

# Application of Soft Computing Methods to Increase Sustainability in Construction

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**Abstract.** *In the last three decades the soft computing methods were used by the research community in almost every branch of construction, providing successful and convenient solutions for different problems in civil engineering. This paper presents some of the applications of these methods – especially neural networks (NN) and support vector machine (SVM) - in sustainable construction, i.e. its economic, social and environmental aspects. Soft computing applications were made in the last several years by our research team at the Faculty of Civil Engineering in Skopje, N. Macedonia, in collaboration with other authors from our and other countries. Several predictive models were developed using: general regression neural network (GRNN), support vector machine (SVM) and radial basis function neural network (RBF NN), using predictive modelling software DTREG. Applications of these models cover most of the aspects of sustainability in construction. Models were focused on predicting: road structure construction costs, bidding price in construction, sustainability assessment at early facilities design phase, predicting construction cost and construction time and predicting consumption of energy in buildings. Some of the mentioned developed predictive models are hybrid, composed of process-based and data driven models which contributed very much to the improvement of the accuracy of the predicting. The general conclusion is that the soft computing methods are a useful tool for developing models in the area of all aspects of sustainability and their application can lead to increasing sustainability in construction.*

**Keywords:** *Sustainable Construction, Soft Computing Methods, Predictive Modelling.*

## 1 Introduction

The construction industry creates conditions for the whole development of the country, but it can have some negative impact on the sustainability aspects: environmental, social or economic aspect. In that regard, balancing society’s needs with environmental and economical demands, the construction industry should fulfil the present society needs, but with respect to its future needs (Chendo, 2013; Rafandadi *et al.*, 2014).

The implementation of sustainable construction procedures is a slow process, mostly due to the widely spread opinion that they are time, effort and cost more demanding than traditional ones (Dobson *et al.*, 2013). Hence, meeting the sustainable aims has become a construction project participants’ challenge and researches’ focus worldwide. They have researched different sustainable aspects using various of techniques and methods. Some of them are soft computing methods (SCMs). SCMs are noted as useful for developing models for different sustainable problems in construction (Polat *et al.*, 2014; Ahmad *et al.*, 2014; Arida *et al.*, 2016). Therefore, the aim of this paper is to present a brief review of the authors’ research on several construction

sustainability issues by using SCMs. The models were focused on predicting: sustainability assessment, bidding price, construction time, construction cost and energy consumption of buildings.

*Sustainability assessment:* Facilities construction is globally noted as having large consequences on sustainability aspects. Thus, in spite of the existence of numerous obstacles, balancing sustainable issues and their incorporating in facilities construction and maintaining is a challenge for all participants in the construction projects (Aksorn and Charoenngam, 2015). Therefore, the early design phase is seen as a phase with high impact on facilities sustainability due to its providing drawings and specifications for the facility in accordance with the clients' wishes and needs (Crawford, 2013). Facility design which integrates the sustainability issues provides benefits for the project participants, the facility users and the whole society (Adeyeye *et al.*, 2013). But that is a complex process which puts designers under pressure. Therefore, construction project managers can support the inclusion of sustainability aspects in the facility's design which will lead to increasing the money value of the facility, while providing satisfied customers and construction of eco-friendly facility.

*Bidding price:* Construction companies usually acquire their work by winning a tender. Hence, choosing the bidding price that will win the tender is of particular interest for each construction company. But the decision what price to bid is a responsible, time and effort-consuming process which is influenced by a set of factors (Watt *et al.*, 2009). Therefore, having a model for predicting the price in order to win the bid is useful and it facilitates the decision making process.

*Construction time and cost* are elements that are included in each contract regarding facilities construction. Hence, they have influence on the contract signer's work and reaching the contracted time and cost is signer's challenge. That leads to a number of investigations regarding construction cost and time, such as: their prediction, their overrun, the time-cost relation, their influencing factors, etc. (Abu Hammad *et al.*, 2008).

