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Generating and Evaluating City Building Facades Using Artificial Intelligence

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Abstract: The present study examines the various methods involved in the generation of city building facades. Elements of the entire process are explored – from obtaining the necessary information to using it to create a harmonious urban environment. The methods considered – the recognition and generation of facade elements, the generation of as-built Building Information Model (BIM) and Digital Twins of buildings (DT) – are evaluated against the needs of the generation, as well as what their place is in the foreseeable future development of architecture in the metaverse. The purpose of the study is to present the best practices in the field depending on the needs of the model and to show their practical application. An example is given of using drone imagery to assess the predominant coloration of facades with a view to generating examples harmonious with surrounding buildings. The example uses the scripting language python and different libraries to evaluate the image information and presents the results as a figure displaying the three predominant colors of the given image.

Keywords: Architecture, Artificial, Building, Facade, Metaverse

Introduction

The methods of implementation of artificial intelligence (AI) in architecture are increasing day by day with the development of these technologies – from the generation of floorplans (Inceoğlu et al., 2020; Rahbar et al., 2019), through generative volumetric-spatial models (As et al., 2018; Castro Pena et al., 2021), automation of the technical workflow (Daele et al., 2021). This paper concentrates on the application of AI in a narrower but potentially very important area of architectural models, namely the architectural building facade. Methods for generating facades from an existing model/drawing, as well as those for retrieving information from existing buildings, will be considered. The benefits of these methodologies are related to the processes that the architecture goes through to reach from CAD two-dimensional drawings, through a BIM model, to the creation of DT of buildings. In the research each of the already mentioned methods is going to be concerned as to establish and evaluate its advantages or disadvantages.

Study

There are four main sections in the study which allow to specify the examines. Beginning with the methods concerning facade generation in the early design stages, the study then pays attention on the recognition of particular elements on the facades. Continuing with the generation of facade elements as the third section of this very study, it is also essential to put a stress on the generation of as-built BIM and DT.

Facade Design

The generation of architectural design using the means of the computer software has taken over many of the young specialists in the field of architecture. The possibilities of creating many different options for design in as

little time and more complex forms are the main advantages of this approach. The potential of the software design possibilities could be seen as early as year 1991 (Roller, 1991). An example can be shown in the Grasshopper 3D environment with an experiment on different types of algorithmic approach. The parametric set of constraints of that time (using distance parameters for example) is replaced with an evolutionary optimization one (as BioMorpher generative design plug-in) in the present day. (Figure1)

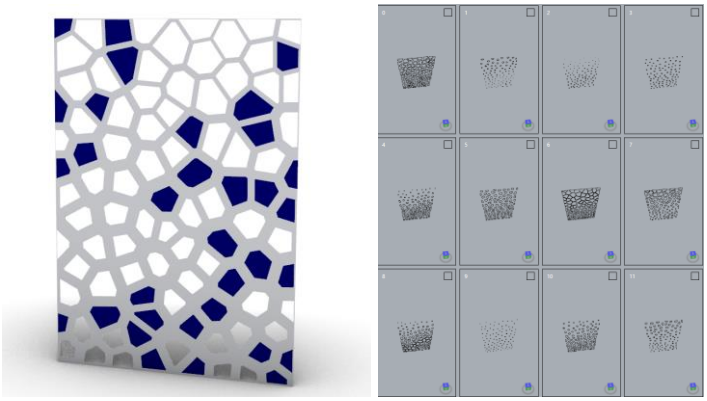

Figure 1. Facade conceptual design

The process, though, should be considered as part of the building design (Wang et al., 2022) – the connection between the building volume, style and other design characteristics is too close. In the early stages of the design is possible to integrate Machine Learning solutions for facade optimization such as solar radiation (El-Mowafy et al., 2022) and other energy simulations (Sebestyen & Tyc, 2020). However, the main goal is to connect all these methodologies in the context of the metaverse – the creation of DT of the buildings. This is possible through simulations already at the design level with smart buildings in mind and setting these goals in the design (Almusaed & Yitmen, 2023).

