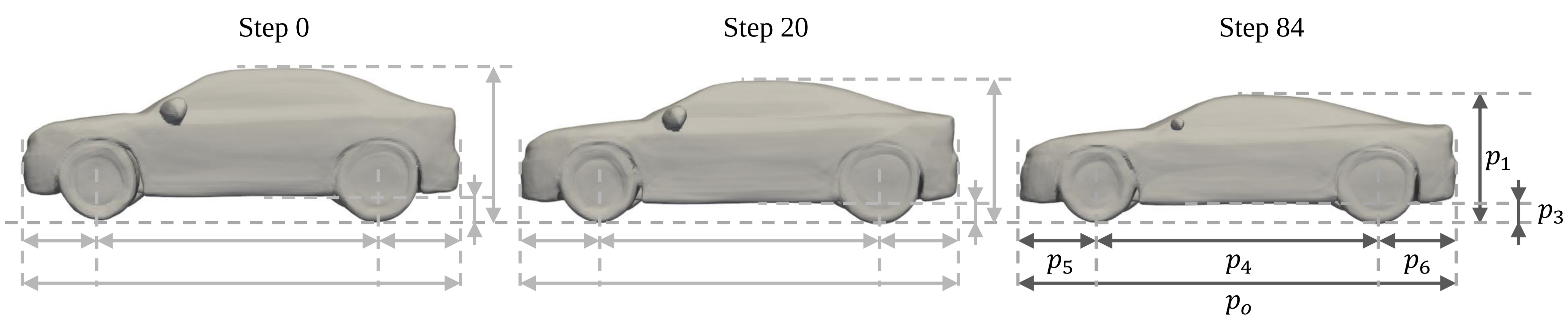
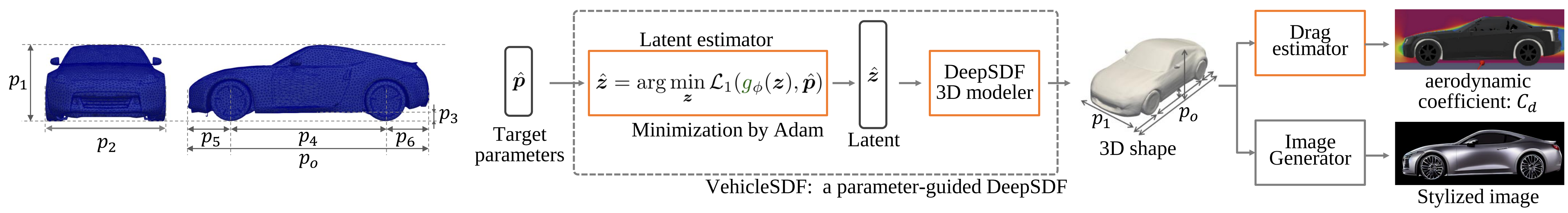
VehicleSDF: A 3D generative model for constrained engineering design via surrogate modeling

