Zip-up Print

Rapid and Assemblable 3D printing Using 2D Flattened Zipper-like Structures

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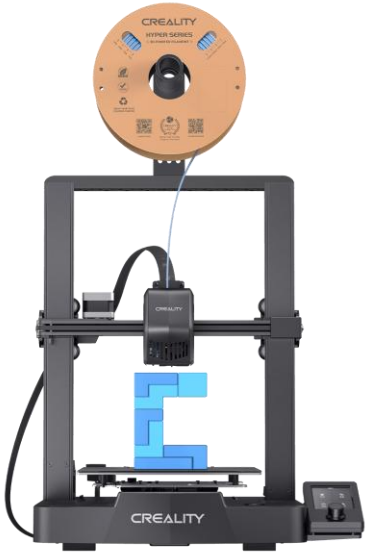
Keio University[1], MIT CSAIL[2], Boston University[3]

FDM 3D Printer

Bambu Lab A1 mini [1]
$210

Prusa Mini [2]
$550

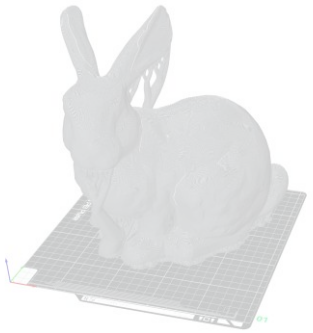


Ender 3 V3 SE[3]
$200

FDM 3D printer has become cheap, easy to use for everyone.

[1]Bambu Lab A1 mini 3D printer, [2] MakerWorld, [3] Ender3 V3 SE

Problem of FDM 3D printing method



Slicing Result

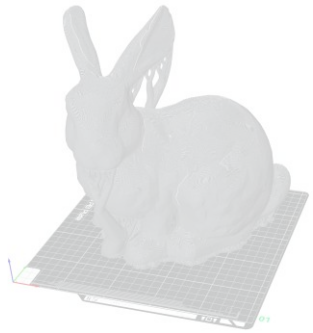
Color Scheme	Filament		
Filament	Model	Support	Total
1	221.96 m 704.73 g	18.07 m 57.39 g	240.04 m 762.12 g

Filament change times: 0
Cost: 19.05

Time Estimation

Prepare time:	7m31s
Model printing time:	14h39m
Total time:	14h47m

Support material consumption



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Total time:	14h47m

Long printing time

Non-oversize

Oversize

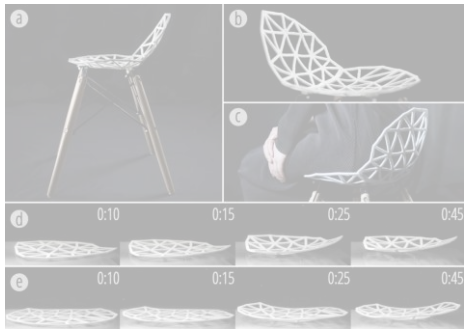
Limited build volume

Entire reprinting for partial modification [4]

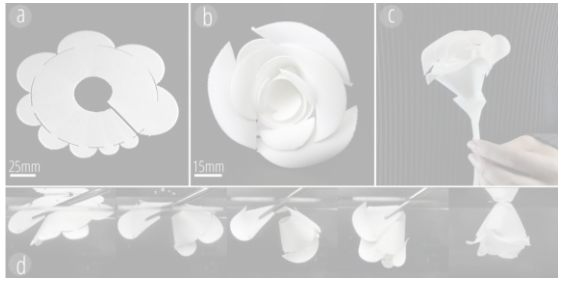
[4] Abdrashitov et al., A System for Efficient 3D Printed Stop-motion Face Animation, TOG, 2020.

Related Work: Rapid Prototyping for 3D Printing

4D Printing



A-Line [5]



Thermorph [6]

Part Decomposition

Dapper [7]

Karasik et al.[8]

Transform 3D from 2D printing

✓ Reduce time and support
✗ Limited volume size

Assembly after printing

✓ Possible to fabricate large-scale objects
✗ Since parts are printed in 3D, reductions in time and support are minimal


Zipper

Zip-up Print

*Developable Surface：faces that are deformable to a plane without stretching or shrinking

Zip-up Print

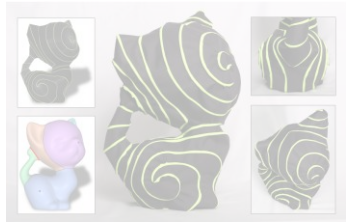
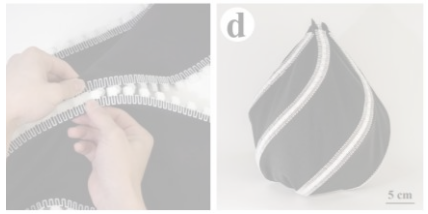
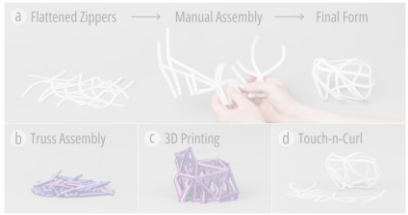
1.Input 3D model

2. Developable approximation & zipper generation

*Developable Surface：faces that are deformable to a plane without stretching or shrinking


Face-changing bear

Related Work: Zipper Structure

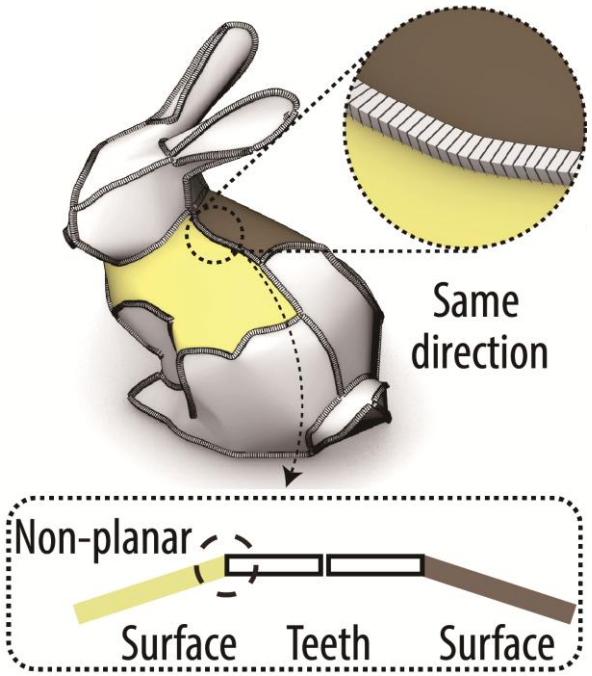
	Zippables [9]	Masuda et al. [10]	Touch-n-curl [11]	Proposed Method
				
Fully 3D printable	Fabric+Commercially available zipper	Fabric+ 3D Printable zipper	Possible	Possible
Input non-developable surface	Possible	Impossible	Impossible	Possible

Proposed method: Fully 3D printable & Input the non-developable surface

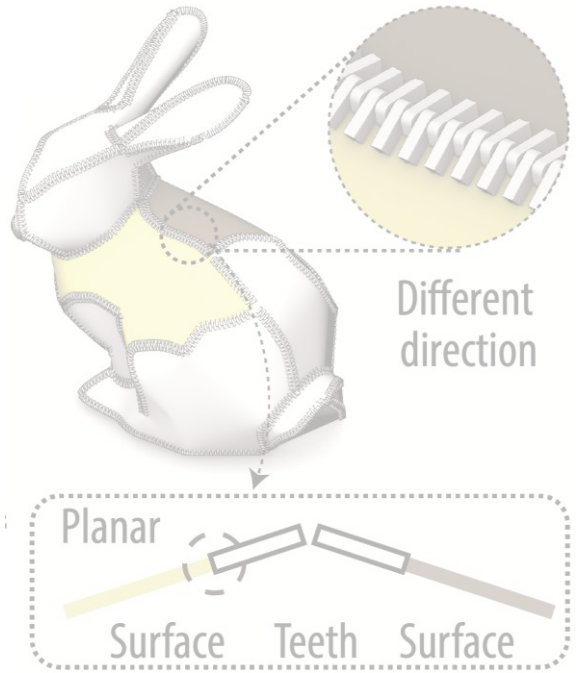
[9] Schüller et al., Shape representation by zippables. TOG, 2018. [10] Masuda et al.,. UIST Adjunct , 2024. [11] Pan et al, Touch-n-Curl, UIST2025.

