Artificial Intelligence Applications in Civil/Construction/Architectural Engineering Education

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Abstract

It is increasingly important to go beyond traditional departmental course curriculum boundaries for some areas of science and engineering education. Artificial Intelligence (AI) is one such field; its applications are very extensive and interdisciplinary. The graduate students should especially be encouraged to learn various applications of contemporary computing techniques including artificial neural network (ANN), genetic algorithm (GA), etc. Civil/construction/ architectural Engineering has exercised a rapidly growing interest in the application of neurally inspired computing techniques. The motive for this interest was the promises of certain information processing characteristics similar to those of the human brain. Soft computing (SC) is an emerging approach to computing, which parallels to remarkable ability of the human mind to reason and learn in an environment of certainty and precision. This paper highlights various applications of AI in civil/construction/architectural engineering especially in SC areas. As an example of a graduate project, this paper demonstrated an ANN and GA based knowledge model where the customer's preferences regarding comfort and safety issues in a large residential multistory flat housing scheme was studied. Architecture/engineering is an applied science where many lessons can be learned from existing structures, their successes and failures, and incorporating them to find out new techniques for a better structure. This implies that the designer should be able to derive from each previous design some qualitative values, especially on user's approval regarding building's safety and comfort quality as to assure a successful design. Architects/design engineers are quite often challenged with soft data, which are linguistic qualitative in nature, and needed to interpret and integrate into their design decision making processes. They should know much about their customer's desires and requirements, and especially customer's preferences when it comes to specific design issues. Hence, post-

occupancy evaluation has gathered great importance as it can form an extensive knowledge base, out of which knowledge can be elicited for the future projects. This is especially true in residential construction industry where customers have various preferences as far as safety and comfort issues are concerned. It was observed that ANN and GA have exceptional ability to process the qualitative data, analyze, interpret and finally integrate it into a sound knowledge model for an architectural design.

Introduction

Applications of artificial intelligence (AI) have gained a broad interest in civil/construction/ architectural engineering problems. They are used as an alternative to statistical and optimization methods as well as in combination with numeric simulation systems. Neural networks are powerful computing devices. They can process information more readily than traditional computer systems. This is due to their highly parallel architecture inspired by the structure of the brain. Applications and research into the use of neural networks have evolved from their ability to understand complex relationships and hidden patterns within large data sets.

<u>ANN and GA- concepts and definition</u>

Neural computing is a relatively new field of artificial intelligence (AI), which tries to mimic the structure and operation of biological neural systems, such as the human brain, by creating an Artificial Neural Network (ANN) on a computer. An ANN is a modeling technique that is useful to address problems where solutions are not clearly formulated or to validate the results obtained through other modeling techniques[1]. The network has the ability to learn by example. Patterns in a series of input and output values of example cases are recognized. This acquired "knowledge" can then be used by the network to predict unknown output values for a given set of input values[2]. An ANN is composed of simple interconnected elements called processing elements (PEs) or artificial neurons that act as microprocessors. Fig. 1 illustrates a simple processing element of an ANN with three arbitrary numbers of inputs and outputs[3]. Each PE has an input and an output side. The connections on the input side correspond to the dendrites of the biological original and provide the input from other PEs while the connections on the output side correspond to the axon and transmit the output. Synapses are mimicked by providing connection weights between the

