SoundScapes & Architectural Spaces

Spatial sound research in digital architectural design

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The paper presents ongoing research focusing on the development of digital tools and methodologies for spatial design based on non-Euclidean geometries. It addresses the way sound can be used both conceptually and acoustically in the early stages of the design process, examining digital architectural design and modeling based on three-dimensional sound visualization and the acoustical analysis and evaluation of complex curved surface geometry. The paper describes SoundMatrix, the first part of a digital design tool created by using Max/MSP/Jitter, to assist in the preliminary design of building façades in small-scale urban environments, specifically studying the possibilities of curvature to decrease sound reflection between opposing street façades. Examples from a workshop with the SoundMatrix application illustrate the real-time 3D authoring and sound spatialisation processing currently implemented in the tool.

Keywords: *graphical programming; performance-based design; generative design.*

Introduction

This paper addresses digital architectural design based on sound and acoustics. In the general frame of digital architectural design, sound and auralization are neglected topics, even though the sound environment is a fundamental, yet immaterial dimension of architecture.

The issue of flatness and surface plays a critical role in digital architectural design practices, a point of view that is also described by Imperiale (2000). With the introduction of innovative modeling and visualization techniques in the conceptual phase of the architectural design process, complex mathematical equations are used to describe space and develop form through the creation and manipulation of curved surfaces. Hays (1995) points out that the pursuit of smoothness, which characterizes digital architecture, causes a loss of "reality". By and large, digitally designed curved geometry is perceived as artistic, without reference to architectural history, typology or even physical reality. This research tries to uncover design methodologies based on the physical interaction of sound in space. The boundary surface of the space works as an interface between architecture and the sound waves. The aim is to define a digital design approach and methodology that connects the generation of virtual free form geometry to the actual reality of the build environment.

A few examples of digital design processes and methodologies involving sound and audio data files can be found, but generally, these designs do not take into account the acoustic performance of the spaces and ignore the soundscape that was created. Marsh and Carruthers (1993) point out that, given the significance of room shape as a factor in overall acoustic performance, the ability to interactively relate sound behaviour and space geometry in the conceptual design phase would be of significant benefit.

Integrating both design and analysis into design software will improve the evaluation process of the design's performance and consequently have a positive impact on the result of the design effort. Kolarevic (2001) states that an acoustic performance based digital design method is missing from current design processes. The objective is to develop and use digital tools and methods for (conceptual) architectural design, that integrate sound as physical and functional design criteria in the digital design process.

Rasmussen (1959) suggests that visitors usually catch an overall visual impression of a building and seldom realize all the perceptions that contributed to that impression. Visual and sonic impressions of a space interact to create a multi-sensory experience for the observer and heighten the sense of presence and place within the space. Research into the application of soundscapes to enhance virtual environments has been extensive. Especially 3D sound, in combination with 3D graphics, tends to play an important part in providing an artificial sense of reality for various game software and multimedia applications. So far, architects have paid little or no attention to the design of soundscapes and their potential to enhance and improve spatial awareness.

Sound in digital architectural design

Sound can be related to architectural design in two ways, either artistically or pragmatically. Both approaches are studied in the earliest conceptual stages of design, integrating the field of formal architectural design and the field of design analysis. Environmental acoustics and performance-based architectural design in particular are considered.

Formal design

On the formal level, the study is based on the (3D) visualization of sound information and discusses concepts and techniques for modeling complex curved geometry through time-based digital design processes with sound parameters.

Information taken from a sound source can be used to transform a 3D model, for instance by scaling, which was used in the design process for Paramorph by Decoi, described by De Luca and Nardini (2002). An other example of this kind of transcoding (Manovich, 2001) is the project by Winka Dubbeldam for the Masonry Variations exhibit. Lars Spuybroek's Son O House is an example of a soundscape design, where a sensor triggered interactive installation is an integral part of the project. Kas Oosterhuis has used sound to enhance the experience of a water world in his SaltWater pavilion.

Acoustic design

On the pragmatic level, the study focuses on the physical context, studying the guiding design principles of sound based design processes within a location-specific context. In this respect, it is the performance criteria that inform the design solution. For modeling digitally simulated sound fields, a careful consideration of the reflections from surrounding surfaces is necessary. Dispersion of sound by reflection on free-form surfaces is the decisive factor examined in this research.

