# Chapter 12

## CONCLUSIONS AND CONTRIBUTION

### 12.1 SUMMARY

Optimization is the process of getting maximum benefit from minimum resources. The optimization has been the goal of human being in every field of real life since their evolution. As a result of this, many optimization methods have been developed to resolve diverse optimization problems. These methods have their own merits and demerits. Soft computing tools such as GA, ANN and FL have been proved to solve variety of optimal decision-making problems of real life more efficiently, if properly modeled, compared to available hard computing tools.

Unlike traditional hard computing, which is based on precision, certainty, and rigor, the primary aim of soft computing is to exploit the tolerance to achieve tractability, robustness, a high level of machine intelligence and a low cost in practical applications. In the present study an attempt was made to make the efficient use of various present days' soft computing tools to solve a wide spectrum of structural engineering problems. Number of programs were developed in Visual Basic based on soft computing techniques to fulfill the objective of present study of development of optimization software for use in the field of structural engineering. For each type of optimization problem, separate pre-, main- and post-processors were developed to facilitate respectively easy input of data, proper processing of selected methodology and attractive graphical output depending upon the type of problem.

GA is problem independent algorithm in the sense that sequence of steps is not modified for each new run or each new problem. The methodology is heuristic and is useful when search space is very large or too complex for analytic treatment. Using a population of guesses in GA to solve the optimization problem significantly differs from those solvers using a single guess. The main idea is that the genetic information of a good solution spreads over the entire population. The selection operator picks up the relative fitter strings according to their objective function values. Then the newborn trial solutions are generated from the relative fitter string with the crossover operator. Avoiding the trial solution trapped in a local region is the main idea behind the mutation operator. As GA is robust randomized search method it was employed in design optimization of RCC and steel skeletal structures as well as continuum structures.

FL mimics the approximate reasoning capability of human mind. It is capable of solving decision making problems in fuzzy environment even in a better way than a human expert. In the present work it was exploited to solve RCC design problems as they contain fuzziness and uncertainty in the design method, structural behaviour and material behaviour. RCC design examples varying from that of simple RCC slab and different types of footings to specialized structures like folded plates, silos and hyper shells were attempted.

NNs are the mathematical models which can simulate simple to complex system behavior where the exact mathematical modeling is not possible and available information about the system contains noisy data. Among various ANN models in existence BPNN model was selected in the present study because of its popularity and wide applications. Pure ANN has, however, very limited use in optimization but it can be used as an aid on to other soft computing tools to be more effective.

The principal constituent methodologies in SC are complementary rather than competitive. The complementarity of FL, NN and GA has an important consequence: in many cases a problem can be solved most effectively by using FL, NN, and GA in combination rather than exclusively. When used together they can produce solutions to problems that are too complex or inherently noisy to tackle with conventional mathematical methods. Individual soft-computing tools such as GA, FL and ANN, therefore, were combined in the present work to overcome their limitations and extend their capability to solve wider range of problems. Some of the problems which were attempted by GA and FL separately were also solved by GA-Fuzzy approach to demonstrate advantages over individual methods.

Concrete mix design is the decision making problem in uncertain and vague environment where exposure condition, quality control etc. are expressed in vague terms. Hence concrete mix design problem was solved by Neuro-Fuzzy model wherein certain charts were simulated by BPNN. As optimum concrete mix design optimizes the quantity of ingredients to get maximum strength at minimum cost, it helps in overall reduction in cost of RCC structures and hence it was also included in the present study where GA was used to optimize the mix design carried out by Neuro-Fuzzy approach.

