Neural Computing and Applications
https://doi.org/10.1007/s00521-023-09395-y

ORIGINAL ARTICLE

Use of artificial neural networks in architecture: determining the architectural style of a building with a convolutional neural networks

Ece Cantemir[1] · Ozlem Kandemir[2]

Received: 5 May 2023 / Accepted: 13 December 2023

Abstract
The discussion of "can machines think?" which started with the invention of the modern computer, brought along the question of "can machines design?" by researchers in the design field. These developments in information technologies have also affected the architecture. Artificial intelligence applications are encountered in many areas such as pricing estimation, energy conservation security systems of buildings, ventilation systems, user-oriented interactive design solutions, computer-aided programs used in the plan production phase and design process. When the literature on artificial intelligence applications in the architecture is reviewed, it can be seen that it generally includes shape grammars, graph theory, decision trees, constraint-based models, machine learning methods, RNN (Recursive Neural Networks), CNN (Convolutional Neural Network) and GAN (Generative Adversarial Network) algorithms. In this study, the use of artificial intelligence algorithms in architecture was examined, and an example was designed to determine the architectural structures of different periods by using CNN (Convolutional Neural Network). In the study, the open source TensorFlow library developed by Google and the Python programming language were used. Employing a statistical approach and utilizing convolutional neural networks (CNNs), a study has successfully classified the current flow patterns of buildings based on datasets comprising facades of Gothic, Modern, and Deconstructivist architectural styles. The findings demonstrate the efficacy of CNNs in accurately distinguishing the intricate details of diverse architectural styles. Recognizing elements from different periods using the CNN algorithm can examine not only individual buildings but also the relationship of buildings with their environments. It can also gain an important place in the field of conservation of the architectural discipline. The historical processes, aesthetic features and changes of protected buildings can be learned with the CNN algorithm and can guide restoration decisions. As a result of the study, the employed CNN-based model can correctly classify structures with 84.66% accuracy rate.

Keywords Artificial intelligence · Architecture · TensorFlow · CNN

1 Introduction

The concept of artificial intelligence emerged while seeking an answer to the question "can computers think?" and started to develop after the 1950s. Artificial intelligence can be briefly explained as making the intellectual activities performed by humans autonomous [1]. Tracing the seminal advancements in the field of artificial intelligence, one cannot overlook the groundbreaking article titled "Computing Machinery and Intelligence" by Alan Turing, published in 1950. This seminal work marked the inception of a pivotal discourse on the question of machine sentience. With the Turing Test that mentioned in the article, he could

✉ Ece Cantemir
ecantemir@gelisim.edu.tr

Ozlem Kandemir
ozlemkandemir@eskisehir.edu.tr

1 Interior Design Program, Istanbul Gelisim University, Istanbul, Turkey

2 Department of Architecture, Eskisehir Technical University, Eskisehir, Turkey

Published online: 19 January 2024

manage to distinguish whether a machine is intelligent or not as a result of the interaction of the machine with the human. If a user cannot distinguish whether the machine they interact with is a human or a machine, the machine encountered as intelligent [2]. In 1956, John McCarthy, the father of artificial intelligence, organized the "Dartmouth Conference" on this subject [3]. In 1959, Arthur Samuel made a checkers game that could work on the computer, learns from its own mistakes and improve itself [4]. In 1989, Yann LeCun developed a system that recognizes handwritten numbers using convolutional neural networks. This system, called LeNet, enabled the US postal service to automatically read postal codes from envelopes [5]. In 2006, Geoffrey Hinton seminal work introduced the concept of deep learning, providing a comprehensive framework for understanding the capabilities and potential of multi-layered neural networks [6].

Machine learning, a sub-branch of artificial intelligence has been defined by Arthur Samuel as giving the computers the ability to learn [4]. Machine learning is the process of imparting information to a machine. Large amounts of data are required for machine learning algorithms to perform train and test phases. The algoirthm is taught through training examples and then used to draw valid conclusions for new data. After training, test cases are used to validate the model. There are two types of machine learning methodologies: supervised and unsupervised learning. The process in which an auditor supervises the learning process is known as supervised learning. Neural networks, decision trees, Bayesian networks, support vector machines, identification distributions, k-nearest neighbors, hidden Markov models, and other supervised learning approaches are supervised learning alghoritms [7]. Machines, which learn the relationship between the inputs and outputs of events by examples, make decisions or solve problems by interpreting similar events with the help of the learned information [8]. As can also be seen in Fig. 1, deep learning, which is a sub-branch of machine learning, obtains more useful displays while processing data in successive layers. Deep learning models consist of tens or even hundreds of layers. However, machine learning algorithms are shallower which usually consist of one or two layers [1].

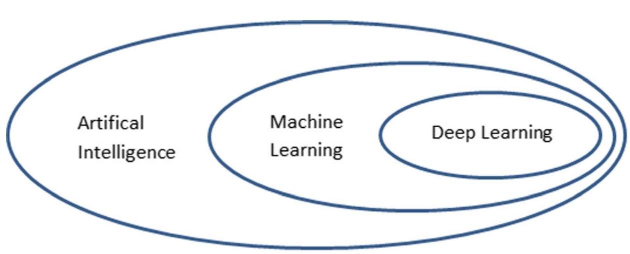

Fig. 1 The relationship between artificial intelligence, machine learning and deep learning

Deep learning studies have become a research topic in many disciplines. Figure 2 shows the images obtained using convolutional neural networks, which is a method of deep learning. In the study, Van Gogh's painting style was transferred to photographs [9].

Convolutional neural networks are neural networks which process data with grid-like topology. A "convolutional neural network" uses mathematical operations called convolution [5] instead of matrix multiplication in at least one of their layers [10]. Thanks to its success in learning, convolutional neural networks are quite common in classification problems. In the mango classification problem conducted in 2020, the model trained with a dataset of 1200 images, provided 100% accuracy [11]. The model with a data set of 15,000 images used to distinguish 15 different handwritten Chinese numbers in 2021 achieved 97% success [12]. Extensive research in the field of deep learning has demonstrated that convolutional neural networks (CNNs) outperform other deep learning architectures in terms of speed and accuracy for object classification and detection tasks. Consequently, CNNs were chosen as the preferred methodology for the application phase [13]. Additionaly CNNs contain many layers and parameters. Notably, CNNs exhibit remarkable efficiency in achieving high performance even with a reduced set of parameters and limited training data.

