Tutors: Prof. Zhu Ning, zhuning@tsinghua.edu.cn
Team: Chia Hui Yen, Ren Tianye
Contributions: Designs & Scripting 80%, drawings 90%, modelling 95%
Notes: paper pending publication in Symbiotic Intelligence: Proceedings of the 6th International Conference on Computational Design and Robotic Fabrication (CDRF 2024)

Details & Joinery:
3D Printing Traditional Joints

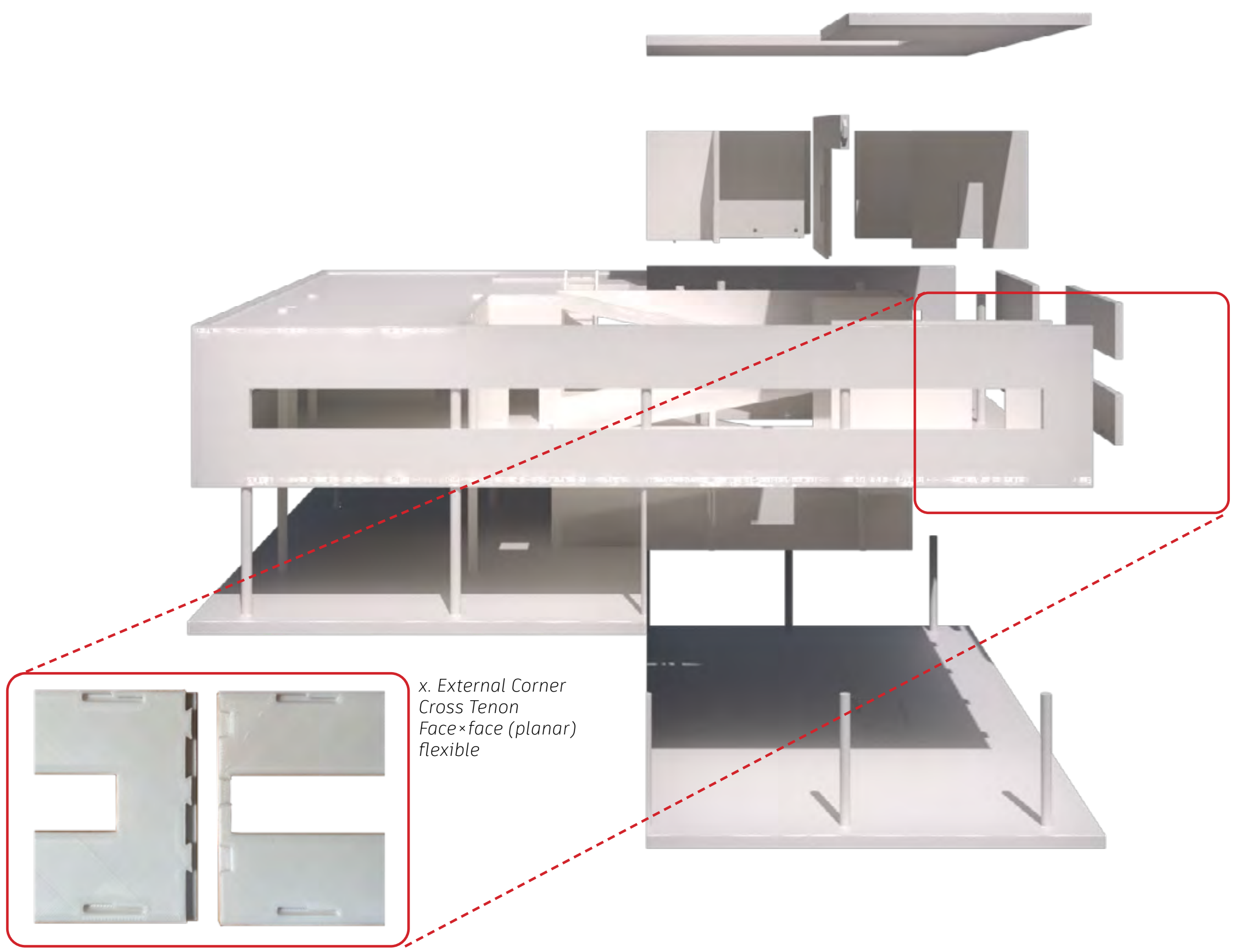
_3D printing, traditional joinery,digital fabrication

July 2023 - September 2023

Introduction

Large-format and relatively precise 3D printing equipment is often prohibitively expensive. In the production of large-scale architectural models, it is common practice to divide the model into smaller units, which are printed separately and then assembled into a complete model. Therefore, the search for suitable assembly methods is necessary. Currently, units of a 3D-printed model are usually joined with glue. However, the irreversibility of adhesive bonding, the toxicity of the glue, the limited weather resistance, and the indefinite structural strength pose challenges to the efficient use of 3D-printed models. Finer models often require special seam treatments at the adhesive joints, such as enlarging the bonding surface (Knoll et al. 2003: P37-38). Such methods do not address the drawbacks of irreversibility and glue toxicity. They do, however, inspire us to design assembly joints that do not require adhesive, thus offering a comprehensive solution to the aforementioned issues.

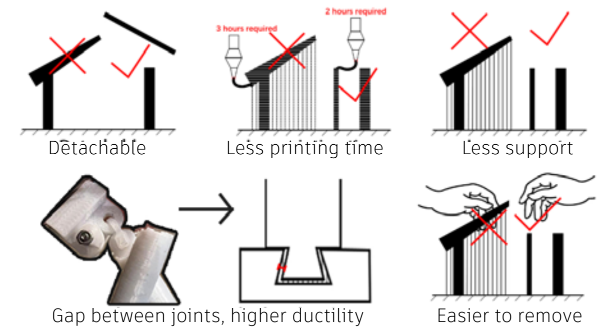
Graphical Abstact:



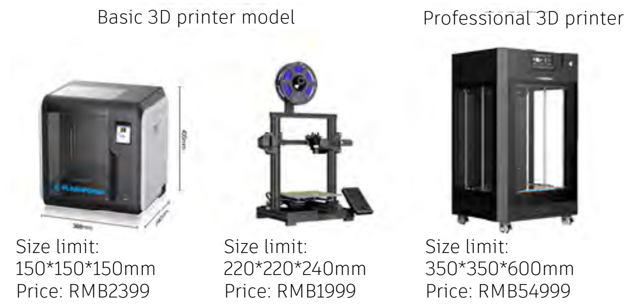
(1) Preface: Research Gap

3D printing joints for architectural models are in high demand in various contexts, including architectural design education, commercial applications, and exhibitions. However, current research on the parametric design of joints primarily focuses on large-scale models, such as furniture and replicas of historical buildings. There is a lack of investigation into models typically used in architectural design at the scale of 1:50 or even smaller. These models have plates of 2mm to 6mm thick, so the design of their joints cannot be directly adapted from the joints used in larger-scale models, taking into account the precision of 3D printers and material strength, among other factors.