Facade Elements Recognition

There are many methods for facade recognition, depending on the needs of the specialist. Material recognition can help the possible reuse of the facade elements, pattern recognition can help the design of similar facades and the information gathered from the facades can be of use in the implementation of augmented reality tools.

The main elements of the facade used in these recognitions are the openings – windows, doors, empty openings as arcs etc. The second group of elements are the plinth and the cornice – the main elements which frame the facade at the bottom and the top. Using them, the main proportions of the facade are depicted and also with the pattern of the openings create a proportional mesh, which is unique for almost every city building facade. The third group of the elements which can be easily automated as recognition element are the alternating design elements.

The image recognition is very useful in the creation of city facades in multiple aspects. On one hand, after recognizing the surrounding urban environment one can design a corresponding building with harmonic volume and facades and on the other – a huge database can be created and used for multiple design tasks as combining different city designs and exploring many possible variations in as little time as allowed by the technology, for example.

The main means for this recognition are the use of Convolutional neural networks (CNNs) and Generative Adversarial Networks (GANs). This doesn't exclude the use of other methods, the use of machine learning, etc. A good example is the use of Markov chain Monte Carlo (MCMC) and its implementation in the window recognition (Tyleček & Šára, 2011).

The use of AI, however, has a promising future in the aspect of speed and accuracy. CNNs, for example, are recognized as a good method for multiple object recognition with relatively high efficiency and precision. (Figure2) They consist of three main types of layers – Convolutional layer, Pooling layer and Fully-connected (FC) layer. Each of these layers has its unique function contributing to the high functionality of the network. Namely, the main layer is the convolutional layer, which works as the feature detector which creates a map of characteristics which are then down sampled in the pooling layer and the FC layer then creates a classification

of the searched characteristics in the input of the CNN. That makes the CNNs easily recognizable as method and open to precision (Deng et al., 2023).

The other main NNs for image recognition are the GANs. (Figure2) These neural networks combine the basic CNN structure with logic based on so-called generator and discriminator algorithms which serve the following roles – the generator generates an image which is then used as an input along with a real-world example of the same image and the discriminator classifies the images as real or fake. The process continues until the generated image cannot be distinguished from a real one. The GANs are gaining more and more popularity due to their good results in the field. Their main advantage is the ability to "self-correct", which is why they generate similar to real data. Accordingly, they can, referring to real data, generate images indistinguishable from them. They combine well both image recognition and image generation and are becoming more and more sophisticated in the latter.

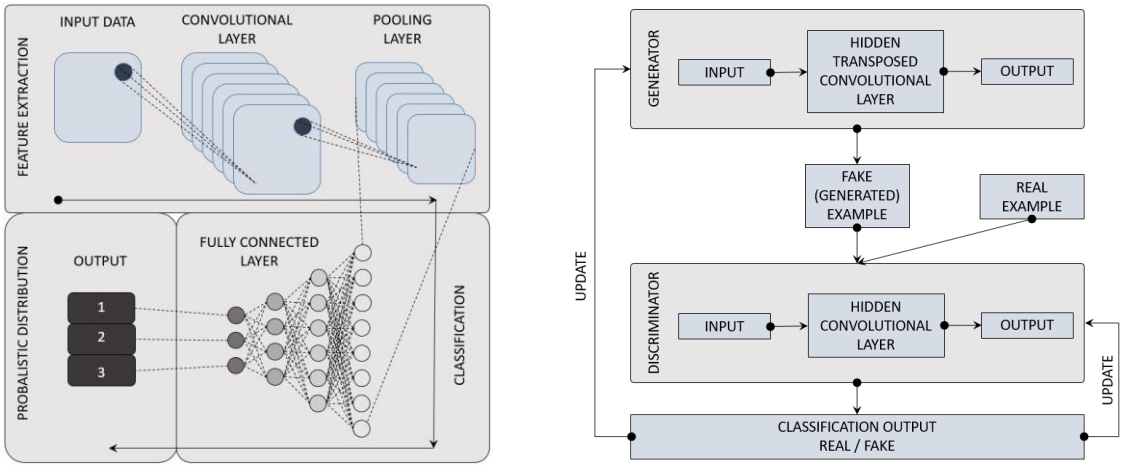

Figure 2. CNN architecture (left) and GANs workflow (right)

