HYBRID OPTIMIZATION FOR COMPLEX FAÇADE SYSTEMS

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ABSTRACT

Evolutionary genetic optimization algorithms (GA) have been used for thermal building optimization in the past. However, the application of these algorithms for optimization problems with a high number of parameters to be optimized can result in solutions not close to the global optimum. Furthermore, the sole use of the Genetic Algorithm is extremely computative intensive. In this study, a hybrid single objective building optimization algorithm is introduced which combines an evolutionary genetic algorithm with another algorithm for local refinement of the parameters. In this study, the GA is combined (1) with the modified harmony search algorithm, and (2) with an interpolation method.

The goal of this paper is (1) to illustrate that the GA does not always provide solutions close to the global optimum for this type of optimization, and (2) to provide a building optimization method, which provides a higher reliability than that the GA alone can provide by using a relatively short computation time.

Results illustrate that the hybrid GA coupled with the refinement method provides solutions close to the global optimum in all of the test runs in this study.

INTRODUCTION

Architects and designers are very often confronted with challenges to find optimal shapes for reducing the overall energy demand as in the design of complex shading structures (Ourarghi and Krarti,2006). When a complex façade structure with repetitive elements is designed, it is in general not clear which shape or structure dimension will lead to an optimal energy demand for the building. A balance between the heat gains and the heat losses must be found for an optimal solution to reduce the energy demand for heating, cooling and artificial lighting (Junghans and Darde, 2015).

The best way to find an optimal solution in a complex problem is to use optimization algorithms. Evolutionary optimization algorithms like the genetic algorithm (GA) have been used and tested successfully in the building sector (Tuhus-Dubrow and Krarti,2010). These types of algorithms are proven to find solutions close to the global optimum for optimization problems with a relatively small number of parameter settings (Bouchlaghem N.,2000).

However, the successful application of this optimization algorithm for complex façade systems with a huge number of parameters to be optimized has not been demonstrated. Another critical aspect of the problem is the extremely high calculation time required by this size of optimization problem. This is especially critical for design processes where the building energy demand must be optimized, because in these cases the use of computationally expensive dynamic thermal simulation programs is necessary. This extensive computation time can be economically not feasible when designers are looking for a solution tendency in the first planning stages.

This paper explores a new approach that combines two optimization algorithms to come up with a robust solution in a much shorter calculation time than the sole use of the GA would demands. The concept is to split up a large optimization process into two smaller processes (hybrid optimization) to overcome the persistent problem of extensive calculation time and to achieve robustness in the optimization process (Schlueter,2009).

Figure 1 shows the proposed concept of the hybrid optimization approach.

The diagram shows the windows with different settings of the shading elements. The shading elements are illustrated in a grey color. Façade No.1 has 40 horizontal stripes, where the thickness of the stripes need to be optimized. Façade No. 2 has 64 tiles, where the size of the tiles needs to be optimized. The first window in the figure shows the general optimization problem with randomly defined parameters. The second window shows the definition of the sub-areas and the third window shows the optimization of the parameters in the sub-section.

In the first step, the GA is used to optimize sub-areas of the shading structure. Each of the sub-areas is assigned to an optimization parameter of the GA. Because of the limited number of sub areas, the problem space of the GA is relatively small. The outcome of the optimization in the first step provides the seed parameter settings for the second step. In the second step, another optimization algorithm or method is used to optimize the parameter settings in the sub-areas. In this study the harmony search optimization and an interpolation method are compared for the use in this second step. The second step is intended to refine the parameter settings in the sub-areas. The advantage of the harmony search is that it can find an optimal solution of a sub-area in using the HS in this case problem without changing the average optimal parameter setting in the sub-area.
The GA cannot be used for the refinement process because it cannot handle keeping the average parameter setting in a sub-area.

A linear interpolation is used alternatively to the HS for the second step. The goal is to compare these two refinement methods to each other.

![Diagram illustrating the hybrid optimization process](image)

**Figure 1 Illustration of the hybrid optimization process, where the harmony search is used for the refinement of the sub-areas**

**METHOD AND SIMULATION**

**Harmony search**

To understand the benefits of the HS for problems of this sort, a brief explanation may be helpful. The harmony search optimization algorithm was introduced by Zong Woo Geem in 2001 (Geem, 2001). It is associated with musical performance processes in which a musician searches for the better harmony of a tone or tones produced by instruments. A good example for the harmony search process is the search of a perfect audio aesthetic harmony. Prior to a classical music performance, each player sounds a pitch within the possible range of his instrument with the goal of making one harmonious pitch combination. The chance of finding a good harmony including all the pitches is increased when the process is repeated, as each player changes the pitch by a certain amount. Depending on the type of instrument, each musician prefers a certain pitch and thus influences the overall harmony or harmony setting. All the produced harmonies are stored in a Harmony Search storage. The size of the HS storage describes the number of harmony settings, which will be stored and updated in the iterative search process. The aim of the musicians to find a perfect harmony is analogous to multi-parameter optimization problems in engineering.