This paper addresses the typification, standardization, and parameterization of connection joints for small architectural models at scales of 1:50 to 1:200. We conduct research into three different types of joint forms—surface joints, line joints, and point joints—along with their dimensional parameters and printing settings. The information above is compiled into a database. Additionally, we offer recommendations for joint combinations in various orientations to ensure secure assembly. Using a 1:50 scale model of a Savoy villa as an example, we validate and showcase our research findings. We also observe that printing detachable models, as opposed to printing integral models, offers advantages such as reducing printing time, minimizing the use of support materials, and avoiding the need for non-detachable supports.



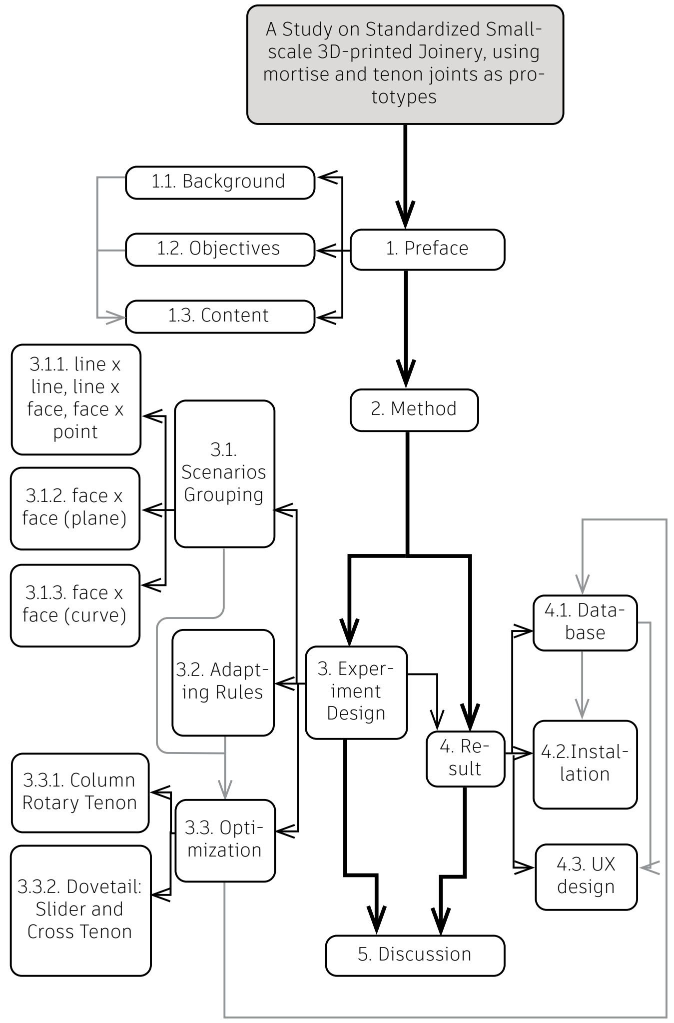
The advantages of assembly nodes



Cost and area limitation of 3D printer

(2) Method

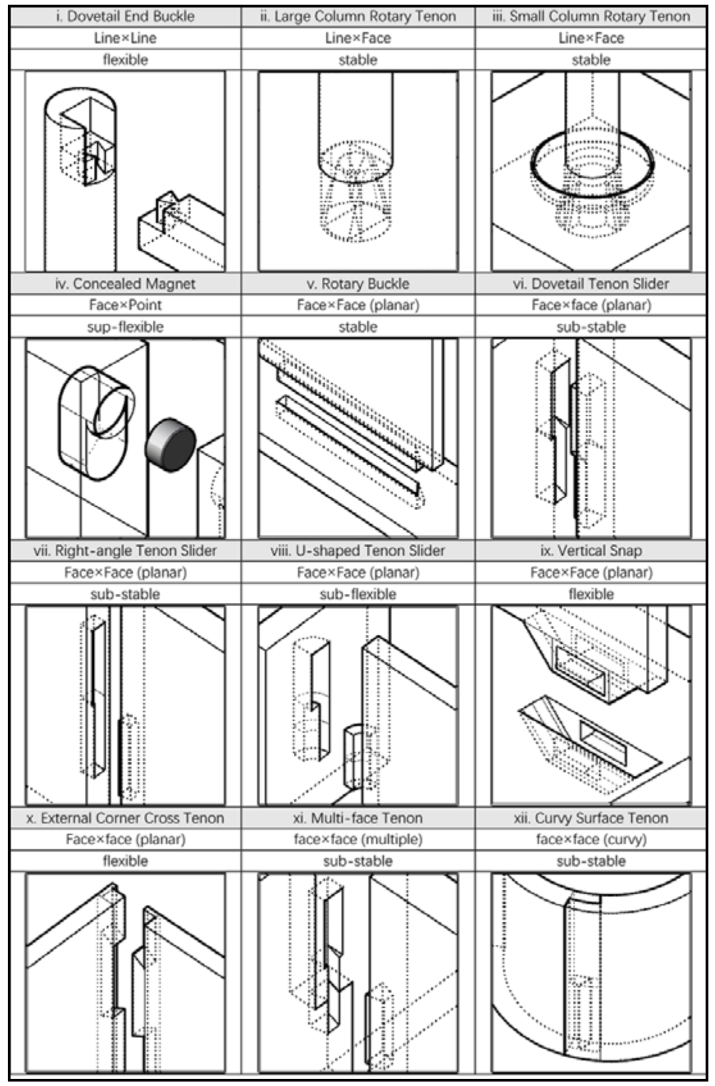
Computer modeling: Rhinoceros 7,
Model slicing: Creality Slicer, Ender-PLA filament was used as the printing material.
3D printers: Creality3D Sermoon V1, printing size of 15cm x 15cm, an accuracy of 0.2mm, priced at approximately 2000-3000 RMB. They are commonly used by students majoring in architecture.