When the model is integrated into the production environment, there may be a risk of overfitting or underfitting, but there is also the possibility that the model will perform successfully. The responsibility of the developer is to constantly monitor the model predictions and compare these with actual results. If data quality is poor, the model may exhibit overfitting or underfitting [14]. In this context, the study carried out an example design using CNN-based application in order to accurately reveal the details of different periods in architectural structures. However, the responsibility for continuous monitoring and evaluation of the maintenance of the model falls on the developer. If the model performs overfitting or underfitting, it is possible for it to be retrained by the developer, which will subject the model to extensive checks on its maintenance, including its training and testing.

To summarize, the objectives of this study are:

- Recognizing Architectural Structures: The study focuses on recognizing architectural structures from different architectural periods using CNN algorithms.
- Examining the Effectiveness of Algorithms: To assess the efficacy of the proposed algorithm, developed utilizing the open-source TensorFlow library created by Google and the Python programming language, in classifying architectural structures.

Fig. 2 Photographing Van Gogh's style [9]

- Examining Potential of Artificial Intelligence Applications: This study aims to reveal the potential of artificial intelligence applications in architectural design and conservation processes.

2 Literature review of machine learning and deep learning in architecture

The developments in artificial intelligence have also affected the architecture discipline. These developments can cause to using artificial intelligence-based models in areas such as design, construction and management. Artificial intelligence technologies are encountered in many areas such as pricing estimation, energy conservation security systems of buildings, ventilation systems, user-oriented interactive design solutions, computer-aided programs used in the design process. When the studies with artificial intelligence in architecture are examined, it is observed that AI-based approches mostly used in interactive facade designing to protect energy efficiency such as natural ventilation and lighting, and is also used in architectural plan production. Ruiz-Montiel et al. [15] aimed to develop an algorithm for plan design by using artificial neural networks. In the study, by using the penalty-reward method, error values were reduced and the production of plans suitable for construction was observed Yıldız and Aktaş analysed environmental data of a building and proposed a façade model with fuzzy logic algorithm, and applied the results to design process [16]. Imdat et al. aimed to determine spatial relationships in floor plans by using GAN (Generative Adversarial Networks) and developed a model to determine the relationships between the spaces in 15 villa plans [17]. Figure 3 shows the graphs created using the GAN algorithm.

Huang and Zheng carried out floor plan design with GAN (Generative Adversarial Networks) [18]. Kayış [19] generated data with Autodesk Revit and Dynamo programs produced a site plan using Convolutional Neural Networks. As a result of the study, it was seen that it is possible to establish models that provide appropriate answers to the design problem with artificial neural networks. Figure 4 includes randomly selected examples from the plot data set consisting of 168,000 images expressing sample environmental data.

Newton also used GANs and a data set containing 1000 images. The results of [20] can be seen in Fig. 5.

Employing a deep convolutional neural network, Yoshimura et al. [21] successfully classified the architectural works of 34 distinct architects with an accuracy of 73%. Figure 6 shows the result of classification of Porto Architecture School by Alvaro Siza.

Uzun [22] examined plan production using the GAN algorithm. As a result of the study, it was seen that plan scheme production was carried out formally, not functional. The application of artificial neural networks in facade design has mostly congregated around facade generation and classification. Yu et al. investigated the use of GANs for facade design [23].

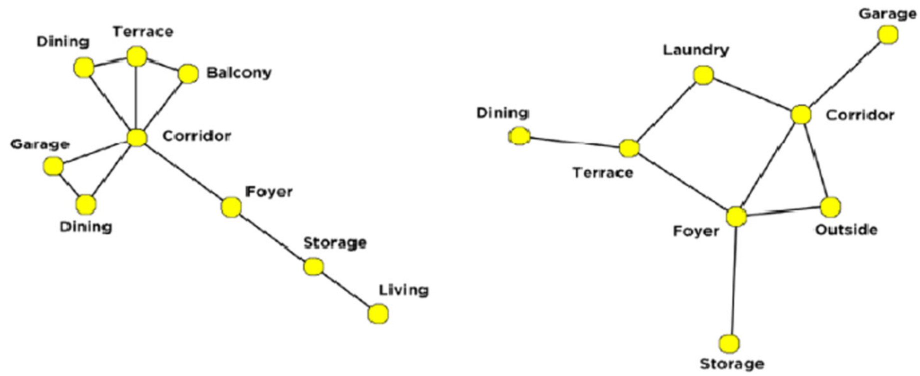

Fig. 3 Subgraphs created through GAN [17]

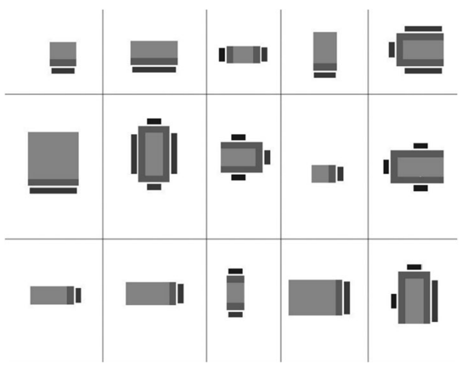

Fig. 4 Randomly selected examples from the plot dataset consisting of 168,000 images expressing sample environmental data [19]

Table 1 summarizes the past studies that have used artificial intelligence methods in architectural facade design and facade classification. As can be seen from the table, which summarizes the studies mentioned above chronologically, there is a wide range of research that can be done in the field of architecture and artificial intelligence.

It can be seen that studies conducted in recent years have been focusing on deep learning algorithms such as GANs and ANNs. This indicates how superior these methods are to other algorithms in the development of both design and prediction models. With the complexity of models and the expansion of data sets, it is clear that the use of artificial intelligence in the field of architecture will become widespread.

The literature examined in the articles shows that the CNN algorithm is successful, especially in architectural facade classification. The following examples are just a few that support this success.

