Design issues of time-based phenomena and the notion of a persistent model: A parametric exploration of acoustic performance

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This chapter reflects on how sound can become part the architectural design process. Sound is a complex phenomenon that traditional architectural drawing tools do not capture well. Parametric tools allow for the encoding of relationships between material, geometry, and acoustic performance in a digital model. Computational simulation tools can give visual and aural feedback on how designs perform. These tools give architects the ability to contemplate the sound of architectural propositions. Different sounds, sound positions, and listener positions can be tested, as can different geometric and material configurations. Using these tools architects can design for sound. Sound should be a part of the architectural design process and in order for it to be a useful design parameter; it must be able to be considered in the digital modeling environment. We form a spatial impression of our surroundings by the way the environment filters sounds. Spatial geometry and material properties in our environment are understood through listening to them. As sounds from multiple sources interact with walls, floors and other architectural elements, a space takes on an aural character. Through an increased awareness and ability to design for the aural experience, architects can achieve more exciting, varied, and better performing acoustic spaces.

1. Experiencing Sound

Beyond building, architecture can be thought of as everything that is about, around, or in, a building. (Betsky, 2008) Architecture is, at least in part, about our experience of space. (Pallasmaa, 2005) Architecture is silent until sound is added by its occupants. Just as we cannot see architecture without light, we cannot hear architecture until there is sound. Through the sounds that we make, we are in constant dialog with our surroundings. The sounds we hear allow us to judge space in several ways: the direction of sound sources, the distance to a sound source or various sound sources, and the dimensions and reflective properties of the walls and surfaces surrounding us. Our ears are sensitive to sounds from any direction and from sounds from hidden objects. (Plack, 2005) The integration of sound into the architectural design environment gives the potential for the production of better sounding spaces which has been proven to increase work enjoyment and efficiency, reduce stress, and increase our learning potential. (Oliver, 2002) Our aural experience is shaped by both psychological and ecological causes; this essay focuses on how the physical environment creates and modifies the sounds around us. Architectural designers can design the properties of this physical environment, and therefore design the aural experience.

The sensation of sound can be divided into two categories: temporal sensations and spatial sensations, and responses to sound, therefore, may be described in terms of combinations of time and space factors. (Ando, 2009) Sound occurs over time, and is experienced in time. The key parameter for the description of acoustic performance for architecture is reverberation time, the time it takes for sound to decay to inaudibility in a space. (Sabine, 1964) The sound design of architecture is about constructing a spatial and time-based experience. "Time is central to our experience of sound, though mostly irrelevant for vision." (Blesser, 2007) Sound is part of architectural experience, yet is a spatial sense different from vision. Currently it is not routinely architects but rather acoustic engineers who are charged with anticipating and measuring acoustic performance for architecture. Sound is not typically considered in a conceptual way for a space during the design process. While there will always be a role for acoustic engineering in sound design, architects need new methods to design for sound.

Figure 1. The Sound Experience – Project Distortion I: This project took as its starting point the desire to create varied experiences of sound and light. The structure needed to adapt to four different sites and programs corresponding to the four days of the Distortion music festival in Copenhagen. Distortion I was a design unit at the Royal Danish Academy of Fine Arts School of Architecture taught by Martin Tamke, Brady Peters, Niels Andersen, Ali Tabatabai, Reese Campbell, and Demetrios Comodromos.

2. Drawing Sound

There is a dialog between the design idea and the mode of expression. Architects are skilled at communicating concepts from their imagination into drawings. Hidden within the drawing is the information of spatial experience, situated between the conceptual nature of the orthographic drawings that represent thought and the perceptual nature of the full experience of the body moving within space. The architectural drawing defines what it means to be an architect; it communicates the design of a building to those who will build it. Concepts such as sound are difficult to draw, yet must be drawn in order to be communicated and built. Drawing has given importance to the role of vision over other senses, such as touch or hearing. (Hill, 2006) Various techniques have been developed to understand the experiential aspects of architectural propositions: paintings and computer renderings can capture light effects, animations can capture motion effects, but how can architects explore sound effects? How can we hear a drawing or representation of a space?

There are several techniques that can be used to explore the sonic dimension of architecture, yet few of these representation methods are specific to sound. Architects do not have a language or graphic convention to communicate ideas of sound, so when sound is drawn techniques are borrowed from the ways that architects describe other phenomena. For example, shading can be used to describe sound (borrowed from descriptions of light), annotation can be added to plans or sections (in the way that drawings describe materials), or arrows can indicate sound directions (borrowed from various structural or mechanical service diagrams). Typically, orthographic drawings are coded with color or shading to indicate the specification of sonic performance. Acoustic performance is typically communicated using numerical acoustic parameters represented as graphic displays specific to a sound source and sound location. Arranged in a spatial grid, this can graphically show the gradient of acoustic performance that exists in a space. A specific sound source is still used, and it is possible to virtually move around the room and understand how performance varies from one position to another. Reflection diagrams are another technique used to show how sound should perform in a space. Reflection diagrams typically show the propagation of sound overlaid on conventional orthographic drawings. Less frequently, designers sketch conceptual diagrams of sound spaces in order to capture design intent. Using parametric modeling techniques, these sketches can become drivers for the generation of geometry and material.

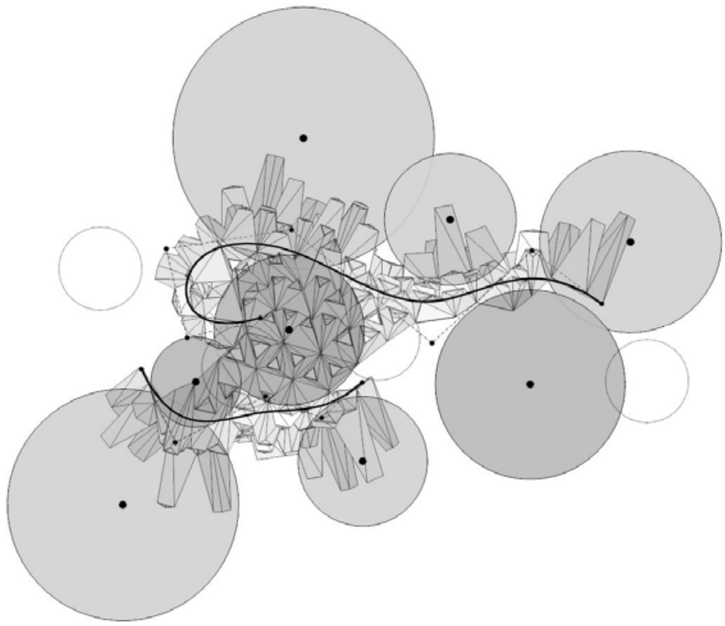

Figure 2. Sound drawing – Project Distortion I: Conceptual sound diagram of one configuration of the installation. The diagram shows control geometry for the generative model, a map of different acoustic subspaces, the generated geometry, and a suggestion of different routes through the structure.

A survey of current architectural design software shows that no software gives feedback regarding acoustic performance. (DeBodt, 2006) However, parametric modeling can allow the creation of custom digital tools which can allow sound to become a consideration during the architectural design process. Acoustic performance simulation can then provide necessary feedback by which the sound experience can be studied and predicted prior to construction. (Peters, 2009) The science of architectural acoustics provides mathematical descriptions and numerical techniques by which acoustic performance can be simulated. However, this in itself does not bring sound into the architectural design process. Designers must be able to explore and play with different aural concepts. Sound design is missing in architecture. The design of the sound experience exists for cinema, computer games, and industrial design, but not for everyday architecture.

3. Modeling Sound Spaces

The majority of architectural drawing and design now involves the use of computers. Using digital drawing tools architects construct digital models of their designs. A model is, by definition, separate from what it represents; it is an abstract description of a system. (Sokolowski and Banks, 2009) In architectural terms, a model is usually a physical or digital representation of a part of reality. Models help designers learn about the real world and by studying models it is possible to discover things about the system the model stands for. Architectural models, and architectural drawings are, by necessity, abstractions of reality; they do not contain all of the information of reality in them. Models with less information are faster to build, easier to understand, and can produce more design options in less time.

A parametric model, also known as a constraint model, allows designers to explore relationships. (Woodbury, 2010) It is a mapping of relationships and constraints between elements in the model. The use of the digital as a tool and a medium allows for algorithmic design, and the designer as tool builder (Whitehead and Peters, 2008). As the parametric modeling environment is flexible and can be extended with computer scripting, it is possible to integrate knowledge from engineering and science. Parametric modeling techniques allow statistical relationships of the science of acoustics to be "parameterized". Wallace Clement Sabine, (Sabine 1960) defined the key parameters of our sonic experience of space as material and geometry. The relationship between surface area, volume, and material properties can be included as part of a parametric model. Then as materials are changed, or the size of the space is changed, the change in the reverberation time of the room can be monitored.

New digital modeling tools and techniques allow architects to create digital models that explore and balance spatial, functional, and sonic performance requirements. Architects are then able to explore new and future design scenarios. A model is wholly descriptive. While new potentials do seem to emerge as the model is studied, these discoveries happen within a system that is already entirely predefined. The use of optimization tools such as genetic algorithms can allow designers to find solutions for specific parameters within large solution spaces. Though these techniques find solutions that may not have been discovered otherwise, the found solutions already existed within the description of the parametric model. Often a solution space can be so large these techniques are needed to "see" them. These new tools and technologies allow for performance criteria and aural relationships to be considered during the design process. These techniques, while they are not creating new potentials, allow for the exploration of potentially unconsidered options and the discovery of hidden optimized conditions within the model definition. In this way, parametric modeling allows for the creation of a tunable digital and design space. Simulation of acoustic performance allows us to hear our designs.

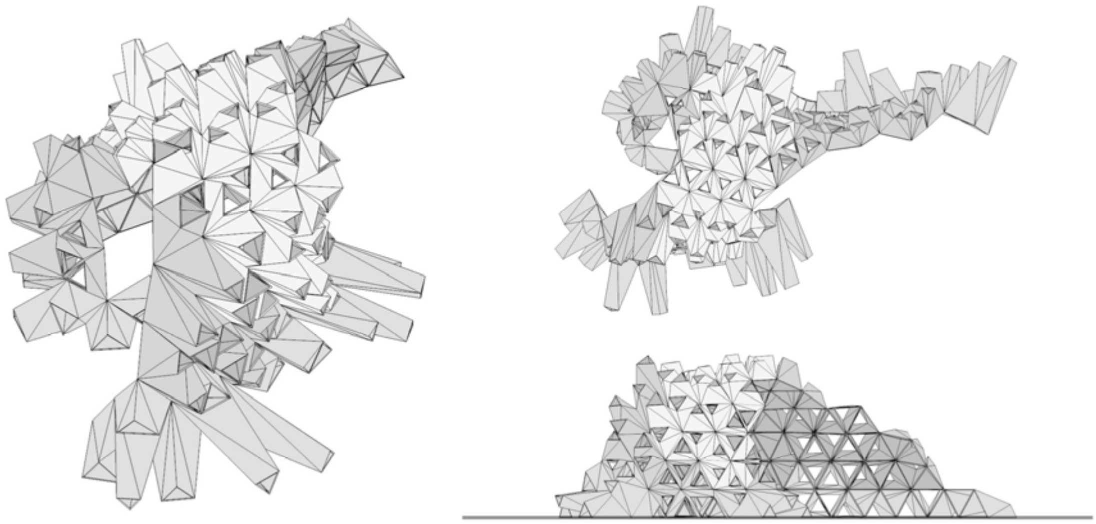

Figure 3. Parametric Model – Project Distortion I: Different parametric software programs were used at different phases of the project. Grasshopper, Maya, and Microstation were used to draw, explore, and generate the geometry.

4. Simulating Sound in Space

Simulation is the repeated observation of a model. While a model is an abstract description of a system, a simulation is the description of the behavior of that system. The simulation allows for the imitation of a real-world process over time. (Sokolowski and Banks, 2009) Simulations can be used to show the eventual real effects of alternative conditions and courses of action. They are used when the real system cannot be engaged, because it may not be accessible, it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist. (ibid.) A simulation is not wholly descriptive. When a simulation is begun, the outcome or result is not necessarily known. Simulations do not prescribe to the view that, given a sufficient amount of detail, everything can be predetermined, in the way models are predetermined. It has been shown that it is the errors in the description of models that are used to describe systems, rather than the random nature of the environment, that accounts for the inaccuracies in prediction techniques. (Orrell, 2007)

Simulations can be used in architecture to predict the aural characteristics of a space before it is built. Computational techniques have been developed that allow for the calculation of acoustic parameters such as sound level, reverberation time, and quality of speech. These techniques have been implemented in commercially available acoustic analysis software. (Rindel, 2000) Many of these computational techniques and software have been validated as design tools for architecture. (Bork, 2005) Auralization is the processing into an audible result of the acoustic characteristics of a space with a sound signal. The process of auralization requires the calculation of the acoustic characteristics of a space through simulation. Auralization uses a "dry" sound signal, one recorded without any effects of architecture, and processes it with the architecture of a specific space, including the positions and characteristics for the sound source and sound receiver.

A building must be occupied for the sonic part of architecture to emerge, therefore it needs a user. In order to simulate the sonic performance of a space, a user's behavior must be predicted. There is an assumption that a space has a function, and that the optimization of the form and material of the space relates to that function. A relation is established between form, material and behavior. Multi-functionalism can be considered in predicting behaviors because some buildings such as offices or schools may have flexible open plan spaces, and in these cases the behaviors of users should not be narrowly defined.

Performance is the ability of a mechanism to execute an action; it relates to what a thing does and how well it does it. Performance must involve the measurement of an action, and the comparison to an ideal. This comparison determines the level of performance. A performative system is defined by behaviors and how these react to a stimulus. A performative system relates to interactions and behaviors and can inform responsive and adaptive spaces or components. Performative architecture involves the measurement of a condition, the comparison to an ideal, and also the response of the system and the adaption of the system, to better meet the ideal condition.

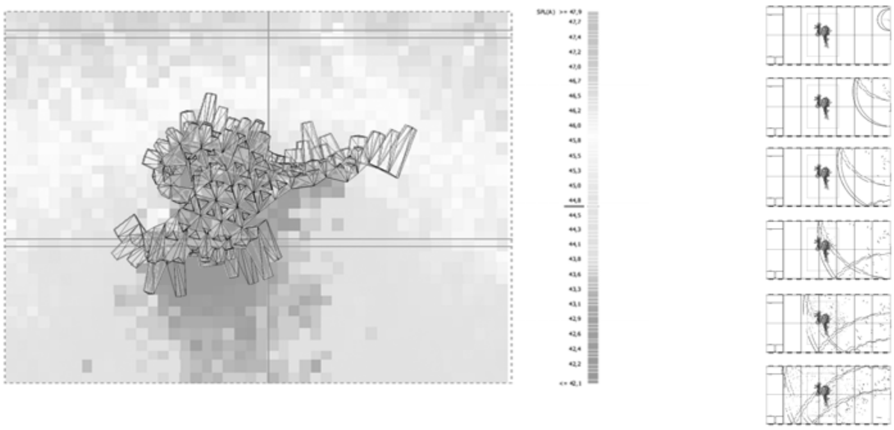

Figure 4. Simulation of Sound – Project Distortion I: Acoustic analysis shows the gradient of sound pressure level (dB) created by the installation thereby creating acoustic subspaces. This sequence shows how sound waves interact with the structure.

5. Adaptive Sound Structures

A building's occupants are always moving about, and building's function will likely change several times in its lifespan. It is entirely possible for the digital parametric model and corresponding simulation routines to take into account a variety of different scenarios: new wall configurations, replacing materials, changing sound sources, new occupants and listeners, and revised performance requirements for various functions. However, the final building is rarely as adaptable as the digital model. There exists the potential for the digital model to persist beyond the pre-building phase into the life of the building to inform how future adaptations can take place. Of course, there exists a spectrum of different scales of adaptation; a space may need to adapt only every 25 years as the function changes, or a space may need to continuously adapt to the changing position of users (sound receivers) and sound sources within the space. Parametric tools and computational techniques should be able to inform this architecture of transformation. This concept relates to a continuous cycle of transformation of a building's performance in relation to measured parameters of its environment. The building's physical state, and therefore its relationship to its environment, could be adjusted through feedback loops. In this goal-directed system, measurement would be necessary to monitor how the current state differs from the desired goal, and also to measure the degree of adaptation required.

In the traditional architectural design process, the drawing is superseded by the building. The role of the drawing is to be predictive. With parametric drawings tools, simulation techniques, and monitoring and measurement systems there can remain a dialog between drawing and building. This relationship can be used to make the building better, and to adapt architecture to achieve more suitable occupation and use. It is possible to generate and manage building data over time. Using three-dimensional, real-time, dynamic building modeling software, encompassing building geometry, spatial relationships, geographic information, and quantities and properties of building components, building data can be generated and managed during a building's life cycle. This is almost identical to the current definition of the 'building information model'. (Lee, Sacks, and Eastman, 2006) However, a few points must be overcome relating to practical use. With new versions of software released every year, or even every month, how long until these digital models are obsolete? How do these timespans compare to the lives of the buildings they are meant to support? A second issue is the complexity of the digital model. At what point does the digital model become so complex that it is too cumbersome to be useful? A third challenge is that the building information model must allow the continued understanding of the drawing, and the design of architecture, as a creative endeavor rather than merely as a representational task. Through adaptation and renovation, architecture has the potential to improve after its initial construction allowing it to maintain and achieve high design quality.

As discussed, simulations are the study of a simplified model of a system and therefore they contain inaccuracies. Despite the advances in simulation tools for acoustic performance, it is very difficult for anyone at any stage to precisely predict the acoustic performance of a space. There are two main reasons for this. Firstly, simplifications must be made due to the inability of the simulation to accurately reproduce all aspects of reality. These simplifications create a margin of error. Secondly, it is impossible to predict exactly what the nature of the sound will be in the space, where it will be, and who will be listening to it. To begin to address these issues, a parametric digital model can be updated with user experiences and with measurements of the space, and can incorporate an ongoing dialogue between building and drawing. In addition, during the design process, space for adaptation could be purposefully left within the building project. The performance could be tested, and the space could be designed to be adapted to fine-tune the performance after construction. In order to create higher quality spaces relating to sound performance, a cyclical relationship of experience, measurement, and redesign can correct the inaccuracies, and imperfections of current simulation limitations.

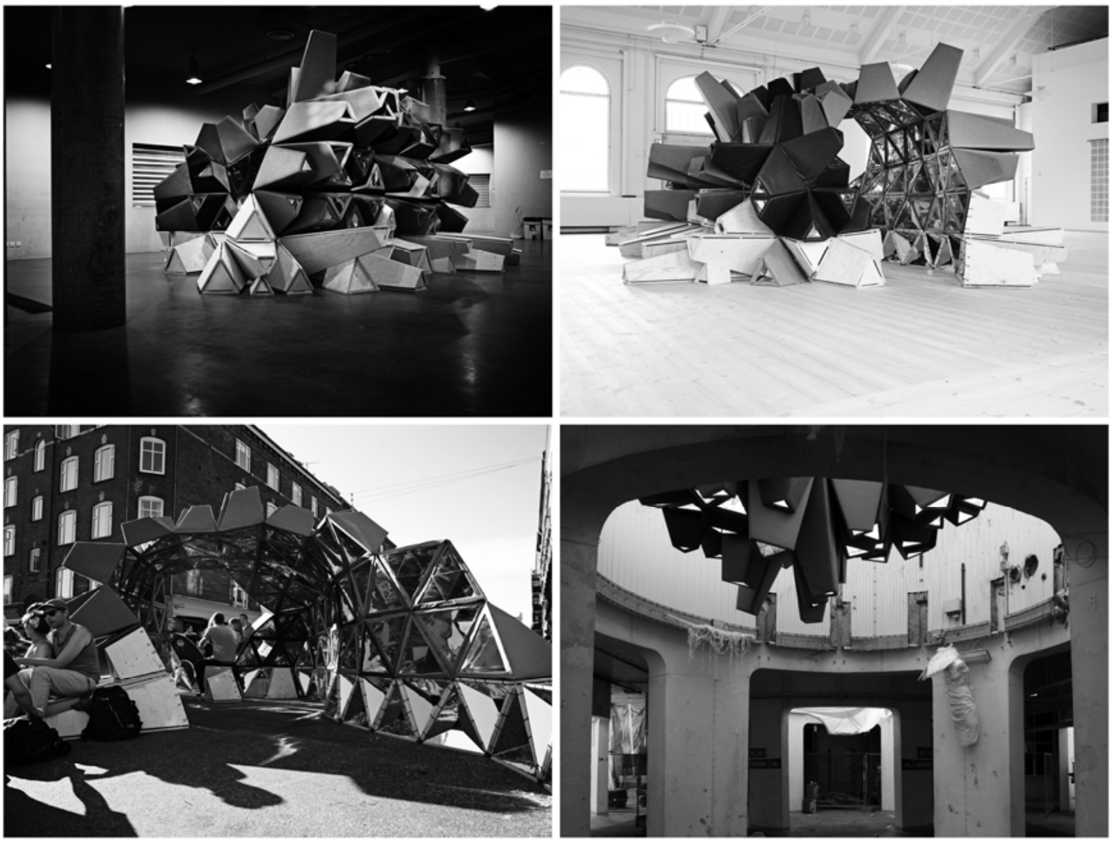

Figure 5. Adaptive Sound Structure – Project Distortion I – The digitally fabricated, reconfigurable pavilion was made up of over 150 individually tuned sound and light cones cut from acoustic absorbing material. Focusing on acoustic and visual performance and its interaction with the inhabitant the installation visited four venues during the festival taking center stage outdoors, in a small nightclub, on the street, and in a crowded lobby. (Photos by Anders Ingvartsen)

Conclusion

Architects are increasingly becoming more able to design for sound. Acoustics, the science of sound, has established techniques for understanding and predicting the performance of sound in buildings and through the use of digital parametric modeling techniques; architects are becoming more able to use some of these ideas in the design process. New computational design methods are increasingly allowing for the integration of acoustic science and architectural design. Simulation can be used by architects to predict the acoustic performance of architectural designs. These three concepts: acoustic science, digital modeling, and simulation, will allow architects to incorporate sound into the design process. What architects need to do now is to develop the verbal language and visual representational tools to refine and communicate acoustic performance in the exploration of this design territory.

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