Zipper Structure

Commercially-available Zipper Structure



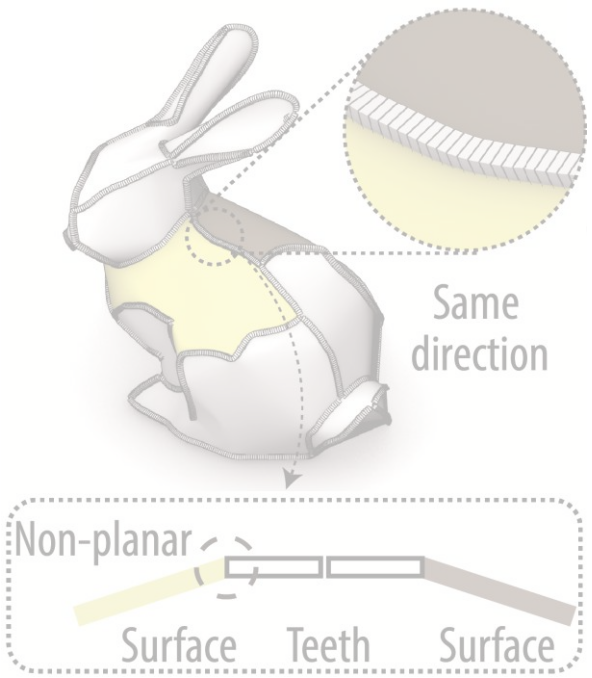
Commercially available zipper



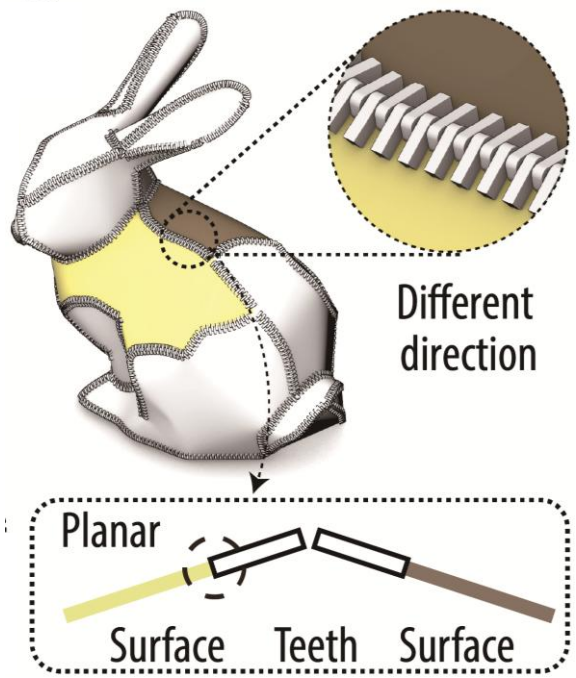
Proposed zipper

Angular mismatch between teeth and surface causes non-planar patches.

Proposed Zipper Structure



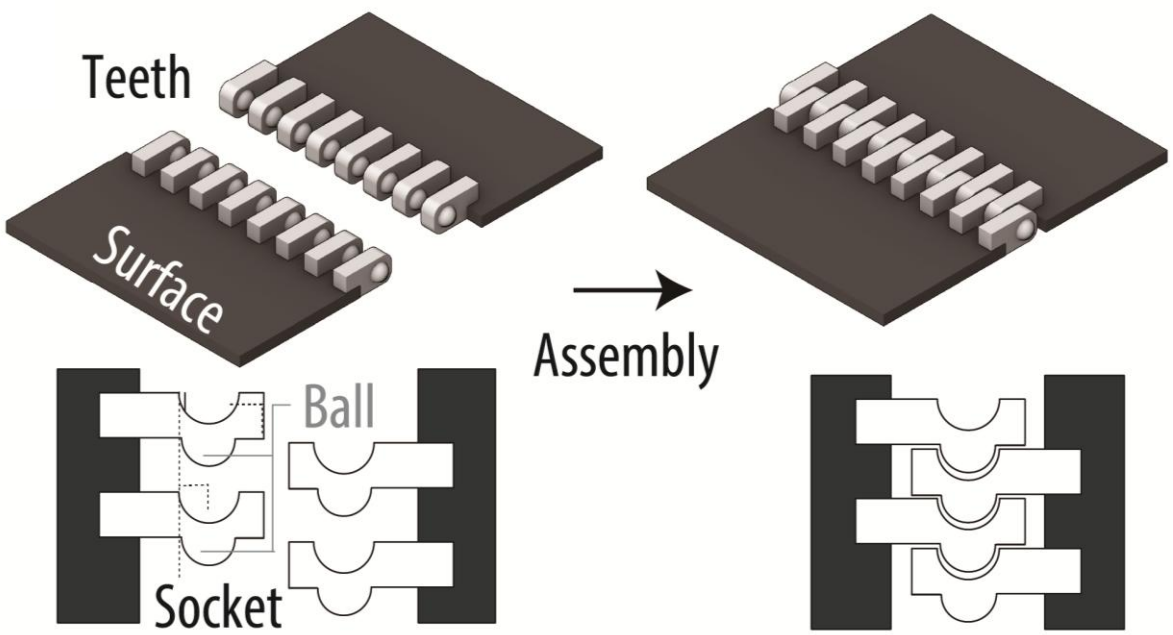
Commercially available zipper

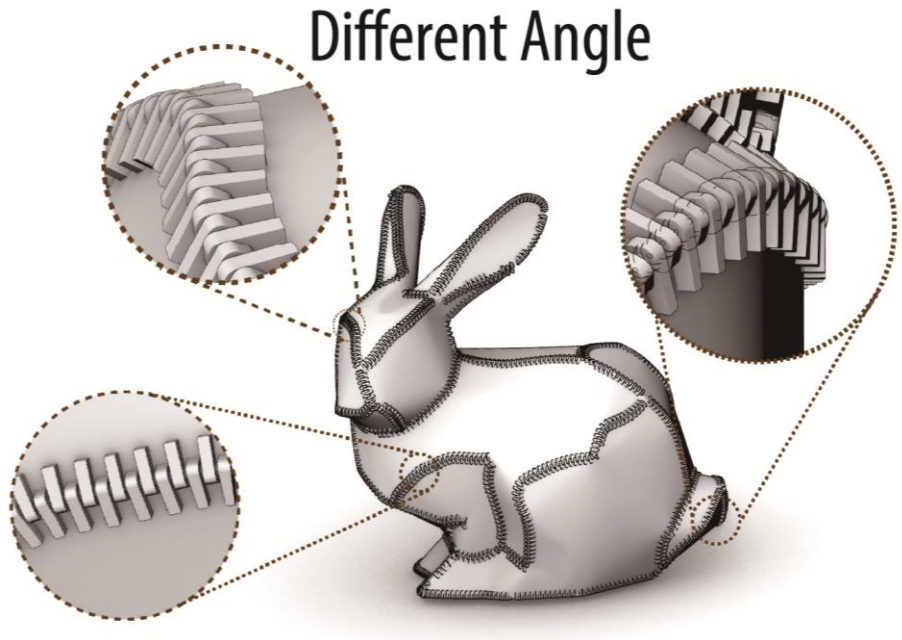


Proposed zipper

Surface and teeth is connected in same direction, which produce planar patches.

