Reprogramming Urban Block by Machine Creativity

How to use neural networks as generative tools to design space

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The democratization of design requires balancing all sorts of factors in space design. However, the traditional way to organize spatial relationships cannot deal with such complex design objectives. Can one find another form of creativity rather the human brain to design space? As Margaret Boden mentioned, "computers and creativity make interesting partners with respect to two different projects." This paper addresses whether machine creativity in the form of neural networks could be considered as a powerful generative tool to reprogram urban block in order to meet multi-users' needs. It tested this theory in a specific block model called Agri-tecture, a new architectural form combing farming with the urban built environment. Specifically, the machine empowered by Generative Adversarial Network designed spatial layouts based on learning the existing cases. Nevertheless, since the machine can hardly avoid errors, architects need to intervene and verify the machine's work. Thus, a synergy between human creativity and machine creativity is called for.

Keywords: *machine creativity, Generative Adversarial Network, spatial layout, creativity combination, Agri-tecture*

INTRODUCTION

Space design can be treated as a process of balancing various factors. As different biochemical factors (e.g. humans, plants, sunlight) imply different needs to be taken into consideration, the traditional way of organizing spatial relationships no longer works. A more efficient method to design spatial layouts is required, machine creativity in the form of neural networks can be one of the possible solutions. However, the argument about machine creativity perseveres. This paper supports the view that the machine does have creativity which is different in speed, capacity, and way of thinking compared to human creativity. With the current technology, machines are better to be assistances of human beings to produce work rather than being the chief designers.

The current advancement in convolutional neural networks allows machines to recognize and process images. Subsequently, Generative Adversarial Network (GAN) has further improved machine's ability of image processing: it can simulate and generate spatial data distribution. To apply GAN in space design, designers need to set specific database to train the GAN-based model first. The aim is to empower

it to design spatial layouts independently. Nevertheless, due to a certain amount of inevitable learning bias in the machines' training process, the application of the GAN-based model cannot be separated from human evaluation and control. In this context, architects' roles have been changed from the planner to the media designer and controller, which includes training machines, evaluating the machines' works and selecting the optimal design solution.

To verify the above point of view, this paper includes the practice of GAN-based models in the *Agri-tecture* block design project (a final year project of Yu, DY, Zhao, JYZ, and Sun, ZYS 2019, RC18, Bpro, the Bartlett, UCL). The *Agri-tecture* block is a new type of urban component which pursues agricultural urbanism. Designers built a dynamic system that connects all the tangible and intangible data together to influence the design process, where the trained GAN-based models provided layout solutions for all mixed-used units inside. With the machines' high calculation speeds, when the environmental conditions or the needs of users change, they can respond in real-time by outputting new solutions. In this way, GAN enables the *Agri-tecture* block to be 'reprogrammable', transferring a static physical built environment to an adaptive one. As a speculation, it will increase cities' potential dynamics if GAN is applied to design city blocks in urban planning.

It is certain that the cooperation between human creativity and machine creativity is complementary. The *Agri-tecture* project was also used to demonstrate a method for architects to cooperate with machines, setting up a vital free communication platform. There is no risk that one creativity may threaten the other. On the other hand, creating a suitable communication environment will promote both kinds of creativities. Indeed, the project pointed out that machine creativity aided by human creativity is critical and will reshape the architecture discipline.

NEURAL NETWORK'S OPPORTUNITIES IN SPACE DESIGN

As being mentioned in 'The Creative Mind - Myths and Mechanisms', "creativity is the ability to come up with ideas or artefacts that are new, surprising and valuable... It's not a special 'faculty' but an aspect of human intelligence in general. (Boden 2003)" Everyone is creative and to a different degree. But is creativity the exclusive skill of mankind? Can machines be as creative as human beings? The answer is still controversial. Some people believe that the machine cannot have real creativity as it is a logical system that operates in a rule-constrained manner. To dismiss this view involves understanding creativity. As described above, creativity means new valuable ideas or processes. When ignoring the idea that machines are restricted by the step-by-step logical reasoning systems, creative machines can be treated as a kind of software that inputs to solve complex problems or generate new valuable ideas to original artworks. Being similar to a human artist or scientist, a creative machine begins its work by framing a problem. This paper agrees that machines have creativity but work in a different way compared to the human beings.

