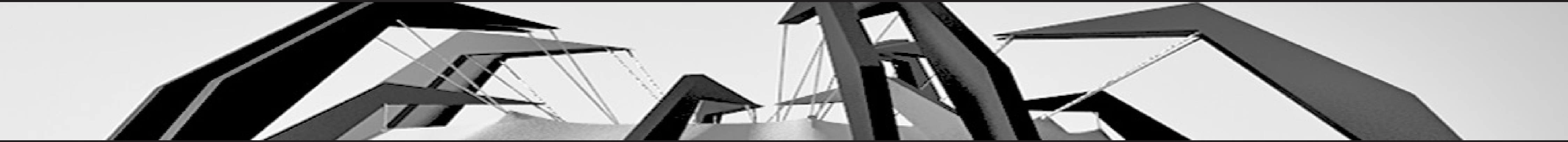


Sonosentio

RESEARCH CATALOGUE

Sonosentio

A thesis submitted in partial fulfilment of the requirements of the Degree for Doctor of Philosophy.

Peter Holmes

School of Architecture and Design

College of Design and Social Context

RMIT University

March 2013

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Signed:

Peter Holmes

Date:

Acknowledgements:

I would like to thank Leon van Schaik for his patience and advice in the pursuit of this work. And also to Melisa McDonald for consoling discussion.

I would also like to that Peter Dale and John Watson of the RMIT Applied Acoustics Laboratories who graciously shared their knowledge and experience.

And Lauren Davis whose assistance and support allowed me to sustain my enthusiasm. And also for her review of my work.

The CSIRO for allowing access to their anechoic chamber without which this work would not have been possible.

Thanks to Mark O’Brien of Benchmark Models for the construction of the physical prototypes of the enclosure and its support structure.

Thanks to Mikee at Kid Neon Images for his digital rendering expertise.

Thanks to Rob George for assistance with geometric mathematics.

And my gratitude to Arup and Marshall Day for the experience and opportunities gained in my many years of service.

And thanks to Pete and Suz for regular dinner and conversation. And to Cookie, where the bulk of the documentation took form.

Contents

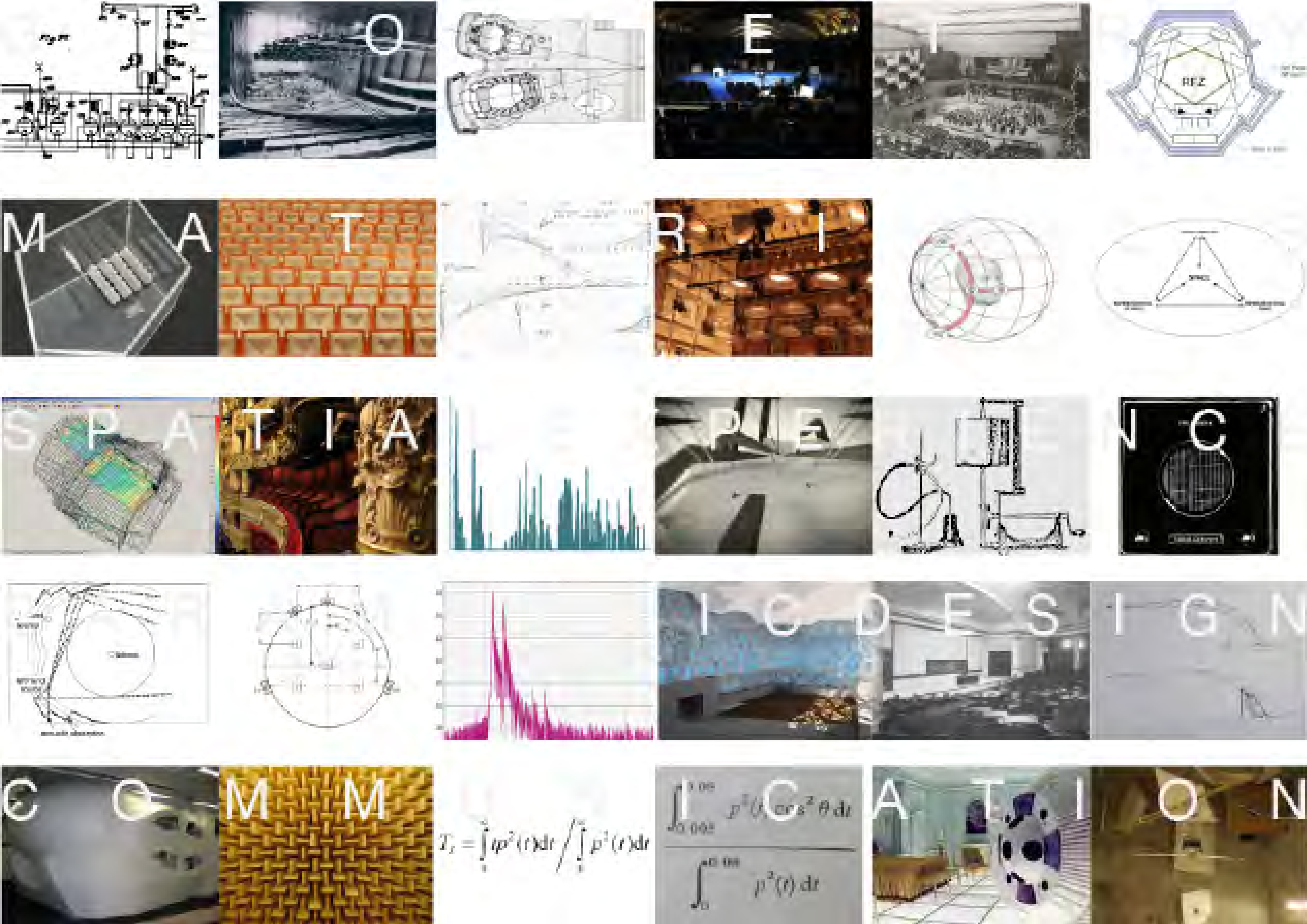
APPENDIX 1 BACKGROUND
APPENDIX 2 COMPONENTS

list of figures

Images by Author except as listed below.