## 12.2 CONCLUSIONS

1. Visual Basic as a programming language for the present work is found quite appropriate due to its Windows based menu driven facilities, easy syntax, powerful graphical features, debugging facilities and availability of a number of inbuilt functions which has helped considerably in faster development of the software.
2. VB also allows easy linking of databases created in Microsoft Access, Oracle etc. This feature of VB proved really very helpful in providing an easy access to various tables like the steel table, permissible compressive stress in steel sections (Table 5.1 of IS: 800), design shear strength of concrete (Table 19 of IS: 456) etc.
3. In event driven programming languages, subroutines and functions can be assigned to certain events of input devices such as single click of mouse, double click of mouse, movement of mouse over an object, loading of an object, pressing certain key of keyboard etc. Also, one can develop the interface in which supports and loading can be assigned graphically on the screen without typing input data manually which makes data entry and editing very fast. All these features of VB helped in developing a software with professional touch.
4. Classical optimization techniques lack a global perspective of the problem and often get converged to local optimum solution. Apart from being serial in nature, they do not have the breadth to solve different class of problem with a single method. All the above problems are eliminated when GAs are used for optimization.
5. Various inbuilt functions of VB are found specially helpful for development of software based on GA. For example, the *Rnd* function generates random numbers which suffice the need of separate subroutine for the same, the functions such as *Mid, Right, Left, Len* etc. are useful for binary string operations of GA such as decoding, crossover and mutation. Thus, no separate coding is required for all these operations in VB based program.
6. Once the algorithm is ready, a fine-tuning of all genetic parameters and penalty factors is required for convergence to occur. The selection of optimization parameters for GA needs a careful study of the entire problem at hand because these parameters are problem dependent. The values of GA parameters such as probabilities of crossover and mutation as 0.67 and 0.03 have been recommended by different research worker after several trials. In the present work, the cross over probability from 0.6 to 0.9 has been used successfully for different problems. Mutation probability varying from 0.002 to 0.05 has been found suitable for different

applications. Also, in the present study single point crossover was operated on every substring after being separated from the main solution string. This helped in faster search for best solution.

7. Various selection schemes are in use nowadays. In the present work the two most popular schemes i.e. roulette wheel and tournament selection schemes have been tried for different problems. Tournament selection scheme outperforms the roulette wheel scheme. Also, incorporation of some of the advanced GA operators like dynamic mutation and Elitist selection scheme in the software has shown considerable improvement in the performance of the algorithm.

8. Elitism that has been used in most of the applications improves the efficiency of the algorithm and reduces memory requirement considerably. For the present work, only a single best individual is retained. However, two or three best individuals may also be retained. Moreover, since the best solution is programmed to appear as the last individual in the generation the intermediate solutions need not be stored. Otherwise, the best solution may occur anywhere during a run.

9. It is observed that GA can not be used for those problems where effect of change in design variables is to either increase or decrease the fitness continuously. GA may actually perform worse than traditional techniques for some of the problems.

10. In the constrained optimization problem the constraints are handled by penalty approach. Quadratic penalty approach has been used in most of the applications and is found to concentrate the search in the feasible region.

11. GA needs no feasible initial values, and this eliminates many troubles. GAs search is non-sequential. It explores a population of trial solutions instead of a single one, and therefore GAs are more capable of locating the global optimum.

12. For stopping iterative process of optimization, one may specify either maximum number of generations or suitable convergence criterion. For simple problems having small search space, it is recommended to use maximum number of generations as stopping criteria to avoid possibility of going in to a large number of loops.

13. Being random search process GA does not guarantee the optimum result in a single run and hence several runs are required to get the result nearer to optimum solution. It is observed that the optimum solution obtained may differ upto 5%, with different run in case of multi variable optimization problems, while in single variable problems the difference is very small.

14. Optimum design of R.C.C. isolated footing takes an average time of 2.297 seconds for a population size of 50 and 25 generations whereas the water tank problem takes 7.293 seconds for population size of 75 and 100 generations. The optimum design of Gantry girder takes an average time of 4.277 seconds for a population size of 20 and 50 generations. The topology optimization of truss problem is the most time consuming problem. The time consumed by a 10 m x 5 m search space problem for a population size of 10 and 1000 generations is 1 hour and 30 minutes i.e. an average time of about 1/2 second for each cycle.
15. Though the rational approach in size optimization of truss is to consider the member areas as discrete variables, the program also provides the facility to take members cross sectional areas as continuous to enable the comparison of the solution obtained with those available in the literature where the cross sectional areas are considered as continuous design variables.
16. In the shape/configuration optimization process, the coordinates of joints are allowed to vary within the feasible domains in addition to member sizes. During this process, the member size and joint coordinates are treated as design variables, giving maximum flexibility to arrive at entirely new structural forms. Provision made in the software for display of all intermediate profiles makes the whole exercise very attractive.
17. From the configuration optimization problem of plane truss, it is found that the convergence time depends on the number of members. Small problems satisfy the convergence requirement in less number of generations.
18. For an 18 bar cantilever truss example, with population size 20 and number of generations 30, the time taken for arriving at optimum configuration is 12 minutes 30 seconds on Pentium III computer with 450 MHz processing speed.
19. For a cantilever truss problem under same loading and support conditions, four different topologies were tried to arrive at best topology which is found to match with the solution available in the literature.
20. The software also encompasses all the three aspects of truss optimization at the same time. i.e. simultaneous optimization of size, configuration and topology of plane trusses using GA. The program uses a novel concept of "sectors" which act as switches for on-off status of nodes and members. Member sections are selected randomly from a database of steel sections. The objective is to obtain such a combination of geometry and member sections that the overall weight of the truss is