Llamas et al. aims to classify 10 different architectural elements using the object recognition method on various structures of the architectural heritage, especially churches and religious temples. The study, conducted on a dataset created from 10,235 images, was tested with CNN architectures at different pixel sizes, and the best result was obtained in the ResNet network with an average prediction accuracy of 0.93. This study aims to provide infrastructure for future studies and to show that object recognition methods are effective in classifying architectural elements by creating the 'Architectural Heritage Elements Dataset', an open source dataset that can be used to classify architectural elements [24]. Kong and Fan [25] aims to process of separating facades in particular is a fundamental step

Fig. 5 Facade design created by David Newton [20] from the gothic data set using contentious generative networks

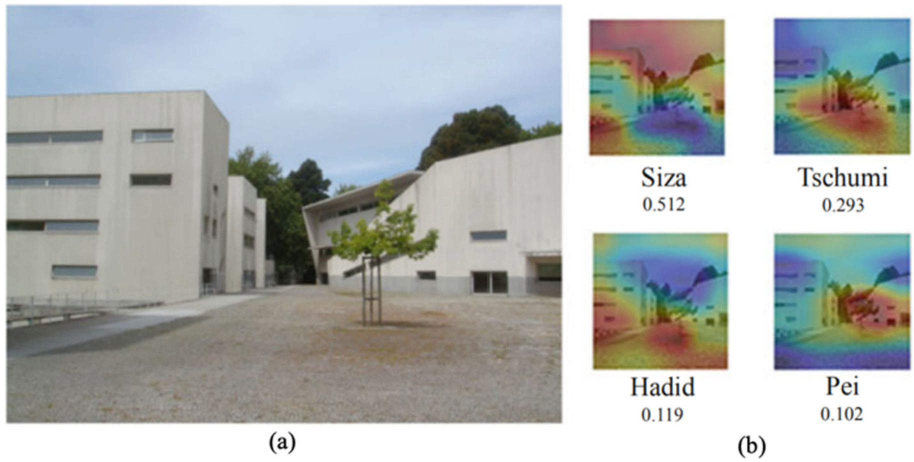

Fig. 6 Alvaro Siza's Porto school of architecture (**a**) and the classification predictions (**b**) [21]

before creating 3D digital or virtual city models. By addressing the limitations of traditional information-based methods and pixel-based decomposition methods that work with less information, a large street level dataset for general scenes was created and a new method combining pixel-based decomposition with global object detection was proposed. This method achieved high accuracy and success on both the classical ECP2011 dataset and the new street level dataset, indicating that the proposed method is effective. Dönmez [26] aims to develop a deep learning-based object detection algorithm that determines the style and period characteristics of traditional Konya houses. This algorithm aims to contribute to the preservation of cultural riches by providing a fast, error-free and effective tool in the process of preserving architectural heritage and transferring it to future generations. In addition, being the first application in the literature, it is important to provide important guidance to decision makers regarding the protection of architectural heritage and to form a basis for similar studies in the future. This study is expected to offer a new perspective on the sustainability and preservation of traditional architectural heritage. Shon et al. [27] aim to use a deep learning model to identify and classify the external elements of Hanok buildings, which are traditional Korean architecture. Recording the facades of Hanok buildings in detail with drawings or image information is laborious and costly. Therefore, this study proposes deep learning to identify the form elements that make up the Hanok façade. The study created 2808 Hanok façade images using 3D modeling and image processing. The MASK R-CNN model classified various elements in these images. Elements such as roof type, windows, lower part of the external wall, and design were determined with high accuracy Shon et al. [28] aim is to describe and document the facade elements of traditional Hanok architecture in Seoul, South Korea. Hanok has a particularly high concentration in the Bukchon district in Seoul, highlighting the need to preserve the social, cultural, historical, artistic and natural values of this architectural style. The study proposes to identify the form elements that make up the Hanok façade using deep learning methods, through three-dimensional modeling of 405 well-preserved Hanok facades. In this context, 2808 image data were obtained and a methodology was developed to identify facade elements using the MASK R-CNN model on this data set. The methodology was used to determine with high accuracy the shape elements of the Hanok façade, such as the roof type, windows, the lower part of the external wall and the design. This approach makes an important contribution to facilitating digital transformation in situations where recording with traditional drawing or image information can be time-consuming and costly.

Table 2 summarizes the past studies that have used CNN methods in architectural facade design and facade classification. As can be seen from the table, which summarizes the studies mentioned above chronologically, the accuracy rate of the facade classification with the CNN algorithm is high.

3 Material–method

3.1 Dataset

The study employed the convolutional neural network (CNN) algorithm, a deep learning technique, to effectively analyze images. For this purpose, data sets with architectural facades for 3 different historical periods (Gothic, Modern and Deconstructivist) were used. The dataset for this study was collected from Google Images. Google Images is a platform that offers a large repository of visual data on a variety of topics. Images obtained from Google Images in creating the data set; facades with Gothic, Modern and Deconstructivist architecture has been

Table 1 Studies using artificial intelligence-based methods in the field of architecture