The analogy of the HS to optimization problems in engineering can be found in the way an optimal global solution is found. The intention of any musician to improve the harmony by adjusting the pitch can be replaced with the optimization of a single parameter in a multi-parameter optimization process. A degree of change in the pitch is analogous to the amount of change in the parameter setting in each iteration.

The initial combinations with parameter settings are defined randomly and saved in the HS storage. In each iteration step, a defined number of pitches are changed randomly according to a pitch adjustment rule. Pitch adjustment describes the possible change in parameter setting change. The pitch adjustment constitutes the refinement process. A large pitch adjustment is designed to avoid being trapped in a local optimum and a small pitch adjustment works as a refinement of the solutions. The randomized search explores the search space more efficiently, while the pitch adjustment rule ensures that the new solution is not too far away from existing good solutions.

After each adjustment, the harmony or objective function is calculated again. If the new harmony or objective function is better than the existing worst harmony in the harmony storage, the new harmony is included and the worst one is excluded. The iterative optimization process is continued until a termination criterion of maximal number of iterations is met.

In this study, the HS is adapted to the special needs for optimizing complex facade systems with a large number of variables.
Figure 2 Principle of the harmony search optimization for refinement

Figure 2 describes the harmony search algorithm visually. It shows the optimization process for one sub-area of shading system 1 in this study. The black horizontal bars are showing the thickness of each horizontal shading element in the sub-area. The vertical red line in the middle shows the average recommended parameter setting of the sub-area and the grey field on both sides of it shows the shift in parameter setting from the average of each shading element.

1 As a first step, the GA will be used to optimize the parameters in each sub-area of the shading system. The results for the sub-areas of the GA in the first step are taken as initial values for the HS. These values are the optimal average value of each sub-area. The parameter settings will be changed randomly without changing the overall average setting in a sub-area.

2 In each iteration of the HS, the parameter settings will be changed randomly. In the presented case study, two parameter settings in each sub-area will be changed in each iteration.

3 The HS storage will be updated, when the new solution is better. The HS storage has 10 solutions.

4 Repeat the process until the termination criterion is satisfied. The magnitude of the parameter setting change will get smaller when no better solution is found after 5 iterations.

Figure 2 shows exemplary how the HS works on the façade with 10 parameters. At first, the set of pitches is defined randomly without changing the overall average of the percentage of façade opening in the sub-area. In this study, two pitches will be changed with a distance of 2 parameter settings in each iteration step. After 25 iterations, the amount of the change of the pitch is reduced to a distance of 1. The HS is interrupted after 50 iterations.

Non-Linear interpolation

An interpolation method has been used alternatively to the harmony search method for comparison.

The non-linear interpolation has the advantage that the transition change between the sub-areas can be done more “smoothly” than the simple linear interpolation. The average parameter setting for the sub-areas, which are defined in the first step (GA) is taken for the seed numbers for the interpolation process. 4 numbers are used for the shading system with the horizontal stripes and 8 seed numbers have been used for the shading system with the 64 tiles. A non-linear extrapolation process is used for parameter settings which are not between seed parameters. The interpolation method is used on both shading systems.

An advantage of the interpolation process is that it does not need a large number of simulation runs for the refinement because the parameter settings are defined by the interpolation equation. It does not need an iterative search process like the genetic algorithm or the harmony search algorithm.

Simulation tools

The simulation software DIVA for Grasshopper was used for the optimization problem in this study. It uses the EnergyPlus thermal simulation environment to calculate the annual heating and cooling energy demand. The energy demand and the internal heat gain of the artificial lighting is calculated by the DIVA software. Results of the DIVA light calculations are imported into the EnergyPlus calculations.

The Genetic Algorithm and the Harmony Search algorithm are developed in C++. The algorithm written in C++ controls the Grasshopper environment.

Shading system

The hybrid optimization is tested on two different complex shading structures. Figure 1 shows the design of the shading systems.

The first shading structure has 40 horizontal stripes, where the thickness of each stripe is variable. The search space for the optimization process has 40 parameters. The hybrid optimization has 4 sub-areas with 10 parameters.

Shading system 2 has a search space of 64 parameters. The opening ratio of the shading system is defined by punctual shading elements with different dimension of the elements. It is divided into 8 sub-areas in the hybrid optimization approach. There are 8 parameters in each sub-area.

