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REVISITING SYSTEMS AND APPLICATIONS OF ARTIFICIAL NEURAL NETWORKS IN CONSTRUCTION ENGINEERING AND MANAGEMENT

ALIREZA SHOJAEI[1] and AMIRSAMAN MAHDAVIAN[2]

[1]*Building Construction Science, Mississippi State University, Mississippi State, USA*
[2]*Civil and Environmental Engineering, University of Central Florida, Orlando, USA*

Artificial neural networks have been widely used for modeling and simulation of different problems in the construction industry, including, but not limited to, regression, clustering, and classification. They provide solutions for complex problems where other modeling methods often fail. For instance, they can capture nonlinear and complex relationships between the variables while many traditional modeling methods fail. However, they have their own limitations. They often can only be trained for a specific problem with a predetermined number of inputs and outputs. As a result, any change that requires an update in the architecture of the network cannot be automatically done and require human intervention. The recent developments in the field of artificial neural networks resulted in new concepts such as neural architecture search, reinforcement learning, and neuroevolution. These new areas can provide new methods for solving past and existing problems facing the construction industry in a more efficient, elegant, and versatile manner. One of the main contributions of the recent developments is networks that can optimize their own architecture and networks that are able to evolve and change their architecture. This paper aims to briefly review the application areas of the artificial neural networks in construction engineering and management and discuss how the recent developments in this field can be applied and provide better solutions.

Keywords: Reinforcement learning, Neuroevolution, Artificial intelligence, Neural architecture search.

1 INTRODUCTION

Artificial Neural Networks (ANNs) are an abstract form of biological neural systems. They have been a pioneer modeling approach in Artificial Intelligence (AI) and machine learning field. ANNs are implemented for a variety of tasks such as regression, clustering, and classification. They are especially powerful in complex pattern recognition and nonlinear relationship modeling, and image processing. Figure 1 illustrates a sample architecture of a feed-forward neural network. The first layer shows the neurons of the input layer; the second layer is called the hidden layer, which here includes five neurons and the last layer is the output layer, which here includes only one neuron. The developer of an ANN model needs to optimize two set of details, first, the architecture of the model and second, optimization of the models' parameters. Tuning the parameters of the model such as learning rate, epoch, initial weights, and biases can be done through different methods such as backpropagation, particle swarm optimization, and many other methods discussed in the following sections.

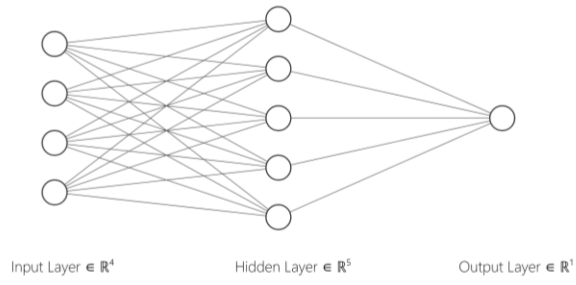

Figure 1. An illustration of an ANN's architecture.

The main problem in developing ANN models is decision making regarding the architecture of the model. Until recently, the decisions regarding the architecture of the ANN models were more of guesswork, where the developer based on experience or testing different values would come up with a not necessarily optimal architecture for the ANN under development. The following sections would provide a review on applications of ANNS in construction engineering and management (CEM), followed by the discussion and conclusion section where the recent developments in ANNS field and their implications in CEM is discussed.

2 COST

Cost prediction is one of the significant areas of study where ANN is applied in CEM field. McKim (1993) successfully used ANN to predict tender price, Williams (1994) used an ANN for construction cost prediction. Al-Tabtabai *et al.* (1998) developed an ANN model for forecasting of percentage increase in the cost of a highway project from a reference estimate. Boussabaine and Kaka (1998) applied an ANN to project cash flow forecasting. Cheng *et al.* (2009) suggested web-based conceptual cost estimates for the construction projects using an evolutionary fuzzy neural inference model that calculates the whole life cycle costs of construction projects by considering substantial items' costs. Feng and Li (2013) proposed an optimization method for cost estimation. Their model integrates the Genetic Algorithm (GA) and Back Propagation (BP) techniques. This study concluded that GA-BP model could get lower predict error which takes longer run time compared to the conventional BP models. El-Sawah and Moselhi (2014) used Back Propagation Neural Network, Generalized Regression Neural Network, Probabilistic Neural Network, and regression analysis models for forecasting an approximate cost estimate of low-rise structural steel buildings and their relevant cost. Yadav *et al.* (2016) developed a cost estimating technique based on the principles of ANN to forecast structural cost of residential buildings. Lee *et al.* (2016) developed a model using the ant colony optimization algorithm to optimize the selection of ANN parameters that can be used to address the cost overruns in projects and improve construction waste management.

3 SCHEDULING AND PRODUCTIVITY

Scheduling and productivity is another area where ANN seems to be widely adopted by researchers. Chao and Skibniewski (1994) developed an ANN regarding the Labor productivity in the construction industry. Boussabaine (1995) developed a neural network system for forecasting construction planning and productivity. Lu *et al.* (2000) developed an ANN regarding the labor production rate for pipe installation activity. It was predicted that the duration of concrete operations via an artificial neural network by focusing on supply chain parameters. Ezeldin *et al.* (2006) estimated the productivity within a developing market for formwork assembly, steel fixing, and concrete pouring activities. Golpayegani *et al.* (2007) presented a framework for planning work breakdown structure (WBS) of construction projects based on an ANN. Bai *et al.* (2009) used four successively arranged neural networks to develop the WBS of the projects using ANNs. Cheng and Kou (2003) developed an object-oriented evolutionary fuzzy neural inference system in order to predict a subcontractor's performance, and duration estimation of slurry walls. Yahia *et al.* (2011) used the number of change orders to develop a project time prediction model.