Hayata Morita, Kohei Shintani, Chenyang Yuan, Frank Permenter

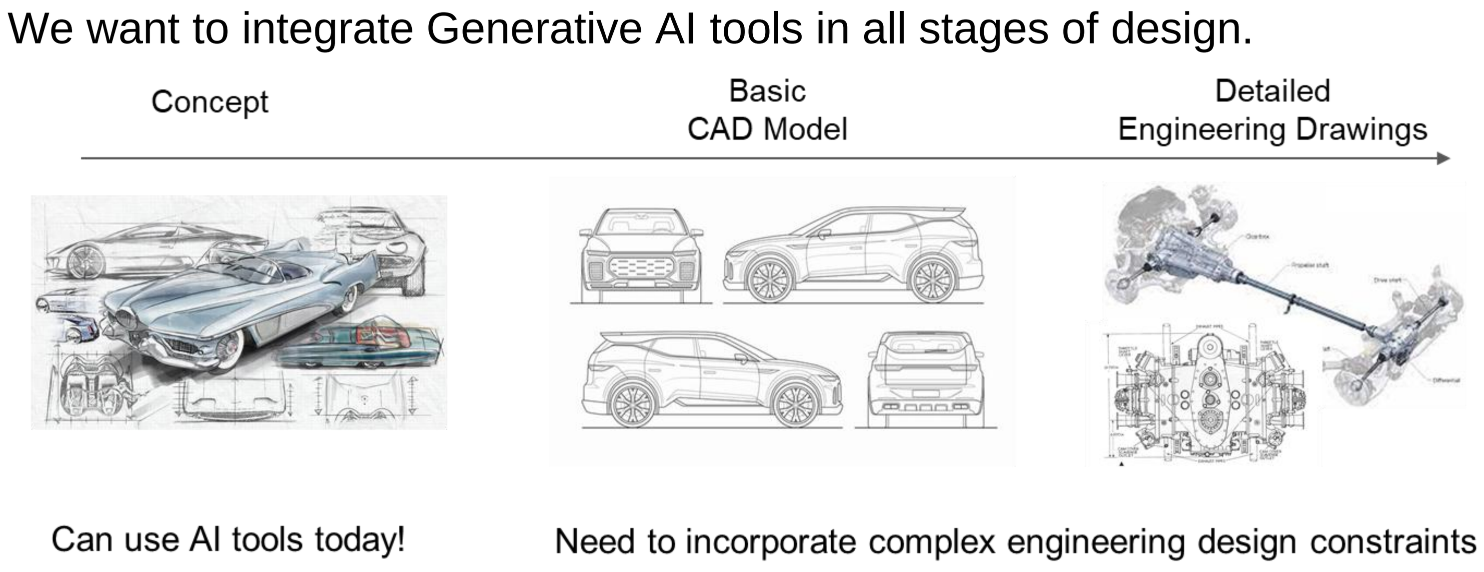
TOYOTA RESEARCH INSTITUTE





Introduction and motivation

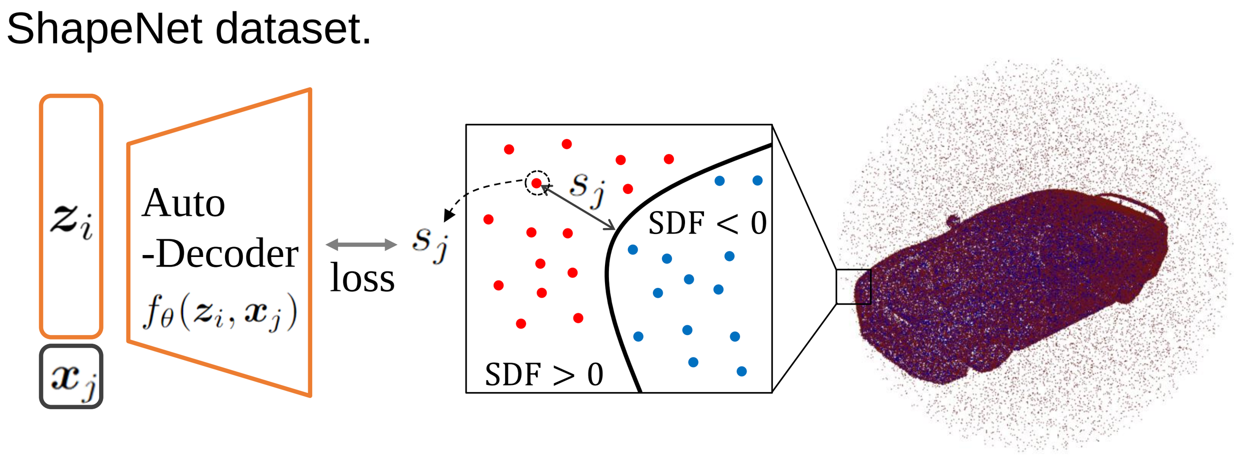
We want to integrate Generative AI tools in all stages of design.



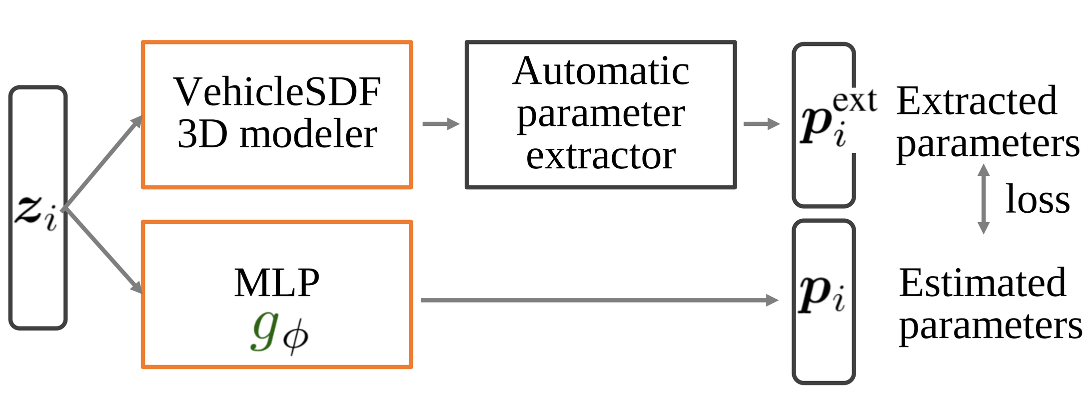
We aim to integrate engineering constraints into a 3D generative model for vehicle design, considering **design parameters**, **engineering performance**, and **styling** simultaneously.