minimum. The most outstanding feature of the proposed concept is that no "ground" structure (which normally acts as a starting point in search of better structure) is required. The only data to be provided is the dimension of the search space within which the truss should lie and the position of support and loads. Although, this feature prolongs the attainment of the global optimum, it gives the software a potential to develop new shapes of trusses which are free from conceptual designs.

21. In the space truss application, the configuration optimization problem takes about thirty minutes time for a population size of 50 and 100 generations on P-III processor with 450 MHz processing speed. However, topology optimization requires about six to eight hours for population size varying from 200 to 350 individuals and 100 generations.

22. Solution of large real-life problems such as optimum design of space truss structure illustrates the capability of the GA based software to consider many such practical large size problems.

23. The total execution time depends on the total number of iterations and the string length. Increasing the string length increases accuracy. However, it increases the time required.

24. It has been clearly demonstrated that the software developed based on GA can be used to find out optimum or closer to optimum solution of the various types of problems. The preprocessor supports the interactive data entry with instant visual feed back by providing the display of structure with joint and member numbering and support and load conditions. The display of results for displacements, reactions and member end actions is handled by postprocessor which not only facilitates faster interpretation of results but also an easy comparison with available results.

25. In topology optimization of continuum plate, the proposed identical initialization demonstrates better performance than the conventional random initialization since the former can help in generating more connected topologies in the early generations. The performance of the bit-array GA is significantly improved when the design connectivity is handled by additional constraint handling technique. As the time for analysis is very important in GA based optimization methodology, different methods were tried to solve the matrices. The time is found to reduce considerably when L-U decomposition method (Gauss Doolittle method) is used instead of inversion of matrix method based on Gauss elimination method. As the cost is directly proportional to the weight of the plate, the optimum solution which corresponds to

minimum weight concept is cost-effective. The cost saving found in GA solution for 6 x 6 mesh is 58 %, for 8 x 8 mesh it is 69 % and for 10 x 10 mesh it is 71%. However, the solution time increases considerably with increase in number of elements.

26. In design formulation based on fuzzy logic, the selection of performance and induced fuzzy set parameters is very important and requires thorough knowledge of the problem in hand. Selection of range of input parameters for developing input fuzzy sets is also very important because the optimum combination is found from this range.

27. In optimum design of different types of slabs, it has been found that as depth increases, the performance parameter $(l/d)_{per}$ increases and induced fuzzy set parameter $(l/d)_{act}$ decreases. Thus the match point satisfies functional requirements (i.e. deflection criteria) giving optimum value of depth.

28. When results obtained from FL based software are compared with the available solutions, the percentage saving in cost in optimum design of different types of slabs is found as follows:

- Simply supported one-way slab = 8.92 %,
- Continuous one-way slab = 13.45 %,
- Simply supported Two-way slab = 5.66 %,
- Continuous one-way slab = 7.45 %.

29. In fuzzy logic controlled optimization of plane frame and grid problems, as number of members increases, the computational time required for optimization also increases.

30. In optimum design of some of the problems, the nature of induced fuzzy sets indicates that some of $\alpha$-cuts has same stress values. To overcome this problem, the interval of $\alpha$-cuts may be increased depending upon the size of problem, which will also reduce the computational time.

31. The developed software allows selection of various geometry restraint conditions depending upon the problem in optimum design of combined footing. It has capacity to deal with axial load, moments and horizontal loads. It also provides analysis results in graphical form, which is easy to understand.

32. The software based on FL indicates about 8.10 % and 4.22 % reduction in cost of rectangular combined footing and strap footing examples respectively.

33. In case of optimum design of cantilever retaining wall, when results are compared with available solution, decrease in depth of base and stem is found using optimization algorithm based on FL and thus the cost of cantilever retaining wall

reduces by about 7.9 %. Further, it has been found that this type of wall is economical up to a height of 7 m. Beyond 7 m height the cantilever type retaining wall is uneconomical because of higher moment developed.