Result

We have designed twelve joints suitable for various assembly scenarios with different levels of stability. A schematic representation of the joints is presented in below table.

i. Dovetail End Buckle	ii. Large Column Rotary Tenon	iii. Small Column Rotary Tenon
Line×Line	Line×Face	Line×Face
flexible	stable	stable
iv. Concealed Magnet	v. Rotary Buckle	vi. Dovetail Tenon Slider
Face×Point	Face×Face (planar)	Face×face (planar)
sup-flexible	stable	sub-stable
vii. Right-angle Tenon Slider	viii. U-shaped Tenon Slider	ix. Vertical Snap
Face×Face (planar)	Face×Face (planar)	Face×Face (planar)
sub-stable	sub-flexible	flexible
x. External Corner Cross Tenon	xi. Multi-face Tenon	xii. Curvy Surface Tenon
Face×face (planar)	face×face (multiple)	face×face (curvy)
flexible	sub-stable	sub-stable



**Stability levels: Stable> Sub-stable> Sub-flexible> Flexible> Sup-flexible

3D PRINTING JOINERY

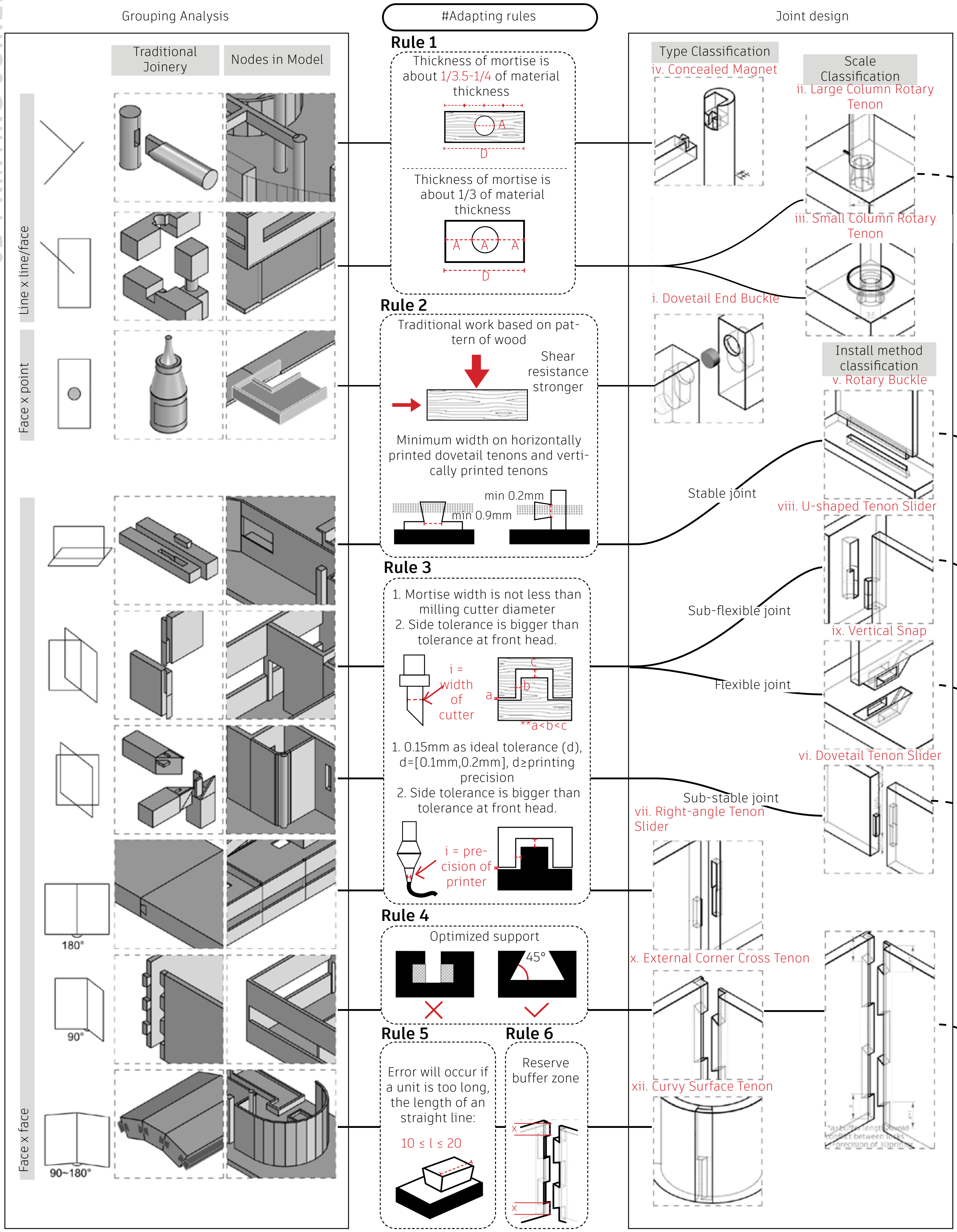
(3) Experiment Design

Our research process encompassed the following steps: 1. Joint prototype design, 2, Installation Method Research, 3. Printing Setup and 4.UX Design

