Enhancing Concrete Property Prediction through Advanced Neural Network Modeling

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Abstract:
The rising concern over building energy consumption has spurred a demand for high-performance construction materials with superior thermal attributes. Accurately assessing these properties is pivotal for crafting energy-efficient materials. However, conventional methods for characterization involve labor and cost-intensive experiments, presenting formidable barriers to precision. Thermal conductivity (TC) is an essential thermal property and a precise TC knowledge is vital for designing materials capable of efficiently managing heat flow within structures. Additionally, compressive strength is a cornerstone property influencing concrete performance and longevity in construction. It signifies a material's resistance to axial loads and is crucial for structural integrity. Accurate compressive strength prediction is paramount for optimizing concrete mixes and ensuring building safety. This comprehensive study introduces a novel methodology in deep learning employing artificial neural networks, specifically a Multilayer Perceptron (MLP) and Generative Adversarial Network (GAN) to predict these properties based on its chemical composition. The dataset for model training was developed from the published literature. We've tested various ANN structures, including a two-hidden-layer MLP with 200-100 neurons, and first results achieved a remarkable consistency (RMSE: 0.176, R^2: 0.98). By bridging the gap between accurate property prediction and cost-effective experimentation, this research aims to revolutionize energy-efficient building material development while ensuring structural integrity, thus contributing significantly to sustainable construction practices.

Keywords:
Artificial neural networks, Building materials, Concrete, GAN, MLP, Thermal conductivity.

1 Introduction

Due to the constant concern about the energy consumption of buildings, there is a growing demand to improve thermal performance. Utilizing thermal efficiency materials in the construction sector is necessary as they preserve indoor thermal comfort, despite fluctuations in the outdoor environment conditions [1]. Many building materials can be used as thermal energy storage materials. As energy efficiency relies on the material's thermal properties, an accurate prediction of their properties is vital for optimizing their performance in a building.

Concrete is one of the most used materials in construction and as a thermal energy storage material (TES) due to its unique features, such as high compressive strength, heat capacity, and low cost. However, as its chemical composition can vary significantly, its properties can undergo significant variations. For this reason, and to be effective as a TES material, it is crucial to have an ideal composition to ensure that its thermal properties meet the required design specifications [2].

Due to the pressing need for energy-efficient building materials, numerous studies have turned their attention to the analysis of thermal properties in construction materials. Consequently, the development of a predictive model capable of accurately estimating the thermal behavior of them emerges as a valuable tool for optimizing their application. While the analysis of thermal properties, like thermal conductivity, is crucial, another fundamental property, compressive strength, profoundly impacts construction materials' performance. Compressive strength is vital to assess a material's ability to withstand axial loads and is to ensure the structural integrity in construction applications.

Deep learning (DL) models can be used to develop such predictive models by learning from large datasets and finding patterns to make predictions. By incorporating DL, the predictive models can adapt to varying conditions and continuously improve their accuracy, making them a valuable tool in optimizing the performance of building materials [3]. Among the models, the Artificial Neural Network (ANN) is one of the most employed ones to solve complex problems and has various applications in several fields [4], [5]. The importance of ANNs lies in their ability to learn and make decisions based on data, which makes them highly valuable. In this way, ANNs can be used to solve problems that conventional or other computational methods have difficulties [6].

ANNs provide an alternative prediction method that is faster, cheaper, and more accurate than traditional methods. However, a few papers are progressing on models to determine the thermal properties and do not have a generalist model. This work intends to fill this gap and develops predictive models encompassing both thermal conductivity and compressive strength using ANN based on the constituents' composition and the concrete's density. This research seeks to advance the field of energy-efficient building materials while ensuring the structural resilience of construction materials, thus contributing significantly to sustainable construction practices.

2 Research Methodology

The following methodology outlines the development of an ANN model for predicting the properties of concrete based on its features, which enables the evaluation of the model potential to foresee this property and shows the efficiency in the prediction speed when compared to the time-consuming experiments, which will provide a reliable model to predict the concrete's thermal conductivity. This methodology is broken down into three steps (Figure 1).

