Reflection

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The goal of this thesis was to explore one step in the larger challenge of automating design by researching the opportunities of applying deep learning models to the design of buildings. The resulting deep learning model came from researching and testing various hyperparameters of 3D generative adversarial networks (GAN) to find an architecture that generates building geometry. Through this process, I developed my own improved 3D GAN architecture to stabilize training and provide more consistent results. The final goal was for the trained model to generate building geometry that has features similar to those in the data set.

Graduation Process

How is your graduation topic positioned in the Master of Science in Architecture, Urbanism and Building Sciences program and the Building Technology master track?

The Master of Science in Architecture, Urbanism and Building Sciences focuses on innovation within the fields of architecture and engineering. This relates directly to my thesis topic, as my thesis is looking at innovative approaches to the design process by applying deep learning to an architectural problem. The building technology track focuses on integrating design and technical disciplines. This means the program has a multidisciplinary focus that encourages students to explore topics that connect different fields. I am following this multidisciplinary process by connecting expertise from the design, engineering, and informatics fields through my thesis. My topic requires knowledge that is very specific to the built environment and also requires the use of research from the field of informatics. Combining these two different specialties allows me to explore a topic rooted in design and engineering with a new lens.

What value did your approach and methodology bring to your thesis?

For my methodology, I focused on a review of the literature and exploratory experimentation and testing. Both aspects were valuable and allowed me to maintain a methodical approach while applying an innovative process to an established problem. The literature review allowed me to understand the solutions from existing research and also learn how to identify common problems that may need to be addressed. Initially, I had expected that the 3d GAN architecture on which I based my research would need minimal changes to work with my problem due to similarities between the two topics. However, I soon realized that I would need to make significant changes to this structure to stabilize training with the new data set. Here, the use of an ablation study helped. Through the ablation study, I tested hyperparameters individually and in combination to identify which changes helped stabilize training. This systematic approach allowed me to pin-point key aspects of stable training. These hyperparameters can be used for the problem of generating building geometry but can also be used in future research. This systematic approach also means that the steps I took are well documented so future researchers can learn from the process, not just have a new architecture to use. The report also explains why specific hyperparameters are used so future research can expand upon the process and learn from it.

How did the approach influence your result and what were the strengths, weaknesses, opportunities, and threats of your method?

The method and the research has a number of strengths and weaknesses, also summarized in Figure 1.1. One weakness is that a process of trial and error is required to tune and train models. Through the literature review, I realized that researchers have different opinions on how and why certain hyperparameters work. Therefore, when developing the architecture of improved 3D GANs, I needed to try different hyperparameters and set up new experiments based on the previous results. Another challenge of using deep learning models is that the model discovers the characteristics of the data set during training. This means that there is currently no way to fully understand the connection between the training data and the result. Finally, training requires a large data set filled with fairly accurate data, which can be challenging to obtain. There are also a number of strengths to the method. Although an optimal data set was not available during the writing of the thesis, the resulting model can be re-trained once this data becomes available. Because research was done for this specific model, the final data set used for training can vary and can be added to over time. Additionally, this method can be applied to other generative design problems. Future researchers will only need to train on different data sets and tune the hyper-parameters to be able to apply the model to different problems. Finally, through the architecture I developed, I was able to generate buildings in a large geometry space. My thesis is the first research that significantly increases the geometry space (from 64 x 64 x 64 to 160 x 160 x 80). By increasing the geometry space by 2.5 times in each direction, I hope to demonstrate how their application can be useful for building scale.

When considering external factors, there are some opportunities and threats to consider, which are also summarized in Figure 1.1. There are a few threats that we need to be aware of. Data sets related to the architecture, engineering, and construction (AEC) industry are scarce and the limited availability of relevant data sets remains a threat to continuing research. For this thesis, I compromised on the training data because there was not a large enough data set that contained building models of the optimal building typology. In addition, the success of research in this field is based on access to powerful computational resources. Thankfully, TU Delft has the high-performance computing cluster which I was able to use. Without this resource, it would not have been possible to scale up my research. Despite these threats, there are still opportunities. Currently, there is great interest in artifical intelligence and this means that many companies and institutions are collecting data to use to train future models. This means that more data will be available in the future. Additionally, the methodology developed through this thesis is not limited to building technology. The model architecture and the research method can be used as a reference for further research in other disciplines. Finally, automation provides access to design to so many more people. It is an important area of research to continue so that everyone can enjoy well-designed spaces.

What are some moral and ethical issues that need to be considered?