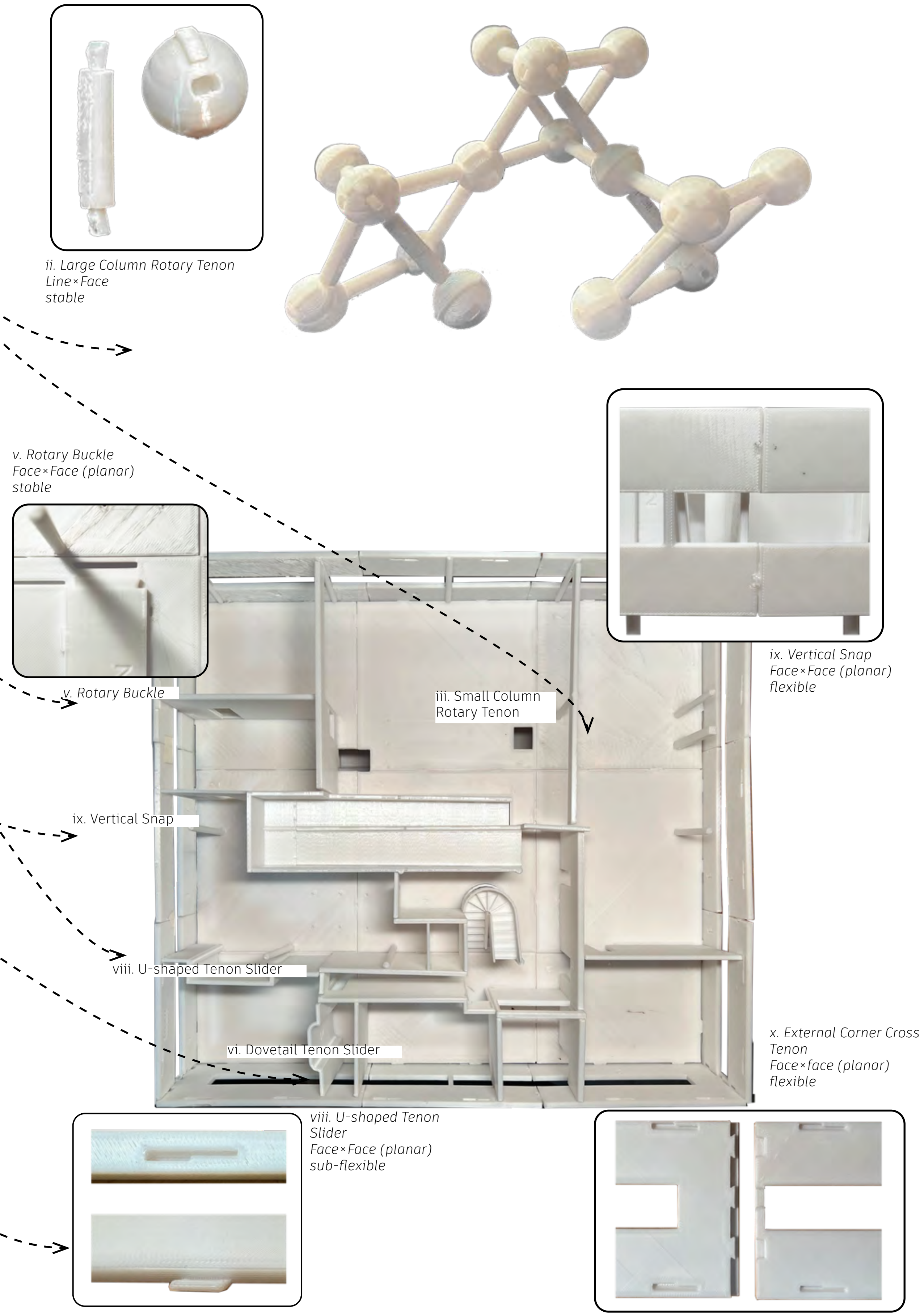
3.1. Scenarios Grouping

3.2. Adapting Rules

Traditional mortise and tenon joints were categorized based on woodworking experience, including face-to-face (non-right angles), face-to-face (right angles), face-to-point, line-to-face, and line-to-line. We analyzed the applicable forms and size rules and adjusted them according to the characteristics of 3D printing.



