Latent Morphologies: Encoding Architectural Features and Decoding Their Structure through Artificial Intelligence

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Accessibility
Latent Morphologies:
Encoding Architectural Features and Decoding their Structure through Artificial Intelligence

By

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Master of Science in Design, University of Pennsylvania, 2019
Bachelor of Architecture, Hongik University, 2017

Submitted in partial fulfillment of the requirements for the degree of

Master in Design Studies
Technology

At the Harvard University Graduate School of Design

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Latent Morphologies:
Encoding Architectural Features and Decoding Their Structure
Through Artificial Intelligence

Harvard University
Graduate School of Design

Master in Design Studies, Technology
Dongyun Kim

Advisor: Andrew Witt
Latent Morphologies:
Encoding Architectural Features and Decoding Their Structure Through Artificial Intelligence

With the advent of Artificial Intelligence, new methodologies have been introduced to the architectural discipline, expanding the current possibilities of design processes. Specifically, generative models created a paradigm shift wherein, instead of spending numerous time designing the entire system for a specific task, designers allowed the overall principle and system to remain in the black box and instead focused on the desired results. These attempts, however, strongly rely on randomness and could not achieve overall controllability so those problems have hindered getting meaningful results.

This research started with building an encyclopedic architectural dataset that can represent general architecture, maintaining its variation. In addition, it explores potential applications, using Generative Adversarial Networks such as StyleGAN to find hidden patterns we cannot identify and their regularity in architectural discourse. Several statistical methodologies are utilized to understand and unveil characteristics in massive data. Especially, using the concept of encoder and decoder, latent space shows incredible possibilities, generalizing architectural features and generating their continuous morphologies which are theoretically infinite.
Background and Problems

Dataset Construction and Exploratory Data Analysis
Methodology I: Multi-class StyleGAN
Methodology II: Multimodal StyleGAN+CLIP
Conclusion

History of Computation in Architecture (2019)
Stanislas Chaillou

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https://spaceandtim.es/projects/social_sim_components_idea_propagation/
https://www.architect-ly.com/l-system-bracketed-solid
On Convergence and Stability of GANs (2018)  
(Mescheder et al.)

AI & Architecture: Towards a New Approach  
(Stanislas Chaillou)
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Paradigm shift

Creating a rule
(Algorithmic approach)

Finding a pattern
(Artificial Intelligence)
Background and Problems

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Traversing Features (Seungmook Kim, Sukyeong Cheon)
Problem I: Limitation of architecture dataset

Architectural style dataset (2014)  
(Xu et al.)

Façade dataset (2017)  
(Isola et al.)
Problem II: Limitation of controllability
Problem II: Limitation of controllability

Traditional StyleGAN architecture

A simple version of GAN architecture
Problem II: Limitation of controllability

Latent space refers to an abstract multi-dimensional space containing feature values that a human cannot interpret directly, but which encodes a meaningful internal representation of externally observed events.
Problem II: Limitation of controllability

Missing link between visual features and represented latent vector
Research Questions:

Is there an implicit rule that can create a style in architecture?
What are hidden patterns or features we cannot identify?
Is there any regularity?
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Computer Science
Architecture
Data Science
Generative Design
Narrative
Design
Big data Analysis
Data Visualization
Finding hidden patterns and their regularity
ML
DL
Automata
Decision-making
Genetic Algorithm
Design Finding hidden patterns and their regularity
Background and Problems

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Dataset Construction and Exploratory Data Analysis
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Dataset source

- Enough number of projects to create an encyclopedic architecture dataset
- Good quality images, descriptions, and additional data
- This platform can represent how the general architecture looks like
Dataset example
**Dataset example**

**Project name:** BO Hero
Architecture: Tomato Design
Location: Pe Sen, Vietnam
Built: June 2019

**Sympo:** Resilience Architecture
Material: Concrete

A six-year ago couple approached us, more or less on our own, to design their second home. The site is at the threshold of a new era, with its rear facing the sea, and its front overlooking the town. The couple witnessed the town’s transformation from a quiet fishing village to a bustling tourist destination. They had a clear vision of their new home: a place where they could retreat from the chaos, yet remain connected to the vibrant community around them.

