrasound Data

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1 Introduction

Recent advancements in 3D printing have enabled the fabrication of physical model derived from medical imaging data. Such models have found increasing application in clinical education, surgical planning, and medical device testing. In particular, the fabrication of elastic anatomical models allows for a more realistic representation of the mechanical properties of anatomical tissues. This project focuses on the fabrication and evaluation of watertight cardiac models derived from pre-segmented ultrasound meshes using 3D printing techniques. The work includes mesh preparation through surface extrusion, experimental evaluation of wall thickness, print orientation, and mesh junction design to ensure watertightness. Material selection and post-processing strategies, including elastic materials, and surface coatings, are investigated to achieve structurally stable and functional models. The scope further includes qualitative evaluation of the printed models under ultrasound imaging to assess their stability for ultrasound-based applications. This report documents the overall progress of the project, including methodology, design and modeling, fabrication process, and experimental results.

2 Methodology

2.1 File Preparation

The ultrasound-derived cardiac meshes were provided by Siemens Healthineer. The meshes were pre-processed to generate printable, watertight geometries suitable for additive manufacturing. The original mesh files were converted into standard 3D printing formats following geometric refinement. For evaluation purposes, each cardiac chamber was processed and saved as an individual model to enable independent assessment of printability and watertightness.

2.2 3D Printer Specifications

This project utilized an *Original Prusa i3 MK3S+* fused deposition modeling (FDM) 3D printer available at the university. The printer was suitable for fabricating the cardiac models using standard printing parameters without the need for additional hardware modifications. For the application, PrusaSlicer-2.9.3 was used to fix the mesh and initial printings and UltiMaker Cura was used for detailing modification of the print settings. Most of the printings were done using UltiMaker Cura.

For the additional printing, Original Prusa XL5T was used along with PrusaSlicer-2.9.3.

2.3 Material Selection

For initial printing trials aimed at verifying the printability of the cardiac models, polylactic acid (PLA) filament was used due to its ease of printing and dimensional stability. To better replicate the mechanical softness of cardiac tissue, thermoplastic polyurethane (TPU) 95A filament was subsequently employed. TPU 95A is a flexible and elastic material characterized by rubber-like elasticity, resilience, and durability, making it suitable for producing soft-touch surfaces.

To further investigate the effect of material flexibility, TPU 82A and TPU 60A filaments were also used. Among these, TPU 60A exhibits the highest degree of flexibility, producing parts with rubber-band-like behavior and maintaining significant elasticity even at non-zero infill densities. These materials enabled a comparative evaluation of mechanical compliance and printability for soft cardiac model fabrication. Table 1 summarizes the filaments used in this project.

Material	Brand	Shore Hardness	Flexibility	Remarks
PLA		Rigid	Low	Used for initial printability testing
TPU 95A		95A	Medium	Soft-touch, elastic material
TPU 82A	Recreus	82A	High	Increased flexibility
TPU 60A	Recreus	60A	Very High	Highly elastic, rubber-like behavior

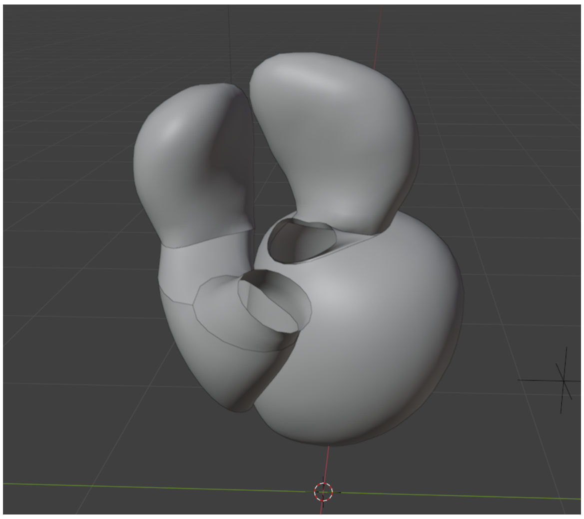
Table 1: Material properties of filaments used for cardiac model fabrication