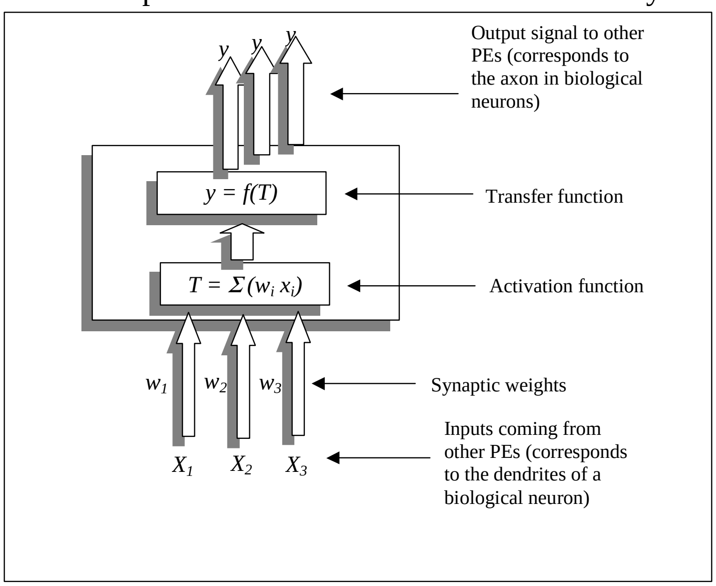

Fig. 1 Processing element of an ANN

various PEs and transfer functions or thresholds within the PEs. During training, once the optimum weights are reached, the weights and biased values encode the network's state of knowledge. Thereafter, using the network on new cases is merely a matter of simple mathematical manipulation of these values. Currently, back-propagation is the most popular, effective, and easy to learn model for complex networks[3, 4]. For the last few years, the first author has been using various ANN back-propagation Multi-layer Perceptron (MLP) modeling techniques in materials science[3, 4], structural/construction engineering[5-7], and construction management[8]. To develop a back-propagation neural network, a developer inputs known information, assigns weight to the connections within the network architecture, and runs in the networks repeatedly until the output is satisfactorily accurate. The weighted matrix of interconnections allows the neural networks to learn and remember[2].

Genetic Algorithm (GA) is an AI procedure based on the theory of natural selection and evolution. GA seeks to solve optimization problems using survival of the fittest with the different solutions in the population. In a typical optimization problem, there are a number of variables, which control the process, and a formula or algorithm, which combines the variables to fully model the process. The problem is then to find the values of the variables that optimize the model in some way. The conventional methods of search and optimization are too slow in finding a solution in a large or poorly understood search horizon, whereas GA is a robust search engine to find effectively the optimum solution in such an environment. GA usually begins with a random solution and keeps revising it until an optimal solution is found. The good solutions reproduce to form new and hopefully better solutions in the population, while the bad solutions are removed. A genetic search progress through a population of points on the contrary to the single point of focus of most search algorithms. It employs a population of strings initialized at random, which evolve to the next generation by genetic operators – (1) selection, (2) crossover, and (3) mutation. The fitness function evaluates the quality of solutions coded by strings. Selection permits strings with higher fitness to emerge with higher probability in the next generation. Starting from a randomly chosen crossover point, crossover combines two parents by exchanging parts of their strings to develop new solutions inheriting desirable qualities from both parents. Mutation flips single bits in a string, which prevents the GA from premature convergence, by exploiting new regions in the search space. GA tends to take advantage of the fittest solutions by giving them greater weight, and concentrating the search in the regions, which lead to fitter structures, and hence better solutions of the problem. There are several literatures available on optimization problems solving using GA [9, 10]. GAs have been applied by many researches in construction scheduling, resources management, and time-cost tradeoff problems [11-14]. A multicriteria computational optimal scheduling model, which integrates the time/cost trade-off model, resource-limited model, and resource-leveling model with GA searching technique was proposed by Sou-Sen and Chung-Huei [15]. Fang[16] described a hybrid approach to open-shop scheduling problems, which combines a GA with simple heuristic schedule building rules.