*Energy consumption of buildings* has an impact, not only on the comfort, costs and other social and economic aspects of users, but also on the environmental aspect. In fact, buildings are among the biggest users of energy, thus prediction of their energy consumption is of particular interest. During the stage of selecting the optimal design of the new building or old building reconstruction/renovation, numerous measures/solutions can be used for reducing the building's energy consumption. Some of them are: system with heat pump from ground source (Michopoulos *et al.*, 2016); renewable energy systems usage and their combination or combination of systems for heating, power and cooling; system installation for energy management, etc. (Farhat *et al.*, 2014; Rasool *et al.*, 2015; Kialashaki, 2018). Thus, of particular interest is to have models for energy consumption forecasting.

## **2 Literature Review**

*Sustainability* outcomes and environment protection are in a significant positive relation (Smith and Rootman, 2013), so for owners the sustainability has impact on their portfolio (Warren-Myers, 2012). Rafindadi *et al.*, (2014) stated that there is no significant difference among project stakeholders on sustainable projects risks, so for Babawale and Oyalowo (2011) the real estate valuers should have more knowledge about sustainability aspects of properties in order to effectively assess their value. For Dobson *et al.*, (2013) there is perception that capital costs

for sustainability are high, which can be an obstacle for the construction.

*Bidding price in construction* – There are different categories of bidding-price models, such as: models that are directed towards maximization of the expected; models based on systems for decision support; models based on artificial intelligence, etc. (Polat *et al.*, 2014). For example: a bidding model that uses generic software for probability estimating of the success is presented by Kitchenham *et al.*, (2005).

*Construction time and cost* relation and their overruns are researched worldwide. Zhang and Ng (2012) solved time-cost optimization problems using evolutionary-based optimization algorithm. Similarly, Afshar and Fathi (2009) used Fuzzy-sets theory for accounting the uncertainty in each activity direct cost, in order to determine the financing cost and required credit. They developed a model for searching the solutions that are non-dominated for the construction objectives: total time, financing cost and required credit.

*Energy consumption of buildings* is among issues that are highly researched, from different aspects and using different methods and techniques. Widely used are: traditional numerical methods, statistical methods and intelligent methods. Promised results were given by: Ekici and Aksoy (2009) using backpropagation ANN; Holcomb *et al.*, (2009) with support vector regression, ANN and multilinear regression; Ahmad *et al.*, (2014) with support vector machine and ANN concluding that hybridization of these methods is suitable for more accurate prediction; Arida *et al.*, (2016) using ANN, particular non-linear auto-regression ANN; Amber *et al.*, (2017) using the Multiple Regression technique; Li *et al.*, (2017) using extreme deep learning approach, etc.

### **3 Methods**

There are generally two types of methods for analysing data: traditional hard-computing and modern soft computing methods. The hard computing methods use an accurately stated analytical model of the process that should be modelled, while the soft computing methods do not need analytical model of the process. The soft computing methods have been developed as an alternative solution for solving the contemporary problems. The two most important constituents of soft computing are learning from experimental data (neural networks and support vector machine) and fuzzy logic methods, but in recent years there are also other: probabilistic reasoning, genetic algorithms, chaos theories, fractals (Kecman, 2001). There are many different types of NNs developed for solving different problems, some of them being: GRNN, RBF NN, polynomial NN, probabilistic NN, multilayer perceptron (MLP), cascade correlation NN. In our research we have used only the first two.

#### **3.1 Data-Driven Soft Computing Methods**

Soft computing methods try to transfer the human knowledge into mathematical, analytical models by finding methods for learning from experimental data.

NNs and SVMs are mathematical computing models that implement the idea of learning from experimental data, and FL systems implement structured human knowledge into effective computing algorithms (Kecman, 2001).

### 3.1.1 Artificial neural networks (ANNs)

NNs implement the functioning of the human neurons. The three most important aspects of the NNs are: implementation of biological neural networks, the concept of parallel distributing processing and the concept of learning and self-organizing (Haykin, 2005). NNs can approximate multivariable nonlinear functions, identifying the interactions between input and output data easily, minimizing some error function which expresses the difference between actual output values and the predicted values by the NN. In our research most often used NNs were: GRNN and RBF NN.