list of figures

list of figures


O E I
M A T R I
S P A T I A P E N C
I C D E S I G N
C O M M I C A T I O N
REZ
$T_s = \int_0^\infty t p^2(t)\mathrm{d}t \Big/ \int_0^\infty p^2(t)\mathrm{d}t$
$\int_{0.002}^{0.08} p^2(t)\cos^2\theta\, \mathrm{d}t$
$\int_0^{0.080} p^2(t)\, \mathrm{d}t$

Sonosentio

Introduction

RESEARCH INTO A NEW SONIC DESIGN PROCESS FOR COMPOSING RESPONSIVE SPATIAL GEOMETRIES.

DESIGN:

“1. to prepare the preliminary sketch or the plans for (a work to be executed).
2. to plan or fashion artistically or skillfully
3. to intend for a definite purpose.
4. to form or conceive in the mind; contrive; plan
........” - Macquarie Dictionary Fifth Edition.

COMMUNICATION:

“the successful conveying or sharing of ideas and feelings”
........” - Oxford Dictionaries online.

Why this project?

This project researches a new spatial design paradigm for creating unique, sonically derived geometric compositions. The research explores this new paradigm through the design of an interactive sonic design environment - Sonosentio.

The research reflects upon the author’s experience in the design of performing arts, media production and theatre technology projects. It specifically considers the process of design for projects where sonic context is one of the principal design considerations, and sound quality represents a major factor in determining the successful resolution of operational and functional requirements.

The sonic character of our environment provides us with a significant spatial awareness of our surroundings and its occupation. As the sensitivity to sound becomes more critical, the sonic character becomes a more significant aspect of the design process.

Facilities such as production studios, performance venues, cinemas and places of worship, require specific consideration of the sonic context in their primary design goals. However, for the majority of buildings, design success is not determined by sonic considerations. The sonic response of these spatial compositions is typically accidental rather than designed. Therefore, our subjective impression of enhancement or degradation by the spatial is imposed rather than designed.

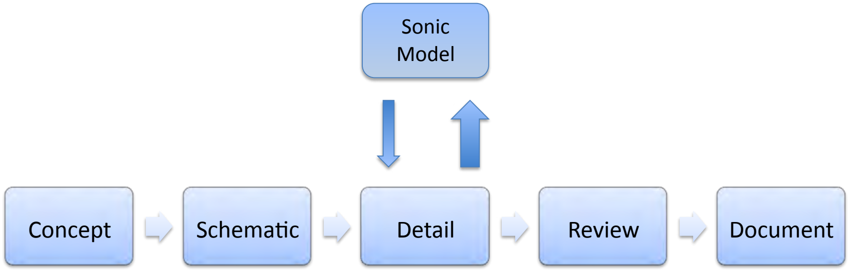
In many cases the sonic considerations for a building will become apparent following completion of construction rather than during design. Rectification replaces design as a process. Financial constraints tend to result in the implementation of a series of incremental, inadequate remedial improvements that merely reinforce the ongoing permanence of failure.

Design of spatial geometry is typically undertaken in the visual domain. Many “sonically” designed buildings are merely facades developed from a reference to sound in a visual context. However, our spatial perception of sonic cues is more enveloping than our relatively narrow and predominately forward facing visual perspective. When we perceive these cues without visual reference our imagination is able to inform us of the spatial realisation based upon previous experience.

Sonic design is also often conducted in a predominately technical context with inadequate consideration for spatial experience or the aural aesthetic. These methodologies typically assess sonic qualities in terms of mathematically derived parameters conceived to quantify and communicate subjective experience.

This research has been undertaken through the design of an interactive environment that investigates a new paradigm for the design process of sonically derived spatial geometries. The project, Sonosentio, is interested in the deliberate design of sonic geometries. The research develops the concept of a sonic sketchpad that allows designers to create geometric compositions in an interactive aural environment. The aim of this research is to explore a new design paradigm using geometries conceptualised through sonic experience. By designing in the sonic realm we are able to compose responsive geometries that could not be realised by existing processes.