Title	Authors	Year	Methods	Description
Design with shape grammars and reinforcement learning	Ruiz-Montiel et al.	2012	Shape gramers	A project aimed at creating two-dimensional layout plans of single-family housing units was developed
Decision making in the architectural design process: fuzzy logic based facade model proposal	Yıldız and Aktaş	2017	Fuzzy logic	The aim of this study is to use support systems to facilitate designers' choice among alternatives in the architectural design process and to guide and manage the design process by using a fuzzy logic-based mathematical approach in the proposed facade model
Artificial intelligence in architecture: generating conceptual design via deep learning	Imdat As, Siddhart Pal and Prithwish Basu	2018	GAN (generative adversarial networks)	A deep learning method approach that uses graphics to create conceptual designs is presented
Architectural drawings recognition and generation through machine learning	Huang and Zheng	2018	GAN (generative adversarial networks)	Recognizing and creating architectural drawings in the study, marking rooms with different colors and then housing plans were generated through two convolutional neural networks
Artificial intelligence in architectural design: the use of convolutional neural networks in site plan design	Mustafa Kemal Kayış	2019	ANN (artificial neural networks)	The aim of the study is to answer the question of how artificial neural networks can be used in architectural design by producing synthetic data to develop a site plan compatible with environmental data and by developing a classification model using convolutional artificial neural networks
Generative deep learning in architectural design	David Newton	2019	GAN (generative adversarial networks)	The aim of this study is to examine the applications of generative adversarial networks (GANs) technologies in architectural design and to investigate their use in selected architectural design tasks, such as the creation and analysis of 2D and 3D designs from specific architectural styles
Deep learning architect: classification for architectural design through the eye of artificial intelligence	Yoshimura et al.	2019	DCNN (deep convolutional neural network)	This study applies the latest techniques in the fields of deep learning and computer vision to find visual differences between the designs of different architectures
GAN as a generative architectural plan layout tool: a case study for training DCGAN with palladian plans, and evaluation of DCGAN outputs	Can Uzun	2020	GAN (generative adversarial networks)	The aim of this study is to automatically generate Andrea Palladio's architectural plan diagrams using generative adversarial networks (GAN) and to evaluate GAN's plan drawing production as a generative plan editing tool
Architectural facade recognition and generation through generative adversarial networks	Yu et al.	2020	GAN (generative adversarial networks)	This study enables the recognition and creation of the building facade

selected. The data set of 1043 images is divided into three as training, test and validation. The train data set with 835 images used to model to learn the relationship between inputs (images) and outputs (architectural styles). 80% of the data set is reserved for the training set and 10% for the validation set and 10% for the test set. The validation set used to tune the model to be trained more unbiased. And finally, the performance of the model evaluated as the results for the test set which contains data the model had not encountered in training and validation phases.

The samples from dataset can be seen in Fig. 7. The architectural styles examined in this study represent three historical eras. Gothic architecture, prevalent from the mid to late middle ages, is characterized by rib vaults, pointed arches, and flying buttresses [29]. Modern architecture emerged amidst the technological, social, and cultural transformations spurred by the Industrial Revolution,

Table 2 Facade classifications accomplished using CNN algorithms

Study title	Authors	Year	Methods	Dataset	Success rate
Classification of architectural heritage images using deep learning techniques	Llamas et al.	2017	CNN and deep learning	AHE dataset	93%
Enhanced facade parsing for street-level images using convolutional neural networks	Gefei Kong and Hongchao Fan	2020	CNN and deep learning	EPC2011	98.2%
A Deep learning based facade analysis method for detection of periodic differences in housings: the case of Konya	Mustafa Alper DÖNMEZ	2021	CNN and deep learning	Traditional houses from the nineteenth and twentieth centuries in Konya	93–100%
Identification and extracting method of exterior building information on 3D map	Donghwa Shon, Byeongjoon Noh and Nahyang Byun	2022	R-CNN and deep learning	Exterior building information	93% (façade), 91% (window)
Identification of facade elements of traditional areas in Seoul, South Korea	Donghwa Shon Giyoung Byun Soyoung Choi	2023	Mask R-CNN and deep learning	Hanok buildings image dataset	Unspecified

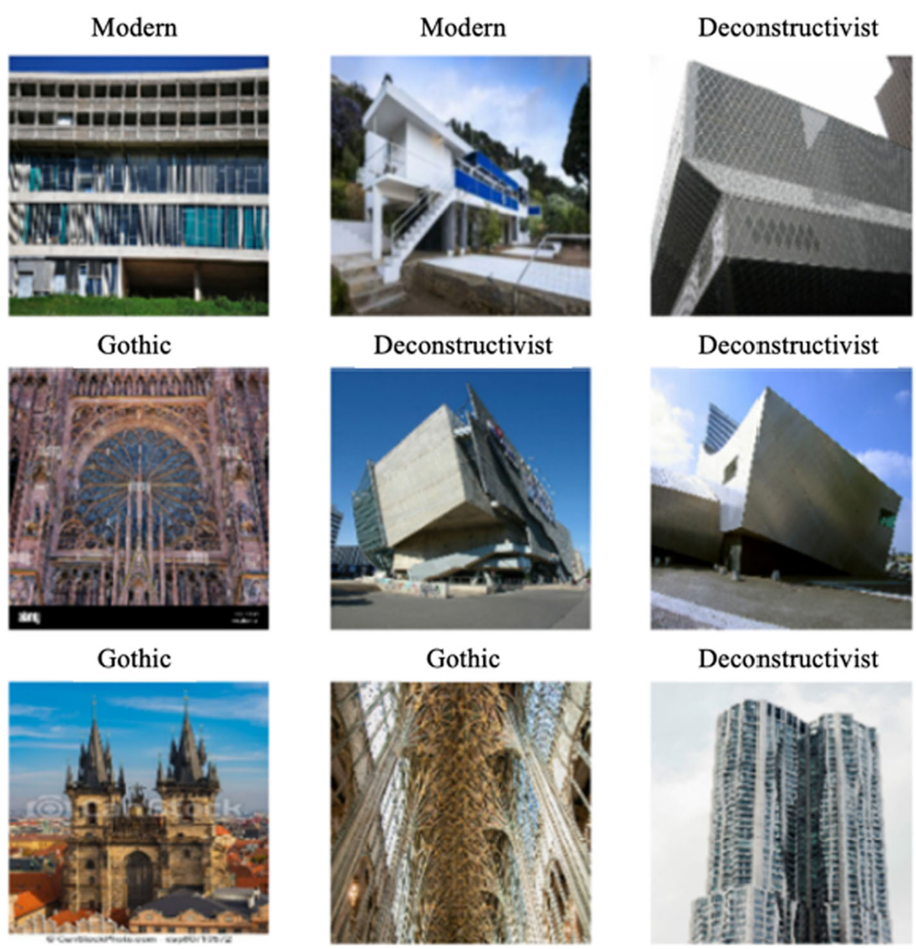

Fig. 7 Sample images from dataset

offering straightforward and functional solutions [30]. Conversely, deconstructivist architecture arose from a thought process that deconstructs and reassembles elements, disrupting pure forms, fracturing them, and imbuing them with novel meanings [31]. Deconstructivist architecture, on the other hand, manifests as a mode of thinking that dismantles and reassembles elements, disrupting pure forms, dividing them into pieces, and assigning new meanings [31]. The distinguishing features of Gothic, modern, and deconstructivist architecture is provided in Table 3.

