The Algorithmic Auditorium: Automating Auditorium Design

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INTRODUCTION

The algorithmic auditorium project (Mahalingam, 1998) started with two main premises. One was that you could automate auditorium design by developing an algorithmic process to generate the spatial form of the auditorium. The other was that you could generate spatial forms based on acoustical, functional and programmatic parameters. Both these premises were realized in the development of a design system for the preliminary spatial design of proscenium-type auditoriums (Mahalingam, 1995).

The characterization of the system as a design system can be called into question. To resolve the issue of whether computers, or more appropriately, computer-based systems, can design, an Architectural Turing Test should be used. Take this scenario in an architect's office. The principal walks into the studio and gives a staff architect the task of generating the initial spatial form of a proscenium-type auditorium. The architect is given general requirements such as the seating capacity, area per seat, the performance type, and acoustical parameters such as reverberation time. The principal walks away. The architect sets to work. After 12 hours, she has drawn a perspective drawing of the initial spatial form of the auditorium, after resolving issues such as volume, seating areas, sight lines, seating slopes and sound reflection panels. Has she designed the auditorium? If she has, then a computer-based system that does what she has done is also designing. This is the basis of an Architectural Turing Test. Given the same input, if a computer-based system produces the same output as a human designer, and the human is considered to be designing, then the computer-based system can be said to be designing as well.

In the design system, non-spatial information is converted to spatial form by an algorithm. This can be said to be the essence of computer-based architectural design, or for that matter, any process of designing material artifacts. This system proves that certain non-trivial design tasks can be automated, therefore, other non-trivial design tasks can also be automated if they are computationally articulated. The auditorium design system is based on performance criteria and their translation into spatial form. It was possible to create this system, because it was possible to computationally articulate the decision making in auditorium design. Rather than focus on the design behavior of the architect in the auditorium design process, the focus was placed on design decision making. This approach acknowledges that designs are created by a sequence of explicit decisions. Design behavior is a larger rubric that surrounds design decision-making. Protocol analyses of design behavior often lead to unresolvable complexity in the articulation of design because they do not focus on the decision-making process. Protocol analyses can lead to computational articulation if they focus on the design decisions that are actually made.

MAIN CONCEPTS

The single main concept used in the design system is acoustic sculpting (Mahalingam, 1992). Acoustic sculpting is the process by which spatial form is generated from architectural acoustical parameters. The sculpting analogy was used because the use of a particular tool for sculpting yields characteristic results. Sculptors use stone chisels, wood carving implements, blowtorches and lasers to sculpt material. What if sculptors working in digital media use abstract mathematical tools to sculpt forms? What if the sculptor's material was architectural space and the abstract mathematical tools were environmental performance criteria? Each acoustical parameter has its performance locus, a spatial form in which the acoustical parameter is generated.

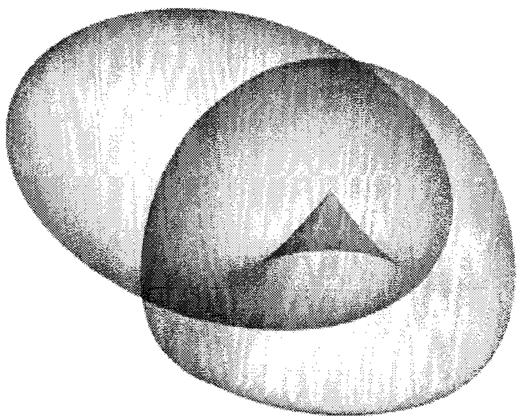

Figure 1. Two performance loci, an elliptical field for the initial time delay gap and an isocandle envelope.

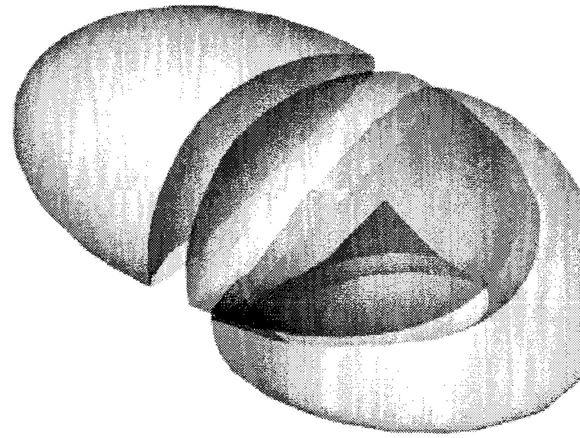

Figure 2. The common optimal space between the two performance loci obtained through the Boolean operation of intersection