EXISTING

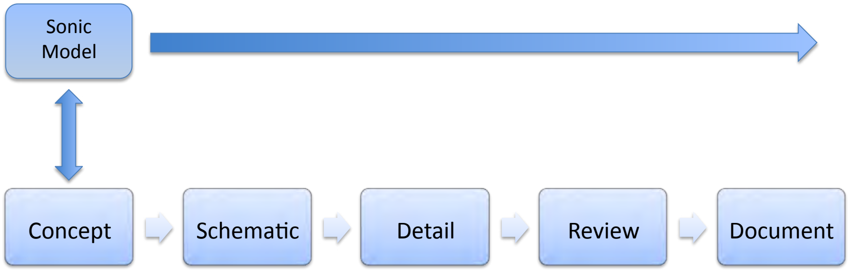


REFLECTIVE

LOOKING BACK

Figure 1: Existing design review process

PROPOSED



CREATIVE

LOOKING FORWARD

Figure 2: Proposed design process

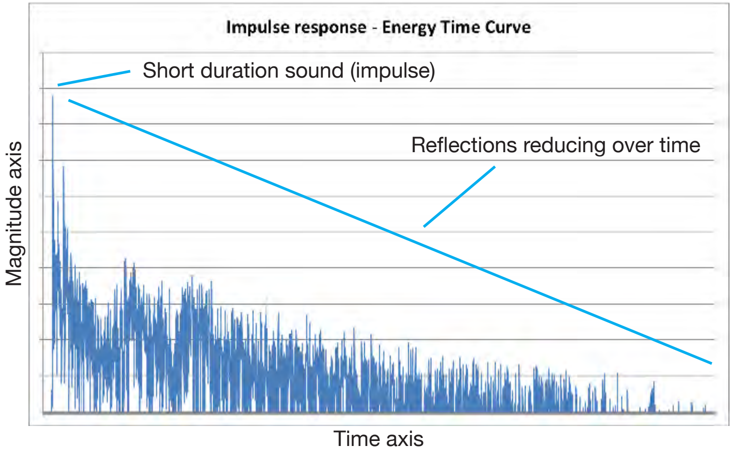


Figure 3: Impulse response

IMPULSE RESPONSE represents a sonic photograph of the response of geometry and materials to sound. It catalogues the sequence of sonic arrivals from a particular source location that combine to provide the spatial impression at a corresponding receiver location. Each discrete impulse in the response contains the distance, intensity and tonal character that describes the geometric features encountered by sound via that path.

For a typical enclosure the intensity of sonic reflections reduces over time as energy is dissipated by material absorption and geometric spreading. The subjective impression of this decaying sequence of repetitions is referred to as reverberation.

The acoustic indicies for objective assessment of space are mathematically derived from the measured impulse response. Although possible, typical impulse responses measurements do not contain spatial information regarding the direction of individual impulses within the overall response.

Research question

This research investigates the design process for sonically responsive geometries.

The fundamental question underlying this research is; “How could designers use sonic response as a primary design process for geometric composition?”

The existing sonic design process is typically characterised as a response to visually conceived geometries. A visually derived geometry is analysed by specialised technical software to derive an “impulse response” which represents the sonic image of the reviewed design. This is equivalent of image rendering in the visual design process.

The impulse response is then used to calculate a series of mathematically derived objective criteria to quantify the subjectively perceived quality of the designed space. The sonic design is therefore undertaken late in the process as a design review rather than interactively as a component of the creative design process.

The project, Sonosentio, does not aim to synthesise spatial impression (production tools), or recreate existing spaces (auralisation), it proposes an interactive space for a new creative design process for sonically responsive geometries.

The initial approach of this research was to investigate the minimum geometries that provide a distinct sonic impression of enclosure. The approach considered the decomposition of existing spaces into the critical geometric components that defined the unique sonic character of the space. These minimal geometries (sparse arrays) were then to be developed into new geometric forms with similar sonic characteristics.

During this process it became apparent that the existing tools for sonic “design” (acoustic ray tracing) have been developed to review and measure existing geometries rather than to creatively explore new compositions. The reflective tools allowed me to measure existing spaces or geometries derived from visual sketches, but I could not sketch an imagined sonic response and derive a visual geometry from that process.

My work in theatrical sound, spatial soundscape and as a musician provided a sonic imagination that could conceive sonic compositions. This was combined with my experience in venue and production facility design to provide a physical context in the built environment for the geometry and palette of materials that create these responsive compositions.

The focus of the research was therefore revised to consider how a “sonic sketchpad” could be used to compose geometries using spatialised sound as the design medium. The project aimed to shift the sonic design paradigm from being a reflective model, measuring visually composed geometries, to an interactive, creative design model to compose new, sonically responsive geometries.

This research explores this new process for spatial design through the proposition; “what would a sonic design sketchpad for geometric composition be?”

This PhD therefore researches a design process where sonic response can be sketched and developed into a geometric concept in the same manner as a sketch on paper is developed into visual form.

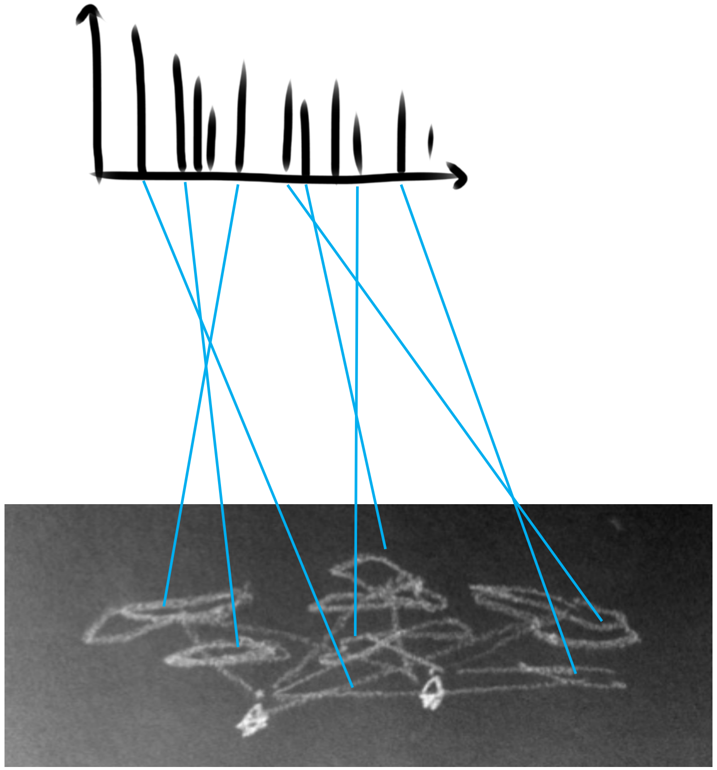


Figure 4: Relationship between impulse response and geometry

Contribution and assessment

"In most architectural schools the projection of sound is illustrated by elementary optical analogues which are often carried beyond their range of validity and may result in the poor performance of many concert halls." - Someville (1963), p4.

SONIC DESIGN

The field of sonic design is occupied by two fields; acoustic engineers and sound system engineers. This distinction between the origin of sound presented in space is a difficult divisional boundary to manage, particularly in the current environment where the requirements for venues is biased toward a carefully designed balance between these two fields.