**Project name:** Qinghe World Natural Aquarium & Eco-themed Pavilion
Architect: LiYudi Architectural
Location: Qinghe China
Built: June 2019

**Sympo:** Cultural Architecture
Material: Glass

The world’s first water-based aquarium & eco-themed pavilion, the construction of the project was driven by the need to showcase the beauty and diversity of aquatic life in a sustainable manner. The design is inspired by the natural landscape of Qinghe, a picturesque town located in China’s Jiangsu province. The pavilion is expected to attract visitors from all over the world, providing an educational and engaging experience for all ages.

**Project name:** Marbella in a Box
Architecture: Arquitectura Arquitecto
Location: Los Angeles, United States
Built: June 2019

**Sympo:** Technological Architecture
Material: Steel

MARBELLA IN A BOX


**Project name:** Morgan, David
Architecture: Glaser-Harari
Location: Santa Monica, USA
Built: June 2017

**Sympo:** Residential Architecture
Material: Concrete, Brick

Contact: The MA 15:19 project located in the neighborhood of Santa Monica is presented as an opportunity to operate in memory, a result of the need for the traditional retail sector market. It focuses on the relationship between the building and its surroundings, exploring the potential of retail spaces in a new context. The project is characterized by a fluid and open design, with the aim of creating a space that is adaptable to different uses, fostering a sense of community and promoting the exchange of ideas between users.

**Project name:** MA 15:19
Architecture: Glaser-Harari
Location: Santa Monica, USA
Built: June 2017

**Sympo:** Residential Architecture
Material: Concrete, Brick

Contact: The MA 15:19 project located in the neighborhood of Santa Monica is presented as an opportunity to operate in memory, a result of the need for the traditional retail sector market. It focuses on the relationship between the building and its surroundings, exploring the potential of retail spaces in a new context. The project is characterized by a fluid and open design, with the aim of creating a space that is adaptable to different uses, fostering a sense of community and promoting the exchange of ideas between users.

**Background and Problems**

**Methodology I: Multi-class StyleGAN**

**Methodology II: Multimodal StyleGAN+CLIP**

**Conclusion**
<table>
<thead>
<tr>
<th>Feature</th>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image</td>
<td>Image</td>
<td><em>(Image)</em></td>
</tr>
<tr>
<td>Project name</td>
<td>Text</td>
<td>School of Engineers in Bretagne</td>
</tr>
<tr>
<td>Architect</td>
<td>Text</td>
<td>ANMA</td>
</tr>
<tr>
<td>Location</td>
<td>Text</td>
<td>France</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>Text</td>
<td>5743</td>
</tr>
<tr>
<td>Built year</td>
<td>Category</td>
<td>2013</td>
</tr>
<tr>
<td>Description</td>
<td>Text</td>
<td>South Brittany's Higher School of Engineering is a microcosm ...</td>
</tr>
<tr>
<td>Meta data</td>
<td>Text</td>
<td>Architect In Charge: Nicolas Michelin, Michel Delplace, Cyril ...</td>
</tr>
</tbody>
</table>

South Brittany's Higher School of Engineering is a microcosm the unity of which is organized around the compact, colorful central monolith from which the building's two wings radiate. The monolith contains two essential areas: the amphitheater and the cafeteria. Starring in the competition phase, the design for this central room was contributed to by artist David Saltiel. The school is part of an overall reflection by ANMA about interstitial spaces. Fostering interaction between students, teachers, researchers and staff, they are essential to the process of the school's positive synergy. Whether they enable students and faculty to isolate themselves (like the faculty council's meeting room and its terrace overlooking the entire building) or come together (like the tiered terraces of the roof), they shape the sense of the same shared place. With each place of higher education it has designed ANMA manifest its ambition to go beyond briefs, offer living space and shared venues that enable students to live and learn together. The polyvalent spaces are organized in a rationale of flows. Study cells where students may meet to work together are added to the traditional classrooms. Learning is no longer isolated but networked and connected. The concourses become public spaces connected to the city. The university thus opens onto its environment with a idea borrowed from the American campus model but applied on a French scale with constraints of density and mixed use with housing briefs. Interactions between the student city and the city of everyday life incorporate these different projects into the same rationale of urban planning.