2.4 Printing Process Workflow

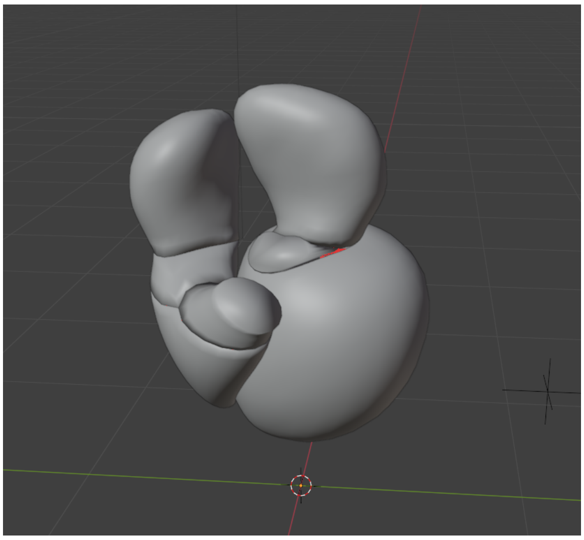
The overall printing workflow consisted of model slicing, printer setup, fabrication, and post-processing. Detailed printing parameters and procedures are described in the subsequent sections. Multiple printing trials were conducted to investigate the influence of wall thickness, infill density, other additional settings, and support generation on printability and watertightness of the cardiac models.

3 Design and Modeling

The ultrasound-derived cardiac mesh was provided in USD (Universal Scene Description) format. The mesh was imported into Blender for pre-processing, where non-manifold geometries were identified and corrected to obtain closed, watertight surfaces suitable for additive manufacturing, as shown in Figure 1a and Figure 1b, also wall thickness has been set initially in Blender. Following mesh optimization, the model was exported in STL (Stereolithography) format for 3D printing. For testing and evaluation purposes, each cardiac chamber was saved as a separate file to allow independent analysis of printability and watertightness.



(a) Cardiac mesh imported in Blender



(b) Cardiac mesh after manifold correction

Figure 1: Pre-processing of cardiac ultrasound mesh in Blender

3.1 Printing Parameters

The cardiac models were fabricated using the default printing profiles provided by the UltiMaker Cura for PLA and TPU 95A materials. Default parameters were selected to ensure stable and reproducible printing conditions. Only wall thickness and infill density were varied during the experiments, as these parameters directly influence structural integrity, flexibility, and watertightness of thin-walled anatomical models. Initially, support structures were automatically generated due to the complex geometry of the cardiac mesh.

Table 2 summarizes the key printing parameters applied across all fabrication trials.

Parameter	**Value**
Wall thickness	1.1 - 2.5 mm
Infill pattern	lightening
Infill density	0 - 20%
Support generation	Enabled / Disabled

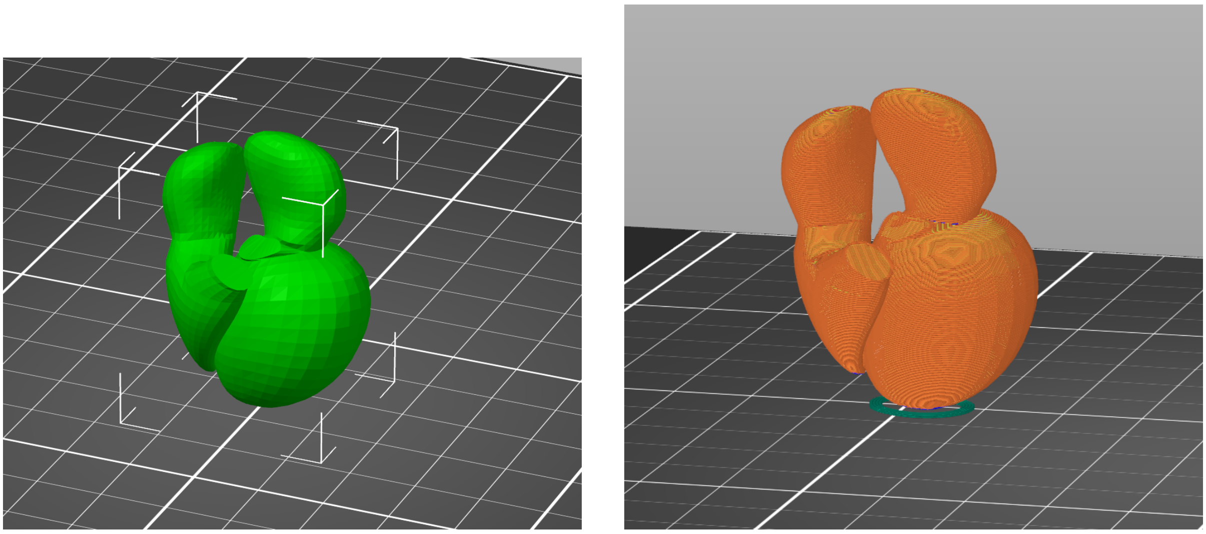
Table 2: Variable printing parameters used in the study