Ball and Socket Structure

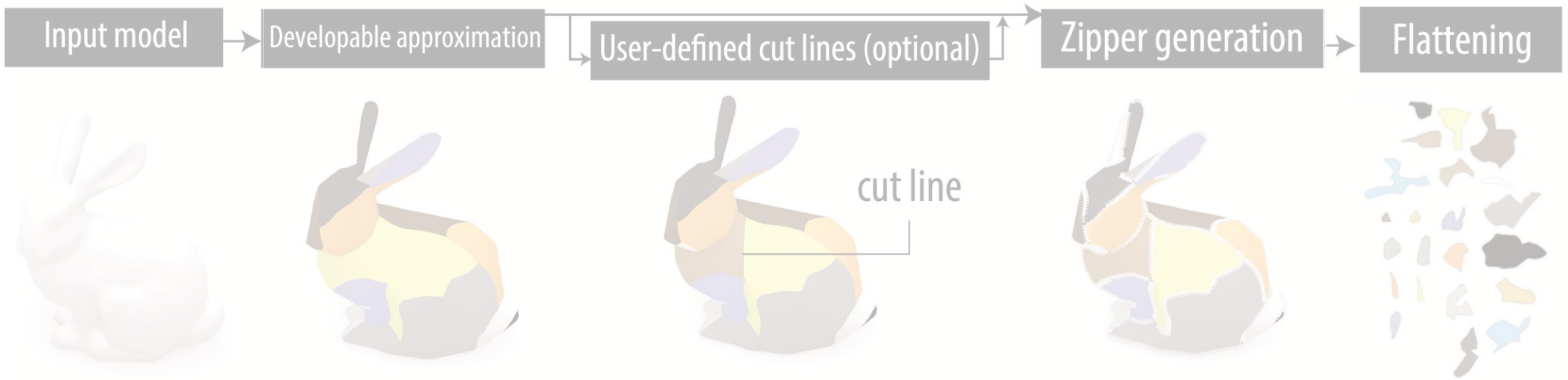




Enable angle-independent connections

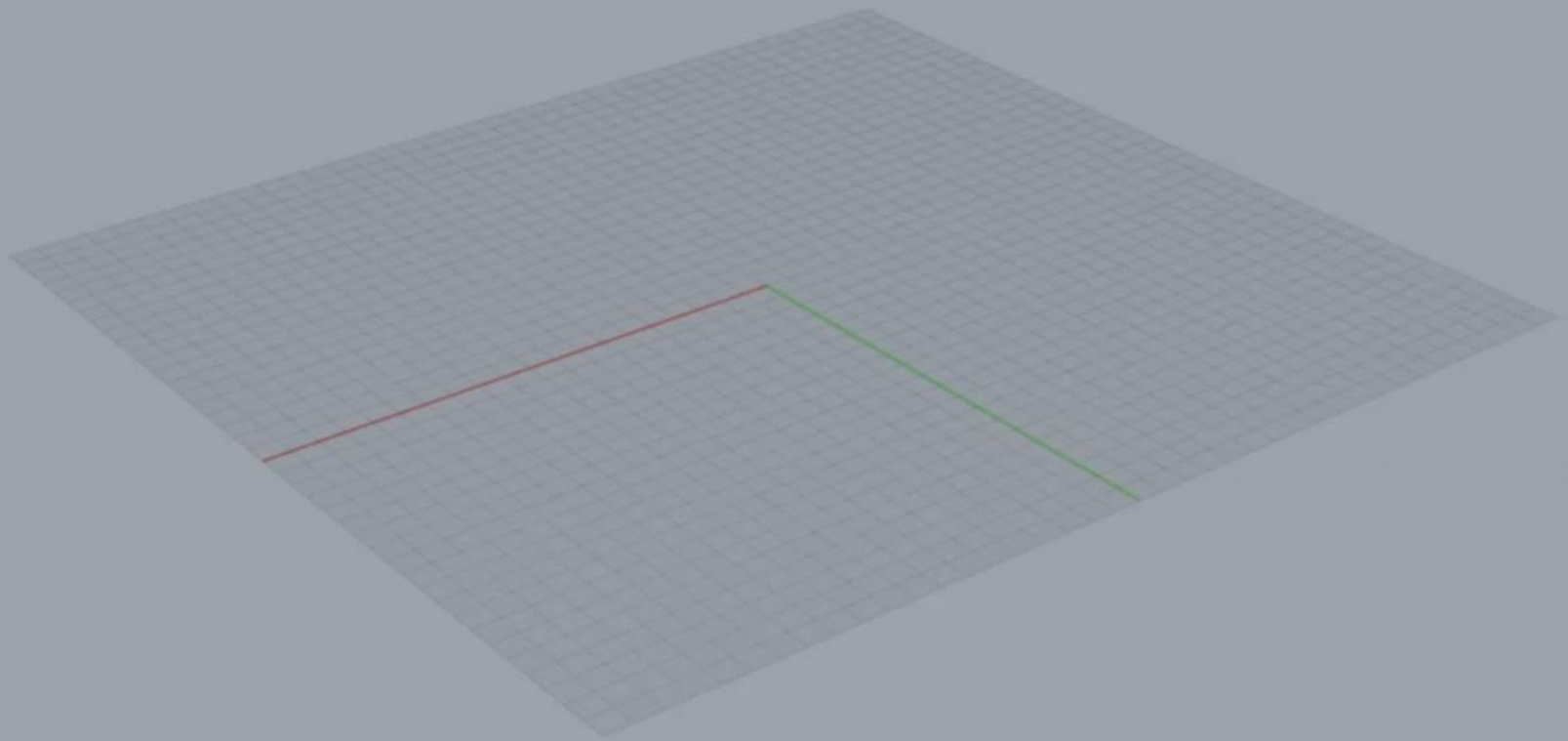
Computational Pipeline

Computational Pipeline



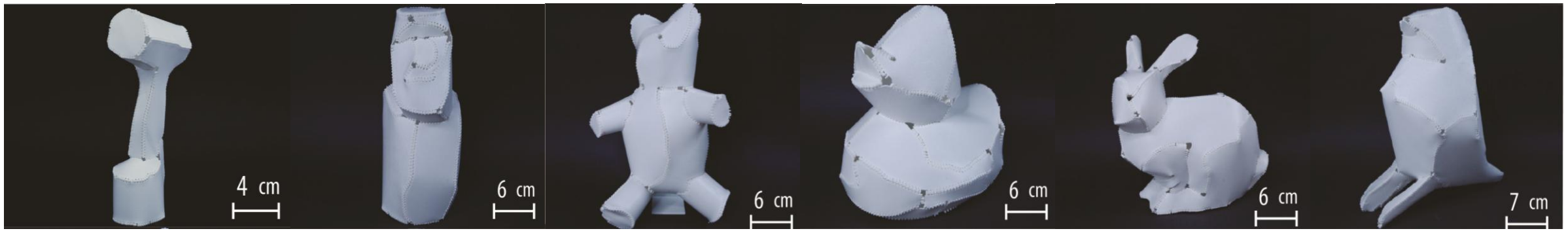
Decompose 3D model into flat patches with zipper