Data analysis

Published projects are getting increased.

The projects have not published immediately after building them. It takes some time to be introduced in ArchDaily, or due to Covid.

Western-centered architecture projects

Imbalance of published project
Data analysis

Distribution of published projects by typology

Distribution of published projects by subclass typology
Data analysis

Distribution of published projects by area

Distribution of published projects by architect
Data analysis

Distribution of published projects by material

Distribution of published projects by color

Background and Problems

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Conclusion
Data analysis

A picture or image is a representation tool and a perspective that people understand when looking at the architecture.

Thus, the image is subjective, but we can understand their perspective and how they see the architecture, seeing the entire images.

Definition of a picture or image in architecture
Data analysis

High-dimensional cartography

Color-based cartography
Latent Morphologies: Encoding Architectural Features and Decoding Their Structure Through Artificial Intelligence

Circular cartography

Data analysis
Data analysis

PCA

t-SNE

UMAP

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Data analysis
## Data analysis

### Western Culture
- Northern America
- Central America
- South America
- Western Europe
- Eastern Europe
- Southern Europe
- Northern Europe

### Asian Culture
- Eastern Asia
- South-eastern Asia
- Western Asia
- Southern Asia
- Central Asia
- Australia and New Zealand

### African Culture
- Melanesia
- Middle Africa
- Northern Africa
- Eastern Africa
- Western Africa
- Southern Africa
- Caribbean
Methodology I: Multi-class StyleGAN
Methodology I: Multi-class StyleGAN

Traditional StyleGAN

Multi-class StyleGAN
Methodology I: Multi-class StyleGAN

Traditional StyleGAN

Input

Random noise

Z

StyleGAN

Output

Image

Multi-class StyleGAN

Input

Random noise

Z

Class

Output

Image

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Methodology I: Multi-class StyleGAN

![Diagram of multi-class latent space](image)

**Multi-class latent space**
Background and Problems

Dataset Construction and Exploratory Data Analysis

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Methodology II: Multi-modal StyleGAN + CLIP

Conclusion

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Methodology I: Multi-class StyleGAN

Original images (from ArchDaily)

Generated images by StyleGAN
Methodology I: Multi-class StyleGAN

Typology category: Public architecture

Typology category: Educational architecture
### Methodology I: Multi-class StyleGAN

<table>
<thead>
<tr>
<th>Public Architecture</th>
<th>Educational Architecture</th>
<th>Residential Architecture</th>
<th>Cultural Architecture</th>
<th>Landscape &amp; Urbanism</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Public Architecture" /></td>
<td><img src="image2" alt="Educational Architecture" /></td>
<td><img src="image3" alt="Residential Architecture" /></td>
<td><img src="image4" alt="Cultural Architecture" /></td>
<td><img src="image5" alt="Landscape &amp; Urbanism" /></td>
</tr>
<tr>
<td>Hospitality Architecture</td>
<td>Industrial &amp; Infrastructure</td>
<td>Commercial &amp; Offices</td>
<td>Healthcare Architecture</td>
<td>Religious Architecture</td>
</tr>
<tr>
<td><img src="image6" alt="Hospitality Architecture" /></td>
<td><img src="image7" alt="Industrial &amp; Infrastructure" /></td>
<td><img src="image8" alt="Commercial &amp; Offices" /></td>
<td><img src="image9" alt="Healthcare Architecture" /></td>
<td><img src="image10" alt="Religious Architecture" /></td>
</tr>
<tr>
<td>Sports Architecture</td>
<td>Others</td>
<td>Interior Design</td>
<td>Refurbishment</td>
<td>Mixed Use Architecture</td>
</tr>
<tr>
<td><img src="image11" alt="Sports Architecture" /></td>
<td><img src="image12" alt="Others" /></td>
<td><img src="image13" alt="Interior Design" /></td>
<td><img src="image14" alt="Refurbishment" /></td>
<td><img src="image15" alt="Mixed Use Architecture" /></td>
</tr>
</tbody>
</table>