Methodology

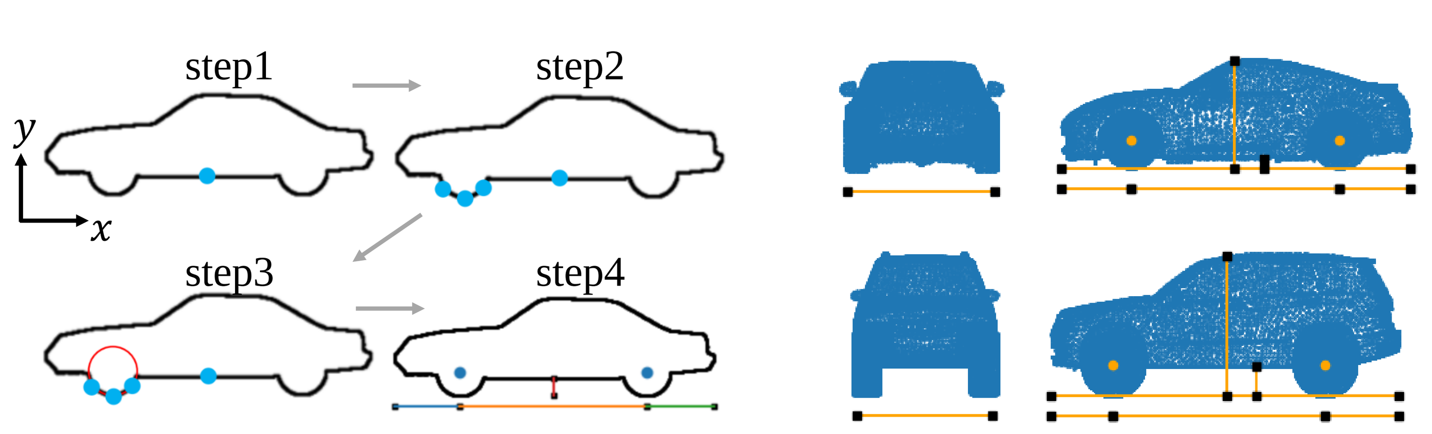
Auto-decoder model[1] was trained to estimate signed distance function using ShapeNet dataset.



To get an ideal latent z corresponding to target parameters, a MLP was trained to estimate parameters from optimized latent z.