Generative Adversarial Network as a mean for machine creativity

Practices in recent years have proven that machine creativity can be used in image processing, such as 'Neural Style Transfer' (a class of software algorithms that manipulate digital images, or videos, to adopt the appearance or visual style of another image). This process can convert any picture into a specific style. For example, converting a common architectural photo into 'The Starry Night's' (Van Gogh 1889) painting style (e.g. figure 1). In the current technological development, the development of convolutional neural networks has advanced the image processing capabilities of machines. Through deep learning, machines are not just capable to recognize or repeat patterns but are also capable to create. A possible scenario would be when architects input a spatial image into the machine, the machine identi-

fies and analyses its content, then tries to generate a similar image. To achieve this, architects need to train the machine using the Generative Adversarial Network (GAN) model type.



Figure 1
Case of Neural Style Transfer based on Neural Network (Gatys Leon 2015).

GAN was firstly invented by Ian Goodfellow and others in 2014 and became widely popular in the music and art domains (Mohit, Rezaul and Pradeep 2018). It is an unsupervised learning based on differentiable generator networks. There are two neural networks models, one for generating and the other for discriminating, which will contest with each other during the calculation (e.g. figure 2).

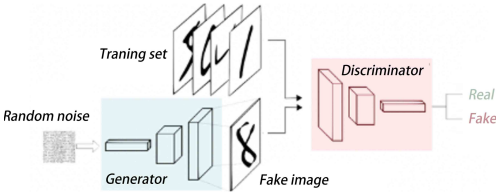


Figure 2
Work Principle of Generative Adversarial Network (Blagojevic Branko 2018).

Stanislas Chaillou and his team demonstrated the possibility of using GAN to aid architecture design. Their thesis, *AI+Architecture, Towards a New Approach* could be summarized into three parts: (1) generated and qualified floor plans through GAN, (2) classified floor plans into different architectural style and analyzed its hidden logic, (3) created a platform where users could 'browse' through generated design options. This series of work did not only further shape machine creativity's potential for architecture, but also provided a well-structured framework for other scholars to explore and develop GAN's applications.

Differences between machine creativity and human creativity

Neither human creativity nor machine creativity is completely random. It can be understood that machine creativity is shaped by human creativity. Compared to human creativity, the advantage of the machine is its high efficiency and strong adaptability to figure out complex problems. On the other hand, human creativity has high sensitivity and is better at dealing with extreme or unpredictable conditions, which makes it irreplaceable.

Stanislas Chaillou suggested that "there will be no agnostic-AI for Architecture". Machines often create a variety of "accidents" through a fixed set of patterns. It is hard to explain what exactly is the "work pattern" inside the machine, but the machine contributes to more and more creative work, such as painting, composition, etc. Nowadays, machines are better at assisting human beings to produce creative work rather than working independently. The machine creativity mentioned above, which converts any photo into the style of Van Gogh's 'The Starry Night' is a good example. In this process, the machine learns to identify a particular artistic style, separates it from the image content and applies this style to other images. This conversion example paves the way for further creative work and artistic style research. Therefore, machine creativity and human creativity have their own unique and irreplaceable roles. Evaluating the differences between them can help architects to achieve the largest synergic effect.

The articulation of the GAN-based model: between generation and discrimination

When using the GAN-based model to design spatial relationships, the spatial layout is treated as a specific form of data distribution. This kind of model uses the feedback loop between its Generator and the Discriminator to improve its ability to generate targeted images, which also refers to the spatial data distributions.

The Generator is trained to create images that are similar to real images from the data set, while the Discriminator aims to recognize images from the data set. When the Generator generates an image, the Discriminator will provide it with feedbacks on the quality of its output. In response, the

Generator adapts to produce a more realistic image. Through this feedback loop, the GAN-based model slowly builds the ability to create similar data distributions between generation and discrimination (Chaillou, 2019). Eventually, the trained GAN-based models are capable to generate multiple similar layout schemes (new similar data distributions) quickly according to the existing spatial layout rules (data distribution samples).