Same vector, but different typology category
Methodology I: Multi-class StyleGAN

Latent walk, traversing different categories
Methodology I: Multi-class StyleGAN
Methodology I: Multi-class StyleGAN

Projection of high-dimensional space
Methodology I: Multi-class StyleGAN
Methodology I: Multi-class StyleGAN
Methodology I: Multi-class StyleGAN

What was effective
- It can generate diverse variations in the same class.
- It was successful to observe general architectural characteristics in the selected class and by isolating all the factors except for the class, the differences between classes were obvious.

What was lack
- It was hard to interpret the visual characteristics in a way a human can understand as well.
Methodology II: Multimodal StyleGAN+CLIP
Methodology II: Multimodal StyleGAN+CLIP

Background and Problems

Dataset Construction and Exploratory Data Analysis

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Methodology II: Multimodal StyleGAN+CLIP

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Conclusion
Methodology II: Multimodal StyleGAN+CLIP

ArchDaily metadata in web

The main structural order is composed of beams of great expression in the longitudinal and transversal directions...

project description

pair images

ArchDaily Dataset

Text Encoder

Image Encoder

visual-text representation

Text Encoder

Image Encoder

CLIP embedding space

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Methodology II: Multimodal StyleGAN+CLIP
Methodology II: Multimodal StyleGAN+CLIP

\[
\text{Loss} = \arg \min_w \left[ \text{CLIP} (G(w, t)) + \lambda_2 \| w - \hat{w} \|_2^2 + \lambda_{1D} L_{1D}(w) \right]
\]

For manipulation

Cosine distance

Text

Updated latent vector

For similarity to the input image

Original latent vector
Methodology II: Multimodal StyleGAN+CLIP

Pattern | Properties | Weather | Artist
---|---|---|---
Brick elevation | Commercial building | Sunny weather | Picasso
White reflective metal elevation | Old house | Snowy winter | Salvador Dali
Fractal pattern elevation | Highrise building | Rainy weather | Vincent Van Gogh
Methodology II: Multimodal StyleGAN+CLIP

<table>
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<th>Weather</th>
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<td>Highrise building</td>
<td>Rainy weather</td>
<td>Vincent Van Gogh</td>
</tr>
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</table>

Original Image
Methodology II: Multimodal StyleGAN+CLIP

- Ghost house
- Picasso style
- Sunny weather

- High rise building
- Shrubs and trees
- Red brick elevation

- Vertical columns
- Commercial building
- Multi-story building
Methodology II: Multimodal StyleGAN+CLIP

- Ghost house
- Picasso style
- Sunny weather
- High rise building
- Shrubs and trees
- Red brick elevation
- Vertical columns
- Commercial building
- Multi-story building
Methodology II: Multimodal StyleGAN+CLIP

Feature manipulation in StyleGAN latent space

- Height
- Weather
- Material

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Methodology II: Multimodal StyleGAN+CLIP

Feature manipulation in StyleGAN latent space

Height

Material

Weather
Conclusion
Conclusion

• This research urges the architecture discipline to create and curate an architectural-centered dataset to discover and understand insights into it.

• Compared to image-only-based datasets, image-and-text-based datasets can be useful for diverse future research because it has resilient and expandable potential.
Conclusion

• The research created a tool for better understanding unstructured architectural datasets and it is a powerful way to create explicit structure in implicit structure using Neural Networks.

• Training neural network with ‘architecture-centered’ datasets (currently available models such as VQGAN+CLIP, DALL-E-2) is a general-purpose model which can be said ‘under-fitting’ to architecture, but this research proposed ‘over-fitting’ to architecture using ‘architectural encyclopedic dataset’ from ArchDaily, assuming that ArchDaily can be representatives of buildings in the world.