34. The prepared software can optimize the silos up to a capacity of 39000 kN. It has been observed that silos are most economical between capacity 24000 kN and 37000 kN because they utilize maximum tensile strength of concrete. Beyond 37000 kN capacity silos are not that economical because of tremendous increase in thickness. Moreover, different types of design graphs calibrated using the developed software with different weight of fill as a main function, may prove very useful for finding directly the optimum values of variables such as height of silo, diameter of silo, thickness of side wall, percentage steel for side wall and cost without making use of the software.

35. The optimization study of the Vee-type of folded plates indicates that such plates are most economical with inclination angle between 45 and 50 degrees. If angle is less, the plate width reduces, resulting into lesser concrete in compression zone. Hence compressive stress in concrete increases and the constraint on it becomes active. Using FL, the cost of folded plate for the given example is found 19.15 % less compared to conventional design.

36. For the example of 12 m x 12 m size hyper shell, the cost of hyper shell with the design based on FL is found 11.72% less as compared to that based on conventional design. Also, for hyper shells, it is seen that up to 19 × 19 m there is increase in cost with size but between 19 m and 21 m there is reduction in cost and beyond 22 m there is tremendous increase in cost and such shells are not economical beyond 23 m x 23 m size.

37. Proposed GA-Fuzzy approach used for optimization of truss configuration performed well compared to pure GA approach. In the example of cantilever truss, weight of the truss obtained in the second run is found to be 5.76 % lower than that obtained in first run due to relaxation in the constraints. The solution obtained by the combined GA-Fuzzy approach is about 1 % cheaper than the pure GA. The optimum solution obtained through hybrid approach is found to violate the constraints by very little amount (i.e. 0.2 % to 1.45 %), which is acceptable due to fuzziness involved in the analysis and design. The solution obtained through GA-Fuzzy approach is found better than four other algorithms reported in the literature.

38. In the simply supported truss example, the optimum weight obtained in the second run is 16.5 % lower than that obtained in first run. The solution obtained by the combined GA-Fuzzy approach is 10.6 % cheaper than pure GA. Only two constraints are found to be violated by only 1.38 % and 0.19 % in the optimum solution. Moreover optimum solution obtained through proposed GA-Fuzzy approach is significantly cheaper than that obtained by pure GA. The example of combined footing addressed using this approach also showed superiority of GA-Fuzzy approach over pure GA and pure FL approach. Also, in case of topology optimization of in-plane plate problem, the hybrid approach gives 3.7 % more economical solution compared to pure GA.

39. The main advantage derived of combining GA with ANN is that time taken to train the network is reduced considerably, as in this case first the parameters are optimized using GA and those optimized parameters are further used for training the data using ANN. Thus it is not necessary to spend time and effort in determining the parameters of ANN by trial and error.

40. Along with advantages, disadvantages go hand in hand. When GA is applied to resolve the difficulty in determining the parameters of ANN, GA also uses trial and error to determine the parameters of the genetic operators. The selection of population size, number of generations and crossover and mutation probabilities plays an important role and hence must be selected with utmost care.

41. In the example of modeling confined compressive strength and strain of circular concrete column, the BPNN simulator gives RMSE of 0.0024 after 500,000 training cycles and takes training time of 42 minutes. GANN with weight optimization gives better results as compared to BPNN simulator and takes less training time and training cycles. On the other hand, the total time taken in topology optimization and further training the optimum topology with BPNN was 1 hr 6 min 28 sec after which the RMSE of 0.0024 was obtained. This is more than double the time taken by weight optimization.

42. From the example considered in the present work, it can be concluded that for weight optimization, the GANN simulator outperforms traditional neural network training. GA based search do considerably better than random search for weight values. On the other hand, architecture optimization by a GANN simulator comes with a high computational cost. If only one specific problem is to be examined, the search for a good architecture using GA can hardly be justified. Using a relatively poor architecture and spending more computation time on excessive training will be more

fruitful. However, if the goal is a good topology for a large class of similar problems then the application of GANN architecture optimization is recommended.

43. The fuzzy optimization problems have been tackled by many researchers using mathematical programming techniques. In the present work GA has been used for solving fuzzy optimization problem of design of combined footing and design of plane truss. For this GA program was bit modified by incorporating fuzzy logic in constraint handling technique of GA. The proposed modification is found to provide competitive solutions.

