THE APPLICATION OF MULTIPLE-OBJECTIVE GENETIC ALGORITHMS FOR CONTROLLING SOUND QUALITY BY ARCHITECTURAL FORM DESIGN

SURAKIST HUNPAISARN and CHAWEE BUSAYARAT

Faculty of Architecture and Planning, Thammasat University, Rangsit Campus, Pathumthani, Thailand

Presently, the architectural design responding to the sound environment has become to play an important role in the design process. New technologies such as simulation and optimization models through a computer allow us to discover the possibility of shapes, forms, and materials that respond to a specific condition of the acoustic environment. However, due to the complexity of variables, we have to face the difficulty of how to evaluate the calculated result. How should one know if the said design is suitable successful for the activities in that area? One of the solutions is using the genetic algorithm, which refers to the scenario simulation and adjustment to find the most suitable model. It provides the possibility of shape and materials to be the best result to design the architecture responding to the sound environment. The objective of this research is to propose a guideline for using genetic algorithms for architectural design by using sound quality as the Fitness function to find the optimal solution terms of shape and material used. The proposed process takes reverberation time of sound and audio ray-tracing into consideration. The result of this research shows applications, abilities, and limitations of genetic algorithms in the domain of architectural parametric design.

Keywords: Parametric modelling, Architectural Design, Reverberation Time, Ray-tracing.

1 INTRODUCTION

Presently sound quality in the building is an important factor in designing architecture. The design requires expert suggestions for considering the invisible environment such as sound. This issue has attracted a lot of research attention (Wu and Clayton 2013). This research is interested in the use of the computer-aided design of small-scale architecture considering the sound environment in the experimental area. The objective was to study the theory and criteria determining sound quality in the building and the use of genetic algorithms to find the optimal solution. Sound quality criteria contained several variables and each of them was used in different activities or area functions. In this research, we focused on using the reverberation time as the variable showing the resonance in the room which is part of sound quality identification. Ray tracing was also used to see a suitable condition to get the wanted sound source location. These variables and methods were used as the fitness function for the genetics algorithm to adjust the parametric shape for the most suitable result.
This study uses a student activities area in the botanical park of the faculty of architecture, Thammasart University, Rangsit campus as an experimental area to design the small-scale architecture. It was an open space surrounded by trees and a small bleacher. The original function of the area was multi-purpose for the students to arrange activities such as seminars or meetings. Most of the audio activities in this area use the human voice.

2 LITERATURE REVIEW

In 1913 the sound expert architect, Sabine (1922) started using ultrasonic to test sound property with the 2D Model Section. It is the beginning of the model simulation using the “Scale Model”. This process is widely used in several methods. The problems of using a scale model are its accuracy and detail, as well as the variety of design solutions. Because it costs resources and time in model production. Using the computer to calculate the variables and simulate the sound environment is today’s preferred option. The developed resource and technology allows architects and engineers to access to up-to-date designing tools. The new tool such as the genetic algorithm (G.A.) allows users to work with suitable searching and optimizing solutions. It was the computer science theory and is currently used as a basic function for AI development. The multi-objective genetic algorithm (MOGA) is the determination of the fitness function considered the multiple objectives with multiple variables. It is more flexible but time-consuming to solve the problem as this process is more complicated (Gen et al. 2008).

Peters (2010) proposes a project composed of 4 steps requiring various tools from the overall shape design, internal pattern, detailed shape design, and assemble production design. Each of the designing steps used a different sound checking tool according to objectives. The Pachyderm Acoustic Simulation is used for calculating the Reverberation Time in the area together with Grasshopper to find overall shape design. The internal pattern design and detailed shape design use Odeon to calculate reverberation time and sound pressure level. Each tool was able to provide different analyses and require different analyzing time. However, the 3D model transferring between each tool causes many problems. It was complicated, time-consuming, and needed to be done correctly especially the parameter setting process.

A project using the genetic algorithm for determining the location and area to install the sound absorbing sheet in the office was proposed by Vlaun et al. (2016). The objective was to use the least sound absorbing material with full efficiency according to a specific standard. This research used rays tracing to calculate the sound pressure and sound intensity relative to the distance between the sound source point and the receiving point in the 3D simulation. The genetic algorithm was used to identify the location to install sound-absorbing sheets in the building walls. The fitness function is the value of sound pressure and intensity lost per distance and material used. The result showed the efficiency of genetic algorithms in interior design to respond to a sound environment.