Acoustic engineers typically have an aversion to reinforced sound. Sound system engineers typically consider the room to be an unnecessary impediment to the performance of their technologies. For this project I am using the term sonic design to describe an integrated approach to sound that applies both acoustic (passive building elements) and active (reinforcement) techniques to the concept of design of geometries for sound.

This PhD proposes a fundamental change to the process of sonic design for physical geometries from being a reflective process, to an interactive, creative process.

The research offers the potential to define a new approach that is a foundation for sonic design as a primary geometric composition tool. This would allow responsive geometries to be initially conceived in a sonic context and then the resultant geometry to be reviewed and interactively restructured in collaboration with other design disciplines.

The research proposes a reversal of existing processes that place sonic design as a secondary consideration, even where sound is a major factor in the project success.

It deliberately presents sonically derived geometries as a primary design methodology and proposes the use of sound as the principal design medium for performing these design exercises.

Sonic design for major projects is typically approached as an engineering review of developed design to identify potential issues and provide recommendations for rectification to allow the design process to proceed unimpeded. The supine engineer.

This process has resulted in significant difficulties where, while there may be some appreciation of the technical aspects of sound and geometric design, the associated experiential design is overlooked, often due to inexperience or inappropriate experience in the field.

The contribution of this research is the proposition of a new approach to the sonic design process where geometric composition is undertaken proactively using sound as the design, presentation and communication medium.

Designers are often obsessed with controlling sound, not experiencing it and letting it speak with its own voice. Sonic design is about balance, reinforcement and geometric composition conceived in harmony. Where sonic design presides over failure, the issues tend to be due to major failure rather than subtle qualities.

Assessment of this work should be undertaken on the basis of the fundamental premise; "a new process for sonic design as a creative method of geometric and material specification".

This premise does not dismiss collaboration, in fact the intention of this work is to enhance collaboration by making the sonic decision making process more accessible to collaborators with less experience in the field. Assessment should consider the context of this research within the real world of design practice and how existing design review practices constrain creative processes and do not provide optimal integration of design disciplines.

The research achieves this by dismissing the technical dimensions applied to sonic design. It also takes away the personalised vocabulary that often impedes effective communication and provides an environment that uses sound to interactively design and communicate sonic geometries.

The brush, palette and canvas paradigm developed for this project has been chosen as a method of researching an interactive sketching method for sonic geometries.

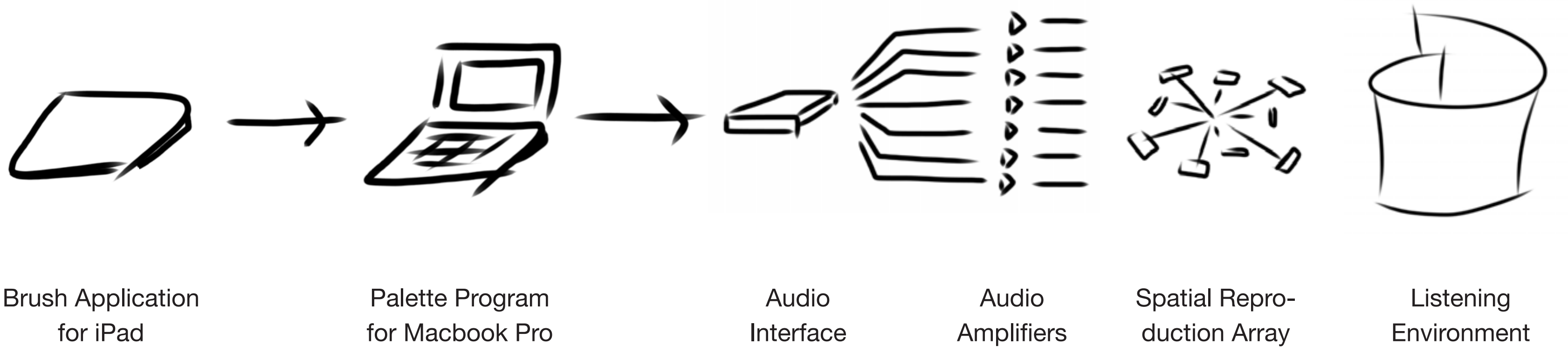


Figure 5: Scope of Sonosentio project

Scope

Scope of project

This PhD researches a new sonic design process. The work proposes an interactive, creative process in place of existing processes that are based on measurement and rectification of visually derived geometries.

The research is conducted through the design of an immersive, interactive environment, Sonosentio. The composition of the Sonosentio project is described in the sketch on the facing page. For this research, the scope consists of the design of;

- an iPad application for user interaction
- a parametric simulation program
- an array of electrostatic loudspeakers
- a sonically neutral listening environment.

Apart from the audio amplifiers and audio interface, the application, software, speaker array configuration and enclosure were designed by the author.

For the purpose of this research project these components have been developed to proof-of-concept to demonstrate the practicality of implementation of this design environment with existing technologies.

The design of the system draws upon the experience of the author[1] in the areas of:

- theatre sound design and technology
- design for performance venues
- design for production studios
- soundscape composition
- design of simulation and auralisation environments

The software and hardware developed during the course of this research is presented as a proof of concept to demonstrate the practicality of the project within existing hardware and software technologies. The project offers significant potential for future research to develop and refine each of the components outlined in this work.

Existing acoustic modelling software is intended as a review of design rather than proactive design tools. The analysis is based on the review of a 3D model that is complete and water-tight[2].

The Sonosentio project was originally conceived as a method for investigating the process of design for incomplete geometries. Unlike the measurement process employed by existing acoustic modelling, the Sonosentio project presents a new paradigm for sonically sketching a room using a sparsely distributed array of elements.

The sparse array project mentioned in this document illustrates the potential for creative design through the application of the Sonosentio design environment.