44. Unlike some controllers with hundreds, or even thousands of rules running on dedicated computer systems such as in Expert Systems, in present work a unique Fuzzy Logic based system using a small number of rules and straightforward implementation was proposed to solve a classic problem of concrete mix design. Application of the fuzzy model to a hypothetical concrete mix design and comparison of the results with available literature, demonstrated its ability to tackle the mix design problem in any practical setting.

45. Various shapes of Membership Function (MF) have been tried for different variables. It is found that S-shaped MF suits best for target strength, quality control and zone of fine aggregates whereas Triangular shaped MF suits best to find percent of fine aggregates and w/c ratio.

46. The Weighted average method of defuzzification has proved to be the most suitable method; considering accuracy of obtained results as well as looking to programming simplicity associated with the method.

47. The developed software for mix design is quite general which after taking into account all adjustments displays the mix design results in quite attractive form and can be safely used for different size of aggregates i.e. 10 to 40 mm, different types of workability i.e. very low, low, medium and high and under different exposure conditions such as mild, moderate, severe, very severe and extreme and for any grade of concrete form M20 to M60.

48. The results in terms of quantities of cement, fine aggregate, coarse aggregate and water obtained through the present study for the various grades of standard concrete mixes proved that the neural networks and fuzzy logic can be conjointly used to accomplish the specification of relationships among numerous variables in a complex dynamic process of concrete mix design. This clearly shows that the conventional

method, which is approximate, is tenable to be treated under the integrated AI concepts of fuzzy logic and neural networks.

49. Multi-objective evolutionary algorithm ENSGA-II was used to optimize the mix proportion obtained from Neuro-Fuzzy approach. The algorithm was tested using benchmark problem presented in IS code. This algorithm gives number of non-dominated results. So, to select one good solution from the obtained results by ENSGA-II, hybridization was carried out for dual objectives of cost and strength during the calculation of fitness for any solution. The objective functions used for optimization was based on maximizing the strength and minimizing the cost. In optimization problem BPN model facilitates prediction of 28 days compressive strength for generating the non-dominated front and for calculation of cumulative fitness. Again to verify the optimized mix proportion BPN simulator was adopted, which confirmed the validity of obtained results. Thus hybridization of different soft computing methodologies looks logical and strongly justified.

50. From the comparative study between GA based and FL based software it has been found that GA is more suitable particularly for steel structural optimization where design variables are discrete in nature and FL does not find application in such cases.

51. Fuzzy logic is more appropriate for RCC structures which involve fuzziness or uncertainty. It does not involve much of the calculations as in GA. It gives the result faster than GA but does not guarantee global optimum. Also designers experience plays an important role in deciding the range of variables in FL.

52. GA is more suitable to problems containing large numbers of variables such as problems of combined size configuration and topology optimization of plane and space trusses which can not be solved by merely fuzzy logic based $\alpha$-cut method. Although GA takes more computational time there is a good possibility of getting global optimum or near global optimum solution.

53. Main advantage of GA and FL can be achieved by combining them as it is applied in configuration optimization. It not only gives the near optimal solution but also considers the fuzziness involved in design.

## 12.3 CONTRIBUTION

1. In most of the applications of soft computing tools reported in the literature direct processing of the algorithm has been carried out without any interactive graphical processing. In the present work, pre-processor has been developed to facilitate menu

driven entry of data with suitable feedback on screen for each type of application separately. While main-processor is developed based on the selected algorithm for optimization, the post-processor not only facilitates display of convergence graph but also provides the output such as reinforcement detailing etc. in graphical form. All these features included in the software for very large category of problem not only makes the software versatile but also makes the application of the software quite attractive.

2. Varieties of RCC structures such as retaining wall, water tank, silo, folded plates, combined footing and hyper shells have been solved using both GA and FL based optimization algorithms which have not yet been reported yet in the literature. It is found that GA gives near optimal solution while Fuzzy logic gives the results taking in to consideration imprecision involved in the design methods.
3. A large number of new steel structures have also been attempted in the present work for different types of optimizations i.e. size, configuration and topology optimization using GA and hybrid techniques.
4. In the topology optimization of plane trusses variable rate mutation operator has been proposed which gave the results better than constant rate mutation. In variable rate mutation to get better genetic diversity the mutation probability is kept larger in the initial generations which is then reduced in the later generations to allow GA to converge to an optimum solution.
5. Existing classical optimization techniques have not yet received the appreciation of practicing engineers, as the built in models are too difficult to understand. It is in this context the application of fuzzy set based approach offers a simple and potential alternative to conventional optimization.
6. In the GA-Fuzzy approach the concept of fuzzified constraints has been proposed to improve search in optimization of truss configuration and proved to be better than all other available algorithms.
7. In the space truss topology optimization the proposed methodology gave the results better than those existing in the literature. Further the reported results by others were found to give unstable structure whereas the suggested methodology always leads to a stable structure.
8. A successful attempt has been made for optimum design of concrete mix using combination of GA, FL and ANN which has not been tried so far by any researcher. The modular strategy adopted in the present work for capturing different design