A new way to organize a dynamic spatial relationship: opportunities and challenges

According to the characteristics of GAN, a series of judgments can be made. For example, the trained GAN-based models made it easier and faster to test, expand, and create hundreds of different solutions as options for a concept. Meanwhile, they can deal with much more complex design problems if the design parameters can all be transferred into a readable data. Their speedy computations enable the design results to be dynamic and responsive to the users' needs.

Moreover, the machine can liberate the architect's pursuit of creative work. When the common part of the brain is deactivated, the other part of the brain responsible for creativity will be activated more effectively. Therefore, when machines are handling lots of repetitive work, architects can focus on creative designs and expressions.

Therefore, the challenge architects need to face here is to find an efficient way to cooperate with machines, including but not being limited to how to build a database for machine learning. How can architects efficiently train machines and generate 3D spatial layout solutions? How can architects set the criteria for reviewing machine learning results, and how can architects utilize the trained machine in their practices?

TRAINING AND APPLICATION OF GAN IN AGRI-TECTURE

To verify the above presumptions, GAN-based models were built and tested in a specific design prototype called *Agri-tecture*. *Agri-tecture* was derived from the terms agriculture and architecture, it is a new combination of agriculture and the built environment. It aims to bring food production into otherwise agriculturally overlooked urban areas. From one perspective, *Agri-tecture* can be considered as a new pattern of interaction between plant space and human space. When designing this 'cross space', the designers should not simply consider the needs of the human beings or plants. Instead, designers should place them with all other relevant biochemical intensities (e.g. sunlight, water, soil) on the same platform, let them interact with each other and find the balance of their needs. To create a better-balanced ecosystem for the "users", the *Agri-tecture* block should not be static. It should be a dynamic system that can change when plants, human beings, or the environment changes. Machine learning based on GAN allows *Agri-tecture* to be adaptive.

Training Pix2Pix models to design spatial layouts

There are many algorithm models derived from GAN. Pix2Pix, a model based on GAN, is the most appropriate model for this design thesis. It can transform an image from type A to type B, i.e. a Google plan map to an aerial map (e.g. figure 3). From the technical perspective, Pix2Pix has a similar potential to transform spatial prototype (an initial floor plan) to an organized plan layout. However, the Pix2Pix can only process two-dimensional images currently. As space is a three-dimensional 'material', the ultimate goal in this thesis is to generate three-dimensional spatial layout solutions by machines. To achieve this goal, two specific Pix2Pix models were trained and applied sequentially in the following steps.

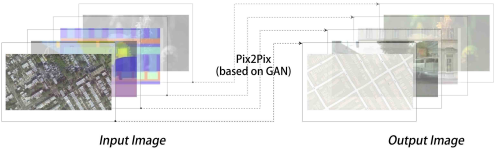


Figure 3
Previous Work of Pix2Pix (Isola Phillip, Zhu Jun-Yan, Zhou Tinghui, Efros A. Alexei 2017).

Figure 4
Examples from the 'Plan to Pattern' Training Database (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)

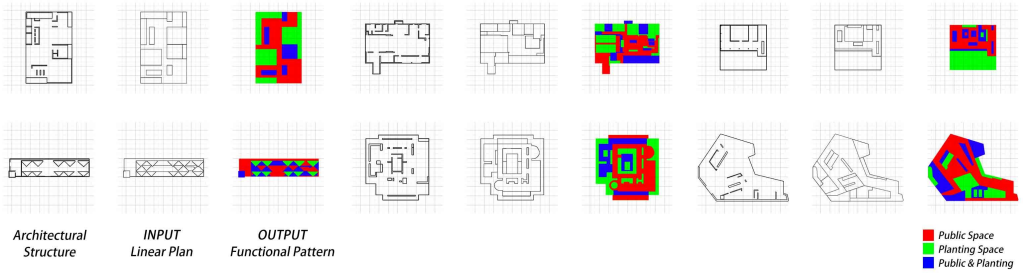
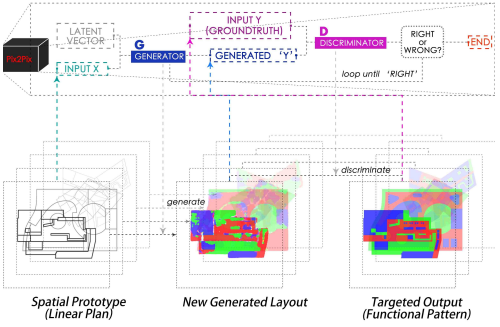