Studying sound reflection paths, Foster and Partner's design of the debating chamber of the London City Hall was adapted according to the results of Arup's acoustic simulation.

Digital Design tools

Current CAAD software can assist architects in visualizing, simulating, analysing and/or evaluating emerging design solutions. However, most programs include just one or two of these features, generally separating performance analysis from geometric modeling. Kolarevic (2005) observes an apparent "disconnection" between geometry and analysis in the currently available digital tools. In CAAD and modeling software, some analysis is available. For example, Rhino 3D is a NURBS modeller, used in product design and architecture, which offers structural analysis. Acoustical analysis is however missing from these applications.

On the other hand, acoustic analysis software, such as room acoustic modeling programs Odeon, CATT Acoustic or Ramsete, allow the import of geometric models. The design can be analysed and edited, but there is no modeling or design process integrated in the software. Andrew Marsh's Ecotect, a program for analysis of light, heat and acoustics in the conceptual design stage, has its own set of modeling tools, but does not support auralization or design generation based on sound parameters or audio files. Huopaniemi, Lokki and Savioja (2002) describe auralization as the modeling and simulation of sound propagation from sound sources to the ear drums of a listener through the modelled space. Software especially developed for the auralization of the sound environment, like the DIVA auralization system, also supports the import of existing models, and is not directed at designing.

In soundscape rendering, the computation of sound propagation paths from sound sources to receivers in architectural environments has been studied and publicized extensively. Among others, Ray tracing, Beam tracing and image source algorithms have been developed to simulate the soundscape in a particular environment. The majority of applications for soundscape rendering make abstraction of the surface profile, only considering the height, not the actual silhouette. Prof. Kang developed such a tool in Java, with the focus on analysis. (Kang et al, 2003)

Design Applications

There have been several research projects that have investigated and programmed applications for acoustic design generation and support. Mahalingam (1998) presents the development of a CAD design system for the preliminary spatial design of proscenium type auditoriums. He introduces the concept of "acoustic sculpting", an algorithmic process to generate the spatial form of an auditorium by deriving architectural parameters from acoustic parameters.

RPG® developed Shape Optimizer™, a tool to acoustically optimise curve shaped walls. Within the imposed constraints of surface depth, width and motif, various shape modifications are automatically evaluated.

Application Concept

Architectural design based on sound and auralization is explored by developing software with Max/MSP/Jitter, using Max/MSP's programming environment and programmable objects for sound, together with Jitter, a set of matrix data processing objects optimised for video and 3-D graphics, including 3D geometry and Open-GL objects. The SoundMatrix software patch is the first part of an application that is being build as a virtual tool with a link to the actual reality of constructed space by means of the physics and math of sound. SoundMatrix was made for the 2006 ADSL workshop "InterAction" at the Higher Institute of Architectural Sciences Henry van de Velde in Antwerpen, Belgium, together with the SpaceCustromizer tool, which was designed for Henriette Bier, based on her concept of SpaceCustomizer (Bier, 2005). The theme of the workshop, InterAction, was implemented for movement in SpaceCustomizer with color tracking and in SoundMatrix with sound recording.

In the workshop, the concept of "locus" was introduced, as described in Mahalingam (1998). Apart from being the Latin word for "place", in planar geometry, loci are lines traced by points according to certain rules and conditions. Acoustics can become a form giver for architecture, when these rules are set by acoustic parameters. In the SoundMatrix tool, the amplitude of the audio mix and the distance to the shape were used as the guiding design principles.

Following the laws of physics, the application generates the visualization and auralization of architectural surfaces and spaces and is intended to facilitate digital design and allow architects to work on formal, aesthetic and acoustical aspects of conceptual free-form surface modeling.

The SoundMatrix's design patch currently supports real-time interactive 3D modelling of a NURBS surface and auralization of the related soundscape. Different sound information can be used as input, such as sine tones generated by harmonic numeric data, real-time or recorded microphone input, sampling and sound synthesis. The sound mix of selected audio-inputs is applied to generate the surface deformation.

Implementation

Initially, two parallel surfaces are created, corresponding to the representation of opposing façades of a street in a small scale urban environment. Both planes are NURBS surfaces, and while one remains flat, the other is deformed, generating organic 3D curved geometry visualization of the Audio data. Formally, the deformation is controlled by the sound parameters. At the same time, a real-time sonification of data is implemented. It is possible to create acoustic gestalts by means of mapping algorithms that relate the data to the acoustic parameters.