Import mesh and Developable approximation

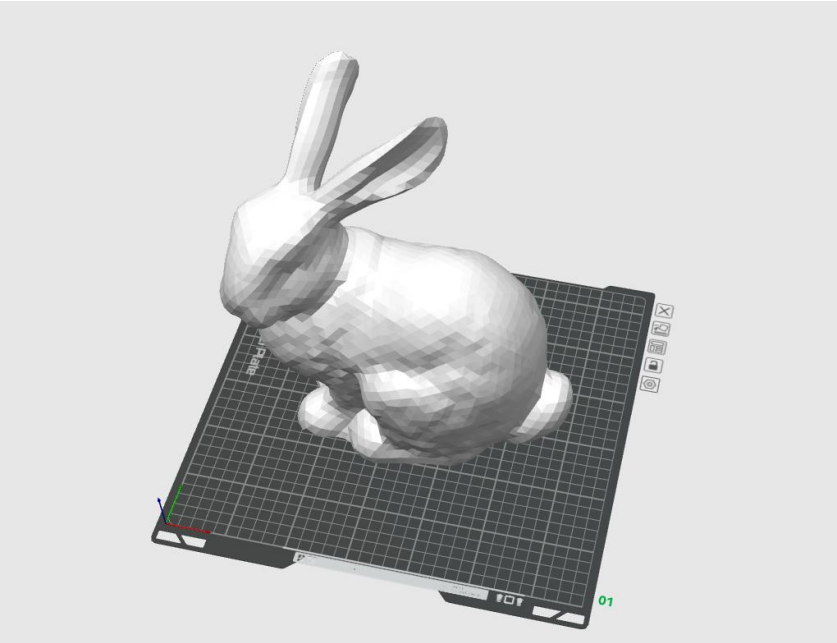


Results & Evaluation

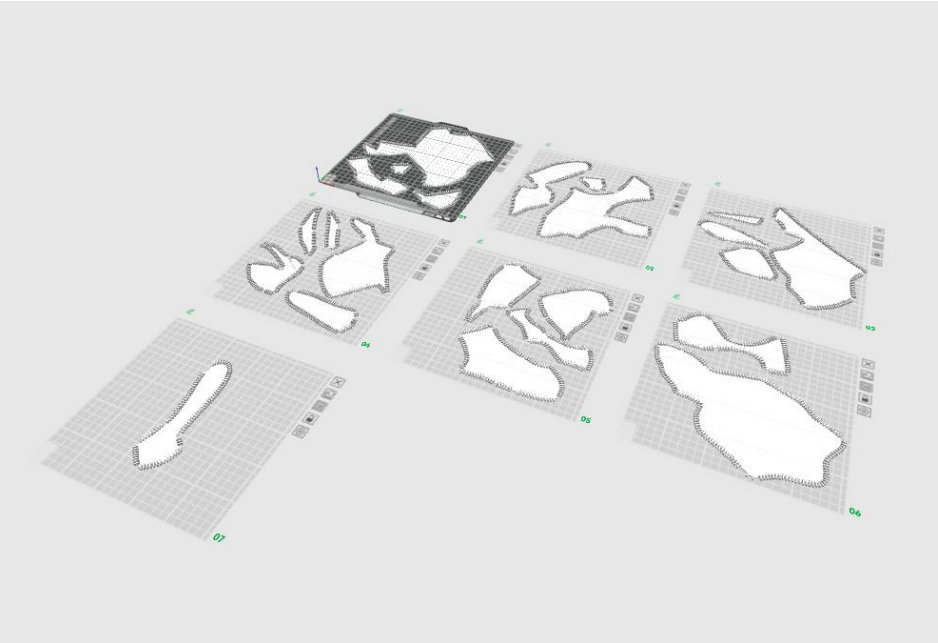
Results



Evaluation: Support Material and Printing Time



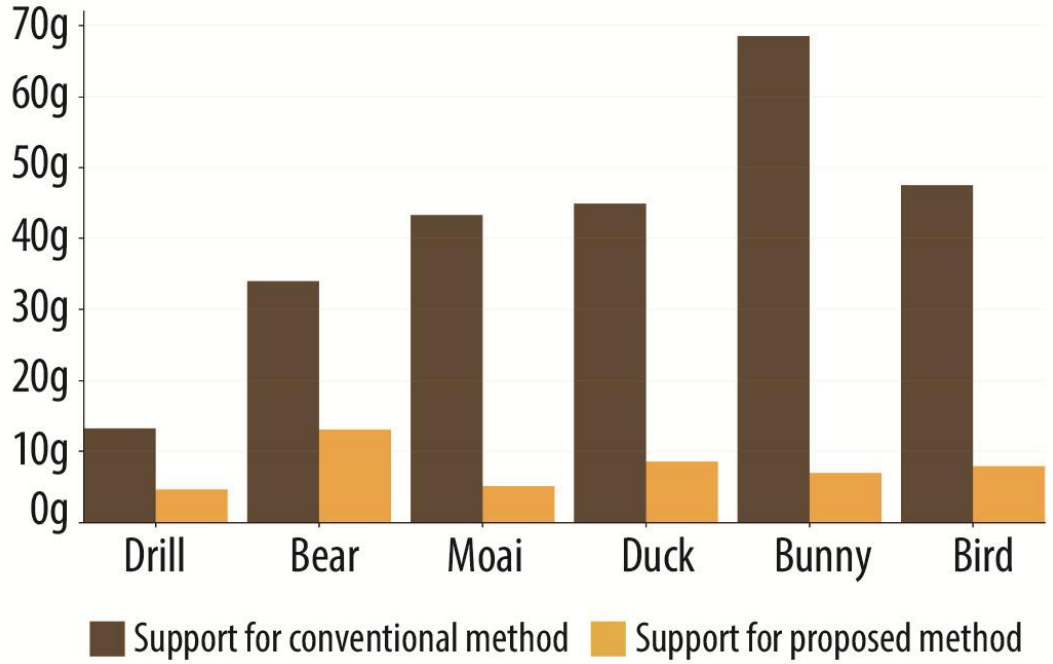
Input 3D model

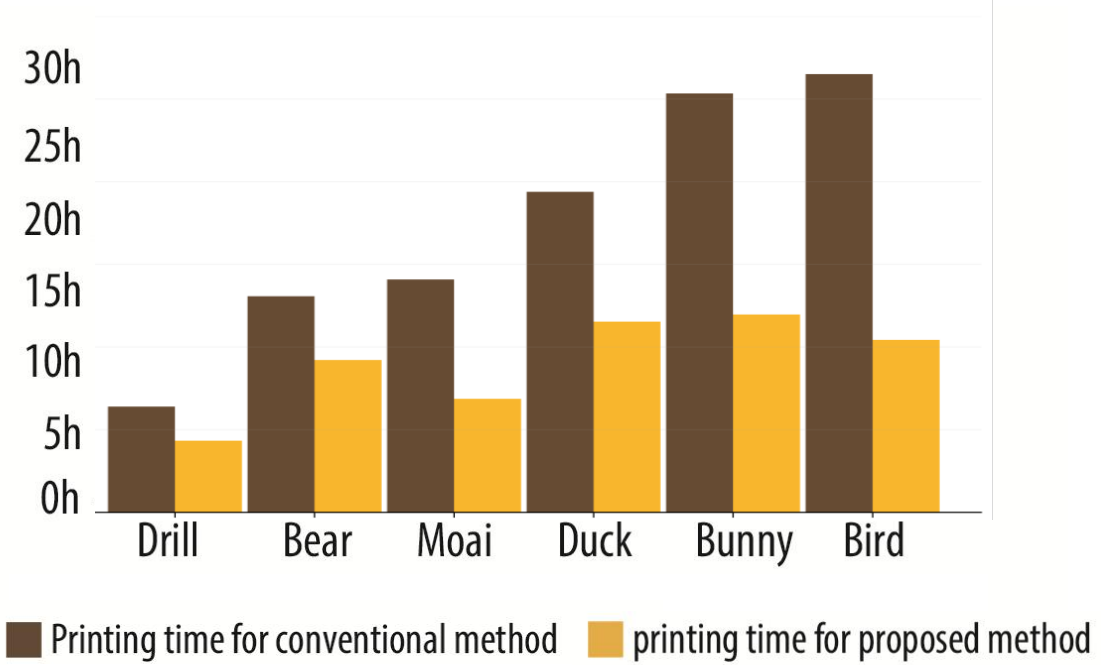


Proposed method

Compare input mesh with proposed method in Bambu Studio

Evaluation: Support Material and Printing Time





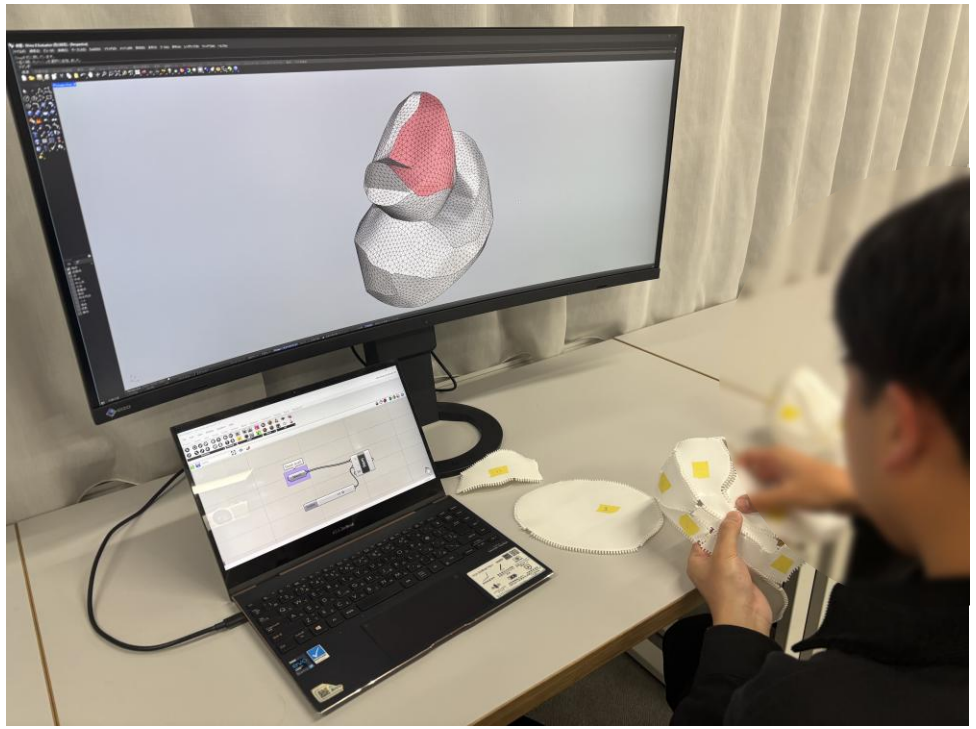
Support material

-77.4%

Printing Time

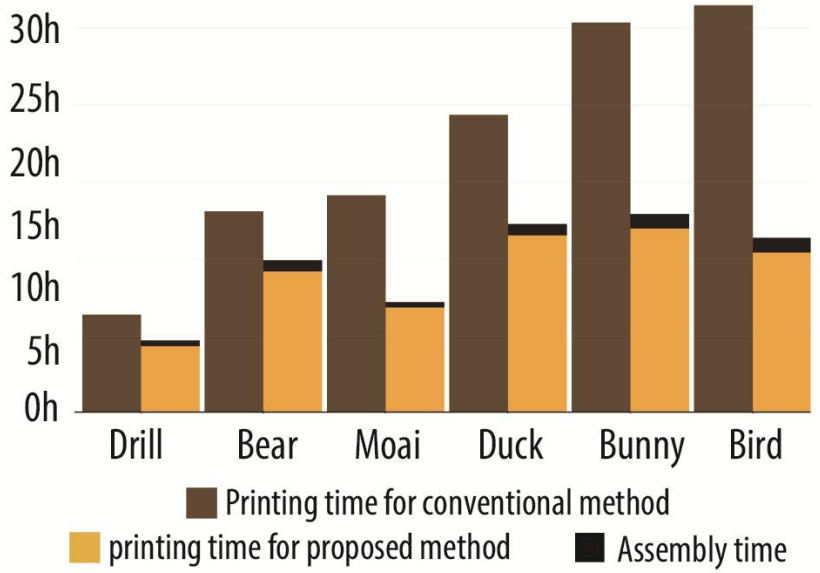
-44.4%

Assembly Time



Conduct the user study to record the assembly time.