Facade Elements Generation

The generation of facade elements is very useful tool based on the NNs discussed in part B. In the given example (Figure3) a conditional GAN is being used. (*Image-to-Image Demo - Affine Layer*, n.d.) This pix2pix software generates an undistinguishable from real images based on an input from the user. The facade is created using modular input. The modules are represented as colorful fields in which the different color represents a different facade element. The output is not always a full image and has many disadvantages. Generating images in a certain architectural style, for example, as well as using a certain element design would be a field for future development, but could be achieved with a significantly larger input database for the neural network. However, this software example shows the base this NNs lay and the rich opportunities for development in the field. With the upgrade of this methods they can be used in the architectural profession, as well in other fields and also in the technical support of the urban environment (Zhang et al., 2022).

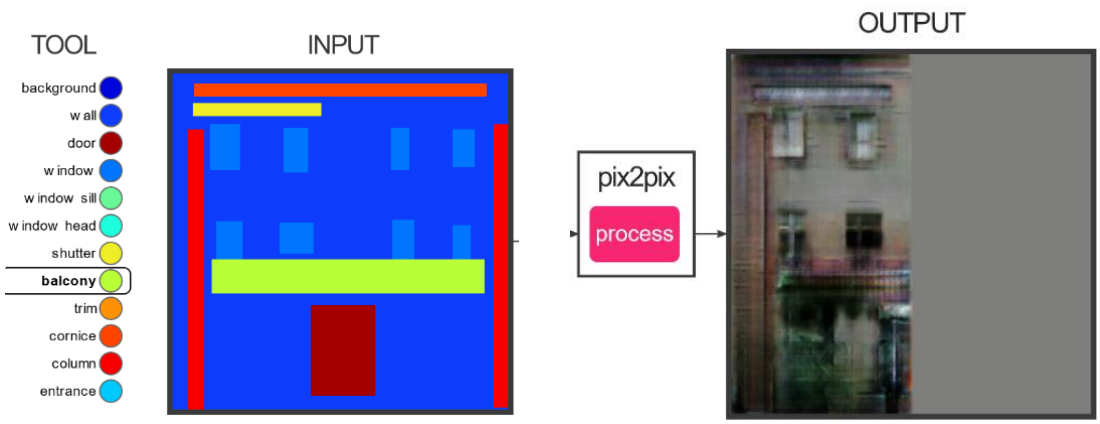

Figure 3. Facade creation based on elements

As-built BIM

The building information modelling (BIM) is developing at a rapid pace. This organization of the construction process supports both cost reduction during the design and construction of the buildings, as well as their long-term maintenance. It is far easier to create such an organization along with designing new buildings than for existing ones. This makes any technology aiding the process concerning the existing building stock very valuable. Such are the technologies that create as-built BIM based on laser scanning of the buildings.

The generation of an as-built BIM has many advantages. It can accompany the preservation of immovable cultural heritage (Jiang et al., 2022), can optimize the consumption of existing buildings and can be used as a basis for reconstruction and bonding with newly constructed buildings or parts of them. The information needed for the generation of a model like that can be used at the same time to detect particular details as facade materials, for example.

The models are created based on photogrammetry using laser and image databases collected from the existing buildings. The technology used creates point clouds which then can be imported into a BIM software (ArchiCAD or Revit, for example) and used to model a digital copy of the building. This method of digitalization of the buildings and their parameters is not yet fully developed so there is a good opportunity for new technological approaches – as the design of a parametric facade template which can be modified based on the collected data from the scans (Dore & Murphy, 2014).