Programming

Max/MSP is a graphical programming environment for music, audio and multimedia, used to design cross-platform programs and user interfaces. Programming takes place in the Patch window, where Max/MSP Objects, represented as boxes, are connected with patch cords. The program library contains objects to perform a wide range of tasks, from basic arithmetic to waveform editing, etc. The SoundMatrix application consists of two main patches, SoundMatrix and Spat4, and a number of sub patches for different sound source input and export options.

SoundMatrix

The Main patch contains a Lissajous Modeler (De Bodt and Galle, 2005), a mixer interface to activate

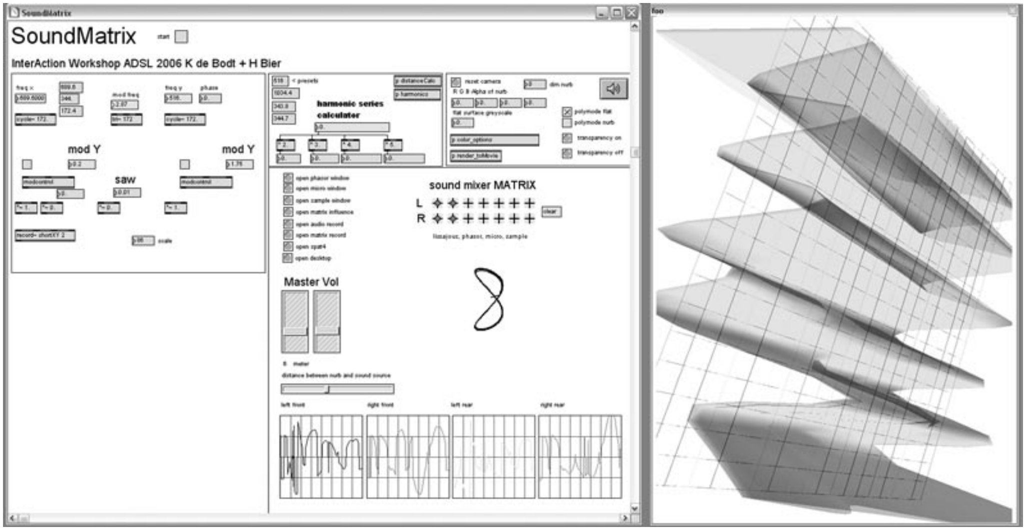

Figure 1
SoundMatrix main interface patch

and combine different sound sources and OpenGL visualization objects for the generation and adjustment of two Nurbs surfaces .

The surfaces are created by the Jit.gl.nurbs object with a control point matrix. One surface is deformed by mapping the amplitude modulation of the audio data to the control point matrix of the NURBS. The amount of displacement of the surface indicates the level of amplitude modulation.

The IRCAM patch Spat4 holds a quadratic setup of speakers and the calculations and settings for reverberation, early reflection balance and high frequency roll of. These effects are applied to the audio stream and simulate a 3D spatial sound field with speaker panning.

Input and export

A number of sound sources can be used to influence the shape of the NURBS surface. Next to the sine wave modulation of the Lissajous Modeler, the patch contains a phasor, microphone input and recording and the use of samples. Each can be used separately or in combination with each other. The sound is mapped on the NURBS surface by iterating the matrix of the control points. The amplitude is converted to a greyscale representation matrix with values between 1 and 0. This matrix is used to displace the surface according to the calculated value.

Max/MSP is able to record and export images, video, audio and jitter data files. An export for 3D geometry is not available in Max/MSP or Jitter. 3D geometry can be captured and reused from 3D graphics applications running on Windows OS with the OGLE OpenGLExtractor by Eybeam R&D. Ogle is a plugin for the OpenGL DLL Proxy GLIntercept by Damion Tribelco, which intercepts the OpenGL data stream. OGLE takes the information collected by the GLIntercept proxy and writes out a 3D geometry file in a standard obj format.

Workshop

The students were given the assignment to generate a visual and audible representation of a small scale and a large scale space. They examined the differences in spatialisation by the reverberation effect linked to the distance between the Nurbs surfaces. The exercise was intended to create, experience and adapt a soundscape design by listening to audio cues.