Fabrication Time (Including Assembly Time)

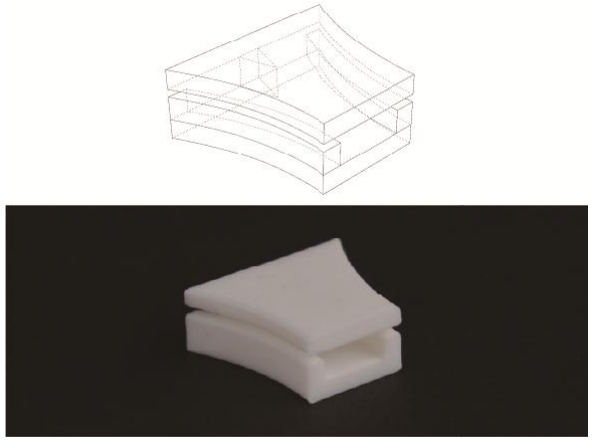


3D printing time vs printing time and assembly time of proposed method

Measure the assembly time in user study (N = 5)

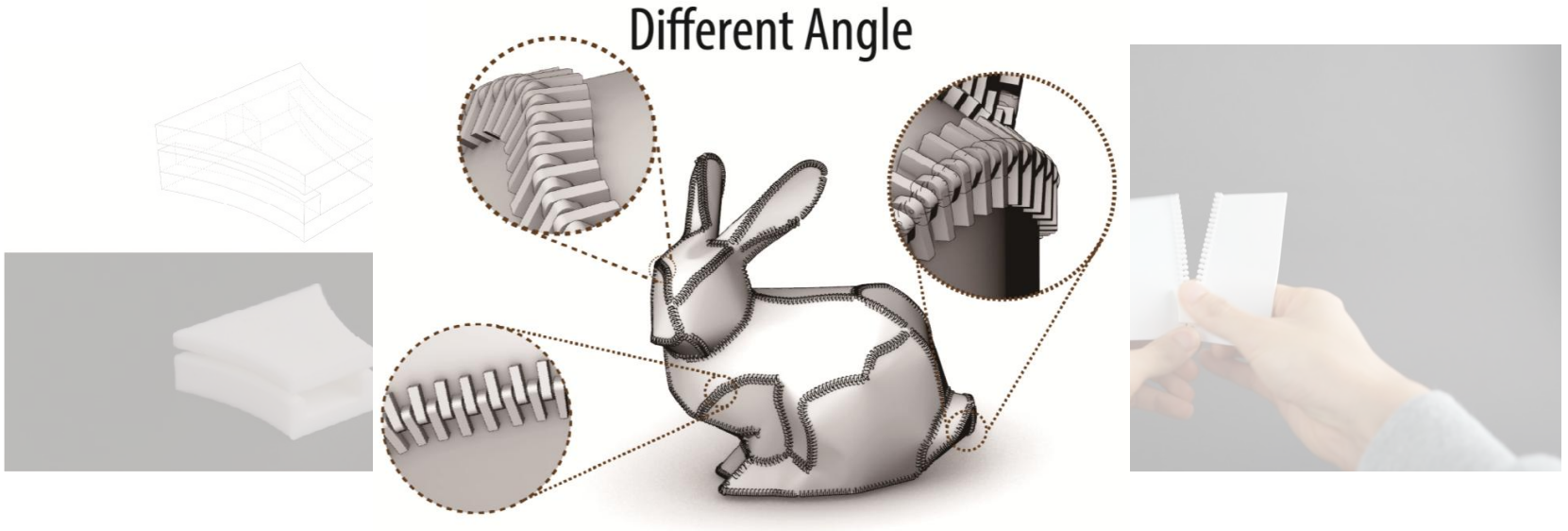
Results: reduce 40.4% on average

Limitations and Future Work: Slider-based Assembly



Y-shape slider：works if the teeth angle with fixed

Limitations and Future Work: Slider-based Assembly



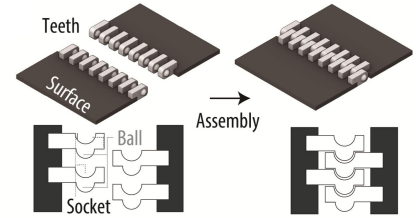
Y-shape slider：works if the teeth angle with fixed

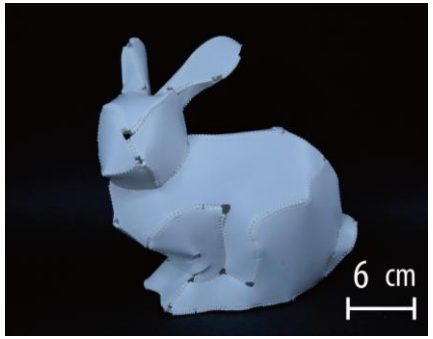
...but not works if the teeth angle is not fixed

Zip-up Print:
Rapid and Assemblable 3D printing Using 2D Flattened Zipper-like Structures

Takumi Yamamoto, Jiaji Li, Akib Zaman, Noah Barnes, Yuta Sugiura, Stefanie Mueller, Koya Narumi

Background	FDM3D Printing: (1) Support (2)Time , (3)Size , and (4) Partial modification
Related Work	4D Printing, Part decomposition
Zipper Structure	Ball and Socket Structure
Pipeline	End-to end pipeline enable developable approximation and manually added seams.
Results and Evaluation	Reduce support material and fabrication time
Applications	Large-scale objects and partial modification
Limitations	Slider-based Assembly