Application Example

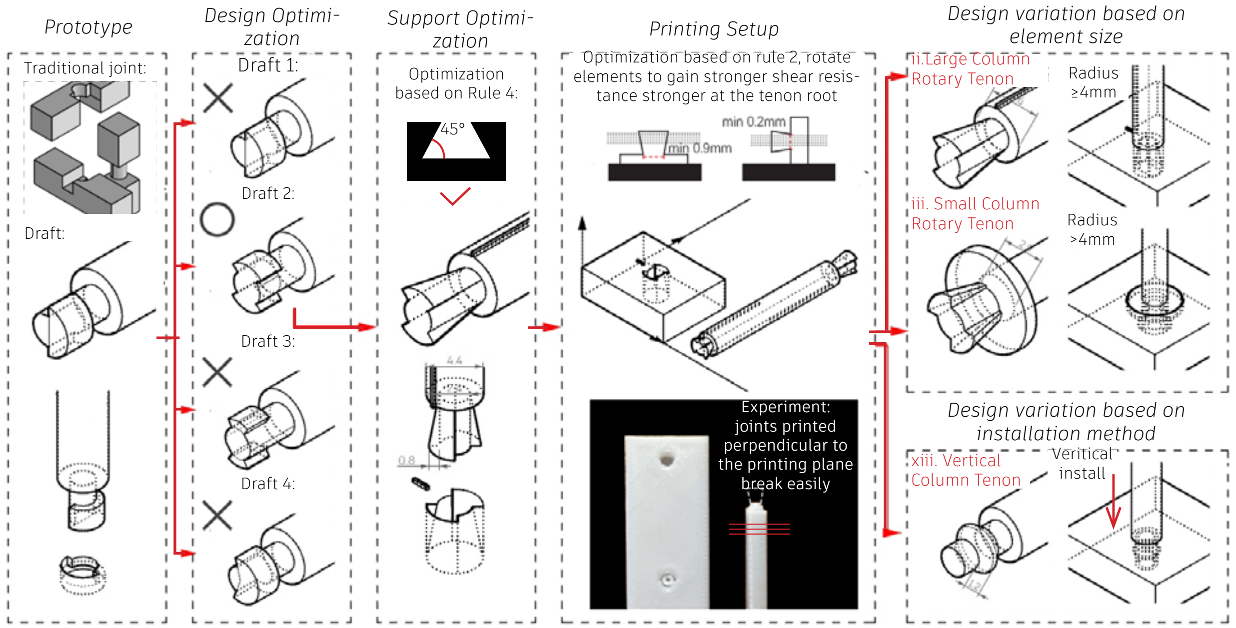


3D PRINTING JOINERY

3.3. Optimization

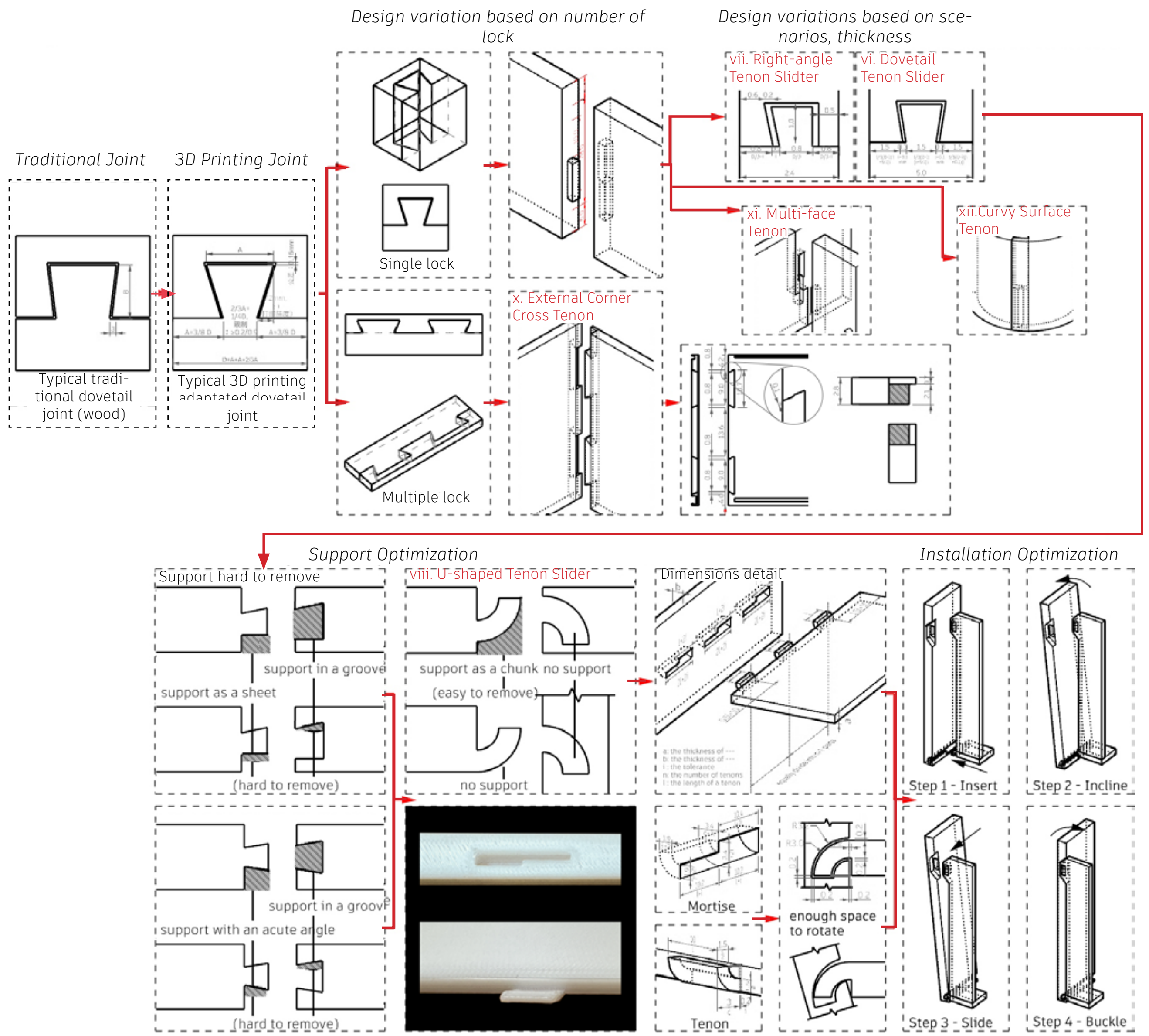
Iteration Example 1: Rotating Joint

Taking the variants of the traditional dovetail tenon (ii. iii. vi. vii. viii. x.) as examples, the design optimization process is illustrated in Figure 3.

