Acoustic Environments

Applying evolutionary algorithms for sound based morphogenesis

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Abstract. The research investigates the application of evolutionary computation in relation to sound based morphogenesis. It does so by using the Sabine equation for performance benchmark in the development of the spatial volume and reflectors, effectively creating the architectural expression as a whole. Additional algorithms are created and used to organise the entire set of 200 reflector components and manufacturing constraints based upon the GA studies. An architectural pavilion is created based upon the studies illustrating the applicability of both developed methods and techniques.

Keywords. Evolutionary Computation; Algorithmic Design; Architectural Acoustics; CAAD/CAM processes.

EvolUtionary Algorithm as Approach

Various methods for optimising acoustic environments through simulating a volume exist as commercial packages with the intention of clarifying the sound performance of a pre-conceived design proposal. With known factors and equations for acoustic evaluation, it is, however, possible to let the machine create a computational search for a performance oriented architecture, letting acoustic criteria drive a morphogenetic process. This requires a search method, whose aim is to alter the design until a desired performance level has been reached. Different search methods can be mentioned e.g. Simulated Annealing, Neural Networks and Genetic Algorithms (Brownlee, 2011). The latter, Genetic Algorithm (GA), is chosen in this work, due to versatile utility and its direct implementation in commercial software, which therefore makes it accessible to the general designer beyond this work.

The GA’s conceptual construct, developed by John Holland in the 1960’s and 1970’s (Holland, 1992) mimics the evolutionary processes in nature by populations, reproduction and heredity, with the inherent ability for the designer to alter several parameters within the method, such as population size, crossover technique and mutation rate. Much literature can be found on the subject by e.g. John Holland (1992), David Fogel (1997, 2000), David Goldberg and Kumura Sastry (2002, 2005) illustrating not only its diversity on application but also its growing importance as a probabilistic solver for singular- and multi-objective problems.
The projects manoeuvre away from a conventional ‘model-simulate’ approach to a ‘generative-model’ approach but remain to apply singular sound sources. The work in this paper approaches the sound milieu based upon multiple sound sources.

**Design method (machine computation – human computation)**

Besides the technical setup of the evolutionary engine, there are three essential operational parameters for a designer to develop and describe when working with GAs; a) describing the fitness function, b) altering the variables of the population and mutation rate, and c) to convert from genotype (system) to phenotype (design) [1]. Within this work, we have decided to omit the technical setup by utilising the Galapagos Evolutionary Solver for Grasshopper, RhinoCeros, developed by David Rutten [2] and to focus the agenda on exploring the three operational parameters described above.

**Designing the fitness function**

Optimisation of acoustic aspects within the design process asks for a fitness function, which searches a design specific intention that can be described as a number, as a target for the algorithm.

The most used equation for acoustic evaluation, determining the reverberation time, is the Sabine equation describing the amount of time it takes for the sound pressure to decrease 60 dB after the sound source is terminated, RT60.

\[ RT60 = \frac{Ta}{0.16* V / Sa} \]  

The equation is based upon a volume (V), the average absorption coefficient of used materials (\(a\)) and the total absorption in Sabins (Sa).

\[ V = m^3 \]  

\[ Sa = S1 \alpha 1 + S2 \alpha 2 + .. + Sn \alpha n = \Sigma Si \alpha i \]  

\(Sn =\) area of the actual surface (m²)  
\(an =\) absorption coefficient of the actual surface

While being a simplistic measure for the specific acoustic quality, the equation is widely used and functions as an initial fitness benchmark with a resultant number suitable for a genetic algorithm.

Extending the above algorithm as a fitness function could be done through adding more acoustic criteria such as sound pressure levels (dB) through a concatenated performance formulation in the fitness function (Sato et al, 2004). This is, however, omitted due to the focus towards applying performance ‘cost’ to the use of evolutionary algorithms in architecture rather than high-end audacity simulations. An iterative design speed over accuracy is therefore chosen.

**Algorithm variables**

The dominant variables affecting the performance of genetic algorithm are ‘population size’ (the amount of genomes that can be selected and reproduced from), cross over technique (how the information from each genome is paired to become the next generation’s offspring) and mutation rate (the percentage of how often a random alteration to a genome occurs).

**Genotype and phenotype**

The genotype, the evolutionary algorithm, controls the phenotypic behaviour and progression that within this work can be observed in the evolving volume, that is geometrically restrained within an x,y,z-domain.