Figure 5
Training Process (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)



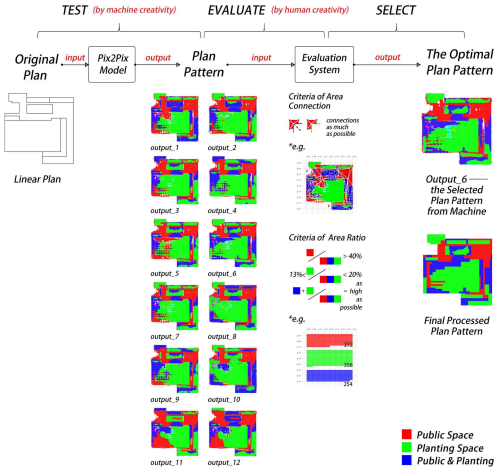
(1) From the prototype to the plan layout: set ' Plan to Pattern' database to train the first Pix2Pix model. Machines can obtain a similar design ability based on learning the existing design cases. So, a large number of agricultural building cases were collected as the source of the database, and their floor plans were processed into a universal spatial 'language' that both human beings and machines can understand. After processing, there were two types of the floor plans in the database: the spatial prototype plan i.e. the linear plan, and the plan layout pattern i.e. the RGB pattern (e.g. figure 4). On the plan layout pattern, the different color blocks indicate different functional partitions.

Designers, then, input the processed images into the first Pix2Pix model. The model, through generation and discrimination, learned how to transfer the prototype floor plans to the plan layout patterns (e.g. figure 5).

(2) Test, evaluate, and select. To test the first model's learning status, designers input another new prototype floor plan. As expected, the model generated a series of plan layout patterns. At this point, it is the architects' job to decide whether the machine's solutions are reasonable and select which solution to further develop. In this case, a specific evaluation system was requested to be built.

In the *Agri-tecture* project, the criteria of space should include but not be limited by accessibility, ecological level, micro-environmental experience, etc. Based on these standards, designers reviewed solutions and selected the optimal one accordingly (e.g. figure 6).

Figure 6
Test of Trained 'Plan to Pattern' Model (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)



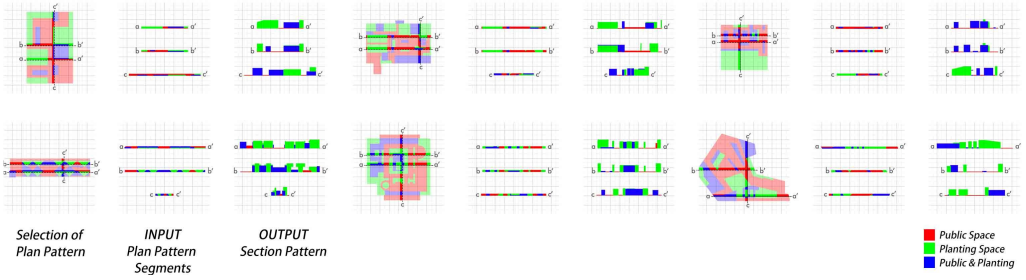


Figure 7
Examples from the 'Plan Pattern to Section Pattern' Training Database (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)

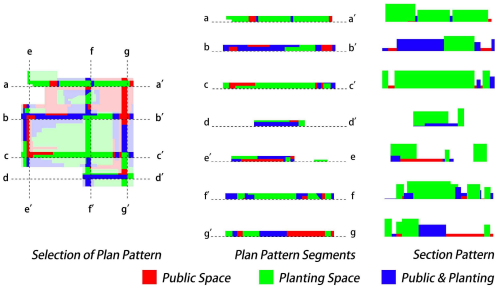


Figure 8
Test of Trained 'Plan Pattern to Section Pattern' Model (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)

(3) From the plan layout to the section layout: set 'Plan Pattern to Section Pattern' database to train the second Pix2Pix model. The plan layouts combined with the section layouts could be the reference to depict three-dimensional space layouts. Therefore, following the same training logic, the second Pix2Pix model was trained with the transformation target from the segment of "plan pattern" to its corresponding "section pattern". Its training database was set on the basis of the first database. Specifically, designers extracted the segments of the plan layout pattern as inputs and drew their corresponding section layout patterns as targets (e.g. figure 7).