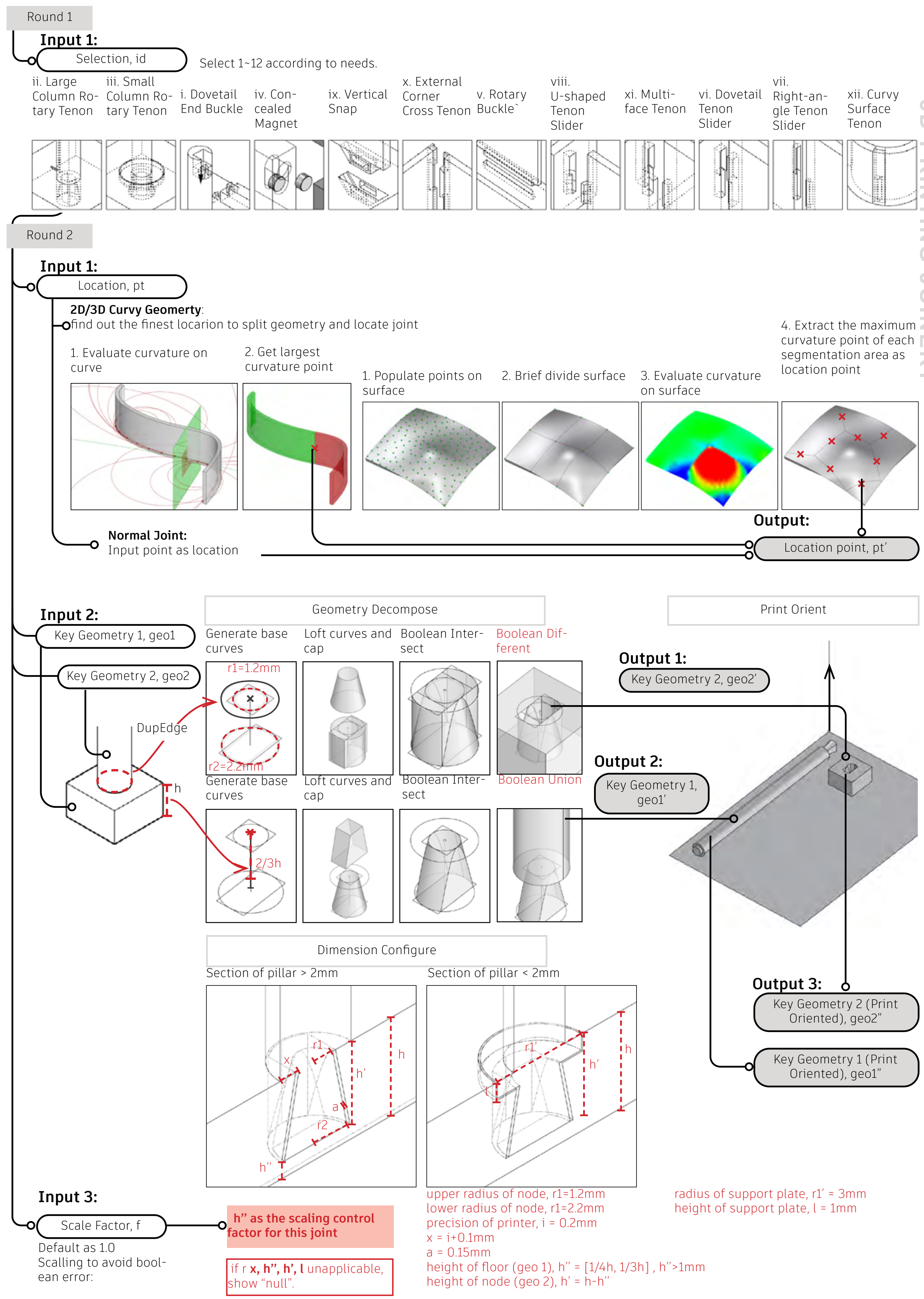


Iteration Example 2: Dovetail Joint

Dovetail as the most important prototype, it can be iterate to multiple varies type of join to apply on different scenerios.



4.1. Database: Geometry Generation Script Framework

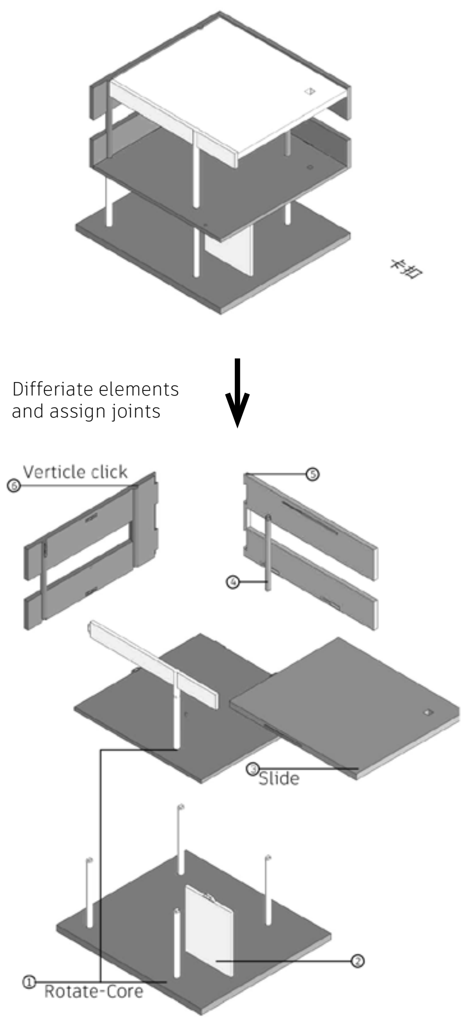


(4) Result

4.2.Installation

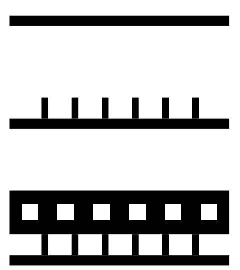
Assign Joint to Elements

0 Decompose Printing ELements

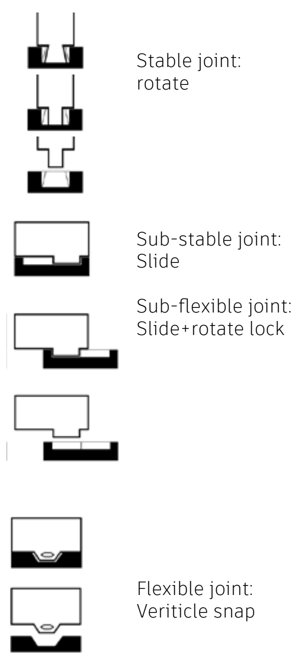


#Assemble rules

1 From lower to upper

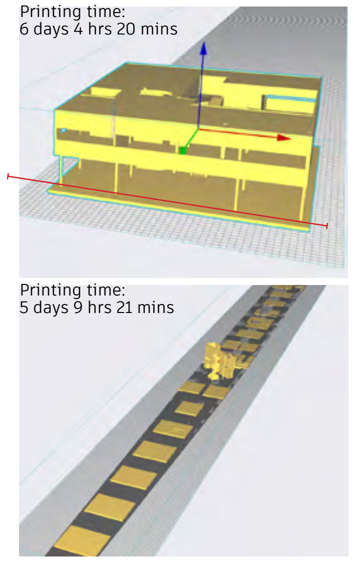


2 From stable joint to flexible joint

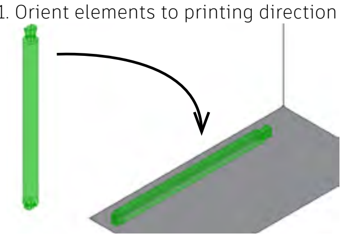


#Printing setting

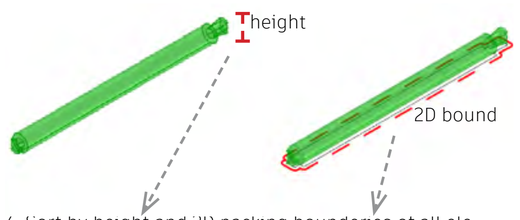
Optimizing printing processsuch as way of printing toincrease strenght, reducesupport and shorter printing time