Wall thickness and infill density were selected as the primary variables, as they have a significant impact on watertightness and mechanical compliance while minimizing the influence of other printing parameters.

Figure 2(a) shows the imported cardiac model and Figure 2(b) shows the model after slicing which is ready to be printed.

3.2 Printing Procedure

The processed STL files were sliced using default material profiles, with wall thickness and infill density adjusted according to the experimental plan. Support structures were generated



(a) Imported cardiac model in UltiMaker Cura

(b) Cardiac model after slicing

Figure 2: Preparation of the car5diac model in UltiMaker Cura

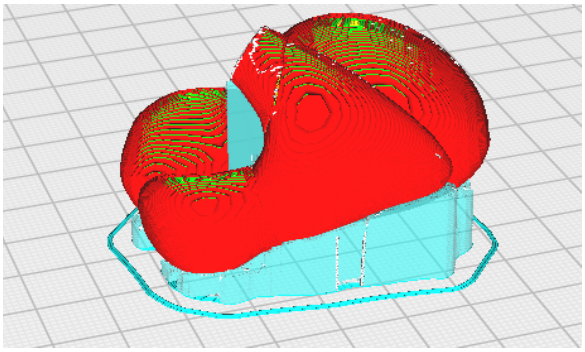
where required to accommodate overhanging features. Figure 3 shows the print process where support structure can be seen as well. After completion, the printed models were allowed to cool, supports were removed, and go through the post-processing for further testing.

Figure 3: Printing process

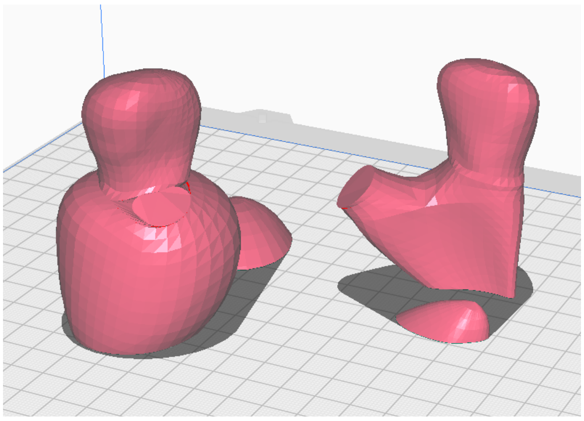
3.3 Post-Processing

For prints fabricated using highly flexible filaments, support removal proved challenging due to the softness of the material. To address this limitation, an alternative fabrication strategy was adopted in which the cardiac models were horizontally segmented and printed as separate parts. Following printing, the individual components were post-processed and assembled to reconstruct the complete cardiac model. LOCIEFE 406 was used to glue the parts togeter.

Figure 4(a) illustrates the cardiac model printed with support structures, and Figure 4(b) shows the horizontally separated cardiac parts.



(a) Cardiac model with support structures



(b) Separated cardiac parts

Figure 4: Strategies used to address support removal challenges

4 Results

4.1 Effect of Printing Parameters on Watertightness

This section presents a comparative analysis of the printed cardiac models fabricated with varying wall thicknesses, infill densities, and support strategies. The primary evaluation criteria were printability, structural integrity, and watertightness.