After training, the selected floor plan layout pattern from the last step was used to test the second Pix2Pix model. The machine's outputs were also evaluated by designers to ensure the rationality of design (e.g. figure 8).

(4) From the 2D layout to the 3D layout: integrate the plan pattern with section patterns to achieve the corresponding three-dimensional space model (e.g. figure 9). Moreover, this conversion process is controllable. In other words, the detail level of the final three-dimensional layout can be increased or reduced by the amount of the machines' processed two-dimensional layouts. By selecting more plan layouts, more section layouts would be transformed, hence resulting a more detailed three-dimensional space layout.

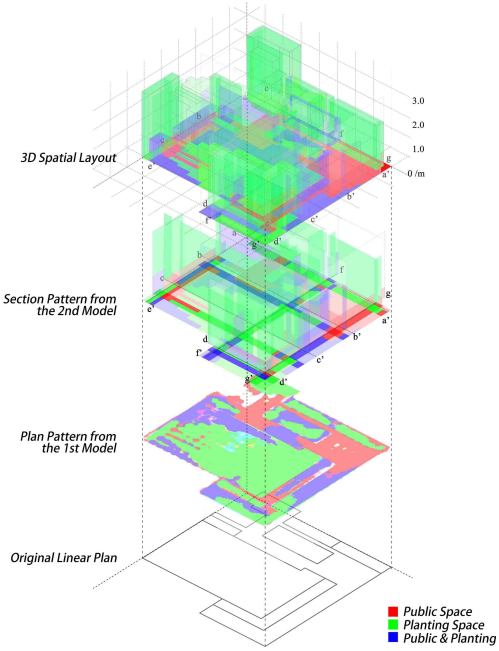


Figure 9
From Floor Plan to 3D Spatial Layout (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)

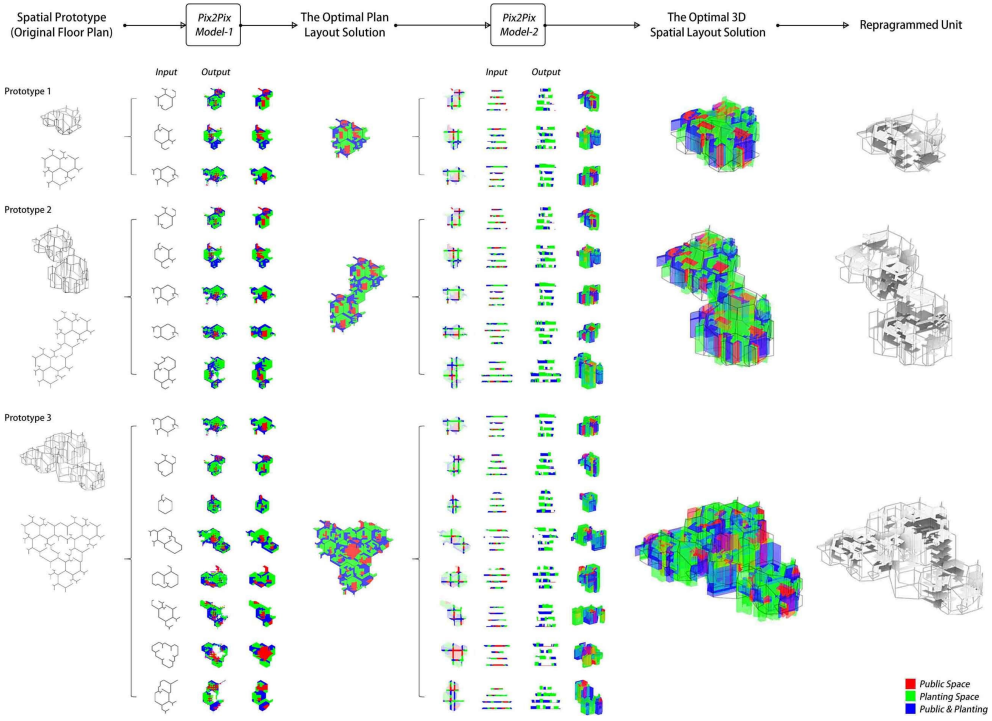


Figure 10
Application of the Trained Pix2Pix Models: Reprogram Inner Space of Agri-tecture Block (Agri-tecture Group, RC18, B-Pro, the Bartlett, UCL 2019)

The trained models' responses to the adaptive system of humans and plants

For general application, the trained models will be used to organize the internal spatial relationship of the *Agri-tecture* block (e.g. figure 10). However, when designing spaces with machines, the evaluation system is not always the same.