This allows the designer to maintain an internal and an external boundary of the volume that can be related to a project-specific site. The displayed studies show the ability of the algorithm to reach a certain reverberation time in accordance with the Sabine equation. This then again can be oriented towards a specific music genre.
Figure 1
Base volume geometry from which the GA alters its point in an x-y-z specified domain.

Figure 2
Series of studies altering the GA's parameters towards a higher acoustic performance.
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Aim, method and application
The work aims at both empirical studies performed through evolutionary algorithmic search towards established benchmark criteria, defined by, among others, the Sabine equation but equally applies the constructive aspects that induce parameters of material accessibility, dimensions and manufacturing processes.

The design method goes through a series of performative steps:
1. Defining the volume, using GAs.
2. Defining reflectors, using GAs.
3. Optimising reflectors for production, using rationalisation algorithms.
4. Rationalising reflectors for manufacturing and assembly, using rationalisation algorithms.
5. Producing CNC files for production, using parametric production techniques.

Defining the volume
The description of the volume follows the methodology described above but with the fitness function searching a minimum reverberation time instead of the one-second used in the preliminary studies. This is founded in the fact that electronic music is unconventional in the sense that it is spread via loudspeakers, rather than instruments. They are, however, already acoustically developed to produce the best sound possible within the loudspeaker cabinet. The pavilion therefore searches the minimal effect on the sound but the maximum protection of the clear sound, thus eliminating the reverberation time. The definition of the volume domain, or algorithmic search field, is determined by the site contextual setup. The setting is used to create a natural boundary for the algorithms to evolve within, considering a clear orientation of the space towards the waterfront as a flow specific characteristic that will set the spatial architectural scene.

Defining reflectors
Rather than being an auxiliary installed element, the intention of the reflectors is, besides their obvious function to improve the acoustics, to make them the identifiable architectural expression. Reflection of the sound is aimed at 1) creating the maximum of reflections between the reflectors without sending the rays back into the listening space or 2) to direct the sound rays away from the pavilion. Both strategies strive towards a clear, low reverberation time for electronic music. The site itself is surrounded by a sound void, the Fjord, and high noise levels from the road.

Defining a reflector that seals from external noise, while absorbing the sound rays, is based upon a geometrical study (based upon an altering triangle) driven by the same evolutionary engine as above, but with the fitness function to maximise the reflection count of each ray. Four models are produced to which the triangular form can change, 1) the length of the normal vector to the surface, 2) the length of the vector from the surface to the sound source and 3) + 4) studies of the first two, but with an ability of variation in the directionality of the vectors towards a source of the normal vector to the surface.

The studies show a clear improvement of the reflection count (absorption) by using a sound source oriented approach and a slight further improvement by allowing the vector that is oriented towards the sound source to deviate. See Figure 4. Traditionally, as mentioned above, acoustic spaces are defined
Figure 4
Study and evolution of optimum reflector geometry towards a maximization of absorption.

Figure 5
Experimental matrix of the four different strategies, clearly indicating the capacity of long stretched geometries oriented towards the sound source with slight heterogeneous variations across the elements.
from a single source or a group source located in the same area. The pavilion explores the spreading of the sound source by implementing loudspeakers situated in each corner of the volume. The complete geometrical organisation of the reflectors is subsequently derived by applying an algorithm that is developed from the prior studies used to identify the varied sound source vectors to the volume.

The algorithm allows a zone of reflectors to focus on a specific loudspeaker, to scale its geometry in order to alter the reflective factor (absorption level) and at the same time open its geometry towards the water and close it off towards the road. Figure 6.

**Production processes**

Lastly the entire model is re-calculated and slightly altered for elements exceeding the CNC manufacturing and wood plate limitations of 1200x1200mm. Production files are generated directly within the model space and allocated on fabrication ‘sheets’ for the CNC laser cutter machine.

**CONCLUSION**

The work explores the potential of using GAs for design morphogenesis. It finds that both general spatial volume and expressive surfaces can be generated from application of acoustic applied equations as search targets on several aspects. After development of volume and reflector performance, an organisation algorithm was applied to rationalise and apply all elements. This was chosen due to the nature of the GA, as their search field would expand to a 20050 number domain due to the many reflectors and the amount of variables within each reflector. The studies showed that the scale of variables and population size are crucial to the GA's performance as a solver to work in preliminary design phases, thus maintaining the GA for initial search and solving. The work finds that a progressive reformulation of the problem is useful in order to target the GA technique's relatively small search space without compromising the ability for stochastic search for moving beyond obvious design solutions to the designer.
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