Assessment of this work should be conducted on the basis of the design process. The environment, Sonosentio, through which this research is conducted is a possible realisation of a new process and the foundation of a tool that would enable that process to be realised. Sonosentio is presented in the form of a “proof of concept”and significant future research is proposed to develop all aspects of the proposition to refine it for use in actual project cases.

---

[1] Refer to Background Appendix

[2] The room model must form a (almost) closed enclosure.”- ODEON Room Acoustic Software User Manual Version 11.

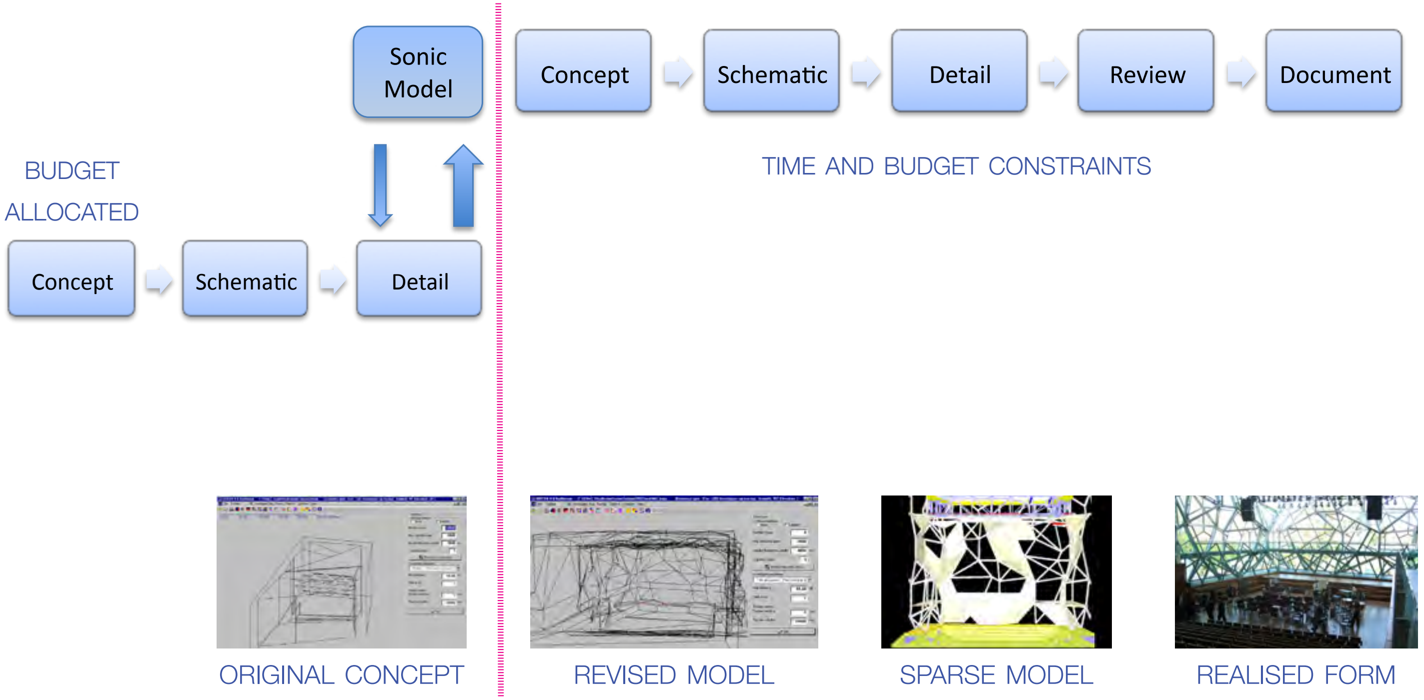


Figure 6: Federation Square South Atrium design process

Federation Square South Atrium (BMW Edge)

The South Atrium was designed as a Multi-purpose performance and presentation space. The original design concept incorporated a two layer glazing system to provide a thermal shaft for ventilation by natural convection.

Following sonic demonstration, the interior was redesigned to dramatically improve the sonic quality of the space.

Figure 7: Federation Square South Atrium

Inspiration

The concept for this research project was first envisaged while working with the Federation Square design team. My involvement included three main areas of the project:

- the ACMI cinemas
- the outdoor plaza sound reinforcement
- the South Atrium (now renamed the BMW Edge)

Each area required a unique design approach. The cinemas were being designed to conform with the THX standards[1] for sound quality. The architectural intention was for the interiors to have monolithic walls, that appeared made of a solid material rather than the typical approach of lining the interior with curtains. The resolution of a "hard", but sound absorbing interior lining was an interesting challenge.

The outdoor plaza sound was focussed upon the stage located at the western end of the plaza. Sound projected from the stage would be reflected by the various buildings surrounding the plaza to provide a sparse, reverberant field that is often characterised by a disturbing echo.

The South Atrium had been conceived as a "multi-purpose" space. The most significant feature was the glazed facade that provided a panoramic view of the Yarra River and the boat sheds and park on the opposite bank.

The design team discussions regarding the South Atrium focussed on the requirement for musical performance in the space.

The original design concept incorporated an interior layer of glazing fixed to the structure that formed a flat surface that was a highly efficient reflector for mid and high frequency sound. The sound reflecting around the space would be a cacophony of repetitions that would render the room unsuitable for the majority of it's intended functions.

The original design was modelled in Odeon room acoustic software and the derived impulse response clearly showed the sonic repetitions from the wall surfaces. Working with Tim Hill of Lab Architects, a new interior model was developed that folded the inner layer of glazing into the structure of the atrium. A significant area of sound absorptive treatment was also added above the ceiling to balance the tonal response of the glazing.

The acoustic parameters did not effectively convey the difference between the models. Therefore, I played two crude sonic representations of the spaces (auralisations) to the architects and the quality of the improvement was immediately comprehended by the team.

At this stage of the process folding the glass into the structure, effectively making each panel and its fixings unique, was cost prohibitive. On this basis, we reduced the area of internal glazing to the most effective areas that would return sound to the stage and audience and deflect a percentage into the ceiling where it would be absorbed by the perforated barrisol [2]and insulation in the upper void space.

This experience inspired a personal investigation into the design of minimal architectural components (sparse geometries) to achieve effective sonic response, and the communication of sonic representation in the design process that culminated in this research.

---

[1] Design standards and certification process for sound reproduction equipment and sonic environment for cinema. Originally developed for the release of the third Star Wars film Return of the Jedi in 1983.

[2] Barrisol is a proprietary, lightweight stretched fabric ceiling system.

Figure 8: Evolving detail from sketch - Peter Zumthor, Bruder Klaus Field Chapel

SKETCH:

“A rough drawing, giving outlines or minimum, essential, or prominent features, especially made as the basis of a more detailed picture; a rough draft or design.”

The New Shorter Oxford English Dictionary, (1993)

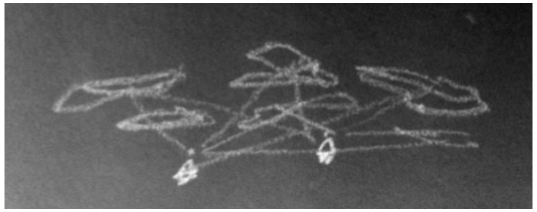


Figure 9: Sketch for sparse geometry concept

Sketching as a design process

Sketching enables a process of evolving detail, from concept to realisation. This design process is consistent through many creative disciplines and is valuable not only as a creative conceptual tool, but also as an efficient method of illustrating ideas to collaborators and clients..

My experience during the Federation Square project had raised the following issues regarding the process of sonic design:

- design was undertaken as review process
- sonic design originated by visual processes
- modelling techniques that are not integrated into process and provide unreliable results
- design parameters which do not directly relate to outcome
- criteria and commentary as communication
- inadequacies in available information regarding material properties
- the process relied on trial and error rather than interactive, collaborative development.

My own sketch of the sparse geometry proposition (Figure 9) actually highlighted these observations by presenting more questions than answers. Although the sparse geometry would prove to be an interesting topic of inquiry, the sonic qualities of the sketch were not apparent, nor was it clear to me how it could be developed into a sonically derived proposition without a significant amount of time spent in the cycle of computer based ray-tracing of various options. I was, in essence still considering design in the visual domain for the purpose of conducting a sonic review.

The importance of the contribution ofearly reflections to the impression of subjective response is the foundation of geometrical room acoustics[1].

What I was seeking was a method of real time sonic design that could be used as a sketchpad by experienced designers to conceive sonically responsive geometries.

This was a process I had explored during the design of the Faderpro[2] system which provided an interactive plotting system for spatial sound in a theatrical context. The system enabled improved communication between directors and sound designers/operators by allowing sound placement and movement to be conducted interactively, in real-time and recorded for consistent replay to support productions. In essence, Faderpro became a sketchpad that allowed direct sonic interaction between the creative disciplines involved in mounting a theatrical production.

In researching I found that the majority of investigations focussed on historic spaces that were considered to perform very well. In my own work, I had discovered that reviewing failure or inadequacy proved far more illuminating than revisiting success based on a historic formula.

The goal of this project is to research a design dialogue between sonic and physical architectures that operates, in the first instance, within the sonic domain. The proposed spatial design paradigm presents an environment where sonic outcome is the precedent goal and sound is the design media. The sonic design paradigm allows the development of new spaces that are initially independent of visual design restrictions and enables the development of both real and imaginary spaces for responsive geometries.

---

1 Barron, M. 1993. p 46-50

2 Refer to Background Appendix p44-46.

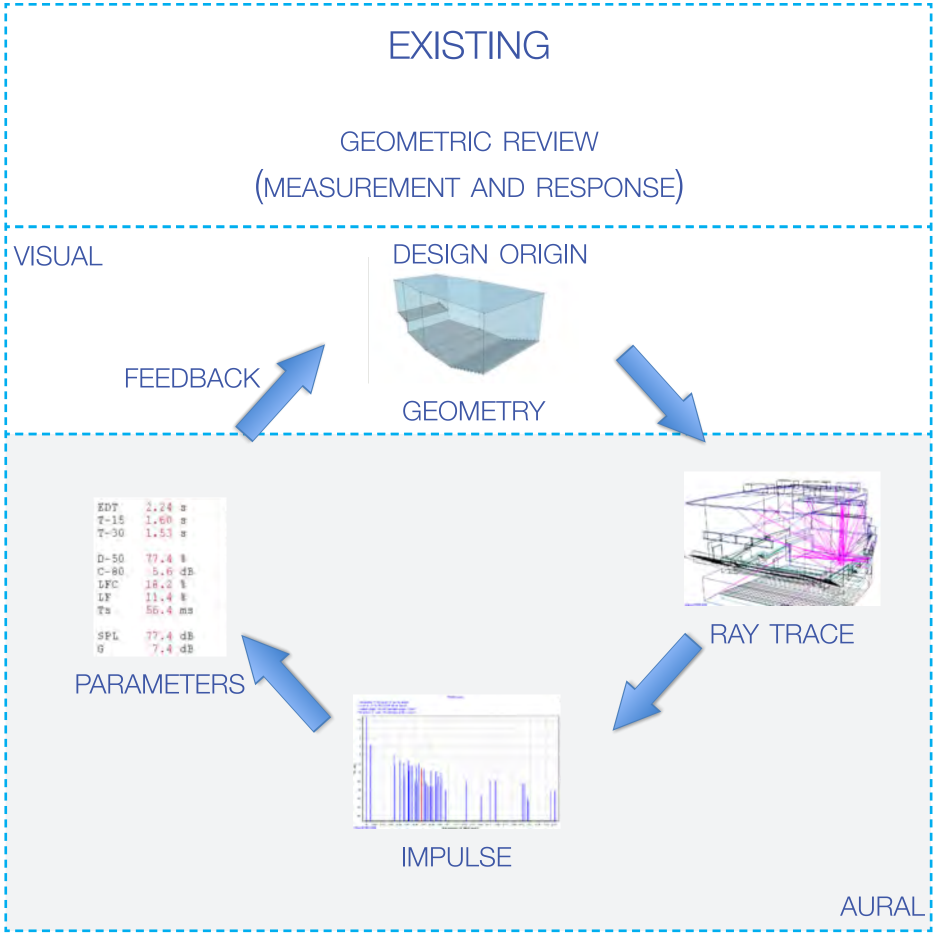


Figure 10: Review process via ray-tracing software for sonic design

Visual geometry as the design medium and parameters derived from sonic measurments used as the communication medium

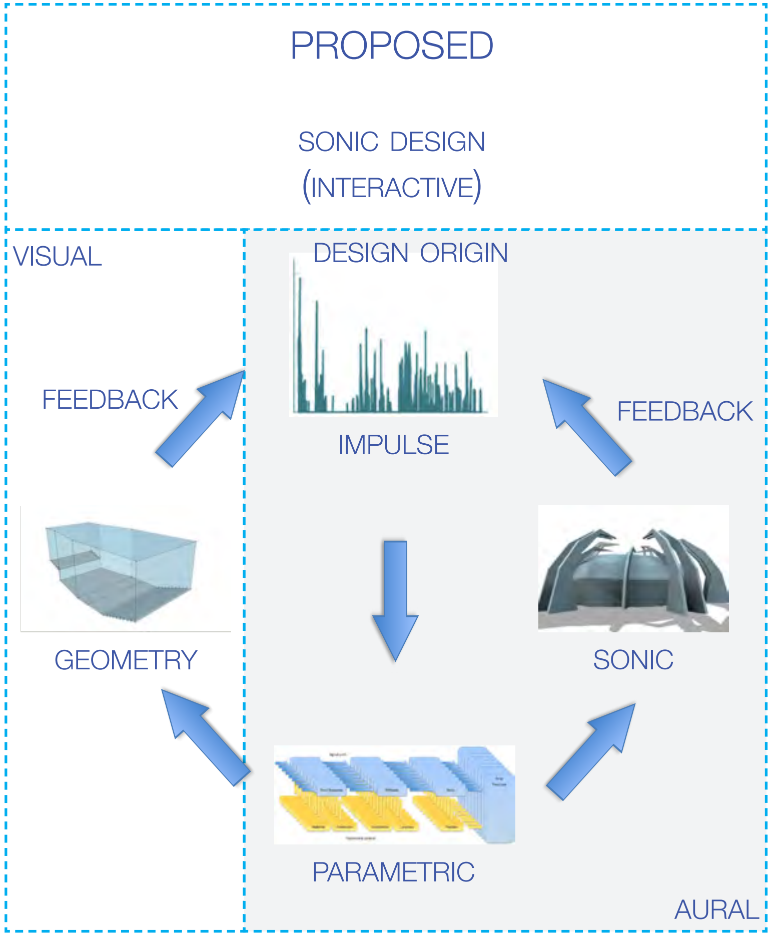


Figure 11: Proposed sonic design and communication process

Sonic response as design medium and interactive, spatial sound reproduction used as the communication medium

> “Professional discussions tend to diverge into computer generated sound paths and frequency modulated video graphs when quite basic questions need to be debated.” - Woolley, (2010), p51

Toward a new paradigm for design

The existing process for sonic design uses the designed geometry to calculate an impulse response that is then reduced to a few representative indices for communication to the design team. This research proposes a method of design where the impulse response becomes the design media for geometric composition in an interactive, sonic environment.

The sonic implications of geometric compositions can be difficult to communicate to design teams whose experience is typically not well developed in the field. Design decisions are often made, and budgets conditions established long before the acoustic review of the developing geometry is conducted.

The design of sonically critical spaces has been the domain of acoustic engineers who review and comment on the performance of visually derived geometries. Historically this process has had success where communication between the engineers and architects is collaborative[1].

The principal tools of acoustic engineering for geometric review are acoustic ray tracing programs[2]. These programs simulate the acoustic response of an enclosed space by projecting rays into a virtual model. A series of objective parameters are derived which provide a broad assessment of the subjective performance of the space. These parameters are used to communicate the perceived quality of the space to the design team and to provide recommendations for improvement.

This work is conducted in the form of reports and diagrams that describe the sonic environment. The work is conducted as a response to visual design.

The difficulty with this approach is that the visual geometry must be completed before acoustic review (design) may occur. For the design of the Victorian Arts Centre the Architect, Sir Roy Grounds, proposed that: “BBN (the acoustic consultants) should initiate the design of the Concert Hall ‘instead of adopting the usual procedure of advising on how to recast, re-design or adjust the architects schematic or preliminary sketch plans after some potentially irrevocable decision affecting room acoustics had been inherited or otherwise built-in to inhibit the best acoustic design’.”[3]

The complexity of design communication using mathematically derived representations of subjective experience can further impede effective collaboration at the early stage of project development.

The Sonosentio project was realised through my interest in the design of sonic environments, both theatrical and real, and frustration with the restrictions inherent in the existing linear processes that constrained creative design through the cyclic method of measurement and response rather than interactive, experiential design.

The development of my sparse geometry concept proved to be laborious in the measurement and response method of analysing visual geometries. The Sonosentio system provides a method of interactively developing sonic response and fundamental geometric composition concurrently.

---

[1] Refer to Background Appendix for examples.

[2] The author has experience with CATT Acoustic and Odeon.