Appendix

Key Points

1.Input 3D model

2. Developable approximation and zipper generation

3. Flattening

4. Printing

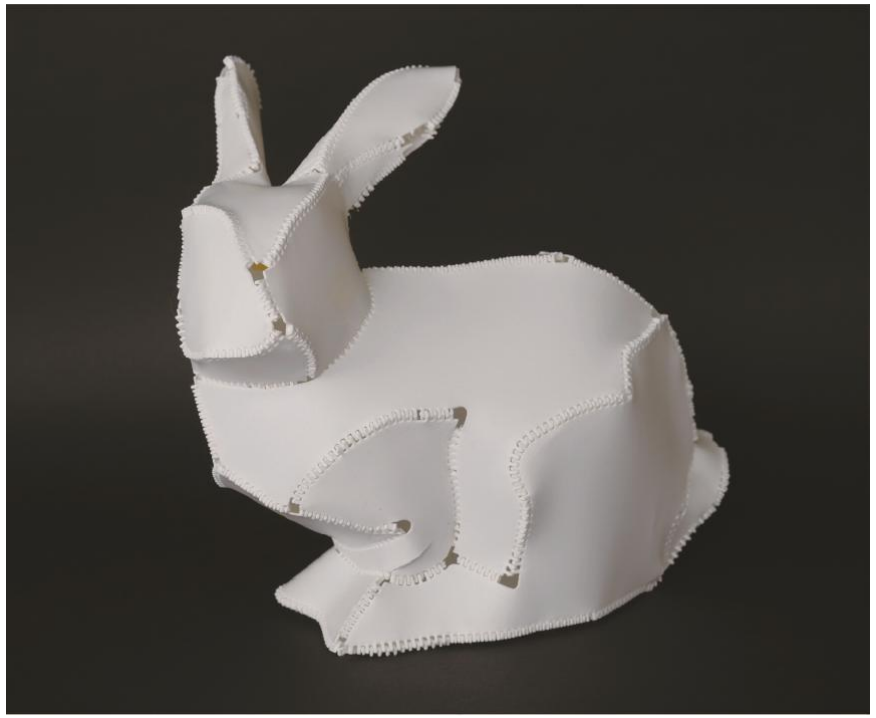
5. Assembly

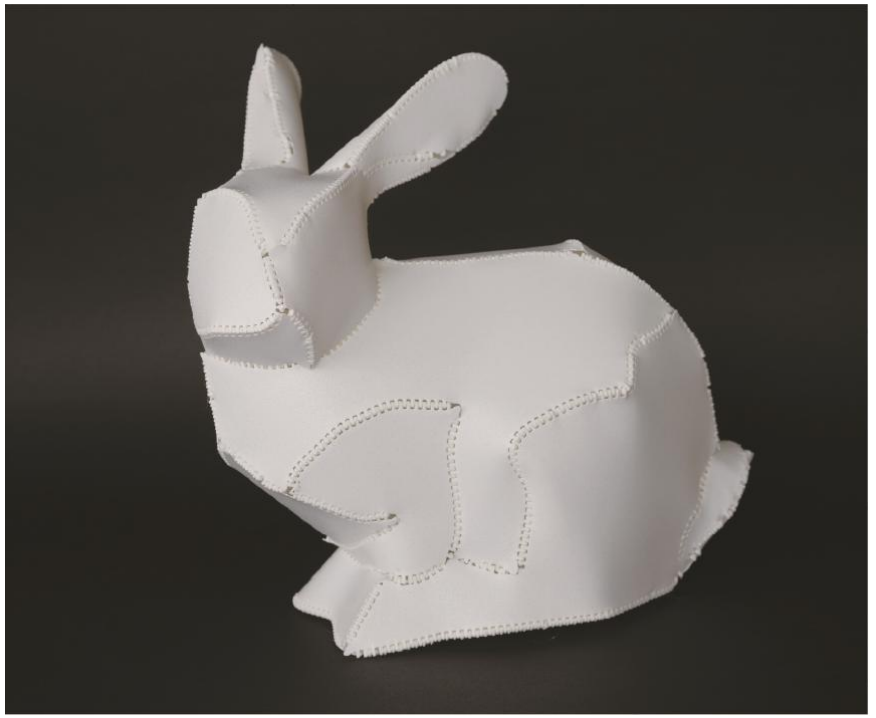
6. Final Object

Zip-up Print

Overview：Output the piece which can connect with zipper
Novelty：Fully 3D printable + Support automatic developable approximation

Discussion: Holes

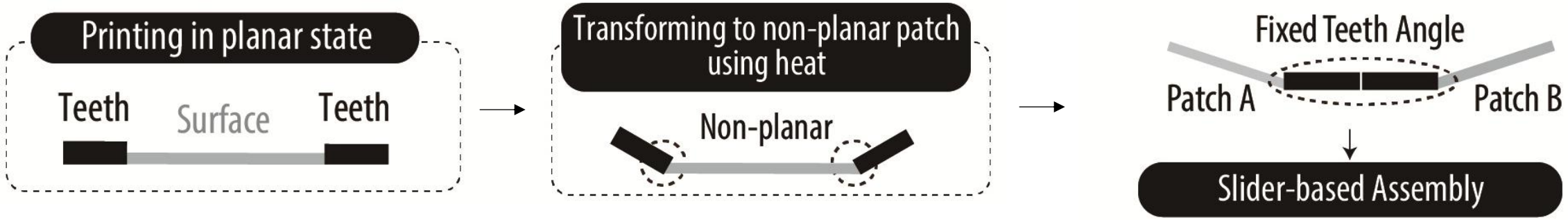




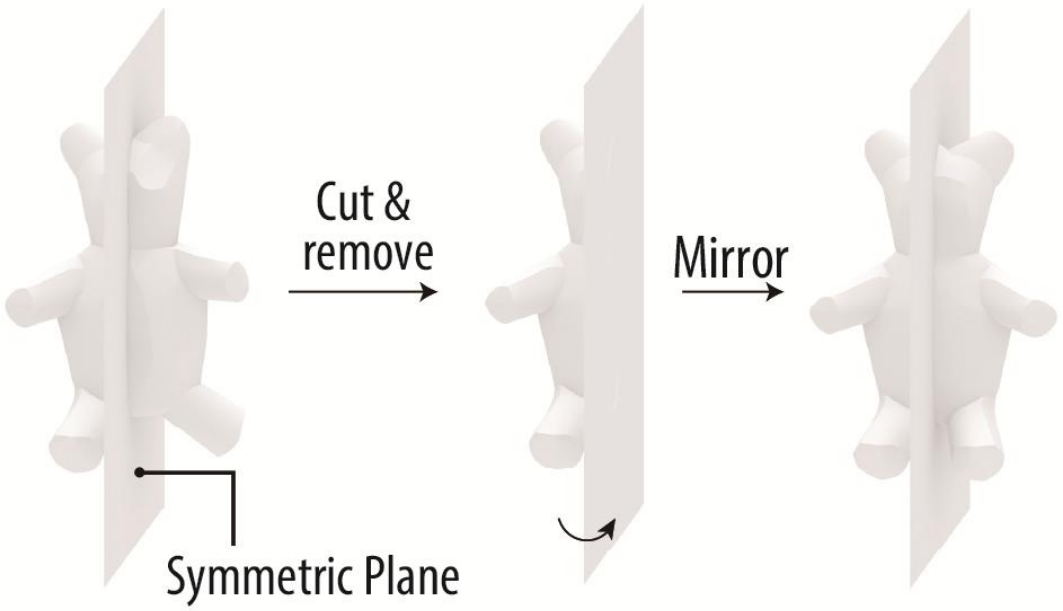
There are some holes at branching points.

Improve the problem by expanding the boundary of the surface.

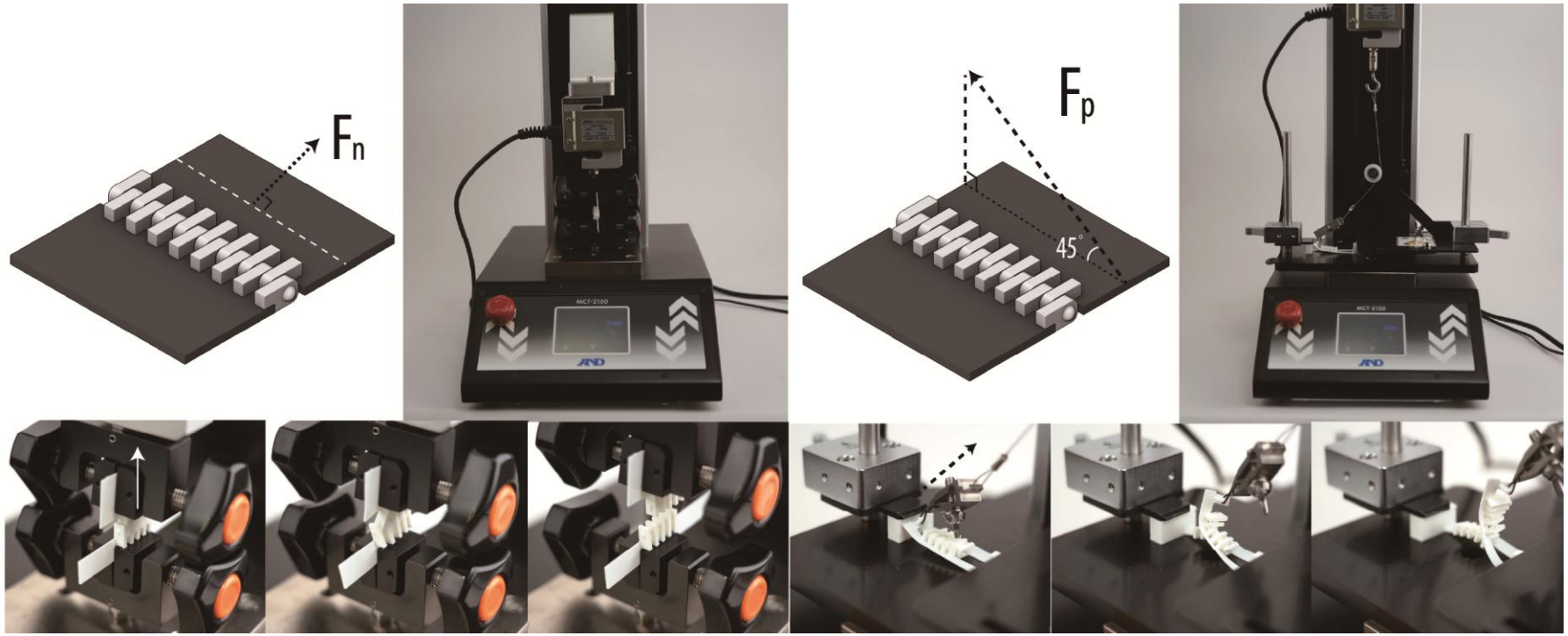
Future Work: Combining 4D printing method