Firstly, the spatial criteria are different for different functional spaces. The *Agri-tecture* block's internal spaces are extracted and divided into various categories, such as 'plant-dominated space' and 'public-activity-oriented space', etc. Referring to the criteria of a good environment, designers set different design objectives and standards for each category. They then input the space prototype plans into the trained models and select the corresponding optimal layout schemes according to their objectives.

Secondly, the spatial criteria will change in changing circumstances. For example, during people's spare time, the number of people being active in *Agri-tecture* will increase, and more space should be used for public activities. In this scenario, the design objectives of particular spaces need to be changed, the proportion of public activity spaces will increase, and the machine-generated layout scheme will be re-selected according to this change.

Through evaluation, multi-users, the environment, various spaces, architects, and machines were connected in a dynamic system. Architects and machines could read and share real-time information. In other words, the parametric in the block, whether it is tangible or not, was transferred into the unified language affecting the design results. The obtained spatial layout was a response to the pursuit of a better-balanced environment.

Spatial qualities derived from GAN-based model

However, there's one question remaining: can architects acquire the best layout solution from the machine? With the current status of technology, the answer is no and here are the reasons. Firstly, a GAN-based algorithm model can only generate data distribution close to its learning target. To improve the accuracy of training, it is necessary to precisely control the parameters within the algorithm during training. Secondly, the "design capability" of the model is limited by the training database. Even if the learning bias generated during training could be ignored, the design capabilities acquired by the machine are still limited by the content of the training database. If more cases were used for training and the more plans were accurately drawn, the machines become more reliable.

Therefore, the level of machine creativity is as limited as that of human creativity, this depends on their learning conditions. The final solution selected through evaluation is relatively optimal under existing capabilities. If the architects blindly rely on the results given by the machines to design, he or she may fall into a utopian dilemma: on the surface, the pursuit of the democratic and objective design process is realized, while actually, the design is manipulated entirely by machines.

A CRITICAL ANALYSIS OF THE SYNERGY BETWEEN CREATIVITIES

A framework was built using the GAN-based model where human beings and machines contributed together. Human beings set up a specific machine learning database to train the model. The trained machine was responsible for analyzing and providing layout solutions for a new space. Meanwhile, human beings developed evaluation criteria to identify and select solutions, and integrated the optimal results obtained by the machine. In this process, machine creativity, being complemented by human creativity, drove the design relationships to generate a more positive outcome. The architecture discipline is going to be reshaped through this development.

Setting communications: complementary creativities

The application of GAN-based models in the *Agritecture* provides a platform for discussion, inviting architects to work with machines. It pointed out that in order to maintain this new partnership of creativities, a free and unobstructed communication platform between human creativity and machine creativity is critical. This free communication can be summarized into three main points. Firstly, the communication should be built on a common language, which means that architects and machines can read each other's work. For example, in the previous layout design process, patterns of different stages were drawn in a corresponded and unified way. Therefore, the abstract three-dimensional space was converted into a readable data distribution. This process sets the language mode of communication to lay out a solid foundation for free communication.

Secondly, the outputs of the creative combinatory process are not single-threaded, but cyclic. The outputs of machine creativity and the results of human creativity will be treated separately as each other's inputs, which accepts detecting and revising, then finally being output in a dynamic mode. This "re-input" behavior is a work mode of communication that increases the constraints of the two creativities. Instead of limiting creativities, these constraints will improve their accuracy degrees. In the design practices, the results of the machine creativity were input into the review mechanism set by the architects, the data was evaluated, and the final selected results were input into the machine again after operating to ensure they are valid in real-time. By detecting each other, human beings and machines eliminated extreme or obviously erroneous calculations.