Test room

The hybrid optimization method is tested in a single occupied office room with a south oriented window. The room has an area of 10 m² and has an internal heat gain of 15 W/m² for the electrical devices and 13 W/m² for the artificial lighting. The building is assumed to be located in Chicago/USA.
RESULTS

Harmony search

Figures 3 and 4 are showing the results of the optimization run of the two shading types when the GA is used solely. For both shading systems, the GA does not produce useful results. The sizes of the shading elements are distributed across the to be shaded opening and do not give a clear tendency towards a useful solution. The parameter size of 40 for the first, and 64 for the second shading system seems to be too large for this type of problem.

A comparison between the results of different optimization results where the GA is used solely shows that there are no similarities. The optimization run for the shading system with 40 parameters needed 622 simulations (run 1) and 616 simulations (run 2) to complete and needed in average 41 generations to find the solution. For the shading system with 64 parameters, the GA needed 852 simulations (run 1) and 848 simulations (run 2) to find the optimal solution.

![Comparison of the optimization results](image)

The total energy demand for the shading system with 64 parameters is between 122 kWh/m$^2$ year (run 1) and 145 kWh/m$^2$ year (run 2).

Figure 3 and 4 (second line) shows the result of the optimization process where the GA is used with a smaller number of parameters. One parameter is used for each sub-area of the shading system. Therefore, shading system 1 has 4 to be optimized parameters with 10 potential parameter settings. Shading system 2 has 8 parameters. The optimization run is repeated 10 times to avoid statistical errors (only two are shown).

The results of these optimization runs show for both shading systems a clear tendency toward a certain solution. A solution with a larger opening area at the upper part of the shading system and a smaller opening at the lower part is preferred for both systems.

The energy demand as the objective function of the optimization problem of shading system 1 is 77.7 kWh/m$^2$/year (run 1) and 78.7 kWh/m$^2$/year (run 2). For shading system 2 it is 78.3 kWh/m$^2$/year (run 1) and 78.5 kWh/m$^2$/year (run 2). These results are demonstrating that the GA gives better results when it has a smaller number to be optimized parameters in the search space.

Figure 3 and 4 (third line) shows the final results of the hybrid optimization method for both shading
systems. The distribution of the opening ratio of the shading elements are arranged slightly different compared to the results of the optimization runs where the GA is used for the sub-areas. The total energy demand as the objective function has been improved by a small amount compared to the results of the runs with the sub-areas. A comparison of the final optimization runs to the runs where the GA is used solely shows that the energy demand is improved at an average of 63%. The average energy demand of the optimization runs where the GA is used solely on the optimization problem with 64 parameters is at 172 kWh/m²·year. The average energy demand of the hybrid optimization is at 82 kWh/m²·year, when it is applied at the same optimization problem.

A comparison of the calculation time of the GA with and without the combination of the HS shows that the optimization process of the solely use of the GA needs significantly more simulations than the proposed hybrid optimization algorithm.

**Figure 4** Comparison of the optimization results for shading system 2 with 64 parameters. Shown are (1) the sole run of the GA with 40 parameters, (2) the optimization results of the GA for the sub-areas, and (3) the final result of the hybrid optimization with the harmony search.
Non-linear interpolation

Figures 5 and 6 are showing the results of the optimization process where the non-linear interpolation is used for the refinement process in the second step. The same results of step one, where the GA is used with the HS, are used to define the seed parameter of the interpolation process. However, the transition between the sub-areas are smoother compared to the hybrid optimization with the HS. The computation time of the hybrid optimization with the interpolation are significantly smaller then for the sole run of the GA and the hybrid optimization with the HS.
CONCLUSION

This paper presents a method for improving the reliability of optimization results of genetic algorithms used for building optimization problems with a large number of parameters. It does this by combining the genetic algorithm with the harmony search algorithm or (alternatively) with a non-linear interpolation. The proposed approach was developed and applied on two façade optimization problems.

The results demonstrated that the hybrid optimization algorithm is able to find solutions closer to the global optimum than the sole use of the genetic algorithm on the same type of complex shading system. Calculation results show that the total energy demand for building operation as an objective function is 51% (shading 1) smaller for the run with the hybrid optimization than the use of the GA alone. It is 32% smaller for shading 2. The computation time of the hybrid optimization was in average 54% (30% shading 2) shorter than that of the sole use of the GA.

The results of the hybrid optimization runs combining the interpolation method are not as close to the optimum as the hybrid optimization with the HS. However, the results are more smoothly and architects are likely to prefer this method for the building optimization process.

REFERENCES


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