For example, the performance locus of the initial time delay gap (an acoustical parameter) is an elliptical spatial field. The initial time delay gap is the difference in time between the time taken by the first reflected ray to arrive at a receiver location and the time taken by the direct ray from the sound source. The initial time delay gap's performance locus is an elliptical field because an ellipse is the locus of a point that moves such that the sum of its distances from two fixed points is constant. The two fixed points are the source and the receiver locations. Similarly, the performance locus of an area of seating that minimizes distances from a point source is a segment of a circle. Deriving the performance locus of a parameter can be based on geometrical, mathematical or statistical analysis. For example, in the design system, some of the spatial implications of acoustical parameters were established by performing regression analysis between architectural dimensions and acoustical parameters recorded in various spaces. The use of performance loci to generate spatial form is a powerful concept. Performance loci of many environmental performance criteria including lighting and HVAC parameters can become form-givers for architectural spaces. Performance loci are a means to derive spatial form from non-spatial information. Multiple performance loci can be resolved into an optimal spatial form using Boolean operations such as intersection (see Figs. 1 & 2). The common space occupied by various performance loci becomes the optimal architectural space. This is similar to the constraint envelopes used in three-dimensional constraint-based reasoning.

Gyorgy Doczi (1981) wrote an important book on the power of limits in which he showed how many forms found in nature and in cultural artifacts were the results of "dinergy" patterns. Doczi showed that the intersection of "dinergy" patterns and their limiting conditions generated various forms of flowers, leaves, shells and fish. Doczi described these patterns as the creative energy of organic growth. Performance loci are like "dinergy" patterns that can be used to generate a new breed of organic architectural spaces. Greg Lynn (1999) uses the concept of animate form, but primarily deals with the transformation (or more accurately, deformation) of architectural forms based on external contextual forces using the "affector" technology available in special effects systems. Lynn's forms accommodate functions in unique and innovative ways, but the form generation process itself is not governed by environmental performance criteria. Animate forms will acquire more power if the transformation or deformation of the form being designed is being done by programmatic, functional and environmental performance criteria. Rather than being a pliant form acted on by external forces, architectural space should unfold as a response to performance criteria.

IMPLEMENTATION

The initial version of the auditorium design system (see Fig. 3) was implemented in 1991 using the object-oriented software development environment ObjectWorks™. The programming language used was Smalltalk. The current version was developed using the VisualWorks™ software development environment, which is also based on Smalltalk (see Fig. 4). The system runs on the VisualWorks™ virtual machine and is platform independent. It can run on PCs, Macintoshes and Unix machines. The design system is modeled as a virtual computer. The various parameters are its input, the spatial form of the auditorium is its output, and the algorithmic process is like an integrated circuit in the processing unit.

The spatial form of the auditorium is a collection of vertices. Each vertex is spatially located by a function of acoustical, functional and programmatic parameters. The vertices are connected based on the typology of the proscenium-type auditorium. The topology of the spatial form is provided by the typology. This topology generates the coupled space configuration of the stage house and the auditorium. The topology is not a fixed topology. For instance, balconies are embedded in the initial topology only to be activated when the parameters warrant it. The whole spatial form of the auditorium collapses to a point, a singularity, when the various parameters are set to zero. The embedded topology of the balcony collapses into the initial topology when not needed. Connecting appropriate vertices creates the different surfaces of the auditorium. Currently an algorithm is being developed (Mahalingam, 1999) that models sound propagation in the auditorium as radiation from surface to surface. This model of diffuse sound propagation allows for a quick assessment of the acoustical parameters of the computer model of the auditorium.

The spatial form of the auditorium generated by the design system can be exported in file formats accepted by commercial CAD (AutoCAD™) and acoustical analysis (EASE/EARS™) software. This allows an architect using the system to further develop and articulate the spatial form of the auditorium generated by the design system. In the design development stage, the spatial form generated by the design system will be the constraining envelope because it is based on the various performance criteria.

