THE ALGORITHMIC AUDITORIUM

A computational model for auditorium design

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Abstract. Auditorium design is a complex task. Various programmatic, functional and acoustical parameters have to be resolved in the spatial design of an auditorium. This ongoing research project deals with the development of a computer-aided design system for the preliminary spatial design of proscenium type auditoriums. The concept of "acoustic sculpting" is used to generate the spatial form of the auditorium from programmatic, functional and acoustical parameters. These parameters are incorporated using a combination of mathematical, empirical and statistical methods. The generation of the spatial form of the auditorium is implemented as an algorithm that is executed on the computer. The spatial form of the auditorium generated by the system is exported as a computer model for design development and acoustical analysis.

1. Introduction

Auditorium design is a complex task. Various programmatic, functional and acoustical parameters have to be resolved in the spatial design of the auditorium. The emergence of sophisticated computational modeling tools has now enabled the creation of design systems that treat the design of auditoriums as an algorithmic process. In this paper, the design of proscenium-type auditoriums is presented as an algorithmic process. This process is implemented in a design system where the generator of the spatial form of the auditorium is modeled as a "virtual computer."

2. Auditorium Design Parameters

The complexity of auditorium design arises from the need to resolve many interacting parameters. Some of the programmatic design parameters of the auditorium include the type of performance that is to be presented in the auditorium and the capacity of the auditorium. Programmatic parameters help decide the dimensions of stage enclosures and seating areas. Functional parameters include anthropometric constraints such as the area per seat, visual constraints such as sight lines, and conditions for visual clarity. However, the key parameters that influence the generation of the spatial form of the auditorium are the acoustical parameters. Acoustical parameters are integrated in the auditorium design system using the concept of acoustical sculpting.

3. Acoustic Sculpting

Acoustic sculpting is the creation of architectural shapes and forms based primarily on acoustical parameters. It can be likened to sculpting, not with a chisel, but with abstract entities such as acoustical parameters. Acoustical parameters become special abstract tools that shape the environment in their own characteristic way, hence the term acoustic sculpting.

In this context, it will be interesting to introduce the concept of a *locus*. In planar geometry, loci are lines traced by points according to certain rules or conditions. A circle is the locus of a point that is always equidistant from a given point. An ellipse is the locus of a point whose sum of distances from two given points is always equal. From these examples, it can be seen that a particular rule or condition can trace a particular locus. The scope of application of the concept of a locus can be dramatically widened by realizing that the word *locus* in Latin means *place*. Architecture involves the creation of places and spaces. A question can be posed - What is the locus of an acoustical parameter? In answering that question, architecture based on acoustical parameters can be created. Acoustics can become a form-giver for architecture. Figure 1 shows how the time delay gap, an acoustical parameter, is used to generate a semi-elliptical spatial field using the concept of the locus.

Acoustical parameters are often measured to assess the acoustical quality of a space or a scaled architectural model. They are indicators of the acoustical quality of the space in which they are measured. However, it is important to realize certain facts about acoustical parameters. Acoustical parameters are location specific. For a given sound source in a room, acoustical parameters vary systematically at different locations in the room. Acoustical parameters also vary when the sound source is varied. Hence, a set of acoustical parameters at a given location, for a specific sound source, can be used only to generate the general features of the architectural space around that location. Figure 2 shows the source-receiver locations used in the design system. This, to stay within the metaphor of sculpting, will result only in a first cut. Different sets of acoustical parameters from different locations can further refine the definition of the architectural space encompassing those locations. It has been found by researchers that at least 10 to 12 sets of acoustical parameters are required to derive the mean values of acoustical parameters in an auditorium (Bradley & Halliwell, 1989). If architectural shapes and forms can be created from acoustical parameters, then a rational basis can be established for the creation of acoustical environments.