*Radial basis function neural network (RBF NN)* is a 3 layered feed forward network (Figure 1 (Sherrod, 2013b)). The values from the input neurons are fed to the neurons from the next hidden layer, which has mutable number of neurons determined by the algorithm for the training process. RBF NN can have one or several outputs, depending on the task which is solved; if it is used for forecasting then RBF NN has only one output, but if it is used for classification, then it may have several outputs, equal to the number of categories of the target variable.

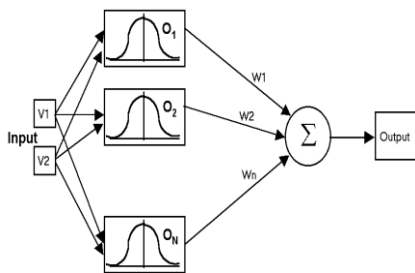


Figure 1. RBF NN architecture.

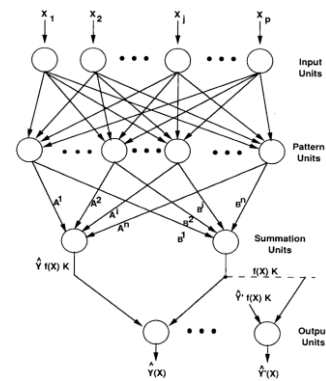


Figure 2. GRNN architecture.

*General regression neural network (GRNN)* is most often used NN in our research. This NN is in most of the cases very accurate and is used for forecasting, control problems, mapping (Specht, 1991). The most attractive characteristic of GRNN is its ability to converge to the optimal solution very quickly, requiring only several samples. GRNN has 4 layers (Figure 2) (Sherrod, 2013b).

### 3.1.2 Support vector machine (SVM)

SVM models have been developed to solve the contemporary problems that have appeared with the standard classical statistical modelling. SVMs can successfully work with standard contemporary multidimensional data sets and also with small training data sets (Kecman, 2001). SVMs have similar architecture as classical NNs. In fact, a two - layer feed forward NN is equivalent to a SVM model which uses sigmoid kernel function.

### 3.2 Bromilow Process-Based Model and Hybrid Modelling

The soft computing methods that were described above are *data-driven methods*, and they do not use any knowledge about the process which should be modelled in a form of some mathematical formula. *Process-based methods* describe the process by some mathematical formulae. The *hybrid modelling* is a relatively new field of investigation and very promising results have been reported.

The process-based model used in our research was the well-known Bromilow “time-cost” model which gives the relation between construction time and construction cost. This model is given by the equation (1):

$$T = aC^b \quad (1)$$

T is a construction time, C is a construction cost (price), *a* is a model parameter which expresses the average time needed for construction of a monetary value, and *b* is parameter which expresses the dependence of the time on cost change (Bromilow, 1969).

## 4 Results and Discussions

Using the methods described above, in the last several years predictive models applied for solving different problems in civil engineering have been developed by the research team from our country and also with collaboration with authors from other countries. The software used for developing the models was predictive modelling software DTREG (Sherrod, 2013a, 2013b). The developed models were applied for forecasting: sustainability assessment, bidding price, construction time, construction cost and energy consumption of buildings. Part of the available data for developing the models was used for training and part of them for validation of the model. The most used methods for validation were k-fold cross validation and random percent. The accuracy of the models has been estimated by the standard estimators: MAPE (mean absolute percentage error), and the coefficient of determination  $R^2$  which measures the global fit of the model.

*Sustainability assessment:* 112 project managers from construction firms in R. Macedonia were participants in an anonymous survey, whose goal was to determine their opinion about the factors that mostly affect the sustainability assessment of the facilities’ preliminary design. The questionnaire developed by the authors consisted of 72 questions, seen as factors that influence the sustainability of the facilities preliminary design. 27 of them were chosen as most representative for building the model. The participants were asked to answer the questions on a 6 point Likert scale (from 1 – unimportant, to 6 – extremely important). The questions were considered as predictors for the model. One of them was considered as target variable – the question: sustainability assessment of the preliminary design. GRNN from DTREG predictive modelling software was used for modelling. DTREG also computes the most important factors that impact the target variable, and the 6 most influential of them reported by DTREG were: 1) work experience, 2) work on several outline design proposals, 3) resolving issues between stakeholders, 4) prioritization of participants in the design phase, 5) procurement management and 6) defining project program and goals. The conclusion from this modelling is the finding that the project managers assessed the social aspects more influencing sustainability and economic and environmental issues less influential. The accuracy of the model was: MAPE= 2.6% and the coefficient of determination was  $R^2=0.84$  (Zileska *et al.*, 2017).

