Masterthesis Title Suggestion: *Self-Supervised Graph B-Rep Encoding and Multimodal Text-CAD Learning for Downstream Synthesis and Analysis*

Student: Hazem Elkazaa

Matrikelnummer: 23660717

Birth date: 17.02.2003

Address: Wilhelm-Busch-Straße 34, 81477 München, Germany

University: Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

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Introduction

Computer-Aided Design (CAD) models are the standard for modern engineering, relying on Boundary Representation (B-Rep) to define mathematically precise surfaces and topological structures. While B-Reps offer superior precision compared to meshes or point clouds, their non-Euclidean, heterogeneous nature presents significant challenges for deep learning, which typically requires structured grid or sequence data. Conventional approaches often resort to voxelization or sampling, losing the "engineering intent" and parametric precision inherent in the raw NURBS geometry.

Building upon my previous work conducted at BMW, which established a pipeline for compressing NURBS geometry via Variational Autoencoders (VAEs) and processing topological graphs using the BRepGPS architecture, this Master's thesis proposes a scaling strategy to overcome the limitations of training on small, internal datasets. The core objective is to develop a robust "Foundation Model" for B-Rep data by leveraging large-scale Self-Supervised Learning (SSL) on the public ABC Dataset.

This research will systematically evaluate different graph learning paradigms (contrastive, generative, and hybrid) to produce a generalized encoder capable of capturing high-fidelity geometric and semantic features. Furthermore, this thesis will extend the utility of the encoder by aligning the geometric latent space with natural language, enabling a suite of high-impact downstream tasks. Specifically, the work will address the construction of multimodal datasets to support text-to-CAD retrieval and automated captioning, the development of labeling strategies for semantic segmentation of mechanical features, and the exploration of generative modeling for automated design synthesis.

Research Questions

- **Optimal SSL Paradigm for CAD:** How do Contrastive, Generative, and Hybrid graph learning paradigms compare in producing a robust, generalized B-Rep encoder when trained on the large-scale ABC Dataset?
- **Text-CAD Dataset Construction:** What methodologies can be developed to automatically generate accurate natural language descriptions and engineering specifications for the unlabeled ABC dataset to construct a large-scale Text-CAD corpus for retrieval and captioning tasks?
- **Segmentation Dataset & Training:** How can we procedurally generate ground-truth labels for functional regions within B-Rep graphs to construct a semantic segmentation dataset, and how effective is the pre-trained encoder in learning these partitions via supervised fine-tuning?
- **Generative Capabilities:** Can the unified latent space be effectively leveraged to support generative tasks, specifically Text-to-CAD synthesis and automated design completion?