The software was used to experiment with different sound input, simultaneously exploring visual and acoustic parameters in the context of space and time. The students developed an auditory understanding of distance and scale in a virtual architectural environment. The examples taken from this workshop demonstrate both the real-time 3D authoring and the sound processing of the software.

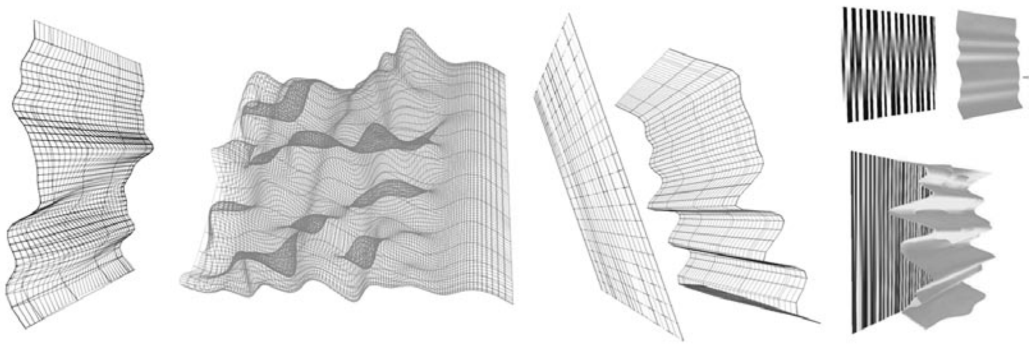

Figure 2
Workshop examples of deformed NURBS surface

Conclusion

In architecture, the visual experience is regarded as the dominant perception and is the main concern of designers. As New Media become more and more a part of our everyday experience, a multi-media approach to design and space will involve not only vision, but also include other senses like hearing. SoundMatrix deals with complex 3D modeling, transformation and auralization in computer aided design in real-time. The SoundMatrix patch is the first part of an application which is being created to support the design and acoustical enhancement of soundscapes. Architecture students used SoundMatrix for the workshop exercises and experienced the simultaneous soundscape auralization as a valuable guiding design assistant. Future work will include the implementation of reflection path rendering to automatically determine the geometry of the surface.

Acknowledgements

This paper has benefited from the results of the workshop organized within ADSL (Antwerp Design Seminars and Lectures) 2006 at the Higher Institute of Architectural Sciences Henry van de Velde in Antwerp, Belgium.

The author would also like to thank Jerry Galle of the Ghent Academy of Fine Arts, Belgium, for his assistance and expertise in Max/MSP.

References

Bier H.: 2005, SpaceCustomiser: Towards System Embedded Intelligence in Architecture, in Research Portfolio - Architecture 2005-2006, Delft University Press, Delft.

Bodt K. de: 2006, Digital Resonance: Sound Parameters in Architectural Design, in K. Oosterhuis, L. Feireiss (eds.), Game Set and Match II Conference Proceedings, episode publishers, Rotterdam, pp. 226-233.

Luca F. de and Nardini M.: 2002, Behind the Scenes: Avant-garde Techniques in Contemporary Design, Birkhauser, Basel.

Imperiale A.: 2000, New Flatness: Surface tension in digital architecture, Birkhauser, Basel.

Kang J., Meng Y. and Brown G.: 2003, Sound Propagation in Micro-Scale Urban Areas: Simulation and Animation, Proceedings of the Fifth European Conference on Noise Controle – Euronoise, Napels.

Kolarevic B.: 2001, Designing and Manufacturing Architecture in the Digital Age, in H. Penttilä (ed), Architectural information Management, Helsinki University of Technology, Helsinki, pp. 117-123.

Kolarevic B.: 2005, Prologue, in B. Kolarevic and A.M. Malkawi (eds), Performative Architecture . Beyond Instrumentality, Spon Press, New York, p. 3.

Manovich L.: 2001, The language of new media, The MIT Press, Cambridge MA

Rasmussen S.: 1959, Experiencing Architecture, MIT Technology Press, New York, p. 232.

Carruthers D. and Marsh A.: 1993, The predictive Capacity of Ray Traced Acoustic Models, paper presented at ANZAScA Conference, Perth, December 1993.

Huopaniemi J., Lokki T. and Savioja L.: 2002, Auralization applying the parametric room acoustic modeling technique – The DIVA auralization system, Proceedings of the 2002 International Conference on Auditory Display, Kyoto.