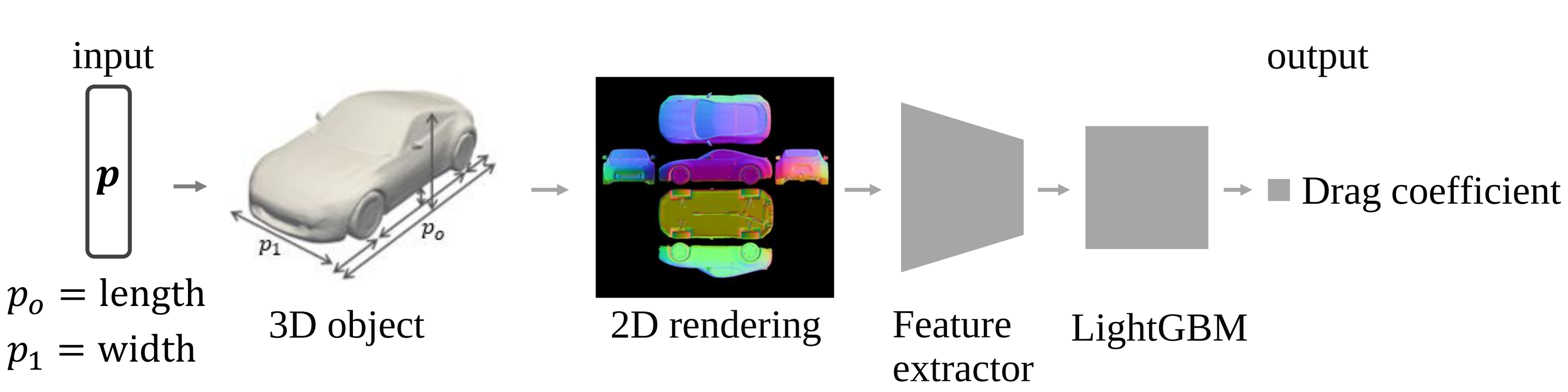


Vehicle geometric parameters were extracted automatically from mesh.

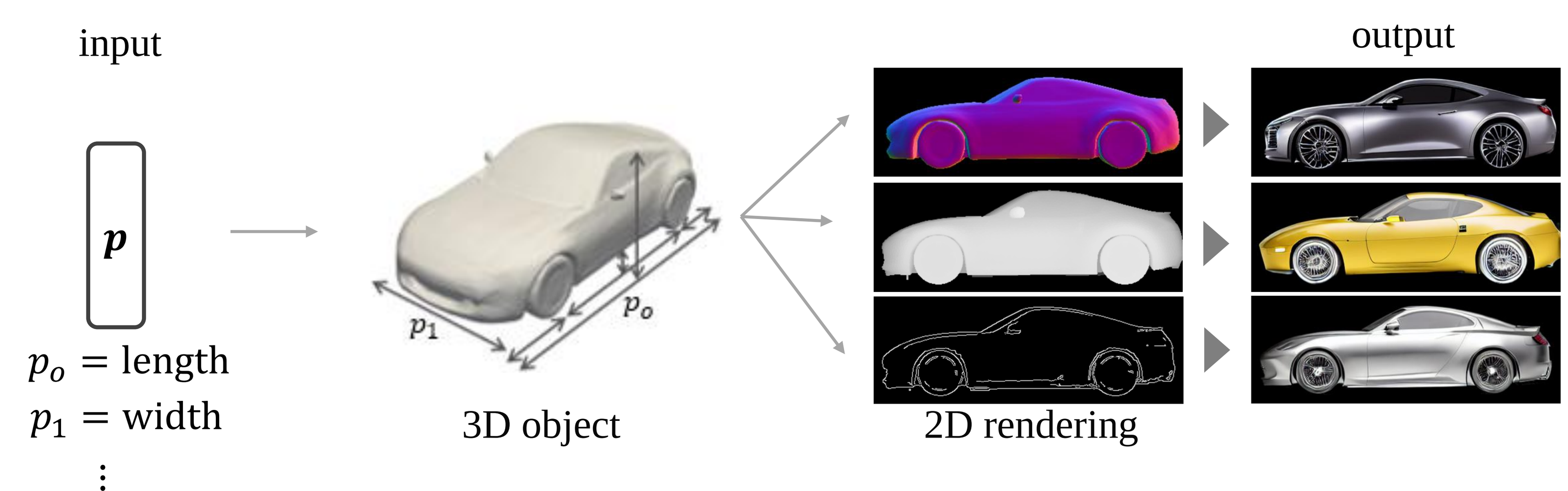


(a) Automatic parameter extractor (b) Examples of extracted parameters

Use case 1: Estimating drag coefficient from 3D model[2]

