CHAPTER 7 *Conclusions*

In this thesis, an optimization technique based on response surface methodology has been presented. Response surface methodology seeks to replace implicit functions of the original design optimization problem with an approximation model less expensive to evaluate. In order to address the issues of the high-computational cost of the implicit function evaluation and the presence of noise in their values, genetic programming methodology has been investigated to build approximation models of the best possible quality.

The selection of the function structure is a critical step in the construction of the approximation. Traditional techniques require the specification of the structure in advance, forcing the designer to assume models of low quality but relatively easy to build. The goal of genetic programming is to evolve mathematical expressions with no assumption about the structure, which is given as part of the solution.

Careful planing of the points where the response is evaluated greatly influences the construction of the approximation. In this thesis, the Audze-Eglais plan of experiments has been used because it presents a "space-filling" property due to a distribution of points based on their maximum separation.

The approximation model is defined not only by the structure, but also by a set of tuning parameters. It has been reported that genetic programming cannot handle constants efficiently. Accordingly, in this thesis, the tuning parameters have been identified by a gradient-based optimization algorithm combined with a genetic algorithm acting as provider of an initial guess.

The previous point separates two possible sources of inaccuracy of an approximation function, i.e. inadequacy of the model structure and errors in the tuning parameters. Different expressions are only compared to each other after being fully tuned. Therefore, the fitness function for each individual approximation model depends only on its structure.

The global optimization methodology has been implemented in a computer code for testing. Genetic programming works with a population of potential solutions built randomly from a library of mathematical functions. In this environment, a solution is an empirical model that approximates the response. The population evolves according to Darwin's principle of survival of the fittest based on the fitness values of individuals. In this thesis, the definition of the fitness value can include derivatives, if they are available. Application 5.4 has demonstrated that the use of derivatives is beneficial for the reduction of the necessary number of points in the plan of experiments.

The developed methodology has been applied to two types of applications: first, with numerically simulated responses and, second, with experimental responses. The former use data obtained from a numerical simulation of a system or a process, while the latter use results of physical experiments.

In the problem of detection of damage in steel structures, genetic programming has successfully approximated the implicit functions of the original model obtained by the finite element method. An important observation from this example is the ability of genetic programming to find a solution in a large range of design variables.

The prediction of the shear strength of reinforced concrete deep beams is another important problem. There is no universally agreed model available and a design procedure has not yet been developed or shows poor agreement in the different codes of practice. Genetic programming has successfully found a model that agrees well with experimental work. In this case, the prediction is valid even outside the range defined for experiments. Engineering judgement has been critical to find a physically correct and compact model that satisfies additional constraints provided by the engineering knowledge.

Genetic programming has also been successfully applied to multicriteria optimization in the process of calcination of Roman cement. First, models have been generated by genetic programming to describe developments of all relevant minerals involved in the calcination process. Second, the strength development has been modelled. The multicriteria optimization has been formulated and a Pareto-optimal set of solutions has been obtained. The selection of the optimum solution has to be guided by the engineering knowledge of the designer. The produced contour plots have been used to better understand the underlying process of the calcination of Roman cement.

All the results of the applications show that genetic programming is a powerful tool for obtaining high quality approximations in real-life design optimization.

Recommendations for further research include the following points:

- Testing of the genetic programming methodology on problems with larger number of design variables.
- Investigation of the relative merits of high-quality global approximations versus iterative mid-range approximations of lower quality.
- Application to problems of extreme complexity where more traditional techniques are hardly applicable because of the prohibitive computational cost.
- Improvement of the computational efficiency of the algorithm, particularly the evaluation of tuning parameters.
- Development of a graphical user interface.
- Parallel implementation for implicit function evaluations and fitness function evaluation.