The first one corresponds to the literature review and data collection of a diverse variety of concrete. If the database presents an inadequate representation of the problem, the model cannot predict the property effectively, thus reducing the model's reliability. Furthermore, for the model to be representative, there must be a sufficiently large amount of data to ensure diversity. First, the model's inputs and outputs are defined according to the available data and the dependent variables. Then, the available data sets from the literature are organized in a CSV file to develop the ANN model. The second one is related to the general process of building the ANN model to predict the thermal conductivity and the compressive strength, i.e., the selection of an appropriate neural network architecture for the prediction task, defining the learning rate of the neural network, the number of hidden layers and neurons in each layer, and the metrics to find the best model for the dataset. The last step is analyzing a case study, where the dataset based on previously published works is plugged into the model to evaluate its accuracy. Besides that, a Generative Adversarial Network (GAN) is also developed for data augmentation to improve the model and guarantee a good prediction.

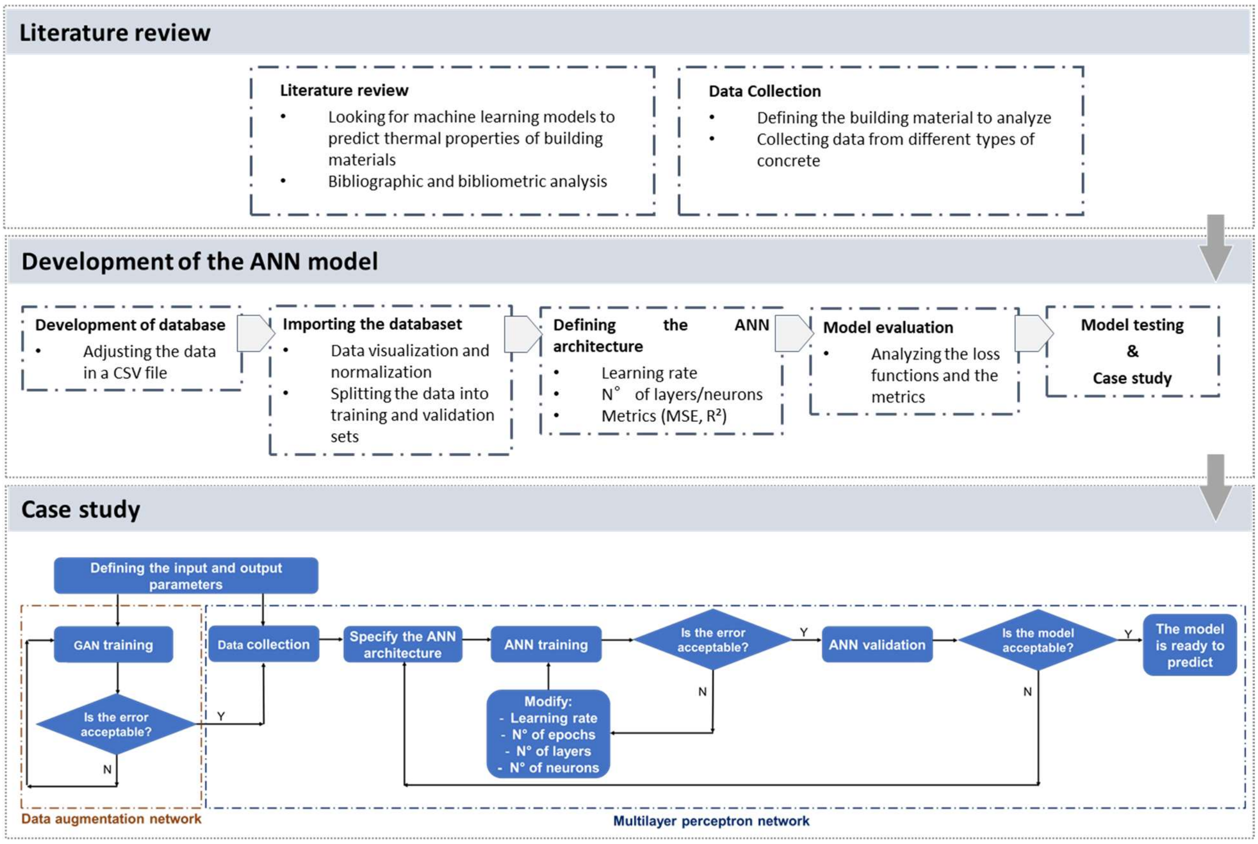

Figure 1. Methodology framework

3 References

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