Multimodal Generative design for smooth latent space explorationN (MuGeN)

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1 Project description

Nowadays, architects and engineers make use of software for parametric design that enables them to generate, simulate and evaluate multiple design instances. However, achieving some specific performance attributes requires a deep understanding of the relation between them and the input design parameters, which is unattainable for most of the problems. Currently, we are carrying out a project in collaboration with the department of Architecture and Digital Fabrication at ETH Zürich on the application of machine learning to generative design, aiming at solving this problem on a particular design case: the construction of a vertical garden, a structure compounded of a set of planted platforms. In Fig. 1 we can observe the actual process of parametric design, from the specification of the design parameters **W** (Fig. 1a), to the simulation and analysis in the parametric design software that allows computing the specified performance attributes **X** (Fig. 1b). In Fig. 1c we simply depict a more visual render of the structure.

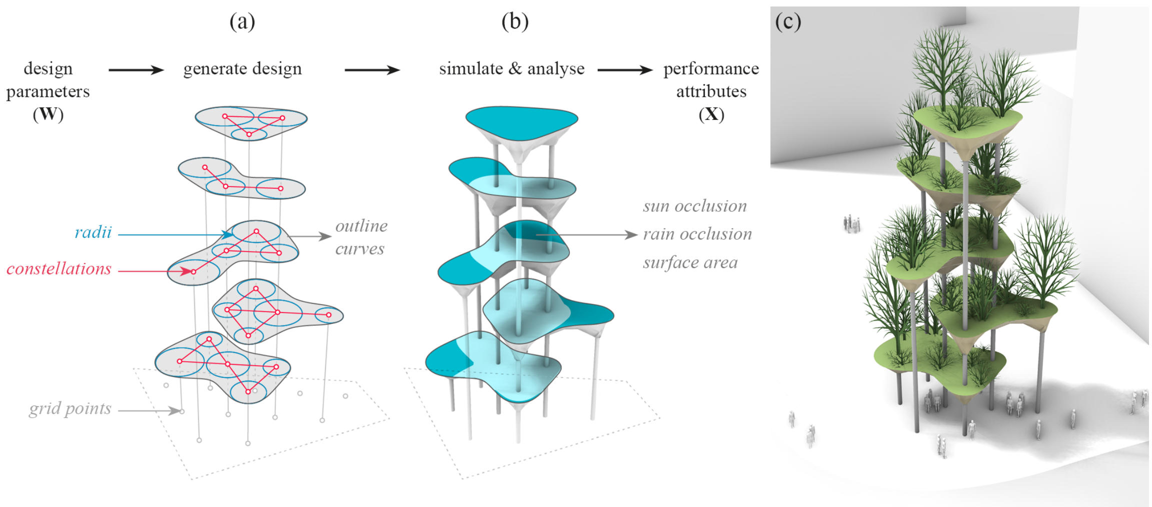

Figure 1: Process of parametric design, from the specification of the design parameters (a), the simulation of specific performance attributes (b), and the finally design achieved (c).

Thus far, we implemented a deep neural network architecture, based on conditional autoencoders, that allows, given some desired attributes **X** (sun and rain occlusion, and total surface), generating on-the-fly a range of possible design parameters **W** that approximate the given design specifications. This enriches the designer's experience by directly providing a varied set of geometries to explore, enabling him or her to focus on criteria that are more difficult to quantify, such as aesthetics.

In the described implementation, in order to capture additional degrees of freedom, we are required to add some extra dimensionalities $\mathbf{Z}$ in the latent space. Then, for the generation of new designs given some desired $\mathbf{X}$, we just need to sample $\mathbf{Z}$ and use the trained decoder section of the autoencoder. As stated before, this had led already to satisfactory results. Nevertheless, the behavior of this latent space $\mathbf{Z}$ has not been studied yet, more specifically, how the variation of these parameters influence the output designs. First, we would prefer that small variations of the values of $\mathbf{Z}$ would lead to smooth variations of the geometric structure. But ideally, we would like to relate each of the dimensions of $\mathbf{Z}$ with interpretable geometrical changes in the structure. For example, if we could find a dimension of $\mathbf{Z}$ that relates with the position of the bottom platform, the designer could manually steer the value of it, generating new designs that still approximate the desired $\mathbf{X}$, and that place such platform in varied positions (perhaps varying slightly the rest of platforms). This idea stems from the current hot topic of disentanglement, which aims at finding interpretable latent spaces.

In the current project, we aim at tackling the aforementioned goals as follows. First, we will study the smoothness of the latent space $\mathbf{Z}$, and how small variations of its values vary the geometrical look of the generated designs. We expect large and random changes of these geometries, as the current model has no notion about the geometrical shapes. Therefore, as second step, we will add another modality to the model, the geometrical shapes of the structures. By additionally feeding this to the model by using a convolutional neural network, we expect to enforce some smoothness on the variation of $\mathbf{Z}$, a first step towards a better definition of this latent space. We will conclude the project by studying the problem of disentanglement, trying to relate specific geometrical properties with specific dimensions of the latent space.

The present project will allow the student getting a larger familiarity with the usage of different neural network architectures, as well as with up-to-date concepts in the DL field. Besides, the application of all these methodologies to the field of parametric design is completely novel, and we may publish this work if the results are interesting and satisfactory. Nevertheless, this also suggests the eminently exploratory character of this project, hence a large dose of creative thinking is desired. Still, the exploration will be fun and interesting, and throughout the development of this project we will be able to investigate various novel methodologies, and their application to parametric design.

2 Additional information

- **Difficulty of the project:** From difficult to very challenging.
- **What will you learn?** Deep neural networks, convolutional neural networks, generative design.
- **Requirements:** Good python level, some knowledge of either Keras or PyTorch, experience with git, machine learning fundamentals, creative thinking.
- **Supervisors:** Luis Salamanca (luis.salamanca@sdsc.ethz.ch) and Fernando Pérez-Cruz (fernando.perezcruz@sdsc.ethz.ch).