Keep Symmetry



Measure the Force

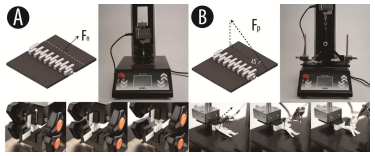


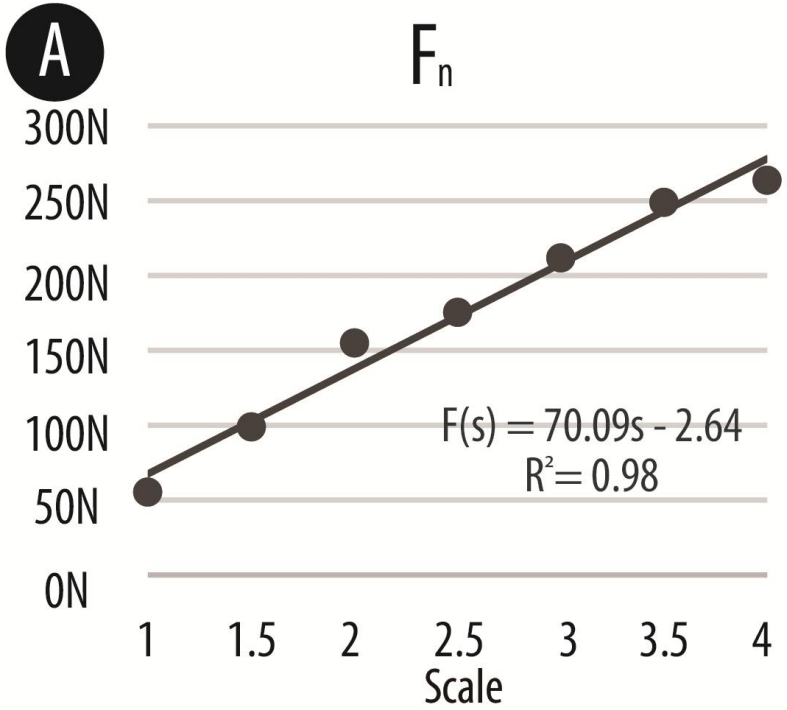
Normal Force (Fn)

Peelable Force (Fp)

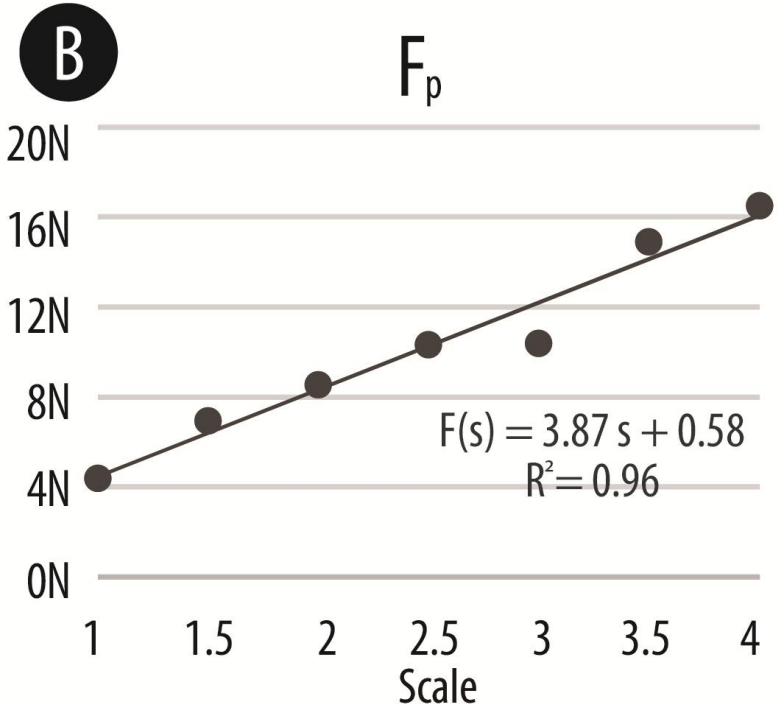
Measure the two types of force using force tester

Relationship between size and Force





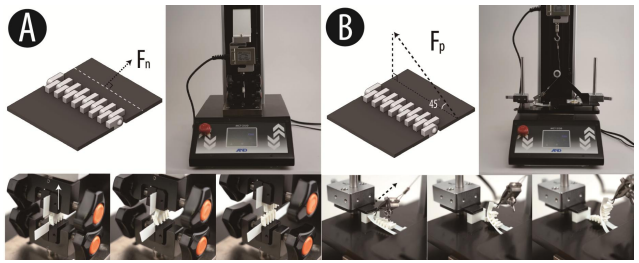
Normal Force

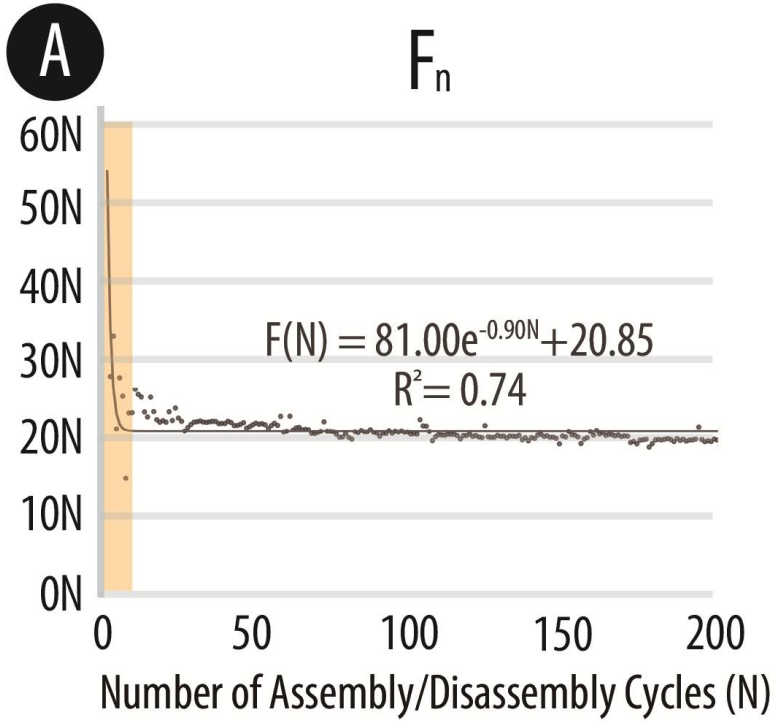


Peelable Force

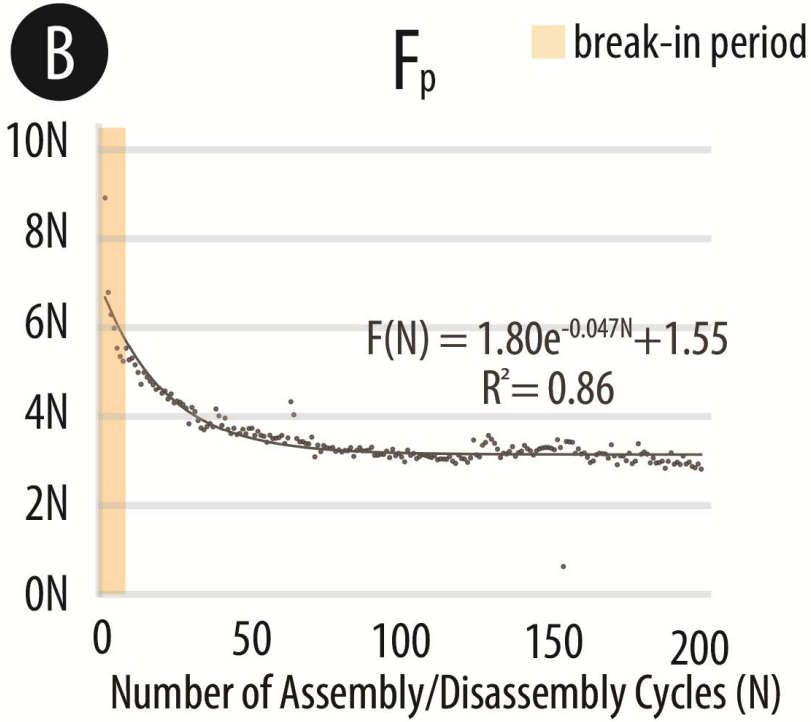
Scaling up the size of the zipper increases the force.
Normal force is larger than peelable force.