As well as as-designed BIM, the as-built BIM can be used for the creation of DT of the buildings. The creation of DT is an important part of the information field linking the existing and future building stock through the internet of things (IoT). This technology allows the use of sensors monitoring various building parameters in real time and their digitization on a model of the building. Thanks to this, important decisions can be made in a short time and foresee future changes and timely overcoming of deepening problems invisible to the naked eye. This is important both for convenience and for optimizing building maintenance costs. Also, using the IoT, a stable connection between real buildings and the metaverse can be created. (Figure4)

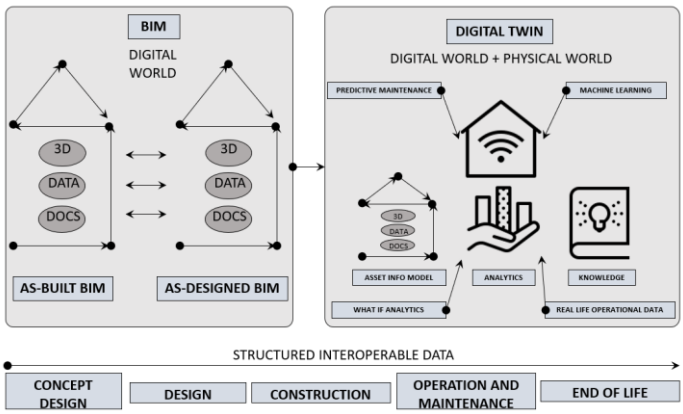

Figure 4. DT of buildings

The main advantage of this methodology and the full usage of the contemporary technologies is the use of structured data which allows the use of its full potential and its easy processing depending on the current needs.

Implementation

The design, recognition and model generation of building facades can be used in all levels of urban development. It can be a part of the foreseeable future processes regarding a block or a city as well as the optimization of the existing stock. The facade is the building element that determines the basic vision of the buildings and their perception by passers-by, which defines it as the main element in the construction of the architectural vision of the spaces. Modern technologies allow all kinds of problems that have arisen in the past, as well as should arise in the future, to be solved on a digital level.

One of these problems is the evaluation of the main colors on the facade. A study is made using image processing techniques. The following steps have been conducted:

1) High resolution drone photos of city facades have been captured. Main attention is paid to the uniform distribution of illumination on the facades in order to reflect correct color information. (Figure5)

Figure 5. Facade image example

2) The drone photos have been loaded into a programming environment (Python) with image processing library (OpenCV). The used libraries have been cv2, numpy, matplotlib.pyplot, os and KMeans from Scikit-Learn.
3) A region of interest (ROI) – specific sections of the facade or the whole building – can be defined. The ROI in the example is defined as the image.
4) The ROIs can be converted from RGB (red, green, blue) color space to HSV (hue, saturation, value), which separates color information (hue) from intensity (value) and saturation. In the example a RGB conversion has been used. A function to perform color analysis on a single image has been defined, which converts color information and reshapes the image into a list of RGB pixels.
5) Color histograms are calculated to represent the frequency of each color in the image. The histograms can be analyzed to obtain various statistics – dominant colors (the one used in the example), color distribution, color proportions, color trends. In the same function K-Means has been applied to identify dominant colors. The n_init parameter (the number of times the k-means algorithm is run with different centroid seeds) (*Sklearn.Cluster.KMeans*, n.d.).
6) The defined function is used for the processing of a single image. Therefore, a specific directory has been chosen and all images in the directory have been listed. A list has been initialized to store the results from the function used on these images. Each image has been analyzed.
7) The color information has been visualized for all of the images (Figure6).

Figure 6. Results visualization – dominant colors

Conclusion

The usage of AI in the field of architecture is rising and so is it in the field of city building facades. Facade generation methods contribute to the development of the architectural profession and the changing demands on

architects today. With the introduction of technologies, it is increasingly necessary for every specialist to be well-versed in the possibilities of AI and to make the most of the opportunities it provides. Each methodology has its advantages and disadvantages and, knowing them in greater detail, specialists will be able to develop together with the technologies, as well as create continuity between their environment and the metaverse.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

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