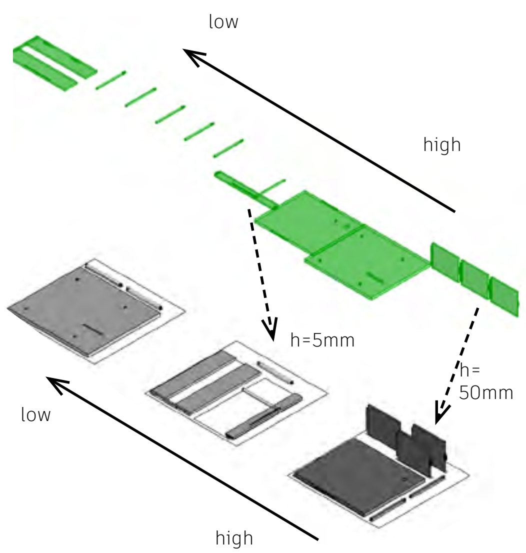
1. Orient elements to printing direction



2. Extract absolute height for each elements and shrink wrap outbound of elements and project 2D to XY plane



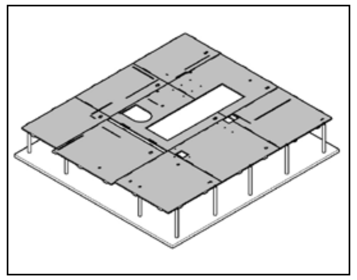
4. Sort by height and 2D packing bounderies of all elements by Open Nest/Circle packing/Galapagos



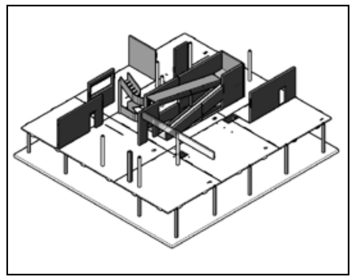
5. Convert file to STL file and Pirnt!

Installation Manual

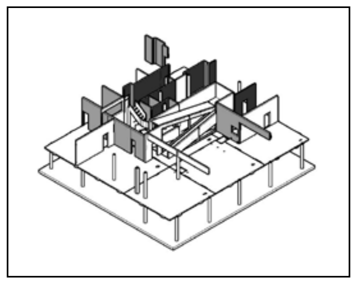
1. Framework zone: stable joint



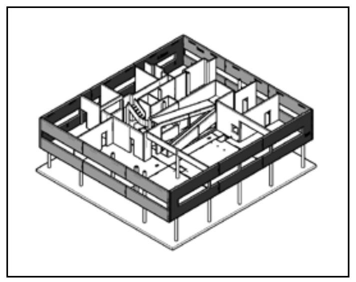
2 Core zone: sub-stable joint



3 Transition zone: sub-flexible joint



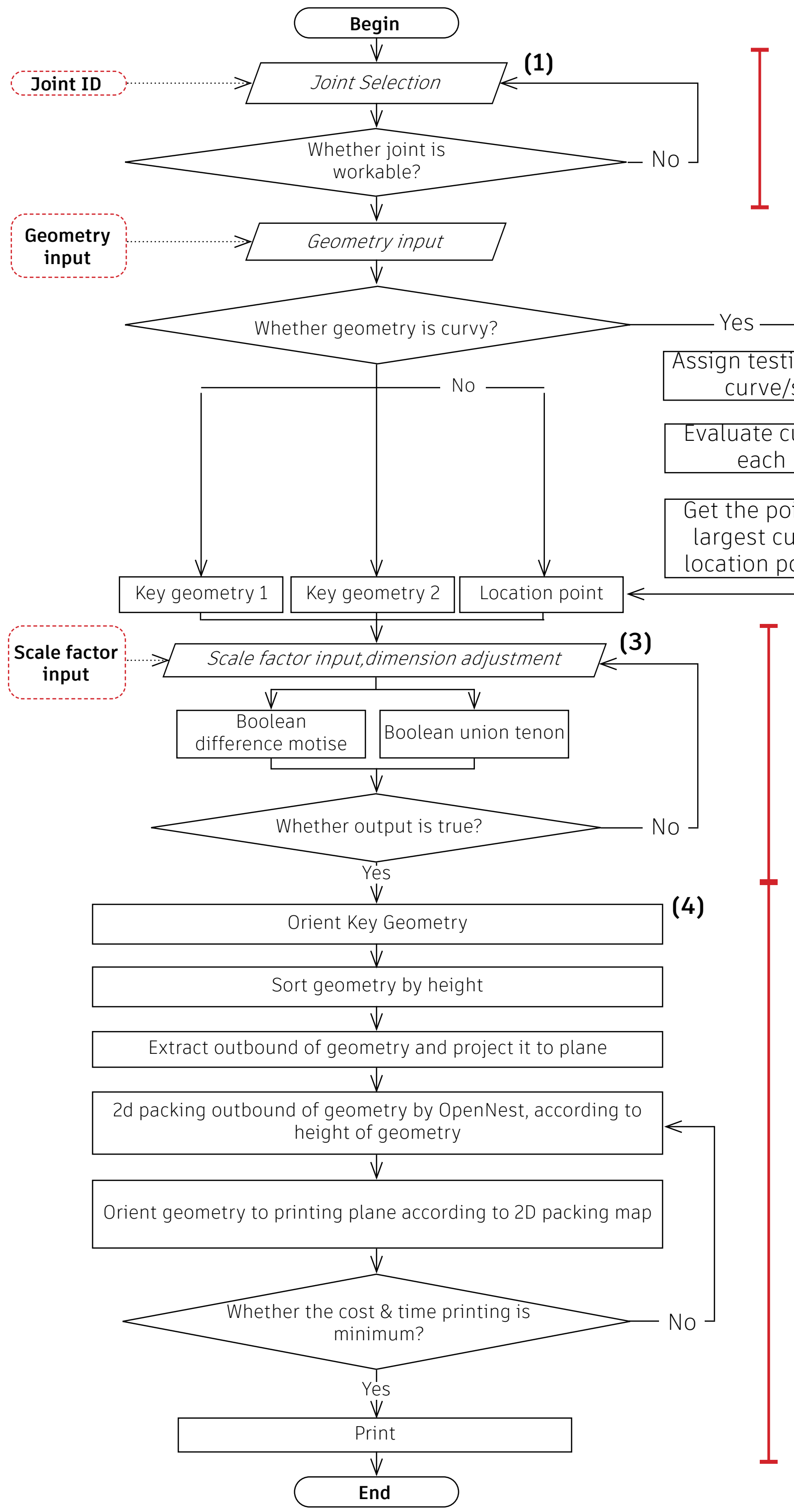
4 Periphery zone and trivial items: flexible joint