3 ARCHITECTURAL FORM DESIGN USING GENETIC ALGORITHMS

The objective of this project is to design a small-scale architecture on 300 m². in a selected experimental site (Figure 1) which is the student activities area in the botanical park of the faculty of architecture, Thammasart University, Rangsit campus. The ground had 6 trees with an average height of 4.5-6 m. This condition limits the height of our design. The design result also requires voids to allow these trees to penetrate through the roof. The selected tools were Grasshopper, Octopus, and Pachyderm. The additional script was written in Python.
Figure 1. Experimental area - student activities area in the botanical park of the faculty of architecture, Thammasart University, Rangsit campus.

3.1 Parametric Modeling

We have defined the usable area of the selected site: 15 m. x 20 m. and at least 2.5 m. in height, to allow the building user to use this area with comfort. Two entrances of the building were selected on the short sides of the site. Two of the remaining long sides were used as structure baring the loads. Then the 5 m. x 6 m. grids were placed on the usable area. The line intersection points of the generated grid were used as control points of the building surface (Figure 3, 1-4). These control points were lifted vertically for 3 m. A developed script allows each point to be moved in 3D space within 0.5 m. limitation (Figure 2).

Figure 2. The boundary area in which the control point can move in the form-finding process.

The building surface is then transformed according to 30 control points. These point positions were set as a genome for the following genetic algorithm process to find the best architectural form in sound control. The surface mesh is constructed by connecting each point using Delaunay Mesh, a Grasshopper component (Figure 3, 5-6). We have also programmed the generated mesh to avoid overlapping with the sitting area and the tree crowns.
There are two possible materials: 10 mm. plywood sheet (0.08 absorption coefficient at 1K Hz.) and sound-absorbing material (1.02 absorption coefficient at 1K Hz.). Ten polygons will be selected by the genetic algorithm to apply sound-absorbing materials based on sound efficiency.

### 3.2 Genetic Algorithm

In this research, the basic parameter settings of the genetic algorithm in Octopus plug-in are: Maximum Generation: 10, Population size: 50, Crossover Rate: 0.8, Mutation rate: 0.9, Mutation Probability 0.2, Elitism 0.5. These settings were selected based on the calculation time and hardware efficiency. The variables used in the fitness function are:

1. **Reverberation Time, RT**: The reverberation time of sound using in a seminar or meeting area is between 0.7-1.1 second at 1000 Hz.
2. **The amount of sound ray-tracing that reaches the receiving area**: in this research, we use 4 sound receiving points and place averagely in the experimental area. By using the ray-tracing method, the sound ray that goes through the receiving areas (12 cm radius spheres at the receiving point positions) will be considered as target reached (Figure 4). This variable would identify early sound reflection and sound clarity.

![Ray tracing diagram](image-url)  
**Figure 4.** Diagram showing the work of ray tracing.
(3) **The difference amount of sound ray that reaches receiving areas**: This variable is used to verify the acoustical proximity of the entire experimental area. The less difference value indicates that the sound volume and clarity would be similar in each receiving area.

### 4 RESULT

The result from the genetic algorithm shows a tri-dimensional graph with various solutions. Each solution contains a score calculated from a combination of the predetermined criteria. (Figure 5, 6-7). The surface form with the highest scores was selected by our developed script.

![Figure 5. The result from Octopus calculation.](image)

The selected design solution was 16 x 22 x 4.1 m. It has the best score in raytracing criteria and 1.02 seconds of reverberation time, which is a suitable value for a small meeting or talking.

![Figure 6. (1) Space plan, (2) Space long cross-section, (3) Space short cross-section, (4) Isometric image of the 3D model showing sound ray movement inside of generated result from the genetic algorithm. Four color spheres inside the space represent sound receiving points in ray-tracing calculation.](image)
Figure 7. A perspective image of a small architecture design based on the selected result.

5 CONCLUSION

This research presents a process of the Multi-Objective Genetic Algorithm (MOGA) in designing a small architecture in an open area using a parametric model to control the architectural form in 3D. A combination of sound-reflective and sound-absorbing material was selected by the developed script to control the sound reverberation time and ray-tracing from the origin point to the receiving point to achieve the most efficiency. In this stage, we experiment with a controlled number of sound-reflective and sound-absorbing material. In a further experiment, we could develop this process to be able to select and manipulate the proportion of materials used through the genetic algorithm, so that the proposed solution could be more flexible and responsive to design requirements. The limitation of this research was hardware efficiency. The calculation of variables through the Pachyderm Acoustic Simulation program is time-consuming and requires high processing power. In designing an architecture that takes sound quality into account, it is essential to plan the working task to maximize the resource.

References

Wu, C., and Clayton, M. J., BIM BASED Acoustic Simulation Framework College of Architecture, Texas A&M University, College Station, TX, USA, 2013.