An Example of ANN and GA's Application

During the last decade, there has been a tremendous growth in interest in information system technology[17, 18] and the application of soft computing techniques to engineering and construction technology. Information technologies are used in various disciplines to address issues such as information processing, data mining, knowledge modeling, etc. Its final goal is to provide necessary aid to professionals during decision-making process. Design professionals are often confronted with soft data, which they somehow need to interpret and finally integrate into design. The architectural task is one such example having linguistic qualities as priory design information. This is especially the case when qualities of certain space are discussed, like for example in post occupancy evaluation of the buildings, where relationship between spatial characteristics and psychological aspects plays an important role[19]. Through a post occupancy evaluation, a designer will be able to look back and evaluate the flaws in his/her previous design. The designer will be able to assess what elements exceed customers' expectations and are significant in repeating in future, as well as those elements that fall short of expectations and may require adjustment for future projects. But in this process the designers are faced up to with qualitative data, and they need to deal with expressions like: bright lighting, bright colors, larger space, better parking directions etc. Thus a special method is needed for representation and processing of such vague expressions and concepts. From the evaluations, designers will come across various design aspects where genuine improvement is needed to achieve the customers' satisfaction, but at the same time they are concerned about financial viability. Therefore, designers need different scenarios from which they can work out the cost and level of satisfaction they will achieve.

The Artificial Neural Network (ANN) and Genetic Algorithm (GA) have exceptional ability to process the qualitative data, analyze, interpret and finally integrate it into a sound knowledge model for architectural design. This paper demonstrates an ANN and GA based knowledge model of customer's preferences regarding comfort and safety issues in a large residential multi-story flat housing scheme. For the study a 320 flat residential housing scheme in Poona, India was taken into consideration. Post occupancy evaluation was performed, in which the existing residents were asked different questions regarding safety and comfort of the structure and also their ideal expectations for each of them. Thus the qualitative data was processed and various different scenarios were worked out which would help the builders for their future projects or expansion of the existing projects.

Site selection

A survey was conducted to find out target customers for a large residential multi-story flat housing scheme (Figure 1), and it was found that the potential customers for such schemes came from the middle and upper middle class of society. Table 1 shows some important features of the residential housing complex.

Data collection: Before the data collection, approval was obtained from the Institutional Review Board (IRB). The data was collected in the form of a structured questionnaire. The questionnaire consisted of various aspects that were related to comfort and safety. In total there were 45 aspects/questions (Table 2). There were two columns, one for the existing structure and another for ideal expectations. The residents were asked to give their opinions about each aspect related to existing structure in the existing column and their ideal expectations about the same in the second column. Five-point scale was used to depict the range of importance from least to most for each issue. We were successful in getting response from 138 residents (one resident response per housing flat).

Figure 1: Multi-story Flat Housing

Table 1 Important features of the residential housing complex

Location	Paud road, Poona, India. Located in the heart of city.
Total area	21850 sq. m.
Number of buildings	20
Total number of flats	320
Number of story	4
Average number of residents per flat	4-6
Common Amenities	Swimming pool, play area for children, small common party hall, jogging track and gymnasium.

Data Analysis:

General Regression Neural Networks (GRNN)

General Regression Neural Networks (GRNN) are known for their ability to train quickly on sparse data sets. GRNN is an artificial neural network (ANN) that was used in this research. GRNN works by measuring how far a given sample pattern is from patterns in the training set in N dimensional space, where N is the number of inputs[20]. Out of the 138 responses, 100 responses for all 45 questions and their averages were trained in a GRNN model. The remaining 38 responses for all the 45 questions were compared in N = 45 dimensional space to all of the patterns in the training set to determine how far in distance it was from those patterns. Figure 2 shows a good agreement between the average and the ANN prediction. Hence, it could be assumed in this research that for every question the best representative value (one value, which represents the response of 138 residents) was very close to the average value of all the responses. Hence, in this research, we had taken the average value into consideration (Figure 3).