4.3. UX design

Algorithm flowchart and corresponding components:

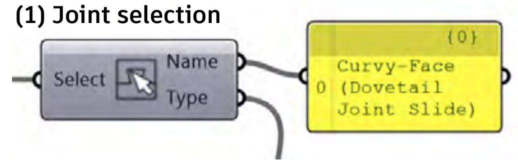
Optimizing printing processsuch as way of printing toincrease strenght, reducesupport and shorter printing time



Algorithm flowchart and corresponding components:

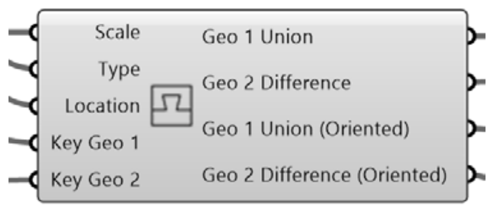
Optimizing printing processsuch as way of printing toincrease strength, reducesupport and shorter printing time

(1) Joint selection

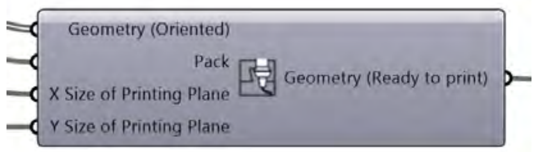


(2) Find Location on Curvy

(3) Joint Generator



(4) Orient to Print



3D PRINTING JOINERY

3D PRINTING JOINERY

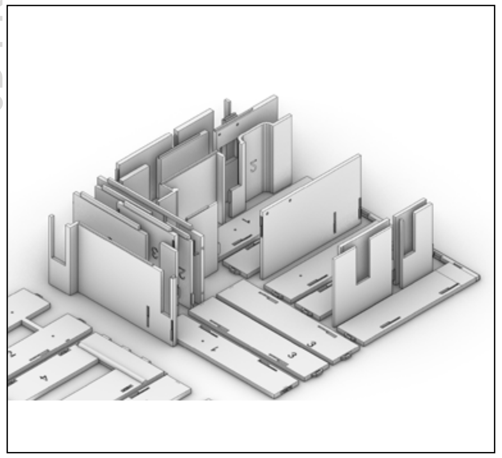
Physical Validation

The study of mortise and tenon joints was deeply explored in the past when material science was not as advanced as it is today. As material science progressed, rigid connectors and adhesives offered more convenient joinery support for constructions. However, as mentioned earlier, these connection methods present issues with weather resistance, structural strength, adhesive toxicity, and non-dismantlability. Hence, a prevailing approach is to combine both methods, incorporating simple mortise and tenon forms with adhesive materials like cement.

Similarly, for architectural model connections, we can adopt a similar approach. Due to the relationship between scale variations and material properties, directly shrinking the joints at a 1:100 scale and printing them is not feasible. Factors such as material properties, toughness, stiffness, adhesives, scale, printing precision, and manufacturing methods influence the process. Additionally, 3D printing, as an additive manufacturing process, possesses irreplaceable advantages, necessitating adaptations in joint design to leverage its strengths.

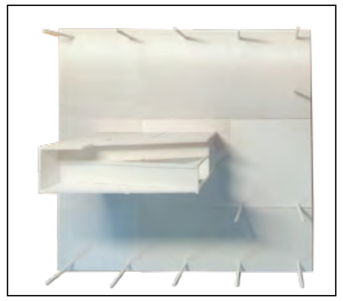
Therefore, our accomplishment includes using mortise and tenon joints as prototypes and, through experimentation and iterative design, obtaining nodes suitable for 3D printing with Photopolymerization Stereolithography (PLS) and meeting architectural model scale requirements. These joints enable connections for large-scale architectural models, surpassing 3D printing size restrictions and enhancing printing efficiency.

0 Printing

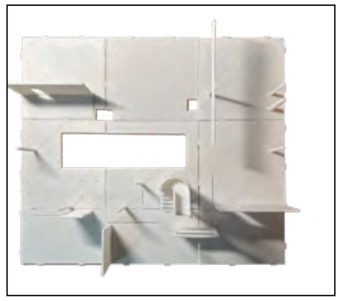


0 Preparation

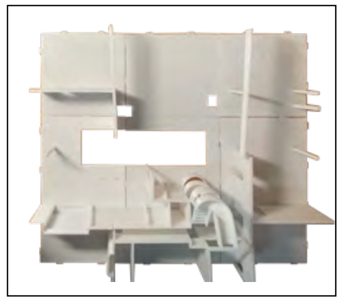
1 Core elements (1st floor)



2 Core elements (2nd floor)



3 Other elements (2nd floor)

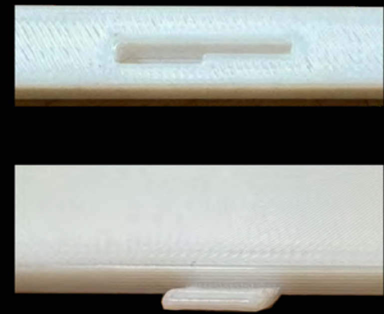


4 Outer walls (2nd floor)

3D PRINTING JOINERY

v. Rotary Buckle
Face×Face (planar)
stable

x. External Corner Cross Tenon
Face×face (planar)
flexible



viii. U-shaped Tenon Slider

Face×Face (planar)
sub-flexible

vi. Dovetail Tenon Slider
Face×face (planar)
sub-stable

ix. Vertical Snap
Face×Face (planar)
flexible

x. External Corner Cross Tenon
Face×face (planar)
flexible

ii. Large Column Rotary Tenon
Line×Face
stable

Other Interior Photos: