TactStyle: Generating Tactile Textures with Generative AI for Digital Fabrication

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UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

BACKGROUND:
Generative AI allows easy personalization of 3D models.

Can 3D generative models replicate tactile properties of textures?

RELATED WORK

Prior Work in Replicating Tactile Surfaces in 3D Models

On-the-Fly Fine Texture 3D Printing

Yan et al. 2021

Haptic Reconstruction

Degraen et al. 2021

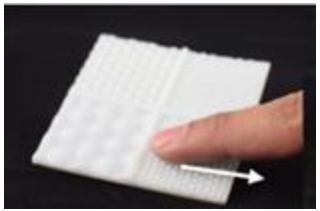
Style2Fab

Faruqi et al. 2023

Metamaterial Textures

Ion et al. 2018

3D Printed Haptics and Tactile Surfaces



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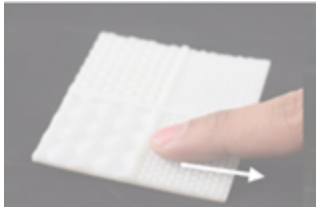

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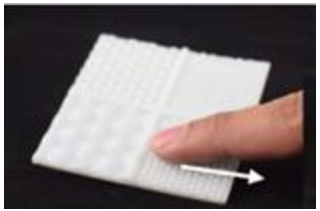

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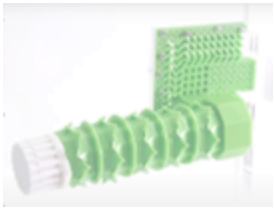

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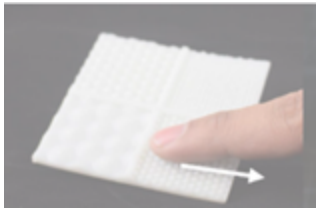

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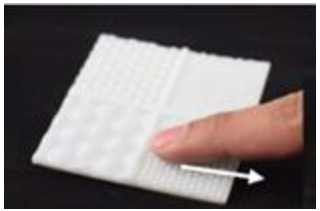

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Previous Techniques for Tactile Replication

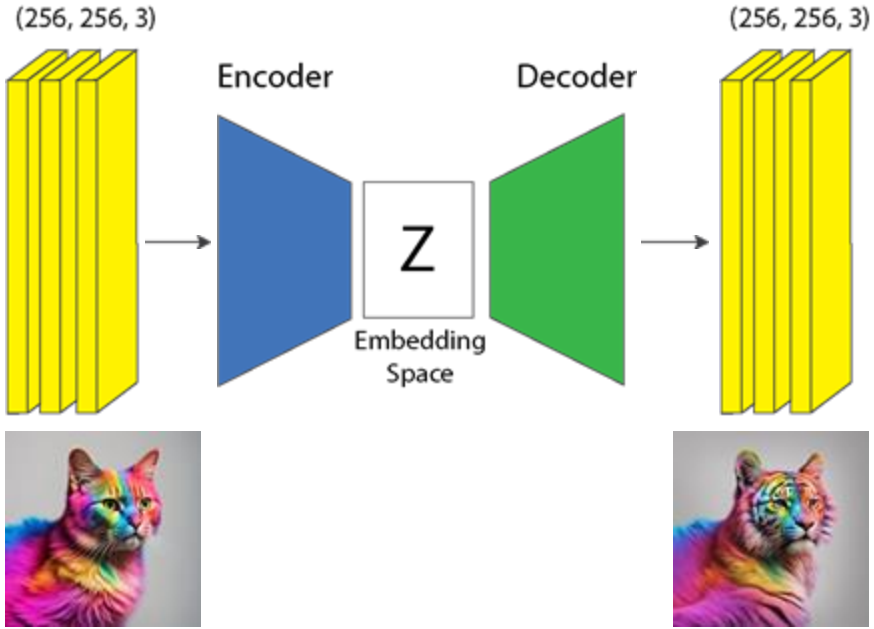
Gelsight Device

Degraen et al (2021)

Previous methods require **specialized devices** to read the **surface microgeometry**

Can we predict **surface microgeometry** given an **image of a texture**?

Stable Diffusion for Image Generation



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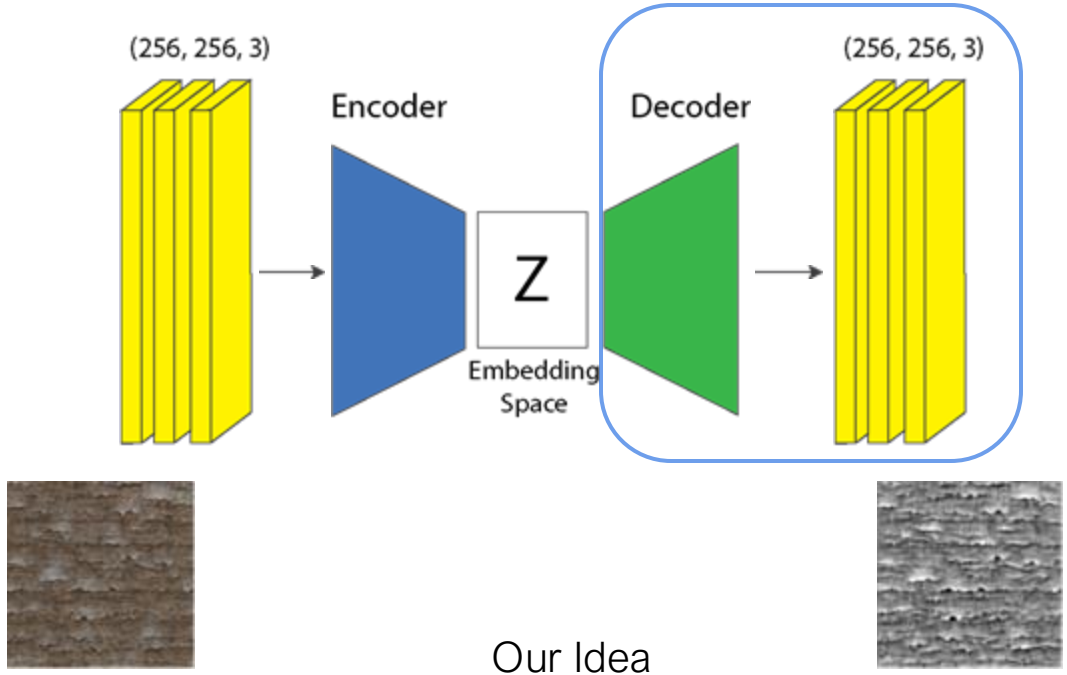
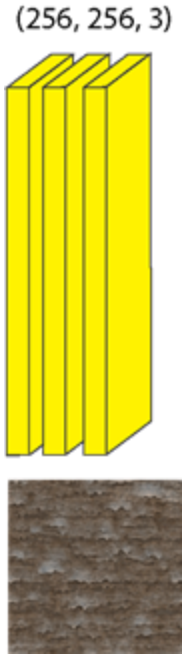


Our Idea

Modify the architecture to output **surface microgeometry as heightfield image**

Texture Prediction Model



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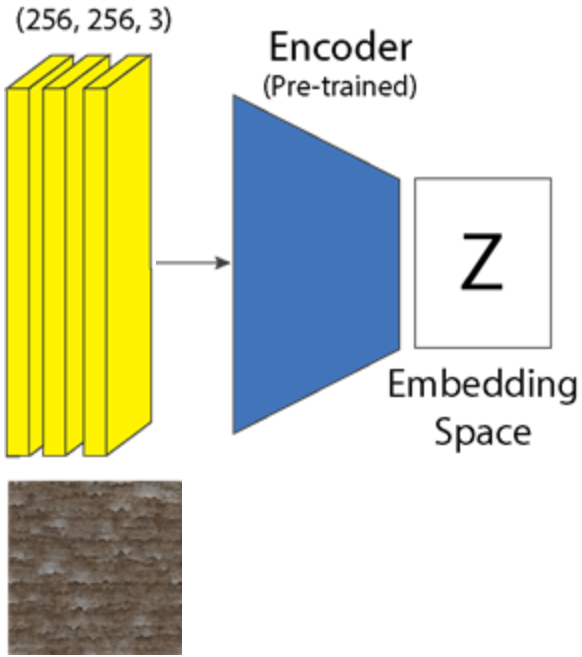

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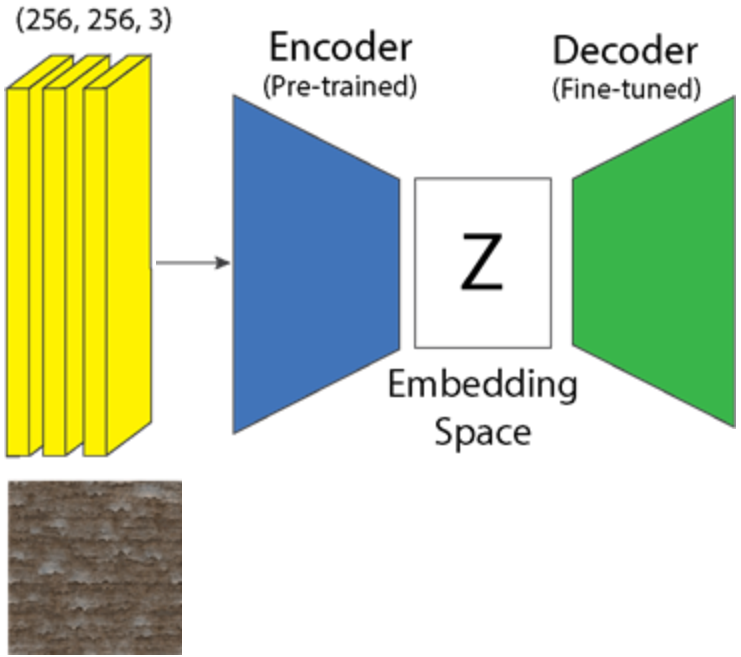

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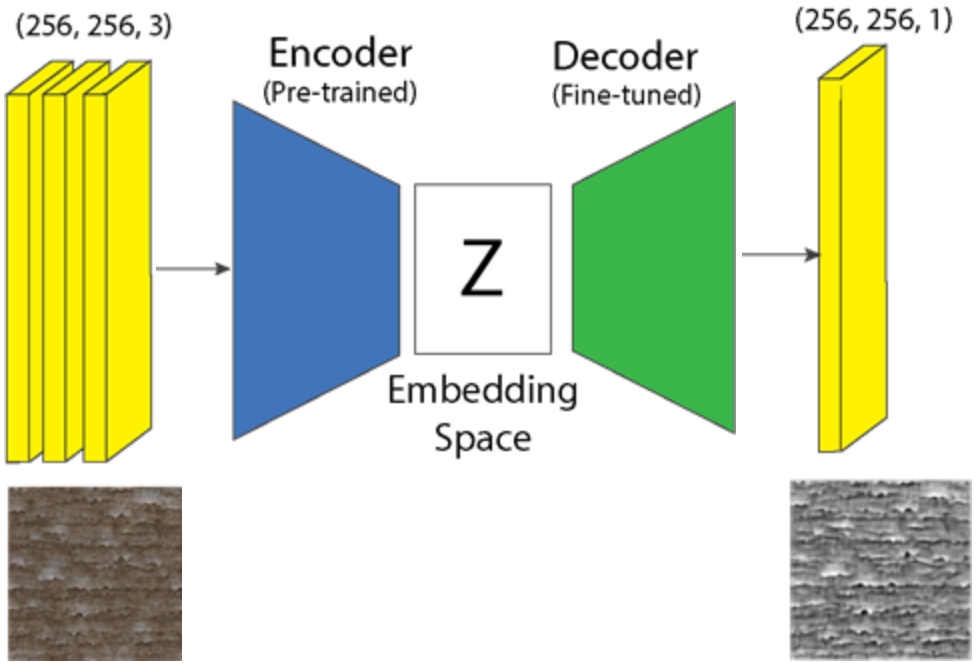

TACTSTYLE SYSTEM DESIGN

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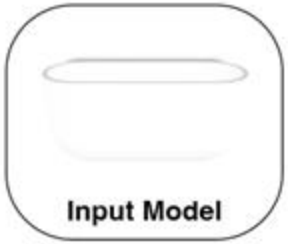

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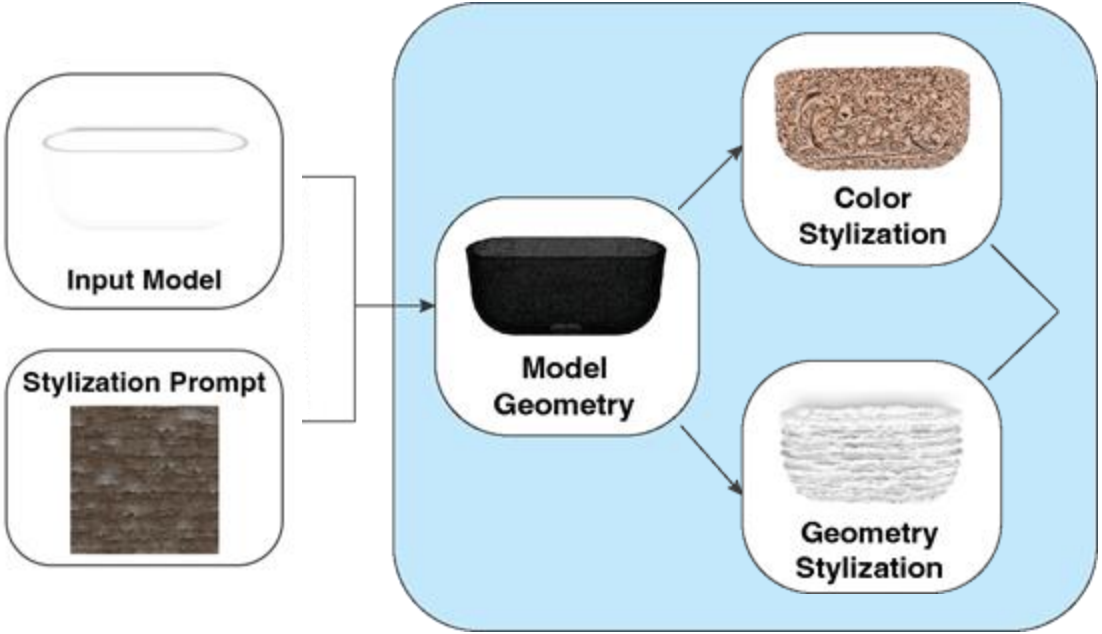

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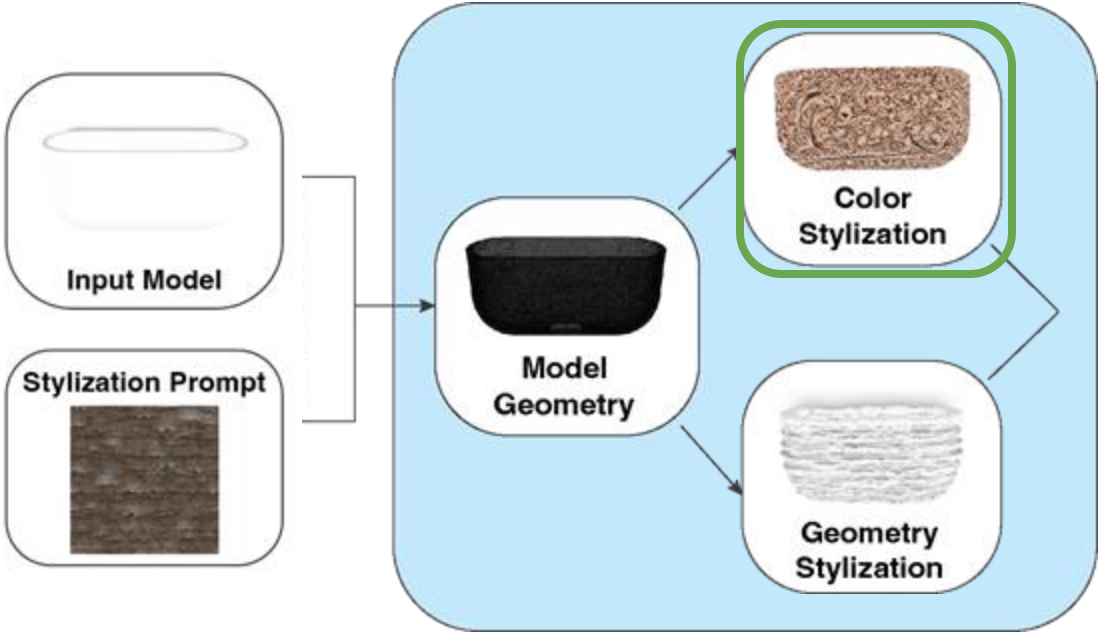

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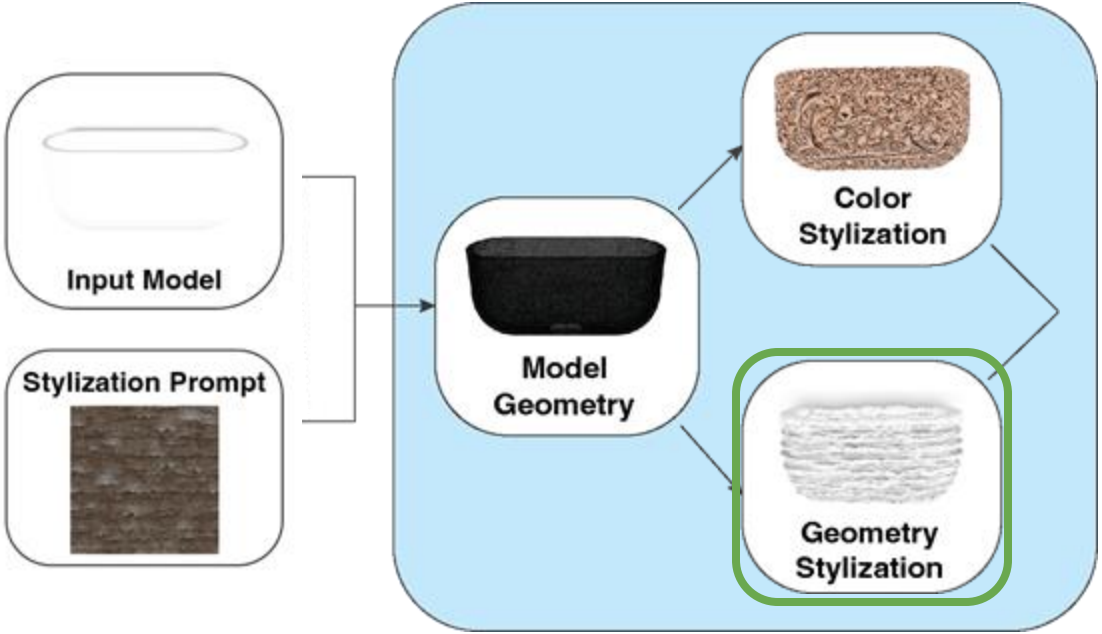

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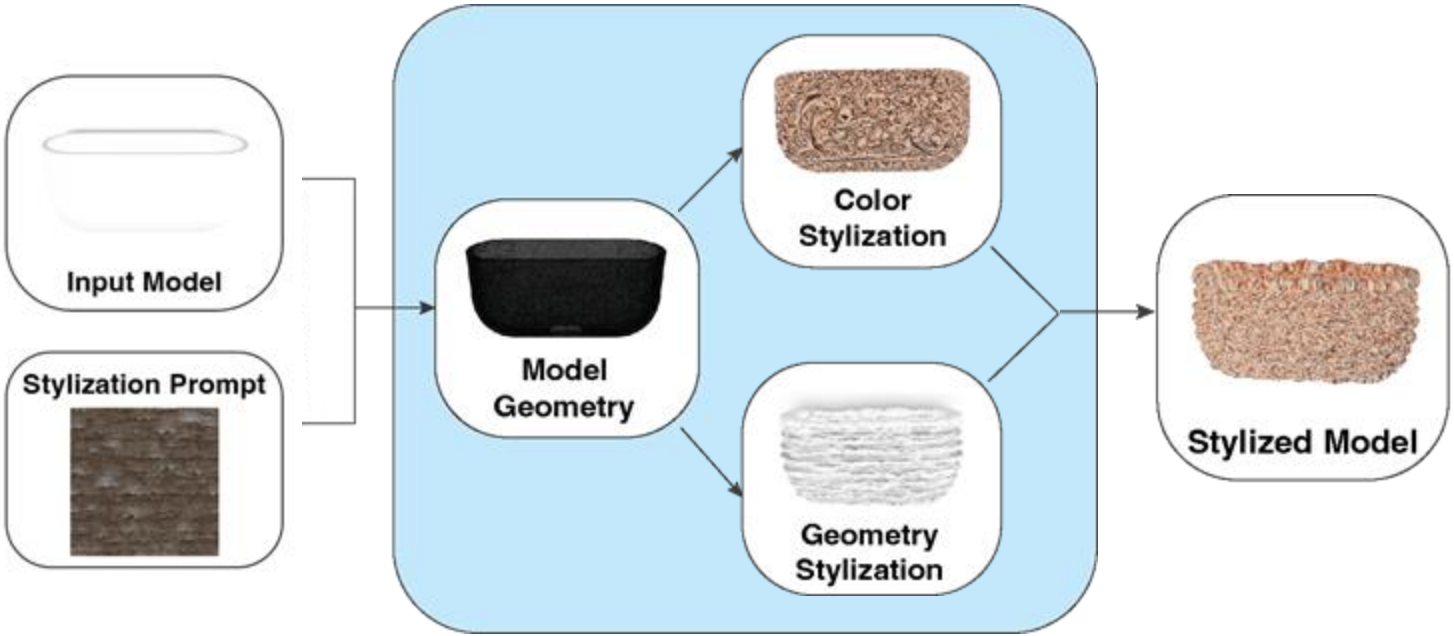
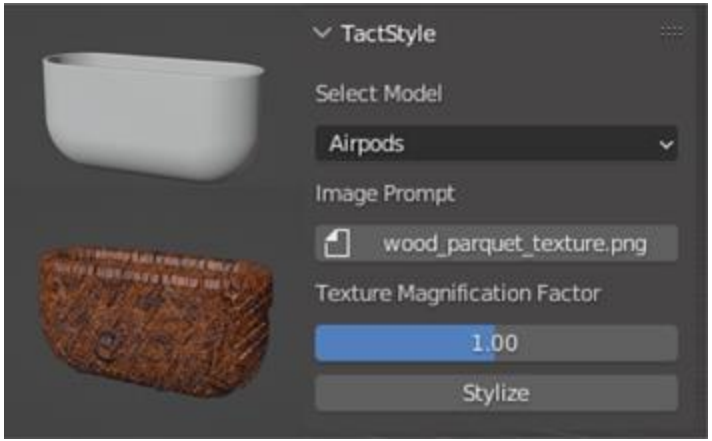


TactStyle User Interface



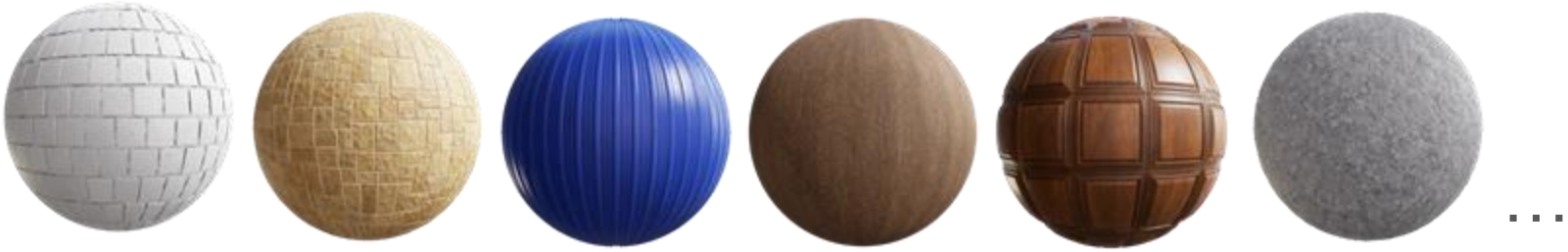
TactStyle is implemented as a plugin to Blender.

Users provide the 3D model and the texture image for stylization.

Users can also increase the amount of height displacement to magnify their texture.

MODEL TRAINING AND EVALUATION

PBR Dataset



500 textures for ‘Parquets’, ‘Wood’, ‘Rocks’, ‘Walls’, and ‘Roofs’ classes.

For each texture, we have image and surface heightfield pairs.

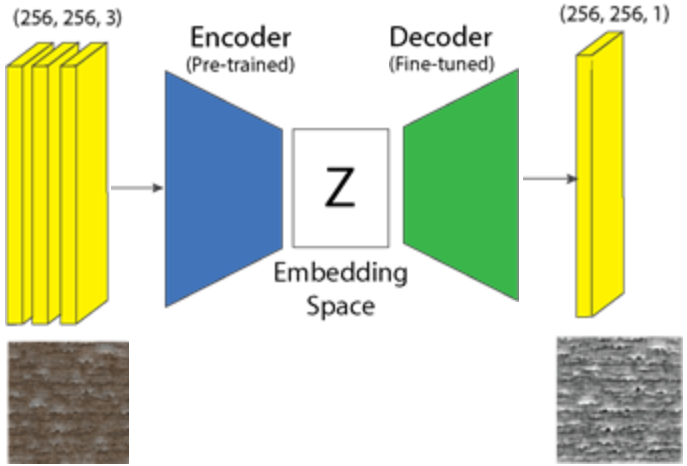
data collected from CGAxis

Model Architecture and Training

We modify and fine-tune an open-source Image-to-Image from Stable Diffusion to generate surface microgeometry as heightfields.

Approach:

1) Additional layers in decoder to learn new features
2) Modify the output layer to generate heightfields
3) Fine-tune the decoder with new data



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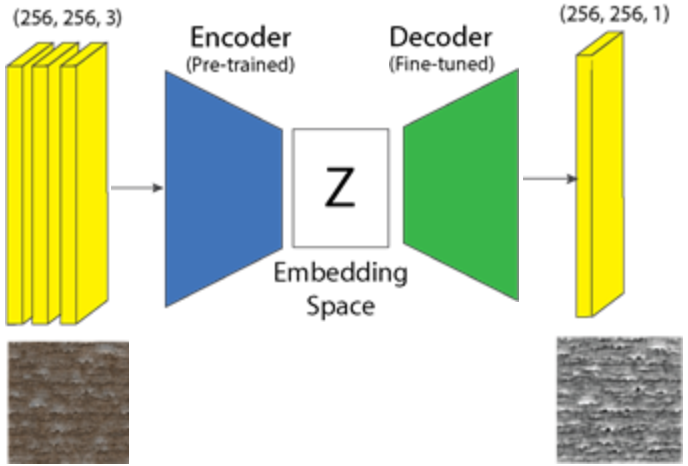
Loss functions:

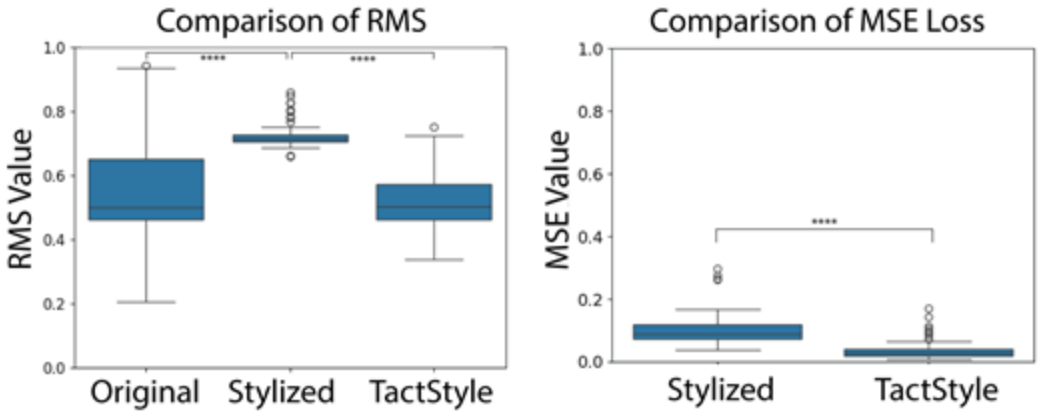
1) MSE: Per-pixel similarity
2) SSIM: Structural features



Technical Evaluation

We evaluate TactStyle's performance on its ability to replicate the surface microgeometry.

Baseline: Style2Fab for stylization



(****p < 0.0001)

PERCEPTION STUDY

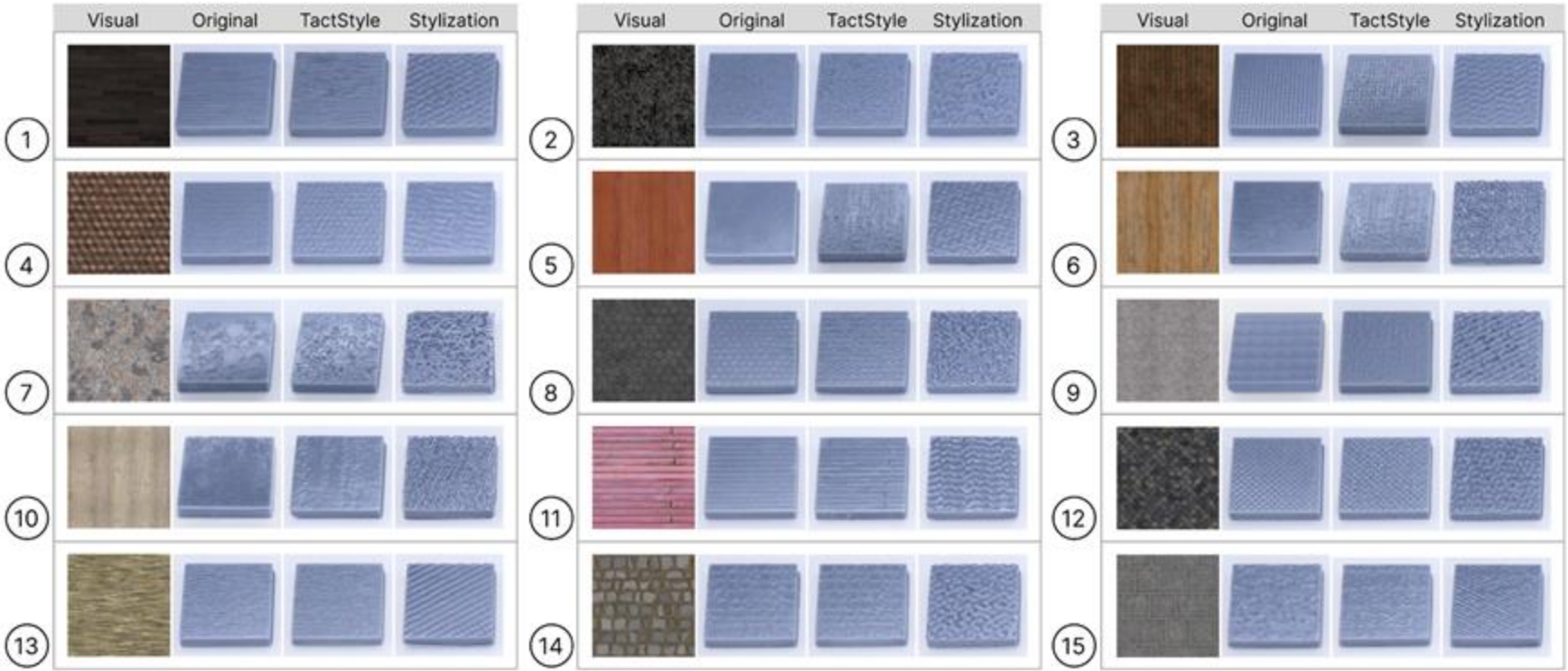
Perception Study - Study Design

We performed a psychophysical experiment to evaluate TactStyle's accuracy.

Conditions:

1) Visual (No heightfield)
2) Original Heightfield
3) TactStyle
4) Stylization

Perception Study - 3D Printed Samples



Perception Study - Tactile Descriptors

Each participant recorded their ratings of several tactile descriptors on a 1-to-9 Likert scale.

Tactile Descriptors:

1) Hardness
2) Roughness
3) Bumpiness
4) Stickiness
5) Scratchiness
6) Uniformity
7) Isotropy

Experimenter side

Participant side

Perception Study - Data Analysis

15 participants

- 6 female, 9 male, Average age= 27.3 years, SD= 5.4

After the study, we analyzed individual tactile assessments with Friedman tests and post-hoc analysis using Wilcoxon signed-ranks tests (Bonferroni-Holm correction).

To highlight relationships between tactile perceptions, we performed Spearman's rank-order correlation analysis.

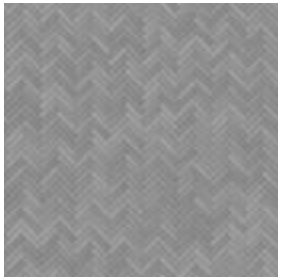
Perception Study - Results

Visual Texture

Roughness
Bumpiness
Stickiness
Isotropy

Roughness
Hardness
Scratchiness

TactStyle



Original Heightmap

Hardness
Scratchiness
Uniformity
Isotropy

Perception Study - Results

RQ1: TactStyle accurately replicates several Original Texture Descriptors.

Hardness, Scratchiness, Uniformity, and **Isotropy** are correlated between **Original** and **TactStyle** samples without exhibiting significant perceptual differences.

RQ2: TactStyle accurately replicates several Visual Texture Descriptors.

Roughness, Bumpiness, Stickiness, and **Isotropy** are correlated between **Visual** and **TactStyle** samples without exhibiting significant perceptual differences.

RQ3: Some textures have perceptual differences between Tactile Expectations from Visual Textures and Actual Tactile Perceptions.

Hardness, Roughness, and **Scratchiness** show significant perceptual differences between **Visual** and **Original** samples.

APPLICATION EXAMPLES

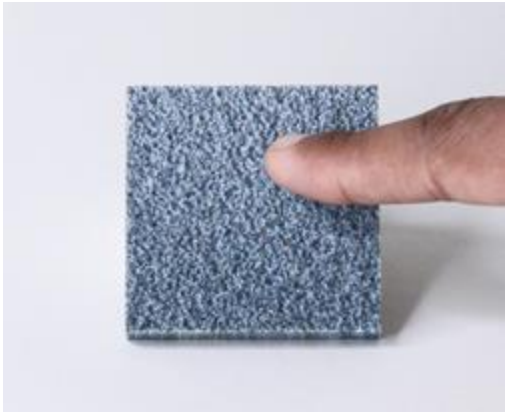
Applications: Home Decor and Personal Accessories

a phone stand stylized with
wood-parquet texture

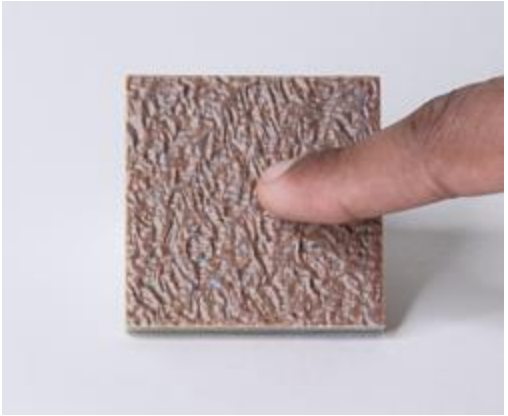
a vase stylized with
granite texture

an AirPods cover stylized with different textures

Applications: Tactile Learning Tools



Volcanic rock texture



Grand Canyon rock texture

Applications: Assistive Devices

walking stick handle stylized with a rough rock texture

DISCUSSION AND FUTURE WORK

Discussion and Future Work

Cross-Modal Texture Design

- TactStyle combines expected tactile features from visual textures with perceived tactile properties from heightfields, enabling cross-modal texture design.
- Future extensions could allow users to generate tactile surfaces from text prompts, similar to advances in VR and haptics.

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- Future extensions could allow users to generate tactile surfaces from text prompts, similar to advances in VR and haptics.

Enhancing Generative AI for Tactile Design

- While current AI tools generate 3D models based on images and text, they lack accurate tactile property generation.
- Extending TactStyle could enable creators to specify both visual and tactile features, producing fabricatable designs with realistic texture information and material recommendations.

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