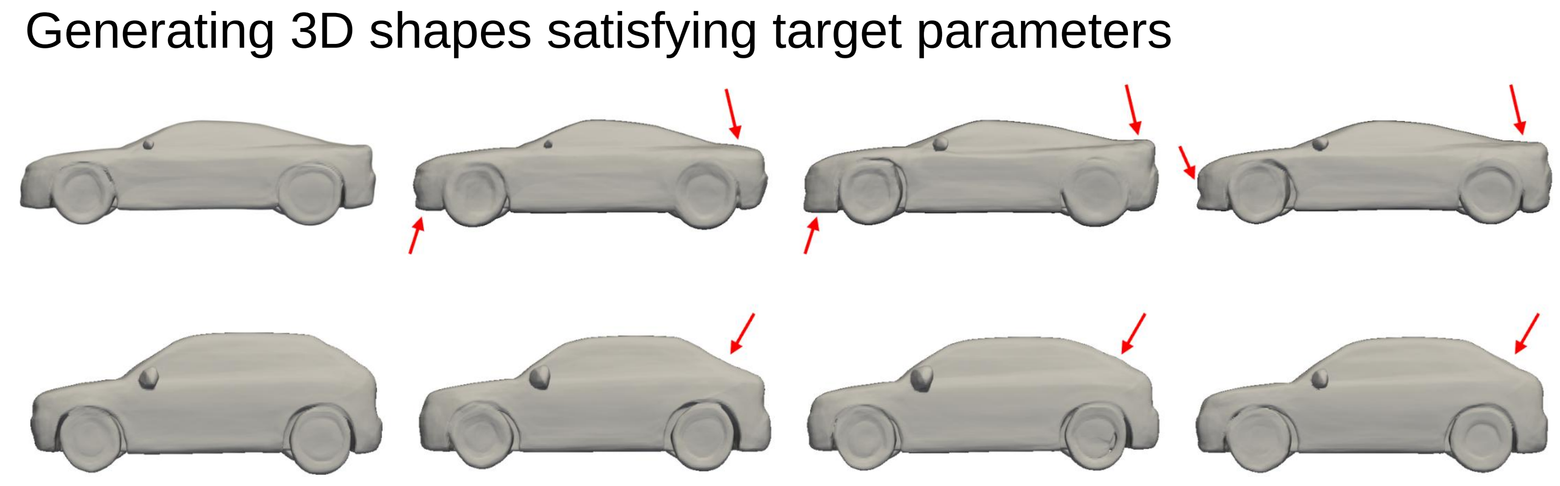


Use case 2: Stylizing realistic images using ControlNet[3]