Deep learning models require large amounts of data. This is very important for the healthier training of the model, the better performance of the model, and the prevention of the overfitting problem of the model. In cases where data is limited, data augmentation is used to solve the problems mentioned above [32]. In this study, a total of 9 data were obtained from a structure using the data augmentation method (Fig. 8).

Fig. 8 Images resulting from data augmentation

3.2 Method

The literature shows that, algorithms such as decision trees, k-nearest neighbors, random forests, logistic regression, and convolutional neural networks can be used for classification problems [33, 34]. CNN algorithms generally show to outperform traditional machine learning algorithms on image processing, pattern recognition, and classification tasks with higher accuracy and faster predictions [35, 36]. For example, The CNN-based system used to identify diseases in mango leaves reached a high accuracy rate of 95.2%, while the fuzzy logic algorithm achieved an accuracy rate of 93.5% [37]. LeNet network, developed by Yann LeCun in 1998, is the first successful model among convolutional neural networks [38].This network was created with MNIST to identify postal numbers and digits on bank checks.

Convolutional neural networks consist of many layers and parameters. One of the most important advantages of convolutional neural networks is that they can be used with less parameters and training. It is generally preferred in object recognition, image analysis and natural language processing studies [39]. Convolutional neural networks consist of convolution, jointing and full connection layers as shown in Fig. 9. The convolution layer is the basis of CNNs. A new matrix is formed when a filter determined in the convolution layer is circulated over the data [40]. Since the selected filter affects the performance of the model and the training process, an ideal filter with optimum results should be preferred [41]. The pooling layer reduces the input size for the interaction layer that comes after it. The reduction in size as a result of the pooling layer causes information loss but also less computational burden in the next layers. The reduction of the data size is realized by the filtering process [42]. Finally, the fully connected layer unites the neurons in the previous layer into a single line [43].

In this study, CNNs with convolutions and fully connected layers with filter sized of 5×5 used. Softmax activation function was applied to the output layer. The code employed for the study had inspired and based on the LeNet study. A simplified version of the model can be seen in Fig. 10.

Table 3 Characteristics of gothic, modern and deconstructivist architecture

Gothic arhcitecture	Modern arhcitecture	Deconstructivist arhcitecture
Vertical lines, spikes	Horizontal and vertical lines	Curvature, distortion, indistinct lines
Ornament	Simplicity, planeless	Causelessness
Additive	Integrity	Fragmentation
Imperfection	Uniformity, sameness	Imperfaction
Historicity	Opposition to history	Undated
Locality	Universality	Illıcality

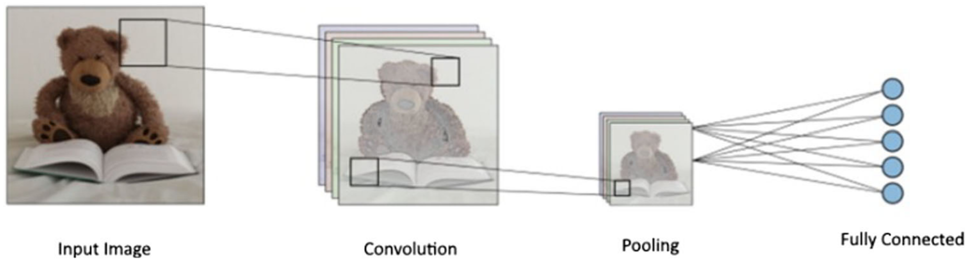

Fig. 9 Convolutional neural network structure [44]

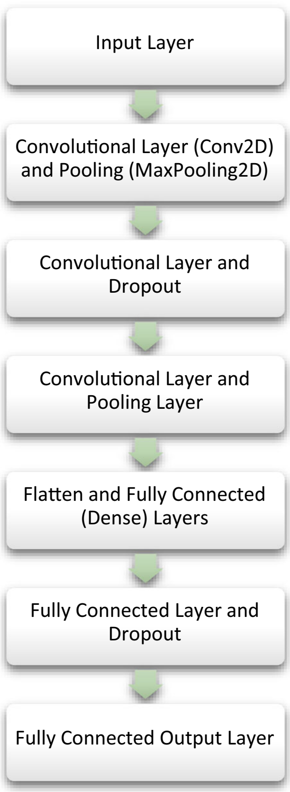

Fig. 10 Structure of CNN model developed for the study

```
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 sequential (Sequential)     (None, 180, 180, 3)       0

 rescaling (Rescaling)       (None, 180, 180, 3)       0

 conv2d (Conv2D)             (None, 180, 180, 32)      896

 max_pooling2d (MaxPooling2  (None, 90, 90, 32)        0
 D)

 conv2d_1 (Conv2D)           (None, 90, 90, 64)        18496

 max_pooling2d_1 (MaxPoolin  (None, 45, 45, 64)        0
 g2D)

 conv2d_2 (Conv2D)           (None, 45, 45, 128)       73856

 max_pooling2d_2 (MaxPoolin  (None, 22, 22, 128)       0
 g2D)

 dropout (Dropout)           (None, 22, 22, 128)       0

 flatten (Flatten)           (None, 61952)             0

 dense (Dense)               (None, 256)               15859968

 dropout_1 (Dropout)         (None, 256)               0

 dense_1 (Dense)             (None, 3)                 771

=================================================================
Total params: 15953987 (60.86 MB)
Trainable params: 15953987 (60.86 MB)
Non-trainable params: 0 (0.00 Byte)
```

Fig. 11 Model used in the study

4 Experimental results

In this study, each image is a 180 × 180 × 1 matrix. These matrices composing the input data are subjected to multiplication by randomly initialized weights. The model is iteratively trained to optimize the weight values. The learning process takes place as a result of this training [12]. The details of the model developed for this study is shown in Fig. 11.

While designing a model in deep learning studies, the algorithms or techniques used are as important as the data. In this respect, some parameters such as the number of training rounds, the size of the data, and the activation function, which the designers need to decide, emerge. The repeated process to find the appropriate values of the weights to be used in the model is called "epoch".