*Bidding price:* A model for forecasting bidding price was developed using SVM method for prediction. Data from 26 tenders were used for modelling out of 54 tenders that were collected from construction firms. Two variables were used as predictors (time for preparation and the price offered) and the target variable was price obtained. The accuracy of the model was with MAPE 2.5%, and  $R^2 = 89.8\%$ , (Petruseva *et al.*, 2016).

*Construction time:* Several hybrid models were developed for predicting time of construction using Bromilow time-cost model (BTC model) as process-based model. One of them was hybrid, composed of BTC model and GRNN model and it was modelled with data for 116 different types of structures: road structures, petrol stations, bridges, education facilities, business buildings, and other. The data was about purpose of the structure, year of construction, region of location, contracted time and cost and also realized time and cost. Target variable was real time of construction, and as predictors were chosen: purpose of the structure, real and contracted cost and contracted time. The accuracy of the model was: MAPE=3.3% and  $R^2 = 93.2\%$ , using purpose of construction (as string variable), and contracted time, contracted cost and real cost of construction as predictors, and target variable was real time of construction. The input values of real and contracted time of construction and real and contracted cost of construction were not their actual values, but logarithm of their values, because of the application of the BTC model (eq. 1). This equation was applied for the relation of the real time and real cost of construction, and also for the contracted time and cost, and these two equations were logarithmized and summarized and the obtained equation was a relationship between their logarithmic values. We shall stress here the importance of the hybrid model which drastically improved the accuracy of the model, because without using BTC model as part of the hybrid model, the accuracy of the model was drastically decreased: MAPE = 31.8%, and  $R^2 = 75.6\%$  (Petruseva, Car-Pusic and Zileska, 2019).

*Construction cost:* One of the developed models for predicting construction cost was hybrid model, composed of RBF NN and BTC model with accuracy: MAPE = 0.64%,  $R^2=99.2\%$ . The data were for 65 objects. Target variable was the real cost of construction, and predictors: contracted cost of construction and real and contracted time of construction, but here also as input values for these variables logarithms of their actual values were used because of the application of the BTC model. Without BTC model as part of the hybrid model, using only RBF NN, the accuracy of the model was: MAPE around 54% and  $R^2$  around 44% (Zileska and Petrusseva, 2017).

*Energy consumption of buildings:* The model developed for predicting building energy consumptions used data for real energy consumption for 55 residential buildings in R. Macedonia, constructed/reconstructed from 2013 to 2018. The accuracy of the model, using GRNN was: MAPE=3.12% and  $R^2=91.7\%$ . The target variable was building energy consumption Q [kwh/m<sup>2</sup>/year], and from all available data, 10 were chosen as most representative predictors, which were related to: 1) thermal transmittances (in W/m<sup>2</sup>) of: walls, windows, floors, roofs, and also: 2) their corresponding geometries and areas (in m<sup>2</sup>) – areas of the floors, walls and roofs (Zileska, Petrusseva and Samardzioska, 2018).

## 5 Conclusions

Sustainability aspects are complex and inter-connected, so their researching and incorporating in construction is an effortful process. Furthermore, there are many sustainability influencing

factors, so it's useful to have prediction models for sustainable aspects. Recently, the most popular soft computing methods used for predictive modelling have been SVMs and NNs (GRNN, RBF NN, MLP, polynomial NN, cascade correlation NN, probabilistic NN). In the last several years we have developed several predictive models using mostly GRNN, SVM, RBF NN, and several hybrid models composed of data-driven and process-based model. The developed models gave a satisfied accuracy in prediction of: manager's assessment of the sustainability in early design phase for the facility, building energy usage, bidding price, construction time, construction cost, etc.

The models presented in this paper showed that the usage of SCMs facilitates the decision making process and leads to increasing the sustainability in construction.

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