Table 2: Questionnaire	
Q1. Easy access to entry and exit gates Q2. Layout plan and proper building numbers at the entrance Q3. Proper direction boards Q4. Big and lighted sign board on each building Q5. Proper visitors and residents parking directions Q6. Bright lighting on internal roads Q7. Easy access to staircase and lift Q8. Spacious staircase and landing Q9. Bright color and lighting in the staircase and landing Q10. Proper ventilation of staircase and lift Q11. Short riser for the steps Q12. Railing in the staircase Q13. Generator back-up for lift Q14. Proper ventilation of the flat Q15. Ceramic tiles flooring in every room Q16. Light and sober shades in the rooms Q17. Good view of the surroundings Q18. Luxury fittings in bathroom and kitchen Q19. Concealed plumbing and wiring Q20. Proper electricity and light points Q21. Good specifications of doors and windows Q22.Wide passages Q23.Air Conditioning of the flat / provision for the same	Q24.Ready phone and cable connection with an extension facility in bedroom Q25. Elevation of the building Q26. Color scheme of the building Q27. External finish Q28. Landscaping in the surrounding areas Q29. Easy access to individual allotted parking area Q30. Bright lighting in the parking Q31. Clear numbering and naming of each parking lot Q32. Concrete flooring Q33. Club House Q34. Small common Party hall Q35. Play area for children Q36. Gymnasium and swimming pool Q37. Jogging track Q38. Security guards Q39. Collapsible door for flat entrance Q40. Enclosed grill for the balcony Q41. Smoke detectors and fire alarms in the flat and the staircase Q42. Safe surroundings Q43. Safety of vehicles Q44. Good building maintenance Q45. Emergency exit for every building

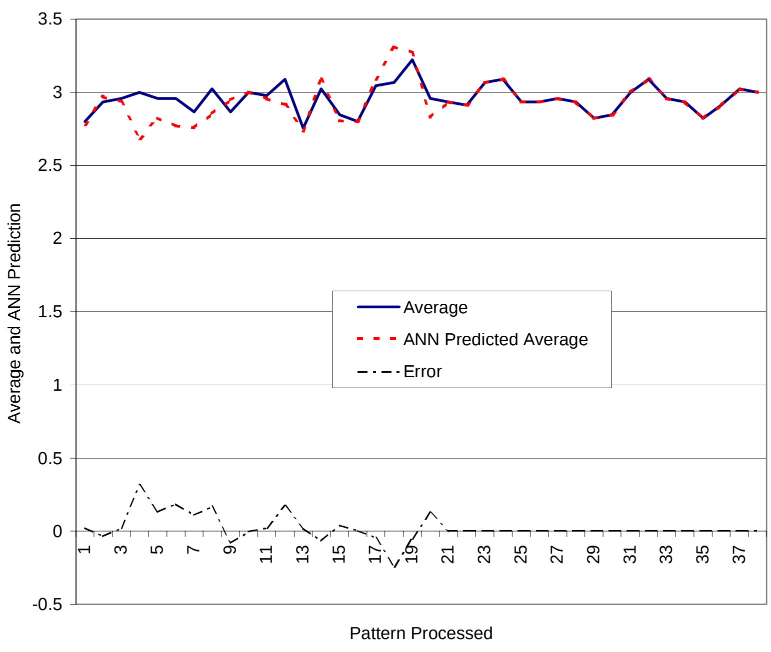

Figure 2: Response average and ANN prediction

Data Grouping

The questionnaire dealt with various issues related to the safety and comfort of parking, flat, building access, exteriors etc. Hence grouping of these issues was done, such as Safety-parking, Safety-flat, Comfort-access, Comfort-flat and so on. Figures 4 and 5 show the groups considering safety and comfort issues respectively where the y-axis represents the summation of positive difference between the expected average and existing average $\sum$ (Exp – Ext). It was observed that some questions affected several different groups.