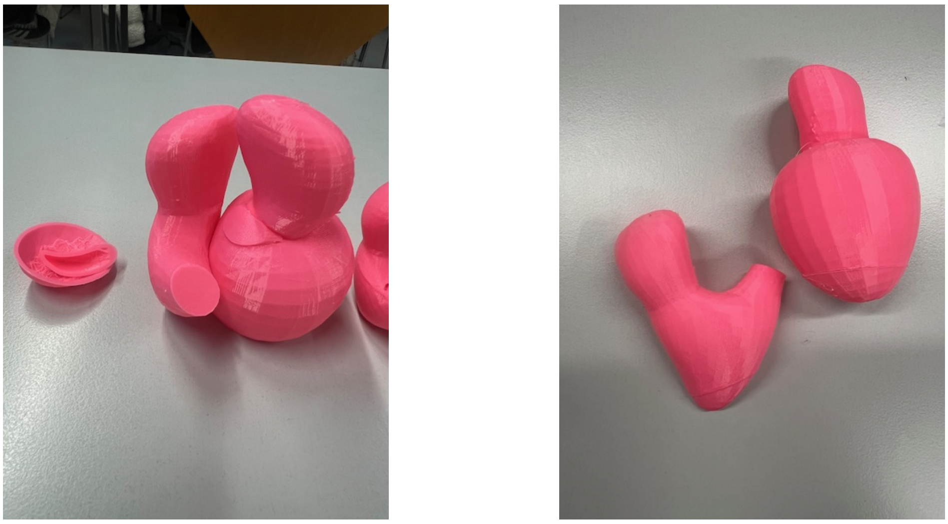
4.1.1 TPU 95A

Models printed with wall thickness below 1.1 mm consitently exhibited leakage, primarily at the junctions between the cardiac chambers and valves. Increasing the wall thickness to 1.2 mm resulted in improved watertightness; however, further increasing the wall thickness to 1.5 mm, combined with a 10% infill density, significantly reduced model flexibility.

Following geometric refinement of the model, a wall thickness of 1.1 mm with zero infill density resulted in no observable leakage during qualitative testing. Infill density was subsequently reduced to 0% in later trials to facilitate the injuction of ultrasound gel. While support structures improved print stability, their removal proved challenging for flexible TPU materials and led to surface damage; therefore, support structures were omitted in subsequent prints.

Due to the complex geometry of the cardiac model, horizontal segmentation was required for successful printing. As a result, the bottom thickness was set to zero enable post-processing and reassembly of the printed components.

Figure 5(a) shows the printed cardiac model and Figure 5(b) illustrates the model after post-processing.



(a) Printing result (b) Model after post-processing

Figure 5: Fabrication and post-processing of the cardiac model

4.2 TPU 82A

Models fabricated using TPU 82A with a wall thickness of 1.5 mm and zero infill density demonstrated consistent watertightness, with no observable leakage during testing. Support structures were not required for these prints, and the resulting models maintained sufficient flexibility as shown in Figure 6.

Figure 6: Printed result for TPU 82A

4.3 TPU 60A

For TPU 60A, models printed with a wall thickness below 1.7 mm and zero infill density exhibited leakage during qualitative testing. To maintain the overall flexibility, keep the wall thickness to 1.7mm, and increase the top thickness to 1.7mm made the object watertight.

A summary of the printing parameters and corresponding watertightness outcomes for each material is presented in Table 3. Full parameter changes for UltiMaker Cura are listed in Table 4.