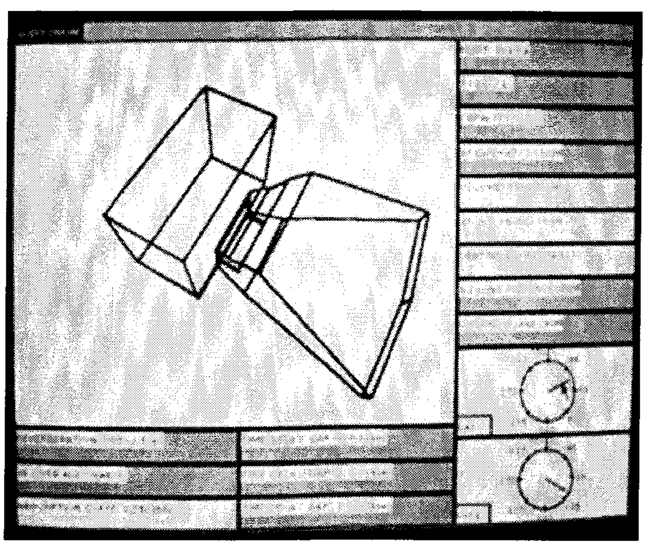

Figure 3. Initial version of the auditorium design system from 1991.

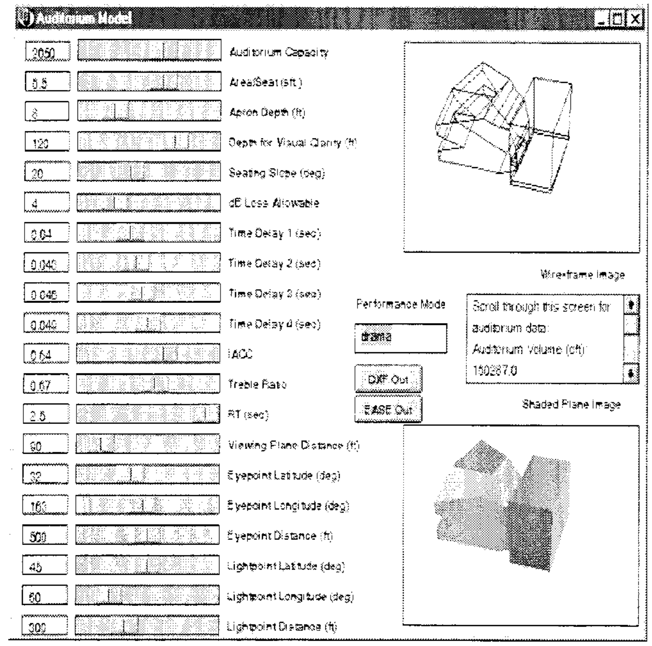

Figure 4. Current version of the auditorium design system.

CONCLUDING THOUGHTS

Acoustic sculpting addresses the generation of spatial forms from acoustical parameters. Similar spatial form generation techniques can be applied to lighting and HVAC parameters. Just as we can ask what the performance locus or spatial form of an acoustical parameter is, so we can ask what the performance locus or spatial form of a lighting or HVAC parameter is! Architectural space generation will become a supple manipulation and visual (?) resolution of the elliptical spatial fields of time delay gaps, isocandle envelopes and isothermal bubbles! Generating optimal forms from performance loci will be the challenge. One can begin the design process with performance loci, yet the final optimization of the spatial form can still be visual, which however, may now be difficult to justify with the spatial articulation of other performance criteria.

REFERENCES

Doczi, G. (1981). *The Power of Limits*. Shambala Publications Inc., Boulder, Colorado, and London, England.

Lynn, G., (1999). *Animate Form*. Princeton Press, New York.

Mahalingam, G. (1999). "A New Algorithm for the Simulation of Sound Propagation in Spatial Enclosures." Building Simulation '99 Conference. Kyoto, Japan.

Mahalingam, G., (1998). *The Algorithmic Auditorium*. Initiative for Architectural Research. Research Poster Competition Winner.

Mahalingam, G. (1995). *The Application of Object-oriented Computing in the Development of Design Systems for Auditoria*. Ph.D. Dissertation. University of Florida, Gainesville, Florida.

Mahalingam, G., (1992). "Designing the Sound Environment: Acoustic Sculpting." ACSA Technology Conference. San Diego.