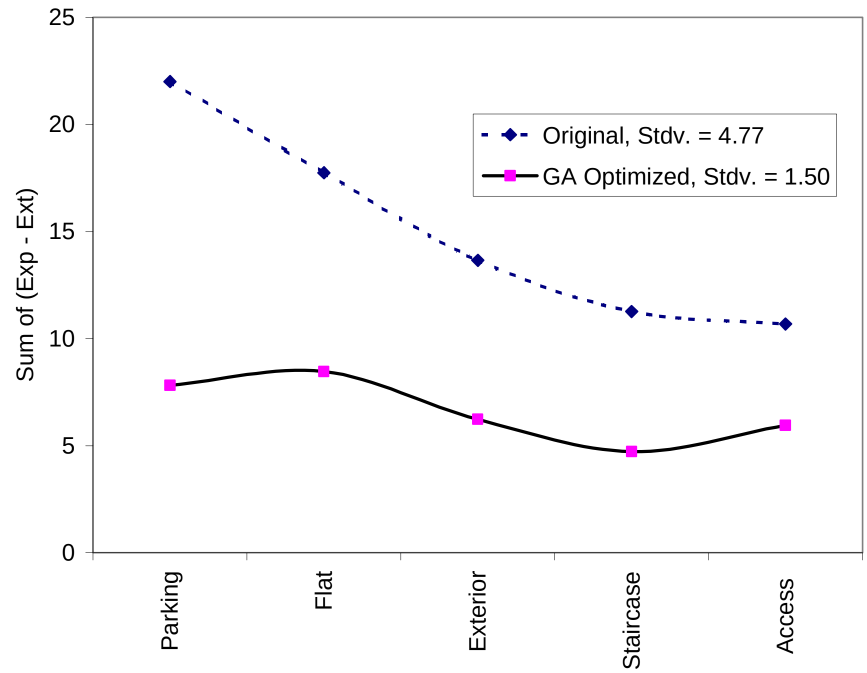

Figure 4: Before and after GA optimization scenario in safety issues

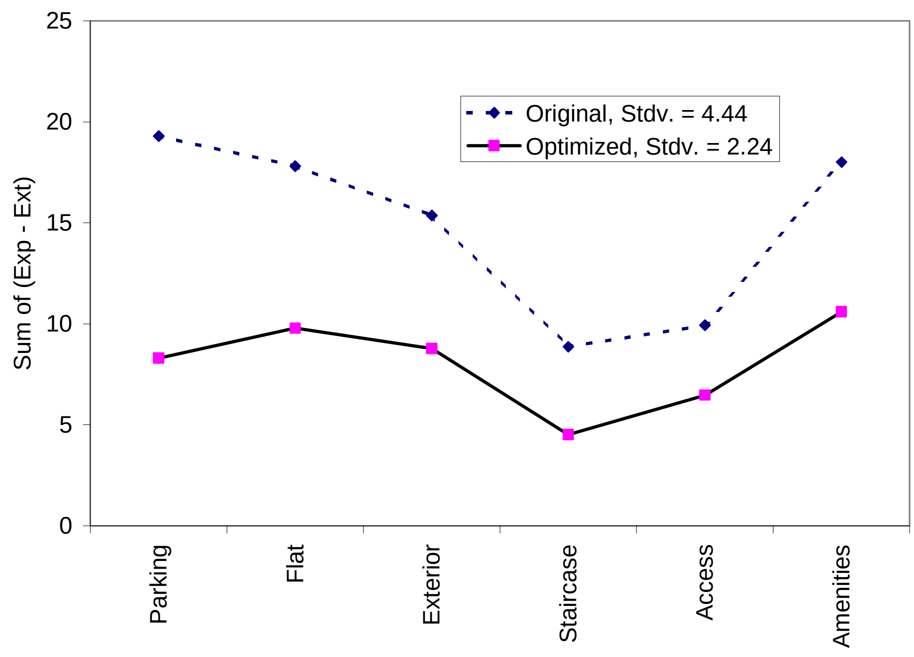

Figure 5: Before and after GA optimization scenario in comfort issues

Genetic Algorithm (GA) Modeling

From Figures 4 and 5 (original curves), it was evident that the maximum number of questions affected two groups namely Safety-parking and Comfort-parking. Some of these questions also affected other groups. For example Q6, which affected safety-parking group also did affect six other groups. Hence if the issues affecting Safety-parking were rectified, there would also be reduction in the ∑(Exp-Ext) for other groups. In this paper, we focused on rectifying the issues in the safety-parking group. Hence chromosomes were set for all the questions which affected Safety-parking group and which had (Exp-Ext) >0. Thus there were 14 different questions, which were set as chromosomes. A chromosome is a part of an individual: each individual in the population may be composed of one or several binary and/or enumerated chromosomes. The contents of all the chromosomes in the individual determine its fitness. The main task of the genetic algorithm is to create individuals with the highest fitness value, i.e., with the best genetics. When using the GeneHunter Excel interface, the adjustable cells represent individual chromosomes for the continuous type. For the enumerated type, all of the adjustable cells compose a single chromosome.

Before the GA optimization was performed the ∑ (Exp-Ext) was 22.07, and overall standard deviation for all the Safety groups was 4.77. To minimize the overall standard deviation for all the data for safety group (Figure 4), the GA was applied using GeneHunter, the software from Ward Systems Group, Inc. GeneHunter includes an Excel Add-In which allows the user to run an optimization problem from an Excel Release 7, Excel 97, or Excel 2000 spreadsheet, as well as a Dynamic Link Library of genetic algorithm functions that may be called from programming languages such as Microsoft® Visual Basic or C. After using GA optimization, it was found that the ∑ Exp-Ext of Safety-parking group was reduced from 22.07 to 6.17 and standard deviation was reduced from 4.77 to 1.50 (Figure 4). Similarly in case of comfort, the standard deviation was reduced from 4.44 to 2.24 (Figure 5). Thus by just rectifying the parking issues also did reduce the ∑ Exp-Ext and standard deviation of the other groups. On the similar basis other scenarios can be worked out using the model. Thus if we would also rectify questions affecting Comfort-flat, then once again it would also affect other groups positively, by further reducing their ∑ Exp-Ext and overall standard deviation. Similarly, by setting chromosomes for all the questions, which affected more then 6 groups, we would get another scenario.