Durability Test





Normal Force

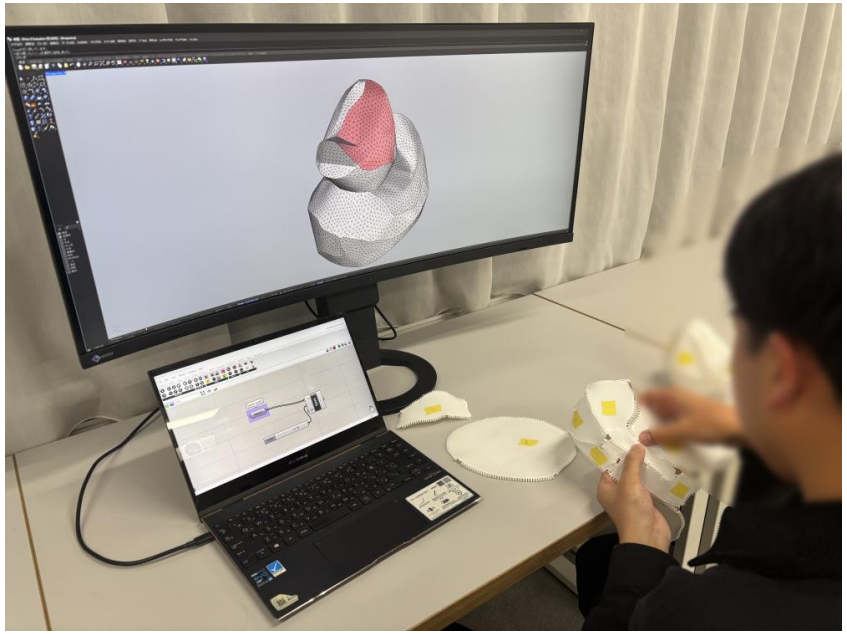


Peelable Force

Force drops sharply immediately after printing (break-in period).

After this break-in period, the force approaches a more stable level and then decreases slowly.

Qualitative Feedback

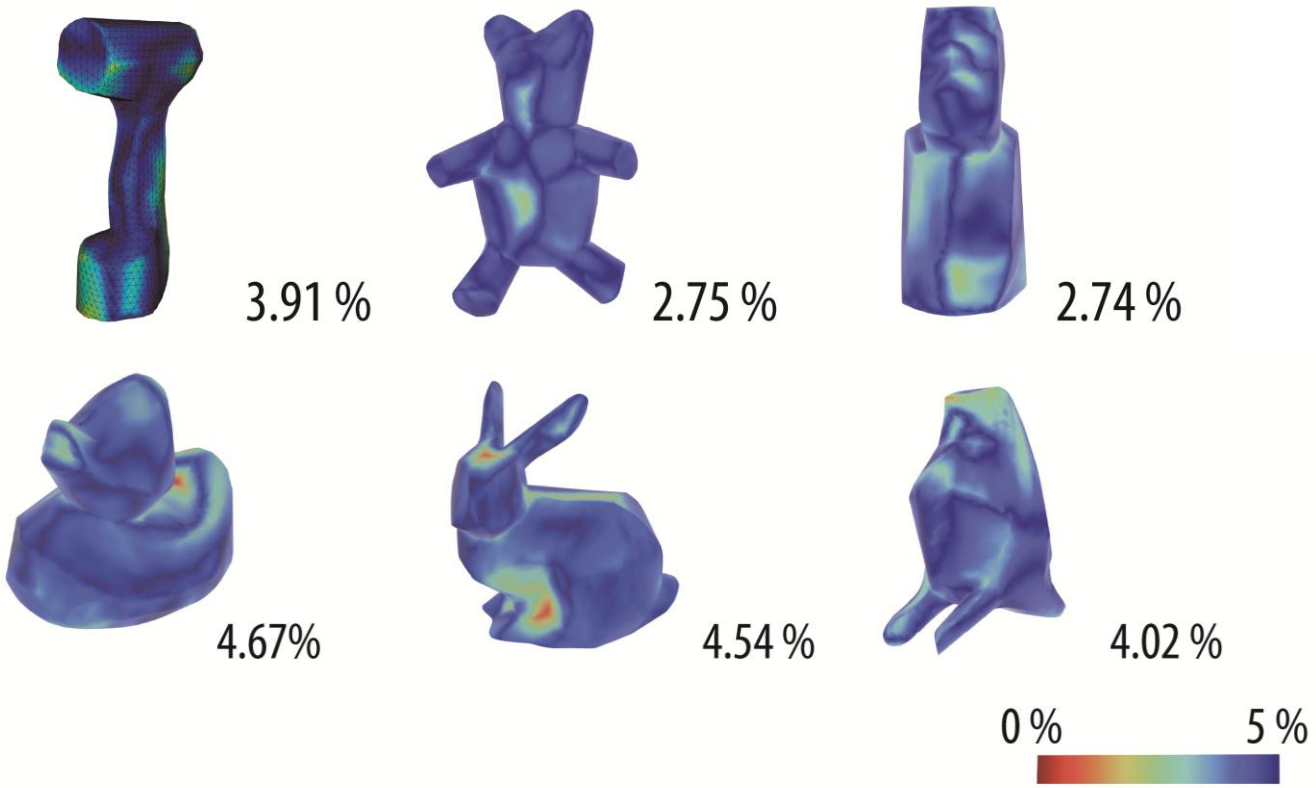


1. Difficulty in joining the last piece due to the connecting soft surface.

    “The last piece requires some ingenuity.”

    “90-degree angled or sharp corners are easier to attach from the outside”

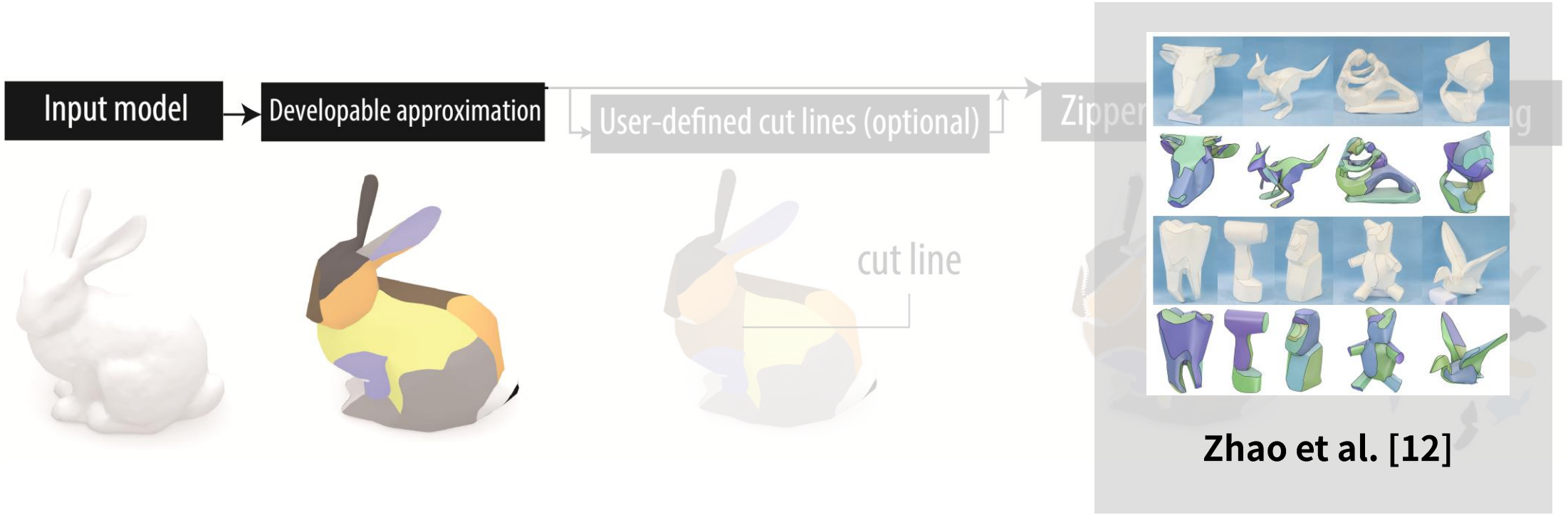
Evaluation1: Shape Accuracy



Compare 3D scanned model with Developable model.

Average Error: 3.77%

Computational Pipeline



Zhao et al. [12]

Optimize the input 3D model into a set of developable patches.

[12] Zhao et al., Developability-driven piecewise approx imations for triangular meshes, TOG, 2022