Material	Wall Thickness (mm)	Infill (%)	Supports	Watertight
TPU 95A	below 1.1	0–10	Yes	No
TPU 95A	1.2	10	Yes	No
TPU 95A	1.5	10	No	Yes (reduced flexibility)
TPU 95A	1.1	0	No	Yes
TPU 82A	1.5	0	No	Yes
TPU 60A	below 1.7	0	No	No
TPU 60A	1.7 with 1.7 top thickness	0	No	Yes

Table 3: Effect of printing parameters on watertightness of cardiac models

Setting	Current changes
Build Plate Adhesion Type	skirt
Generate Support	False
Support Placement	buildplate
Remove Mesh Intersection	True
Remove All Holes	True
Keep Disconnected Faces	True
Merged Meshes Overlap	1.2
Extensive Stitching	True
Infill Density	0
Infill Overlap Percentage	5
Infill Before Walls	False
Infill Pattern	lightning
Top/Bottom Thickness	0
Top Thickness	0.8
Surface Mode	both
Wall Thickness	1.1
Make Overhang Printable	True

Table 4: Changed Parameters in Ultimaker Cura

4.4 Additional Testing using 82A and 60A

One final trial for this project is to make two walls to mimic the actual representation of the heart chambers. *Original Prusa XL5T* was used for this additional experiment to be able to use different filaments for different parts of the meshes. 82A filament was used for outer mesh, 60A for inner mesh, and PVA filament was used for the support material. PVA filament is a water-soluble polymer, so the support material can be removed from the resulting object without damaging itself.

First, using the Blender to create the internal (smaller) chambers to be able to demonstrate the actual chambers as shown in Figure 7. Wall thickness for outer part was set to 1.5mm thickness using Solidify in Blender. Then save the inner part and outer part to two different STL files. Import the outer part first to PrusaSlicer then add the inner part as a part of the outer which is shown in Figure 9. Assign each part to a correct filament. Support materials, which is a soluble filament, were overlapping with other filament which might cause a hole when the filament dissolves. Therefore, support blockers were added to remove all the unnecessary support materials from the mesh as shown in Figure 8.

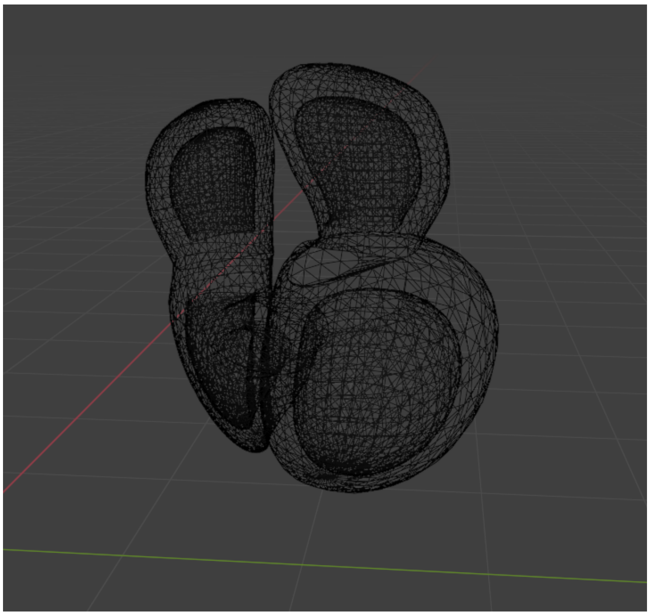


Figure 7: Meshes in Blender

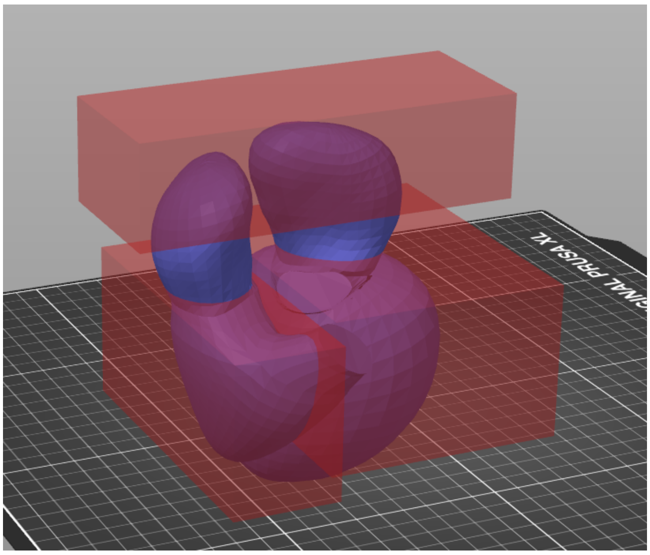


Figure 8: Support blockers to remove unwanted support materials

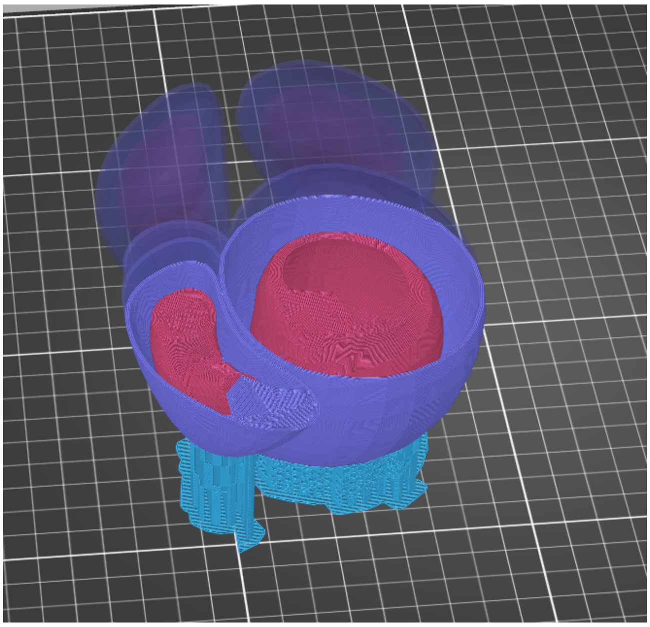


Figure 9: Sliced Object in PrusaSlicer

4.5 Ultrasound Evaluation Results

Ultrasound evaluation was performed on the final printed cardiac model using TPU 95A after injecting gel and water internally. The imaging results demonstrated clear visualization of the model walls. Representative ultrasound images obtained during the experiment are shown in the following figures 10.

5 Discussion

This project initially had some limitations that were outside the defined scope of the study. Due to the difficulty of removing support structures from the flexible filament materials, the cardiac mesh was horizontally segmented to enable successful fabrication. While this approach facilitaed printing without supports, it required post-processing steps in which the printed parts were manually aligned and bonded together. As a result, minor assembly inaccuracies introduced by human handling may have led to small gaps between components, potentially contributing to leakage.

An alternative approach involves the use of soluble support materials, which could allow support removal without mechanical damage to the printed model. Investigating such materials may eliminate the need for model segmentation and reduce post-processing errors. This has been introduced in this project, but the result has not been presented. Further extension of this work could focus on improving the physiological realism of the cardiac models. For example, introducing a dual-wall structure with a compliant material, such as silicone, between layers could better mimic the behavior of cardiac muscle tissue.

Additionally, future work could explore the use of deformable resin-based 3D printing technologies to fabricate models capable of reproducing time-dependent cardiac deformation.

(a) Ultrasound image 1

(b) Ultrasound image 2

(c) Ultrasound image 3

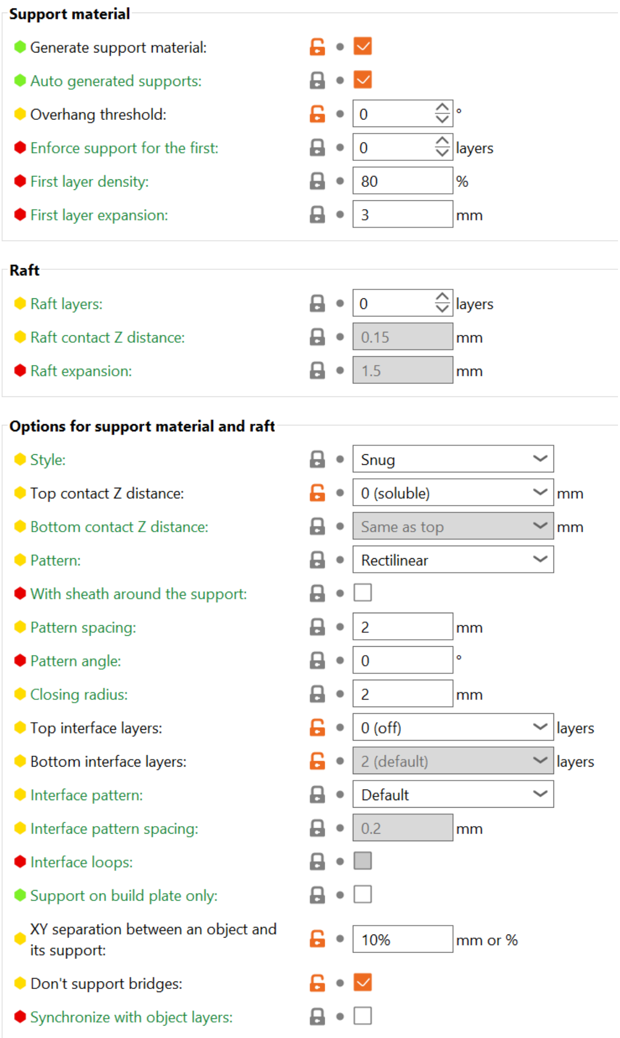
(d) Ultrasound image 4

Figure 10: Ultrasound imaging results of the 3D-printed cardiac model

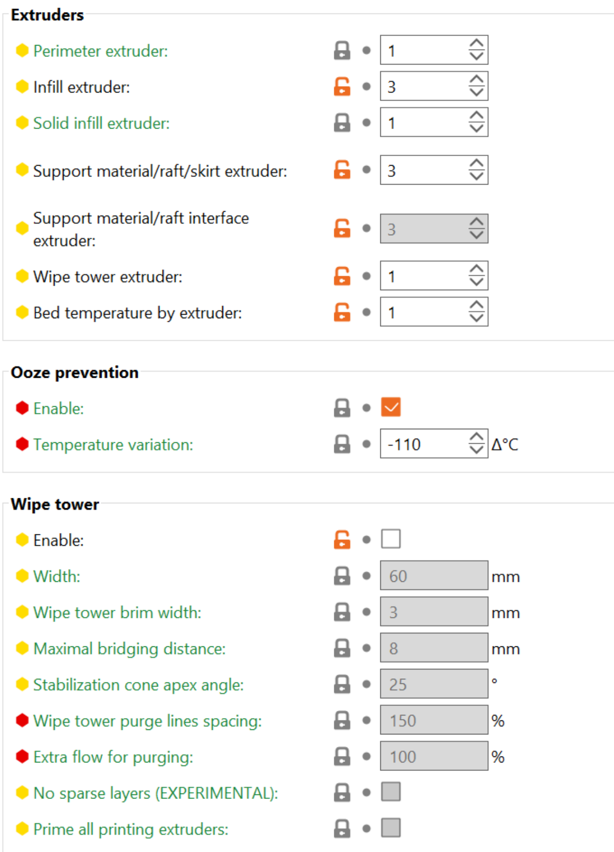
This would allow the physical model to more accurately reflect dynamic cardiac motion derived from ultrasound data, which could increase their relevance for clinical simulation and research applications.

6 Conclusion

This project investigated the feasibility of fabricating watertight, ultrasound-compatible cardiac models derived from pre-segmented ultrasound meshes using 3D printing techniques. The workflow encompassed mesh preparation, material selection, printing strategy optimization, and qualitative evaluation under ultrasound imaging. The result demonstrated that wall thickness and material selection are critical parameters influencing watertightness. Flexible TPU materials enabled the fabrication of soft cardiac models. Support structures, while beneficial for print stability, posed challenges for flexible materials and necessitated alternative fabrication strategies, such as model segmentation and post-processing assembly. Ultrasound evaluation of the final printed models confirmed clear visualization of model walls, indicating that the models are suitable for ultrasound-based imaging applications. Overall, this study establishes a practical methodology for producing soft, watertight cardiac models from ultrasound data.



(a) First Caption



(b) Second Caption

Figure 11: Overall setting parameters in PrusaSlicer for the final mesh