When working with machine learning applications, it is important to consider ethical problems that may be present in the current workflow or future applications. Models trained with human-generated and human-selected data will always have biases. The most important aspect is to recognize this and to check for these biases so that the end result is as fair and equal as possible. One aspect is the data itself. Currently there are not many data sets that contain buildings, and the one I found, I would say, contains stereotypes of specific building typologies based on a western lens. Additionally, the buildings included may be related to specific aesthetics versus what is truly found in specific cities, so buildings belonging to middle- and upper-class individuals or high-end developers are more likely to appear. It is important to continue to grow the data sets to be more inclusive and represent all of the architecture we see around us. Additionally, the labels in the data often reflect societal biases. This is

S	INTERNAL **STRENGTHS**
1	Model can be retrained once more data is available
2	Method can be applied to other problems with different data sets
3	Achieveing higher resolution models than past research shows future promise

W	INTERNAL **WEAKNESSSES**
1	Some trail and error required to tune and train model
2	Not possible to know exactly how the model connects the training data to the result
3	Large data sets are needed for training

O	EXTERNAL **OPPORTUNITIES**
1	Current interest in AI likely means more data in the future
2	Not limited to building technology, can support research in other disciplines
3	Automation brings good design to more people

T	EXTERNAL **THREATS**
1	Limited data set availability
2	Optimal building typology data not available
3	Success depends on access to computational resources

Figure 1.1: A summary of the SWOT analysis of the research approach and method.

why it is critical that data labeling be performed by a large and diverse group of people with different values and belief systems. Even within labeling buildings, labels can have a very specific meaning depending on the region. For example, a porch in the American south is a vernacular architecture feature located in front of the house that is hugely important in the daily social life of people in the region. However, on the east coast of the United States, a porch is frequently located in the back yard and is associated with a more private use for family gatherings and dinner outside. The porch is an example of a similar design feature that has the same name in different regions, but the use, location, and cultural importance vary greatly. Everything we do has nuances, and the best way to ensure that we maintain an ethical approach when applying machine learning is to be aware of our innate biases, check for them, acknowledge them, and correct them when we do realize they exist.

Societal Impact

What is the academic and societal value of your graduation project?

Existing research on deep learning applications within the architecture, engineering, and construction industry has been completed by various private companies, so there is a lack of published information in the area of building design automation. Additionally, research on 3D geometry generation has focused on small geometry spaces and small objects such as chairs. Based on these gaps, I had the goal of generating building geometries and greatly increasing the size of the geometry space. The gaps identified in my literature review present opportunities to expand industry knowledge. By continuing research on how to automate the design process, the industry can provide access to thoughtful design to a wider audience. This thesis helps address this missing knowledge.

The research that was conducted in this thesis also expands the use of the generative design tools that are used today. By discovering more varied applications of deep learning in design, these findings can be incorporated into industry tools such as the software used. In the future, generative design tools could propose more than massing, site layouts, and floors plans. The computer can become the design assistant in the way researchers have been striving. This thesis lays the foundation for the use of deep learning models in generative design tools, so that these tools can propose designs for 3D building geometry. Future researchers can expand on the topic and also explore how GANs and other deep learning models could design not only building geometry but also building systems.

To what extent has the expected innovation been achieved?

This thesis focused on applying an innovative approach to a known design problem. The research focus turned out to be developing a new GAN architecture for generating building geometry in a larger geometry space. I was able to identify a number of hyperparameters, including Wasserstein loss with a gradient penalty, Leakly ReLU, and the RMSProp optimizer that combined into an architecture that produced building geometry. One aspect of the innovation was the combination of hyperparemeters, and another was the large geometry space and working with building geometry. I was able to expand the size of the geometry space increasing from a size of 64 x 64 x 64 to 160 x 160 x 80.

How does your research impact architectural practice?

Despite improvements in software and automation within the field of architecture, little research has been extended to applying deep learning to generative problems. To fill this knowledge gap, I wanted to conduct research on the topic of generating 3D building geometry. The research that has been done on this topic was completed by private companies or is not well documented. The goal of this thesis was to begin to fill the gap in industry knowledge about how to automate the design process through deep learning. By generating building geometry in a large geometry space, this thesis was able to show the potential of GANs. By seeing that GANs can be trained to generate higher-resolution geometry, the industry is hopefully able to recognize the ways in which deep learning models could be incorporated into generative design tools in the future.

How do you assess the value of the transferability of your project results?

One of the strengths of my project is the transferability of the research. The architecture I developed for improved 3D GANs performs well in generating building geometry, but it is also applicable to other generative 3D problems. The model can be re-trained with different data sets depending on the requirement. This applies not only to generative design problems within the AEC industry, other fields can also use the architecture for generative design applications. In addition, the methodology used and the lessons learned by creating this architecture can be applied by other researchers in the future. For example, successful architectures tend to perform well when the network is shallow and narrow, so different hyperparameter combinations can be tested and then scaled up afterwards. Regardless of the industry or the field of study that is interested in deep learning, there is information documented through this thesis that can help others in their development of deep learning models.