4 DECISION MAKING

Decision making due to its complex nature is another area where ANN has shown significant contributions. Kamarthi *et al.* (1992) used two layers BP neural network in order to select the formwork systems. Murtaza and Fisher (1994) developed an ANN model that facilitates decision-making on whether to use a conventional or modularization method to build an industrial process plant. Chua *et al.* (1997) proposed an ANN model for the identification of leading measurement factors that impact budget performance to forecast various management strategies in a project. Lou *et al.* (2001) used the past conditions records to predict the short-term future conditions using an ANN. Lam *et al.* (2001) used an ANN as a decision-making tool to evaluate the prequalification of contractors. Chew and Tan (2003) proposed a maintainability grading system which helps in improving decision-making of wet areas design that ultimately leads to minimum lifecycle maintenance cost using an ANN. Al-Sobiei *et al.* (2005) developed a decision-making tool to employ the services of a contractor that can allow the use of a rational and effective policy by using ANN and GA. Khalafallah (2008) developed a model for predicting housing market performance in order to advocate home developers and real estate investors using an ANN method. Vahdani *et al.* (2011) used a neuro-fuzzy model to estimate the qualitative and quantitative performance of the projects accurately. Sharmik *et al.* (2016) applied a BP-NN in order to estimate the soil characteristics. El-Sawalhi and Hajar (2016) used an ANN to investigate the election of the best-qualified contractor in the Gaza strip. Apanaviciene and Juodis (2005) applied an NN method to propose a model which can help as a decision-making tool for competitive bidding and for evaluating the management risks of the projects. Jamil *et al.* (2009) showed the feasibility of fitting ANN in the development of a simulator and an intelligent system for the forecasting of workability and compressive strength of high performance concrete.

5 LEGAL DOMAIN

Legal domain due to its qualitative nature is not as developed as other areas investigated in this study. Cheung *et al.* (2000) reported using ANN to classify projects in accordance with project "dispute resolution satisfaction (DRS)" which also recognized the sensitive variables that determine projects with adverse DRS and favorable DRS. Fatima *et al.* (2014) develop an ANN model based on identified significant qualitative parameters for minimizing construction disputes and reduce the cost of construction.

6 RISK ASSESSMENT AND ANALYSIS

Risk assessment and analysis due to its quantitative nature is a good candidate for employing ANN. McKim (1993) used an ANN regarding risk quantification. ANN was for cost-based risk prediction and identification of project cost drivers. Al-Tabtabai and Alex (2000) used ANN system to recognize the cost deviations that happen, regarding the political risk involved in a construction project. Odeyinka *et al.* (2002) developed a cost flow risk assessment model employing a BP neural network. The model was tested on 20 new projects with a satisfactory prediction of variation between forecast and actual cost flow at 30%, 70%, and 100% stages. Maria-Sanchez (2004) applied a neural network approach to evaluate the impact of environmental risk in the construction projects. Xiang and Luo (2012) proposed a principal project parties' behavioral risk evaluation model. The BP was employed to avoid subjectivity factors in the risk assessment process. Polat (2012) proposed a contingency estimation model based on ANN to enable managers to evaluate the level of risk in their projects more objectively and systematically. Liu and Guo (2014) used ANN to propose a risk assessment method using rough sets to decrease uncertainties. Moayed *et al.* (2011) applied an ANN and Logistic Regression to model the occupational safety and health of construction workers. Goh and Chua (2013) used a neural network to study the relationship between elements of accident severity and safety management on proactive management. Mohammadfam *et al.* (2015) modeled the factors affecting the health of the workforce and predicting the harshness of occupational injuries using chain analytical approach including ANN modeling and rough set theory.

7 DISCUSSION AND CONCLUSION

The conventional ANN architecture engineering often involves guesswork and trial and error. Beside the user experience, a series of trial and error are needed to get to the point of satisfactory architecture, and even that is not a guaranteed optimal solution. Most of the ANNs reviewed in this paper used gradient descent for optimizing their network. Some studies have used other soft computing methods such as ant colony, particle swarm optimization, and GA. However, their implementations lack the novelty in architecture search, and the optimization only applies to certain parameters of the network. Recent developments (Such *et al.* 2017, Conti *et al.* 2017) opened the door to ANNs, which can evolve and automatically change their architecture and topology to find the optimal architecture by combining evolutionary algorithms and ANNs. The main concept is that an AI that is designed for stochastic gradient descent can change its structure to a better performing structure through reinforcement learning and/or neuroevolution. Zoph and Le (2016) and Zoph *et al.* (2017) used a recurrent ANN to conduct a neural architecture search to generate the optimal architecture of an ANN for the desired task. In other words, they used an AI to build another AI with an optimized structure. The reviewed literature in previous sections shows the versatility and importance of ANN in CEM field. However, considering the possibility of finding the optimal network architecture through computation and not trial and error and the possibility of evolving AI is very promising. Consequently, revisiting the previous work and employing the new ANN systems on the same problems, theoretically, would significantly increase the performance of the previous generations of ANNs in CEM.

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