parameters, making individual network specialized for different input and output pairs offers fruitful results in terms of reality and precision and makes the mix design process more natural and flexible compared to any hard computing tools. It is hoped that the site engineers will make full use of the same to their advantage and will carry out the concrete mix design in a more scientific and technical manner.

9. The developed software is quite versatile as one can solve wide spectrum of structural design problems involving discrete and/or continuous design variables. The software provides the choice of optimizing most of the RCC design problems using not only FL and GA based methodologies but also hybrid techniques.

## 12.4 FUTURE SCOPE

1. Though GA is good for large search space, it may at times get stuck up at a local maximum. This is indicated by a rapid convergence of all the solutions to a single solution early in a run. This area needs to be explored further to improve the ability of GA to get to the true global optimum.
2. As GA also requires trials to determine the parameters of the genetic operators, further research can be carried out to find the way to minimize these trials. Also, in the software developed based on GA other advanced GA operators may be incorporated to see their effect on the results obtained in this study.
3. GA based software may be extended to carry out shape optimization of large truss bridges, transmission towers etc. The time and effort required for such case, however, will be very high.
4. The present work was limited to topology optimization of thin rectangular plate subjected to plane stress condition. This may be extended to rectangular plate-bending problems having holes or no holes. Shape optimization of different types of shell structures may also be undertaken.
5. The problem of topology optimization of circular and annular plate problems under in-plane and lateral loading conditions may be attempted using the suggested methodologies in the present work.
6. The use of genetic algorithms in dynamics of structures still needs to be explored. The different possibilities are: to optimize the frequency of the structures, to find the optimum location of dampers in a structure, to find the location of shear walls etc. This may require domain knowledge of response spectrum method, and will be certainly computationally expensive.

7. In the present work, optimum design of one-way and two-way slabs was undertaken. The other type of slabs such as flat, grid and circular slabs may be taken up for optimum design based on fuzzy logic.
8. Analysis of plane frame and grid problems was carried out in the present work only for static loads. Analysis for dynamic loads and optimum design based on fuzzy logic may be fruitful extension of the present work. The optimization of three-dimensional R.C.C. frames using fuzzy logic may also be thought of.
9. The optimum design of box-culvert, intz type water tank, conical or funnel shaped tank and other such structures may be explored using fuzzy logic concept. Also, other types of foundations like strip footing, raft foundation, and pile foundation may be tried for cost optimization.
10. The use of FL with GA can be explored further by choosing different membership functions to obtain better results for the optimization problems considered here. In the present study FL has been employed to improve the performance of GA, similarly GA can be used to improve the performance of FL.
11. In the present study ANN has been mainly used with other soft computing tools. The possibility of exploiting ANN alone for structural optimization can be explored.
12. GANN simulator for simultaneous weight and topology optimization can be developed. Although cumbersome, simultaneous optimization of number of hidden layers and hidden nodes can also be attempted.
13. In the present work, integration of only BPNN and GA has been tried. Mating of GA with other neural networks may be explored.
14. GANN simulator has been applied in the present work to a couple of small size structural engineering problems. Future work should focus on robust GANN systems that can be used for real large size practical problems. However, one of the major drawbacks of both GAs and NNs is their time consuming processing because of being iterative in nature. Implementing the same in parallel or distributed processing environment may result in faster convergence and may reduce computational time considerably.
15. In the continuum structure optimization, the FEM analysis for large number of elements is time consuming. A trained ANN can be used to carry out this analysis and thus constraint and fitness evaluation which may reduce the computational time significantly.

16. In the present work for modeling of BPN simulator, regression equations were used. It is desirable to develop the relationship between w/c ratio versus 28 days compressive strength of concrete separately for both OPC and PPC cements experimentally and use the same for training and testing of BPN simulator.

17. The software module developed for FL based optimization in the present work was entirely coded in the Visual Basic environment. Coupling the same with MATLAB software, which has an inbuilt fuzzy logic library, can increase the computing power of the software.