The high numbers of epoch can cause the model to memorize the data but to learn it. The low numbers of epoch the harder the model find the optimum weights. In this study, the model was trained for 150 epochs, but the training process was terminated at the 40th epoch to prevent overfitting. In testing, the model successfully classified three architectural styles, Gothic, Modern and Deconstructivist. While 84.66% accuracy was achieved in the training phase of the model, 70.97% accuracy was achieved in the validation phase. At the same time, the training loss was determined as 0.3810 and the validation loss was 0.5266.

There are 3 convolution layers in the model. These layers consist of 32, 64 and 128 of 3 × 3 filters. After the convolution layer, the Rectified Linear Unit "ReLu" activation function (1) is used. The ReLu activation function is especially preferred when the network is deep and the processing loads are high [12]. Softmax activation

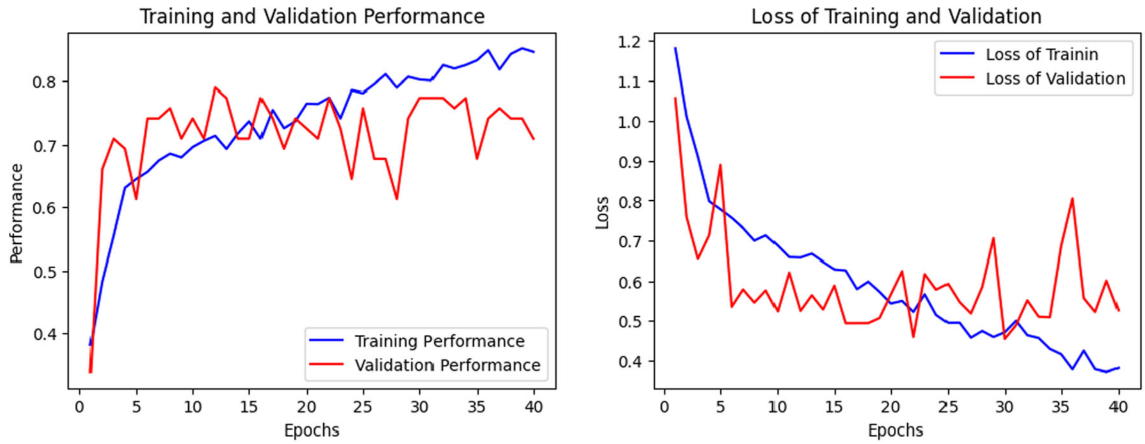

Fig. 12 Training and validation metrics

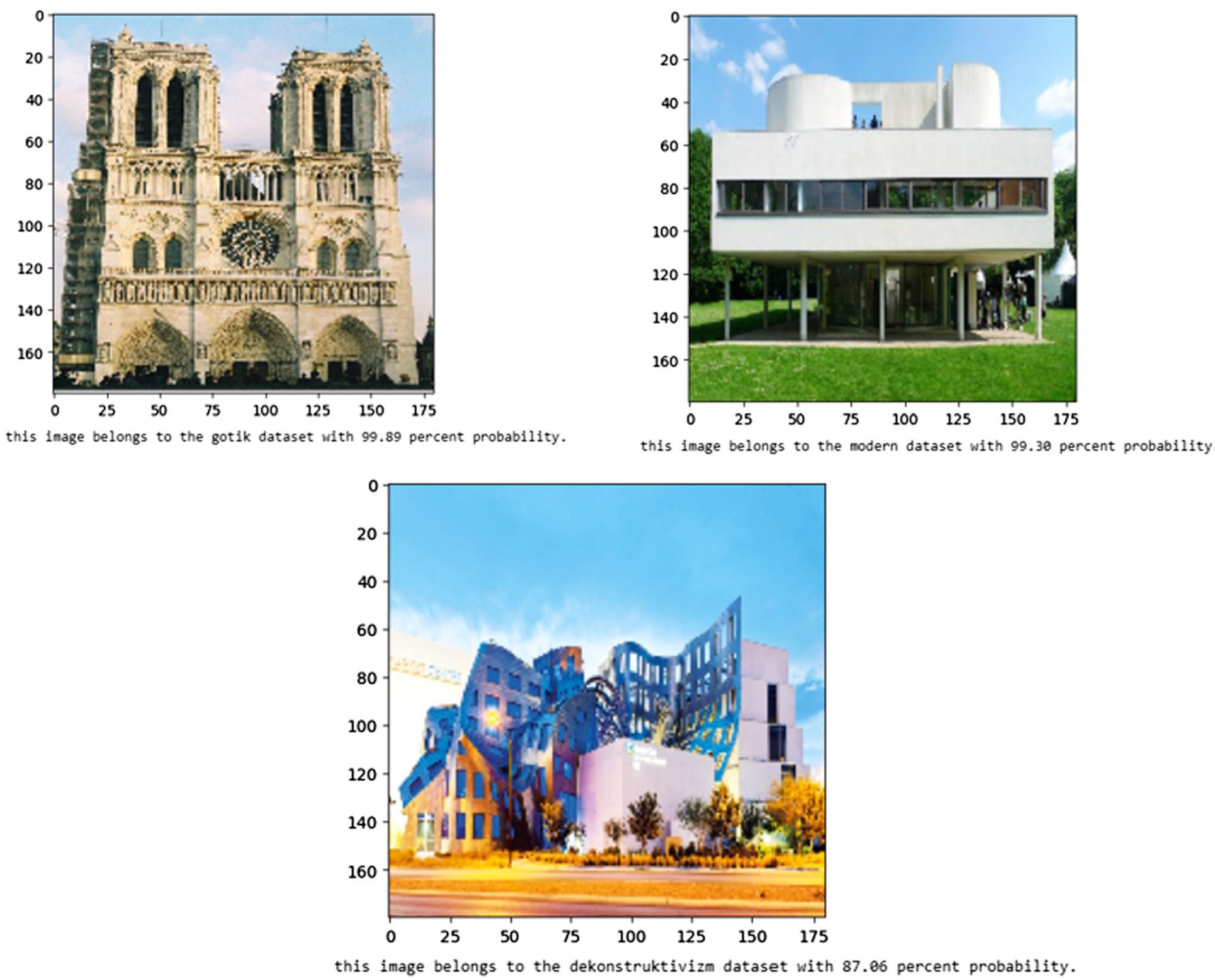

Fig. 13 Results for three different structures

function, which is preferred in multiple classification problems, is used after jointing and fully connected layers. Softmax activation function ensures that the given facade image is placed in the most appropriate place among the 3 groups of architectural styles.

$$y = Activation\left(\sum(W * x + b)\right) \quad (1)$$

Upon completion of the training phase, the model was employed to classify architectural styles from a previously unseen dataset. The training and validation metrics are presented in Fig. 12.