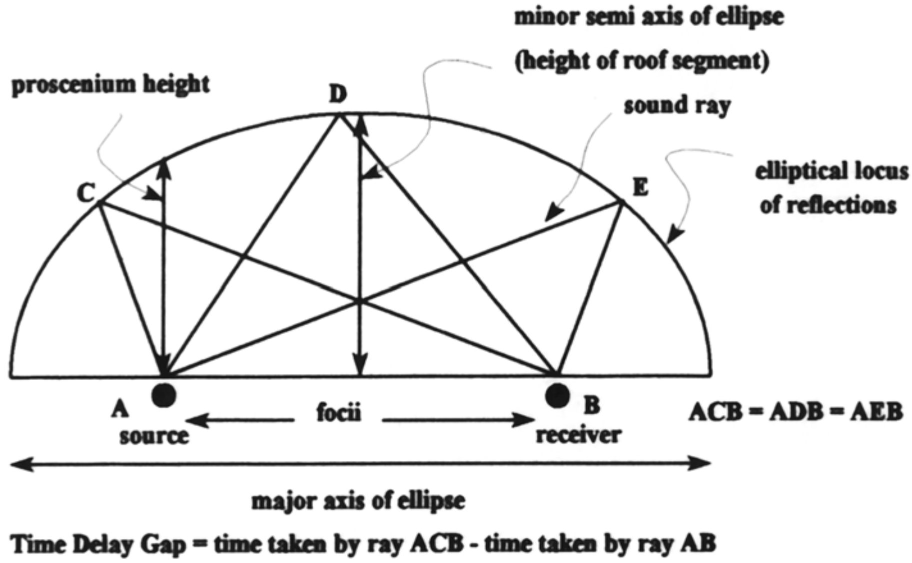

Figure 1. Concept of locus used to derive a spatial field from an acoustical parameter.

Currently, the creation of acoustical environments is a trial-and-error process that tries to match the acoustical parameters of the space being created, probably in the form of a physical model, with acoustical parameters that have been observed in other well-liked spaces. The manipulations of the space's shape and form to achieve the match, are done in an arbitrary fashion, with no explicit understanding of the relationships between the shape and form of the space and the corresponding acoustical parameters. There has been extensive research conducted in the 1960s, 1970s and 1980s by Ando (1985), Barron (1988), Barron & Lee (1988), Beranek (1962), Bradley (1986, 1990), Cremer (1978), Hawkes (1971) and Sabine (1964) to establish those aspects of the auditory experience that are important in the perception of the acoustical quality of a space, and how they relate to objectively measured acoustical parameters in that space. There has not been much research conducted except by Gade (1986, 1989) and Chiang (1994) regarding the relationships between acoustical parameters and the shapes and forms of the spaces in which they are generated.

Acoustic sculpting attempts to define the latter relationships and uses them to create a system that generates spatial forms of auditoriums based on acoustical parameters. This generative system is used as a tool for creating preliminary designs of proscenium-type auditoriums.

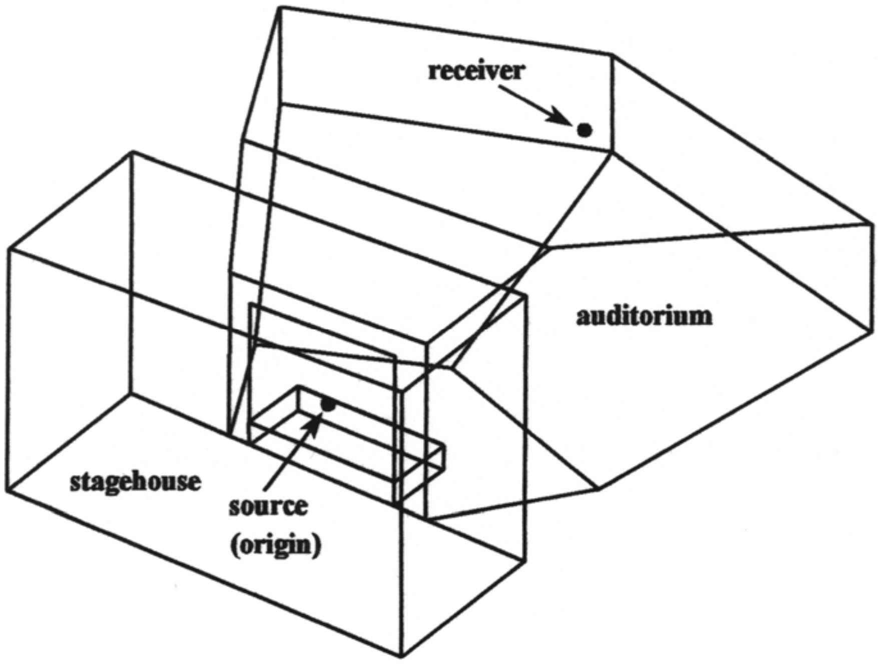

Figure 2. Spatial form of the auditorium showing the source-receiver pair for acoustical parameters.

3.1. METHODS OF ACOUSTIC SCULPTING

The process of generation of the spatial form of the auditoriums is related to the set of acoustical parameters both statistically and theoretically. The acoustical parameters for the generative system are drawn from, but are not limited to, the set presented in the following section. This set of parameters is used by acousticians to study concert hall and lecture room acoustics. These parameters are derived from response graphs of sound intensity variations at the receiving location. Figure 3 shows a response graph. Though the set is extensive, not all of the parameters are used in the spatial form generation stage.

3.1.1. Acoustical Parameters

The acoustical parameters include Reverberation Time, Early Decay Time, Room Constant, Overall Loudness or Strength of Sound Source, Initial Time Delay Gap, Temporal Energy Ratios: Early/Total Energy Ratio (Deutlichkeit), Early/Late Energy Ratio (Clarity), Center Time, Lateral Energy Fraction, Spatial Impression, Bass Ratio, Bass Level Balance, Early Decay Time Ratio and Center Time Ratio, Useful/Detrimental Ratio, Speech Transmission Index and the Rapid Speech Transmission Index.

The different acoustical parameters cited above resolve into related groups that have corresponding subjective perception characteristics. These subjective perception characteristics are classified as Reverberance, Loudness, Clarity, Balance and Envelopment.

A limited set of acoustical parameters related to these subjective perceptions are incorporated in the system (using both statistical and theoretical methods) that derives architectural parameters from the acoustical parameters. It must be remembered that, in the spatial form generation stage, acoustical parameters are not the only factors determining the shapes and forms of the auditoriums. Other factors like seating requirements, visual constraints and other programmatic requirements, along with the acoustical parameters, determine the spatial forms of the auditoriums. The values of the acoustical parameters for use in the generative system are drawn from a database of objectively measured readings in different architectural settings that have been subjectively evaluated as desirable. Based on studies done so far, a generative system based on macrostatic statistical relationships and some analytical theory has been developed by the author. Details of this system are to be found in another paper by the author (Mahalingam, 1992).

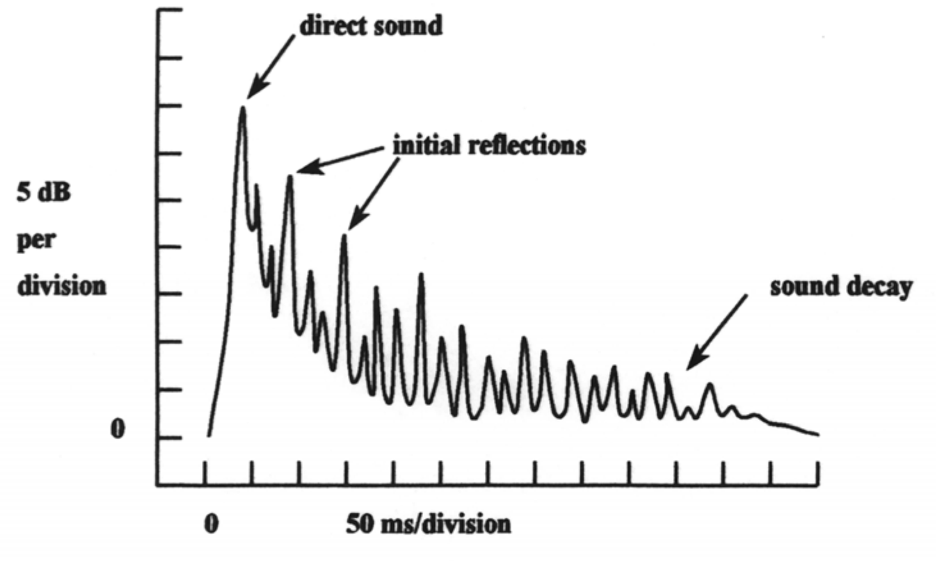

Figure 3. Response graph showing sound intensity variation over time at receiver location.

4. Spatial Model Of The Auditorium

The spatial form of the auditorium is modeled as a parametric object. Each vertex that makes up the topology of the auditorium is spatially located by a function of multiple parameters. These parameters may be directly input by the user of the design system or derived from the user input using calculations. The various parameters are linked in a spatial form generating algorithm using a structure that resembles an ASIC (application specific integrated circuit). Figure 4 shows this relationship of the various parameters. This structure can also be reconfigured as a network or semi-lattice. The connectivity of the vertices that establishes the topology of the auditorium is derived from the spatial type of the proscenium auditorium. The whole design system is a “virtual computer” that outputs spatial designs of proscenium-type auditoriums.

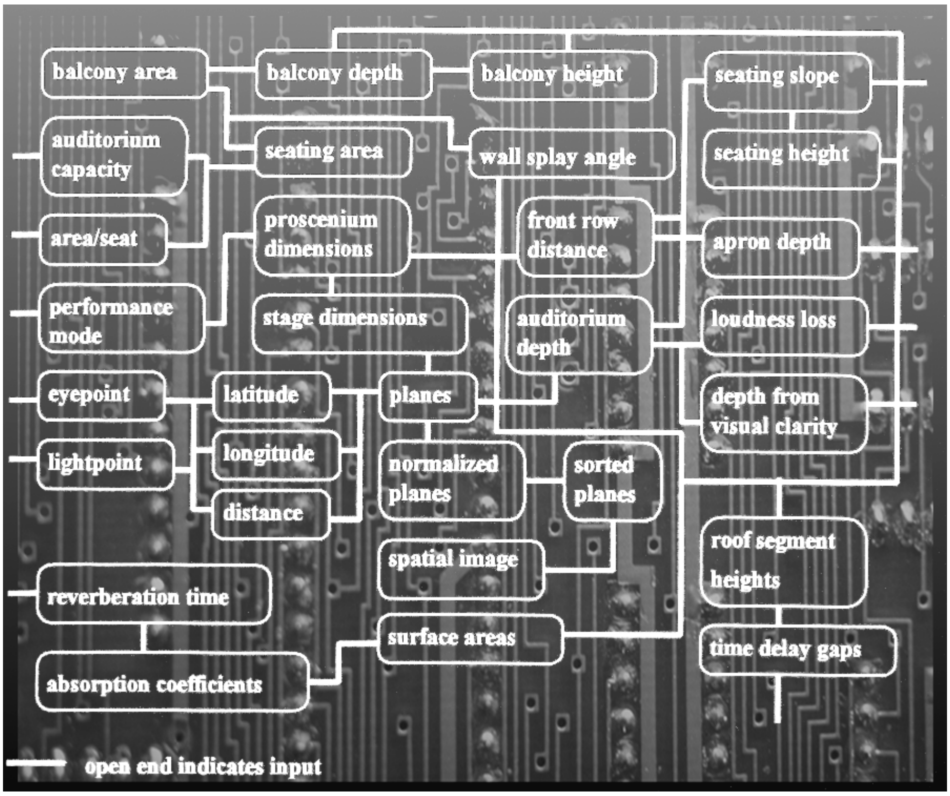

Figure 4. The relationship of the various parameters of the spatial form generator as an ASIC (application specific integrated circuit)

5. What Is A Virtual Computer?

In object-oriented computing, entities are modeled as encapsulations of data, and operations that can be performed on that data. Encapsulation is a computer abstraction. A collection of data and operations normally performed on the data are closely related, so, they are treated as a single entity (rather than separate) for purposes of abstraction. Each encapsulation can be thought of as a virtual computer that is mapped onto a physical computer (see Figure 5) with its own private memory (its data) and instruction set (its operations). The reference to objects as computers was made by Alan Kay (1977). He envisaged a host computer being broken down into thousands of computers (virtual?), each having the capabilities of the whole, and exhibiting a certain behavior when sent a message which is a part of its instruction set. He called these (virtual?) computers "activities." According to him, object-oriented systems should be nothing but dynamically communicating "activities." As such they form an interesting model with which to simulate architectural design. Mitchell's recent call (1994) for a “society of design” with a “collection of agents of different kinds interacting over a network” echoes the ideas of Alan Kay. In another interesting perspective, encapsulations have been likened to integrated circuits rather than virtual computers by Ledbetter & Cox (1985) (see Figure 4).

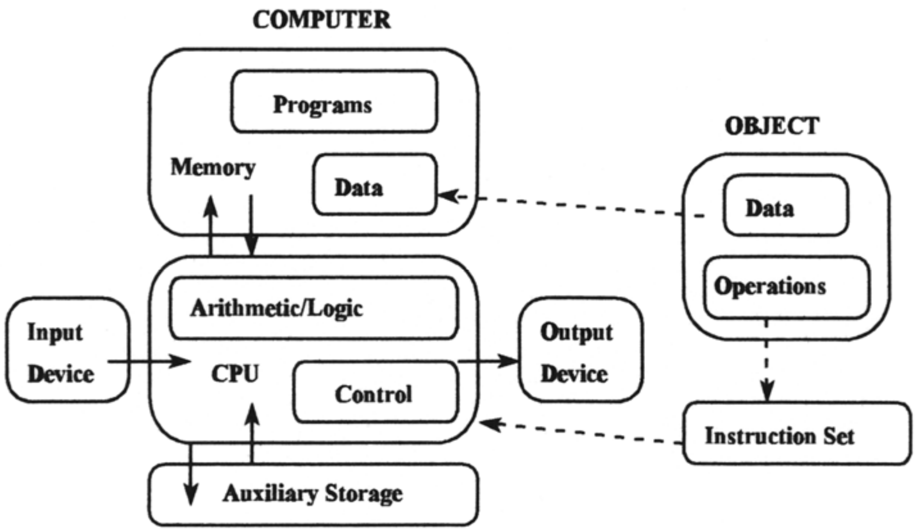

Figure 5. The concept of a virtual computer (or computational object) being mapped onto a physical computer.

6. The Auditorium Design System

The design system used to generate the preliminary spatial designs of proscenium type auditoriums is based on acoustical, functional and programmatic parameters. The computational model of the auditorium is parametric. The various acoustical, functional and programmatic parameters are its data. Procedures that compute the spatial parameters of the auditorium and create its graphic representation are its operations. These data and operations, when encapsulated, act as a virtual computer that is mapped onto the physical computer (see Figure 5). The function of this virtual computer is to output auditorium designs.

The generative system involves an algorithmic procedure for the design of the auditoriums based on constants, user input of independent variables and derived variables. These constants and variables are used to calculate the spatial location of sets of vertices in 3D space that are linked to form wire-frame and shaded plane images of the auditoriums. The topology of the auditorium is based on the proscenium-type auditorium typology. It is a variant topology with the introduction of balconies only when necessary (see Figure 6). The vertices are parametrically controlled and change with changing parametric inputs.

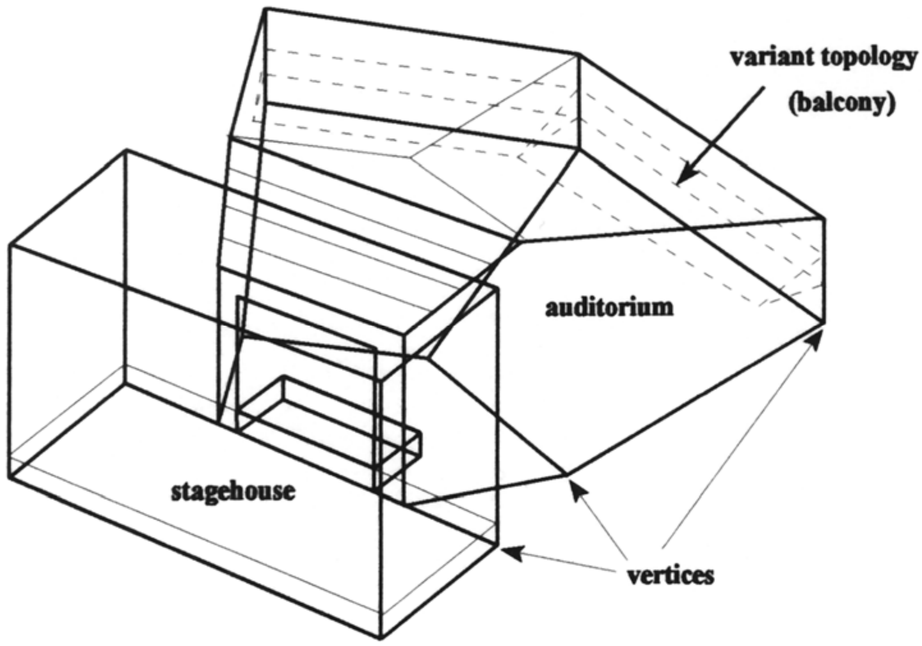

Figure 6. Topological model of the auditorium showing the variant topology for the balconies.

The algorithmic procedure is implemented in the Smalltalk^{TM} object-oriented programming language. The software has a user-friendly menu and graphic interface with which to input acoustical, functional and programmatic parameters. When any aspect of the model is changed, the spatial form is updated. The system provides a dynamic design environment. In the system, the spatial form changes in real time with changing input of the parameters. The auditorium is depicted in true perspective. Once the spatial form is generated, it can be viewed from any angle and from any distance. The systems can be used to rapidly generate alternate designs based on the various parameters.

To limit the scope of the software design to manageable limits, the initial version of the generative system has a limited set of 21 independent variables. However, the total number of variables (both independent and derived) in the system is large, indicating a complex system. An interface has been developed that can transfer the computer model generated by this system in a format readily acceptable by commercial CAD packages (the DXF format) for design development. An interface has also been developed to link this system to acoustical simulation software (EASE and EARS) to predict what the auditorium will sound like if it is built. The view of the computer screen when running the software is shown in Figure 7.

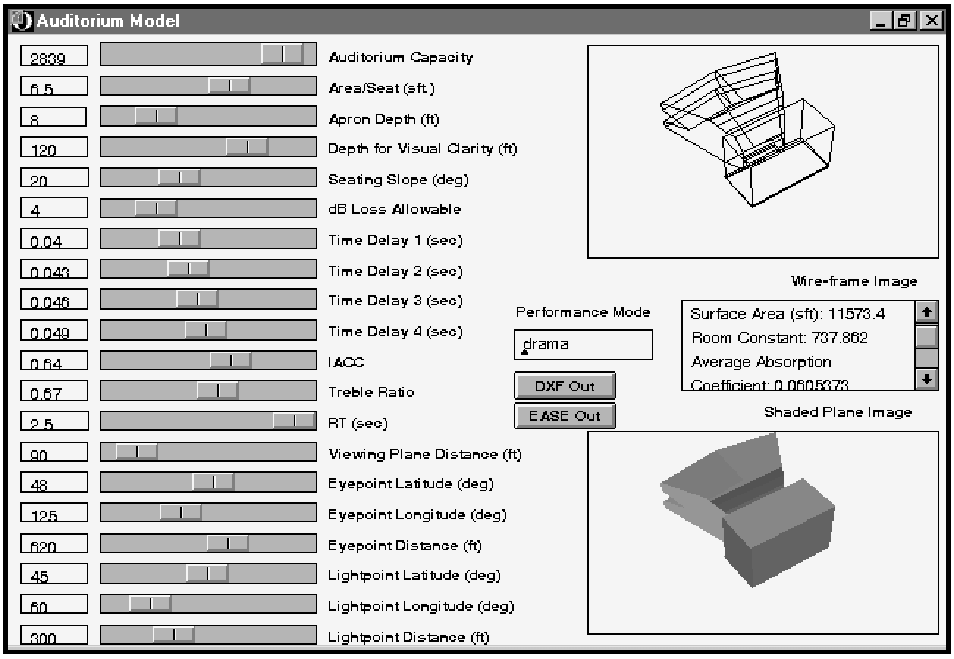

Figure 7. View of the screen of the design system software for auditoriums.

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