Experiments and results

Generating 3D shapes satisfying target parameters

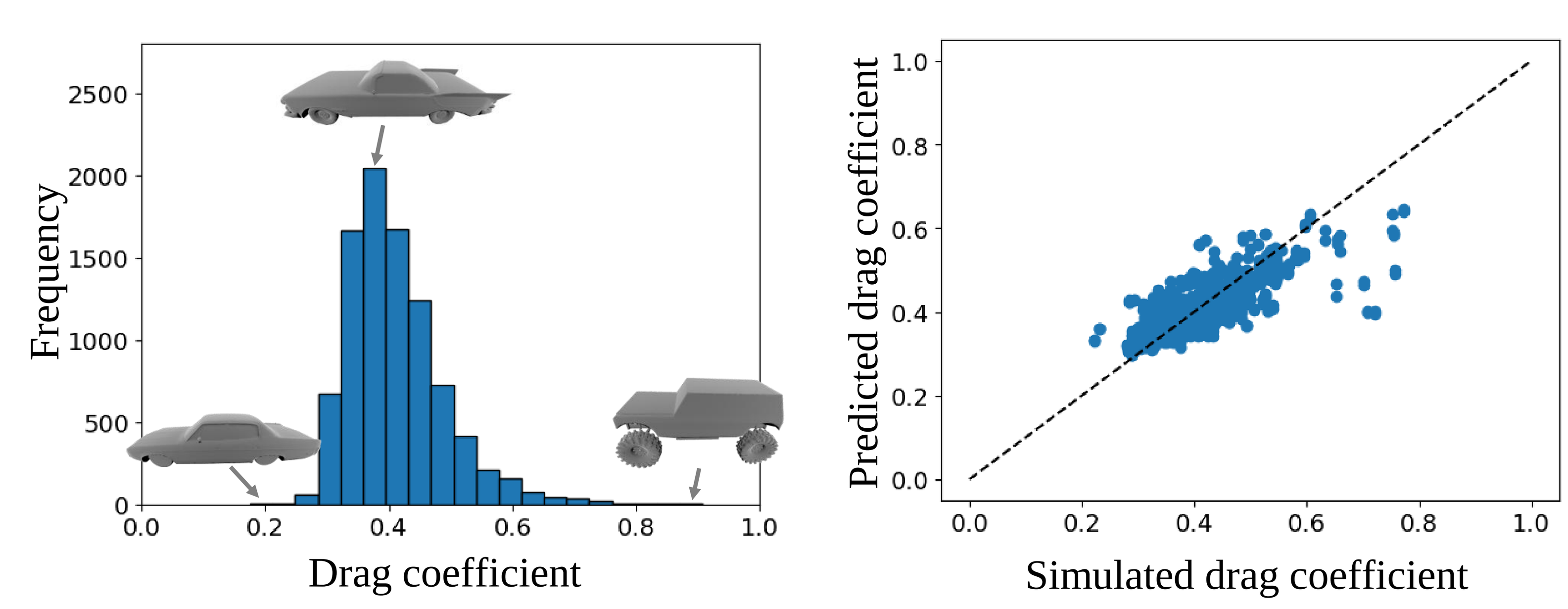


Comparison of target parameters during optimization

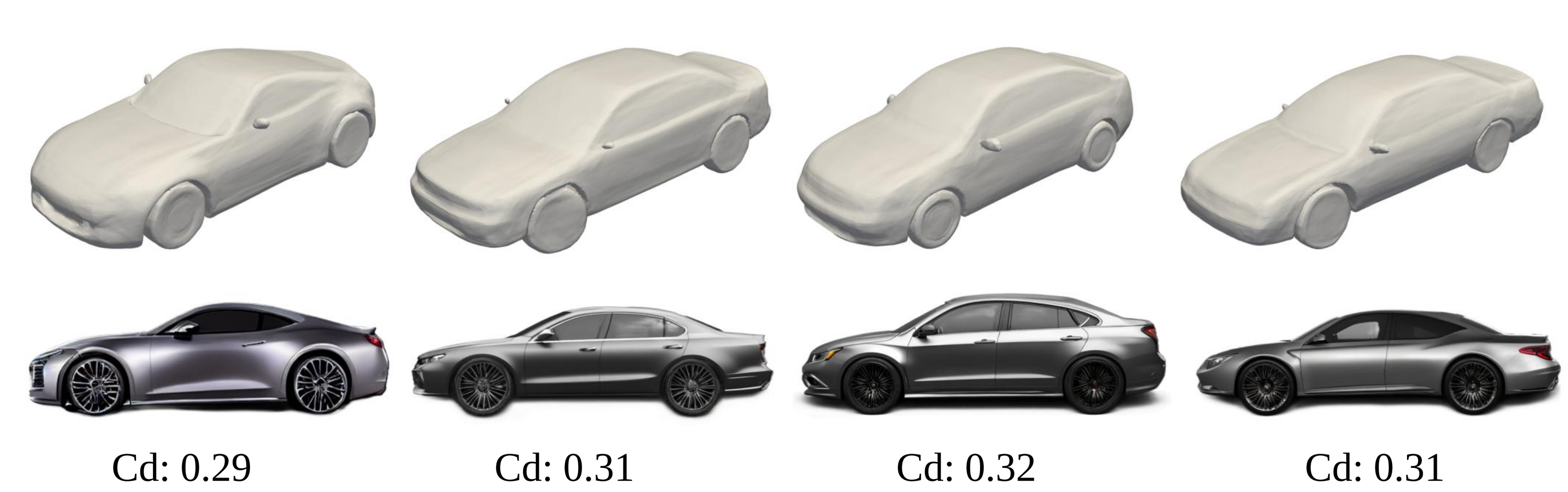
Table 1: Comparison of target geometric parameters and during optimization

Parameters	p_0	p_1	p_2	p_3	p_4	p_5	p_6	MSE
Initial	1.000	0.331	0.396	0.053	0.598	0.194	0.208	5.97×10^{-4}
Intermediate	1.000	0.306	0.425	0.039	0.599	0.203	0.199	1.03×10^{-4}
Final	1.000	0.280	0.431	0.037	0.600	0.200	0.200	2.86×10^{-8}
Target	1.000	0.280	0.430	0.037	0.600	0.200	0.200	-

Drag estimator results:



Estimating drag and stylizing realistic car-design image



[1] Jeong Joon Park, Peter Florence, Julian Straub, Richard Newcombe, and Steven Lovegrove. Deepsdf: Learning continuous signed distance functions for shape representation. In Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, pages 165–174, 2019.

[2] Binyang Song, Chenyang Yuan, Frank Permenter, Nikos Arechiga, and Faez Ahmed. Surrogate modeling of car drag coefficient with depth and normal renderings. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, volume 87301, page V03AT03A029. American Society of Mechanical Engineers, 2023.

[3] Lvmin Zhang, Anyi Rao, and Maneesh Agrawala. Adding conditional control to text-to-image diffusion models. In Proceedings of the IEEE/CVF International Conference on Computer Vision, pages 3836–3847, 2023.

https://arxiv.org/pdf/2410.18986