The successful classification of images belonging to 3 architectural styles, as demonstrated in Fig. 13, affirms the efficacy of the CNN algorithm employed in this study. The model can accurately identify the style of the facade, whether Gothic, Modern, or Deconstructivist in test phase with 84.66% accuracy.

5 Discussions and future scope

Artificial intelligence models trained with convolutional neural networks (CNN) can recognize architectural elements in an architectural product. The pervasive adoption of CNNs in the future is anticipated to empower architects in the decision-making process and in evaluating these decisions with feedback. This enhanced control over the architectural language, cultivated through the intricate and multi-layered decision-making and selection processes inherent in architectural design and production, will undoubtedly revolutionize architectural practice. In the future, architecture discipline and CNNs studies and research will play an important role in the development of architectural product as a single object. It is also thought that CNNs have the potential to support the research process of the context of the architectural product and its relationship with the built environment, which the discipline of architecture has to evaluate as open-ended, and it will also help in the analysis and decision processes of some situations and complex urban problems.

In addition, it can be deduced that convolutional neural networks (CNN) can make important contributions to the field of conservation, since they can identify and distinguish the elements found in architectural products from different periods. The changes, aesthetic features, value and elements of an architectural product, which has been decided to be protected, in the historical process of the building before starting the restoration work, will be able to be determined with the help of CNN by getting support in identifying and distinguishing the elements. These studies, which will be carried out together with the surveying studies, may facilitate the analysis of the structures and the acquisition of basic information that will guide the restoration strategies. In case of incomplete information about the structure under consideration, CNN algorithms trained with architectural elements can be used to evaluate the structure, to understand the real value of the structure and to make decisions for the studies to be done in this direction.

6 Conclusions

Artificial intelligence applications accelerated with new developments in information technologies and started to be used in various disciplines. Applications such as pricing estimation, energy conservation of buildings, security systems, ventilation systems, user-oriented interaction design solutions, plan and facade production and classification, use of computer-aided programs can be given as examples of the use of artificial intelligence in architecture. When the literature is scanned, it is seen that the algorithms used in architecture focus on shape grammars, graph theory, decision trees, constraint-based models, machine learning methods, RNNs (Recursive Neural Networks), CNNs (Convolutional Neural Networks) and GANs (Generative Adversarial Networks). With these algorithms, studies have been carried out on subjects such as plan and facade production and classification. Upon examination of relevant studies, it becomes evident that machines, when provided with predetermined parameters and accurate data, can effectively identify basic architectural layouts, conduct mass studies, and provide accurate classifications. Performing image recognition using convolutional neural networks (CNN) has become popular with the developments in artificial intelligence. In this study, a model has trained with datasets containing facades of gothic, modern and deconstructivist architecture, and then had asked to guess the style of a building façade it had never encountered on training phase. The entire data set is divided into three as training set, validation set and test set. 80% of the data set is reserved for the training set and 10% for the validation set and 10% for the test set. A total of 1043 data were used in the study, 835 of which were determined as training, 104 as validation, and 104 as testing. Open source TensorFlow library and Python programming language provided by Google had used for continuous monitoring and updating of our model. To track the model, it's obtained results by combining data pieces containing the facades of architectural buildings from each period. Our results show that the model can accurately classify different architectural styles. The study provides a promising method for future studies by achieving 84.66% training accuracy and 70.97% validation accuracy with the convolutional neural network model developed for the problem of recognizing architectural styles. In addition, early stopping was used in the 40th epoch to prevent overfitting, which increased the generalization ability of the model. Thanks to a CNN-based model, those from different periods can examine not only individual buildings but also features in relation to their surroundings. Additionally, the discipline can gain an important place in architectural conservation field. Sizes of protected particles, aesthetic properties, and changes in CNN opening can be learned and guide repair decisions. With this study, it has been seen that besides the classification of machines, the infrastructure can be prepared for research on the creation of architectural style and language. The advancement of this methodology has opened up new avenues for mobile and computer applications, enabling a faster and more user-friendly experience by incorporating period and trend analyses derived from cultural and architectural heritage.

Acknowledgements We would like to thank the lecturer Volkan Cantemir for his contributions to the article.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not include human subjects for data collection. Ethical approval is not required.