Thirdly, effective communication between human beings and machines helped to deal with the basic risks that the machine induced. Still, there is a fear that "artificial intelligence is a fundamental risk

to the existence of human civilization" (Elon Musk 2017). While in fact, through communication, the machine's power is supervised and it is the architect who controls the overall development of the design.

Opportunities and limitations in the use of GAN-based model and its combinatory outputs

It is also worth noting that the GAN model carried its specific style, which can be treated as its own personality. For example, when training the GAN-based model for the *Agri-tecture* block, the selected teaching database consisted of architectural cases related to *Agri-tecture*. This process can be treated as encapsulating the existing *Agri-tecture* style in the well-trained GAN-based model. This style will shape the personality of this machine and contribute to the further design processes.

As the GAN-based model targeting *Agri-tecture* can be trained, similarly, one can train other targeted GAN-based models with different architectural styles. In the *AI+Architecture, Towards a New Approach* thesis (Stanislas Chaillou, 2019), the design team trained and tuned an array of models on specific styles: Baroque, Row House, Victorian Suburban House, & Manhattan Unit (e.g. figure 11). The team then used the styles to build apartment units. Each style processed space in a different way, which is both a process of design generation and architectural translation. It can also help architects to identify the spatial patterns of each style and evaluate their capabilities and shortcomings. As Stanislas Chaillou said, "style is not an ancillary, superficial or decorative addendum. Style is at the core of the composition." This GAN-based model can be treated as a design assistant with a unique personality and targeted technology. It can also be used to imitate some underlying building rules as a new way to study architectural forms.



Figure 11
Floor Plans with Different Architectural Styles (Chaillou Stanislas 2019).

However, it is inevitable that this inherited style also limits the effect of the GAN-based model. One GAN-based model is not omnipotent, as its design ability is limited by its training conditions. In other words, different GAN-based models are better at dealing with different design problems. If an *Agri-tecture* style GAN-based model is used for residential unit design, the validity of its output would be compromised. This constraint further supports the necessity to combine efforts of different creativities. Architects should be able to understand the advantages and disadvantages of each GAN-based model, the potential and shortcomings of its storage style, and select the most suitable GAN-based model to solve specific design problems.

The ultimate meaning of the creativities' synergy in the urban realm

Cities can be considered as a collection of construction environments. Nowadays, rapidly growing populations and needs, together with limited resources require cities to become more flexible. Since GAN-based models can help the *Agri-tecture* block organize spatial relationships, can it also have similar effects for other urban components? Assuming the same for office blocks in the city, one adopts the same method to establish an office space-related database for model training, can it produce a new type of office space organization? These are important questions for urban planning and development. This could lead to a new way to reshape the city, which changes the city from a fixed physical environment to an adaptive environment.

CONCLUSION

An era of computing is coming, when computational technologies empower one's understanding of various intelligence. By studying the definitions, characteristics, and capabilities of human creativity and machine creativity, hence combining them into the design project, this paper demonstrated that machine creativity aided by human creativity is full of potentials and promises.

The above design thesis suggested conceptually that the synergy between machine creativity and human creativity would work better than solely individual creativity. This kind of synergy is capable to handle more complex design tasks, incorporating more variables into design considerations, and promoting design relationships to be more democratic. To support this synergy, the paper suggested to create a better communication platform for creativities, where they can communicate in a unified language, while being able to review and set limits for each other. This type of review and limitation is not intended to constrain the development of creativities, but to regulate their work more accurately. It strengthens the 'humanization' of machine creativity and helps architects to better express their creativity.

In addition, the GAN-based model suggested that machines are not unconscious and totally random. Each computing machine internally stores a set of rules during its training, which can be understood as the style of a GAN-based model. This style will affect the results of machine creativity and bring personality to it. Therefore, architects can train targeted machines for specific architectural style requirements. Furthermore, architects can study architectural styles through the results generated from the machine. Through synergy, machines are now teaching human beings in a different way.

Similarly, machine creativity aided by human creativity can be applied to the urban context in addressing different wider architectural needs. This could be achieved by improving the programmability of a single urban block to enhance the city's overall ability in tackling complex ecological relationships. This does not mean that it will become a new absolute dogma in the field of architecture but instead will bring possibilities to urban planning.

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