Now with the scenarios worked out, comes the builder’s judgment into picture. Looking at the scenarios the builder has to decide what is affordable to him/her and how much customer satisfaction will be achieved.

Summary and Conclusions

Artificial intelligence (AI) applications have gained a broad interest in civil/construction/ architectural engineering problems. Its applications are very extensive and interdisciplinary. The graduate students civil/construction/architectural students should especially be encouraged to learn various applications of computing techniques including artificial neural network (ANN), genetic algorithm (GA), etc. Presently, there are no courses on AI applications for the undergraduate and graduate students at the Construction Science Department of Texas A&M University. Under "Directed Studies" (3 Credits), the first author has been teaching applications of AI to interested graduate students. Some interested students do their graduate projects and thesis in AI applications.

This paper highlights various applications of AI through an example and referring other research papers. As an example of a graduate project, this paper demonstrated an ANN and GA based knowledge model regarding comfort and safety issues in a large residential multistory flat housing complex. Through post occupancy of building evaluation, the builders/designers able to assess what elements exceed customers' expectations and are important in repeating in future projects, as well as the elements that fall short of expectations and may require modification for the next projects. During this process, designers are challenged with soft data, which are linguistic qualitative in nature, and needed to interpret and integrate into their design decision making processes. This paper demonstrated an Artificial Neural Network (ANN) and Genetic Algorithm (GA) based knowledge model of customer's preferences regarding comfort and safety issues in a large residential multi-story flat housing scheme. The data in the form of a structured questionnaire regarding comfort and safety issues was collected. A five-point scale was used to depict the range of importance from least to most for each issue. A General Regression Neural Networks (GRNN) model was trained and evaluated in order to determine the best representative response for each question. The questionnaire dealing with various issues related to the safety and comfort were grouped into various grouping for GA optimization, and created various scenarios to improve safety and comfort for the studied housing complex one of which was discussed in this paper. It was observed that ANN and GA have exceptional ability to process the qualitative data, analyze, interpret and finally integrate it into a sound knowledge model for architectural design.

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