References

1. Chollet F (2018) Deep learning with python, vol 361. Manning, New York
2. Powell J (2019) Trust me, I'm a chatbot: how artificial intelligence in health care fails the turing test. J Med Internet Res 21(10):e16222
3. Nilsson NJ (2009) The quest for artificial intelligence. University Press, Cambridge
4. Samuel AL (1959) Some studies in machine learning using the game of checkers. IBM J Res Dev 3(3):210–229
5. LeCun Y (1989) Generalization and network design strategies. Connect Perspect 19:143–155
6. Hinton GE, Salakhutdinov RR (2006) Reducing the dimensionality of data with neural networks. Science 313(5786):504–507
7. Akkem Y, Biswas SK, Varanasi A (2023) Smart farming using artificial intelligence: a review. Eng Appl Artif Intell 120:105899
8. Öztemel E (2016) Yapay sinir ağları (4. bs). Papatya Bilim
9. Gatys LA, Ecker AS, Bethge M (2016) Image style transfer using convolutional neural networks. In: Proceedings of the IEEE conference on computer vision and pattern recognition pp 2414–2423
10. Goodfellow I, Bengio Y, Courville A (2016) Deep learning. MIT press, Cambridge
11. Mettleq ASA, Dheir IM, Elsharif AA, Abu-Naser SS (2020) Mango classification using deep learning. Int J Acad Eng Res (IJAER) 3(12):22–29
12. Kayalı NZ, Omurca Sİ (2021) Classification of chinese number patterns with convolutional neural networks. Comput Sci Spec 2021:184–191
13. Dönmez MA (2021) A deep learning based facade analysis method for detection of periodic differences in housings: the case of Konya. Master's thesis, konya technical university, graduate school of education, department of architecture, architecture science branch
14. Akkem Y, Biswas SK, Varanasi A (2023) Smart farming monitoring using ML and MLOps. In: International conference on innovative computing and communication. Singapore Springer Nature Singapore pp 665–675
15. Ruiz-Montiel M, Boned J, Gavilanes J, Jimenez E, Mandow L, Perez-de-la-Cruz JL (2012) Design with shape grammars and reinforcement learning. Adv Eng Inf 27(2):230–245
16. Yıldız B, Aktaş B (2017) Decision making in the architectural design process: fuzzy logic based facade model proposal. MSTAS 173
17. As I, Pal S, Basu P (2018) Artificial intelligence in architecture: generating conceptual design via deep learning. Int J Archit Comput 16(4):306–327
18. Huang, W., & Zheng, H. (2018). Architectural drawings recognition and generation through machine learning. In Proceedings of the 38th annual conference of the association for computer aided design in architecture, Mexico City, Mexico (pp. 18–20).
19. Kayış MK (2019) Artificial intelligence in architectural design: the use of convolutional neural networks in site plan design (master's thesis). Istanbul Technical University, Institute of Science and Technology
20. Newton D (2019) Generative deep learning in architectural design. Technoll Arch+ Des 3(2):176–189
21. Yoshimura Y, Cai B, Wang Z, Ratti C (2019) Deep learning architect: classification for architectural design through the eye of artificial intelligence. International conference on computers in urban planning and urban management. Springer, Cham, pp 249–265
22. Uzun C, Çolakoğlu MB, İnceoğlu A (2020) GAN as a generative architectural plan layout tool: a case study for training DCGAN with palladian plans and evaluation of DCGAN outputs. AZ Itu J Fac Archit 17(2):185–198
23. Yu Q, Malaeb J, Ma W (2020) Architectural facade recognition and generation through generative adversarial networks. In: International conference on big data and artificial intelligence and software engineering (ICBASE). IEEE, pp 310–316
24. Llamas J, Lerones PM, Medina R, Zalama E, Gómez-García-Bermejo J (2017) Classification of architectural heritage images using deep learning techniques. Appl Sci 7(10):992

25. Kong G, Fan H (2020) Enhanced facade parsing for street-level images using convolutional neural networks. IEEE Trans Geosci Remote Sens 59(12):10519–10531
26. Dönmez MA (2021) Deep learning-based facade analysis method for detecting periodic differences in houses: the case of konya (doctoral dissertation). Department of Architecture, Konya Technical University, Konya
27. Shon D, Noh B, Byun N (2022) Identification and extracting method of exterior building information on 3D map. Buildings 12(4):452
28. Shon D, Byun G, Choi S (2023) Identification of facade elements of traditional areas in seoul. South Korea Land 12(2):277
29. Paul F, Paul C (2000) Gothic architecture (Vol. 58). Yale University Press
30. Dostoğlu N (1995) Modern sonrasi mimarlik anlayişlari mimar-lik-263, s:46. Mayıs
31. Belkıs U (1996) Dekonstrüktivist mimari üzerine değinmeler, mimari akimlar II, der. 0. Tunataş, Yem Yayın, İstanbul, s. 57–59 Esin, a.g.e., s. 48–51
32. Shorten C, Khoshgoftaar TM, Furht B (2021) Text data augmentation for deep learning. J Big Data 8:1–34
33. Borra S, Thanki R, Dey N (2019) Satellite image analysis: clustering and classification. Singapore Springer. https://doi.org/10.1007/978-981-13-6424-2_4
34. Vishal TV, Srinidhi S, Srividhya S, Sri-Vishnu K, Swathika R (2016) A survey and comparison of artificial intelligence techniques for image classification and their applications. Int J Sci Res (IJSR) 5(4):187–193
35. Ren Y, Cheng X (2019) Review of convolutional neural network optimization and training in image processing. Tenth Int Symp Precis Eng Meas Instrum 11053:788–797
36. Sharma R, Hussung R, Keil A, Friederich F, Fromenteze T, Khalily M, Yurduseven O 2022 Performance analysis of classification algorithms for millimeter-wave imaging. In: 16th European conference on antennas and propagation (EuCAP) pp 1–5 IEEE
37. Puviarasi R (2022) Accuracy improvement in disease identification of mango leaf using CNN algorithm compared with fuzzy algorithm. ECS Trans 107(1):11889
38. LeCun Y, Jackel L, Bottou L, Brunot A, Cortes C, Denker J, Vapnik V (1995) Comparison of learning algorithms for handwritten digit recognition. Int Conf Artif Neural Netw 60(1):53–60
39. Grefenstette E, Blunsom P, de Freitas N, Hermann KM (2014) A deep architecture for semantic parsing, proceedings of the ACL 2014 workshop on semantic parsing, Baltimore-MD 22–27
40. Pang Y, Sun M, Jiang X, Li X (2018) Convolution in convolution for network in network. IEEE Trans Neural Netw Learn Syst 29(5):1587–1597
41. Cireşan DC, Meier U, Masci J, Gambardella LM, Schmidhuber J (2011) Flexible, high performance convolutional neural networks for image classification. IJCAI Proc-Int Joint Conf on Art Intell 22:1237–1242. https://doi.org/10.5591/978-1-57735-516-8/IJCAI11-210
42. Tan Z (2019) Vehicle classification with deep learning (Master's thesis, Fırat University)
43. Doğan F, Türkoğlu İ (2018) The comparison of leaf classification performance of deep learning algorithms sakarya university. J Comput Inf Sci 1:10–21
44. https://stanford.edu/~shervine/l/tr/teaching/cs-230/cheatsheet-convolutional-neural-networks

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.