[3] Fairfax, V. 2002. A Place Across the River,p133

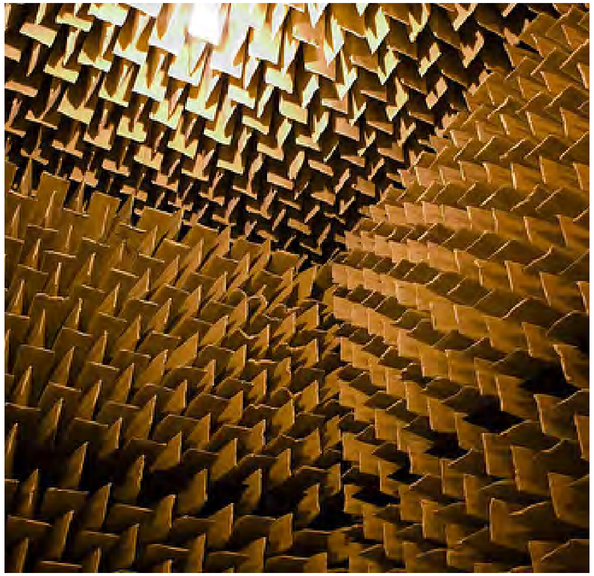


Figure 12: Anechoic chamber

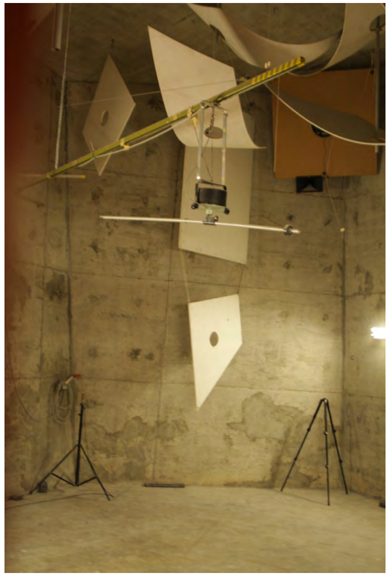


Figure 13: Reverberation chamber

> "All our senses 'think' and structure our relationship with the world, although we are not usually conscious of this perpetual activity"
>
> Pallasmaa J. (2009), p17

We listen to:

- comprehend content
- experience music
- gain information
- assess our environment
- understand geometry
- receive early warning.

How we listen

The amount of detail we derive from our senses is related to the prominence of each. Sound is often experienced subconsciously. For example we may hear a voice from behind, identify it's speaker, accurately locate the position and respond to a vocal query long before we see the source. Hearing rain upon the roof implies a great deal about the exterior environment that we cannot see.

For those who experience sound as a vocation, the comprehension of the sonic environment is enhanced by an ability to understand and quantify the sonic experience. With this understanding, and appropriate tools, the aural environment can be simulated. For example, a soundtrack may follow a cast of adventurers as they enter a cavernous underground chamber such as when Slartibartfast leads Arthur Dent into the planet forges of Magrathea[1]. The audience is taken on the sonic adventure by sound designers who compose the environment using an array of production tools that simulate the space. This work is conducted in a room that allows the designers to prepare the sound in the context of its presentation to an audience.

Aspects of scale, materiality and occupation can be quickly determined by our sense of sound. Many aspects of our environment present themselves sonically well in advance of our visual recognition of their presence. This is exploited in cinema where the sound of the next scene is introduced before the vision[2].

I was briefly involved in presenting a Sound in Architecture elective for architecture students with the RMIT University School of Architecture and Design. To place the lectures in a realistic context I arranged a short walking tour of Melbourne to visit a broad range of buildings each with unique sonic characteristics. In each building I discussed the experience of the sound and acoustic response of the building. I explained how the materials contributed to the experience and various factors related to the sonic experience of occupation of the space. This contextualisation of the lectures assisted communication of the sonic concepts considerably.

In our general experience of our environment there is an expectation that the sonic and visual image of our surroundings will be related. Rooms where this relationship is abnormal make people uneasy about their surroundings. The most common examples of these spaces are anechoic chambers[3] and reverberation chambers[4]. These are typically used for scientific purposes, however, the sense of being in an anechoic space is disorienting. People who have not previously experienced such a space feel uncomfortable.

This extreme relationship between sonic space and visual space was one of the foundations of the sparse array project. It proposes the opposite of an anechoic chamber where an outdoor space is given a sonic character that implies enclosure. Discrete reflections are provided either by suspended planes or electronic reinforcement to create a sequence of reflections that imply an enclosed reverberant space.

---

[1] Hitchhikers Guide to the Galaxy - BBC LP recording, 1979

[2] The cinema term for this technique is a sound bridge.

[3] An anechoic chamber has walls that entirely suppress sonic reflections. The aural experience is similar to be in an unbounded space such as outdoors.

[4] A reverberation chamber has walls that are highly reflective to sound.

> Sabine "....employed a variant of Rudolph Koenig's 'dancing flame' device to study the sound in the Fogg Lecture Room, but there was no useful way to interpret the results. Sabine thus abandoned all attempts to look at sound, and instead chose the seemingly obvious, but long neglected, alternative of listening to it." - Thompson, E. Soundscape of Modernity (2004), p35

Sharing the experience

Acousticians tend to share information regarding the spatial experience of sonic environment as either computationally derived numerical descriptors, or commentary in a personal vocabulary of subjective terminology.

The Faderpro spatial sound system[1] was a valuable lesson in communication of sonic experience using sound as a medium. Conveying the concept of its operation either texturally or verbally was difficult, even to sonically aware individuals. However, when the system was installed in a venue and connected to a spatial sound reinforcement system, a simple wave of the mouse brought immediate comprehension of the concept and the potential for creating spatial compositions that supported and responded to performances.

As Sabine had discovered while working on the Fogg Art Lecture Hall[2], there is a compelling argument for listening to sound to comprehend its performance in space.

The fundamental goal of this project is to allow designers to work in the medium in which they are designing and to be able to share their design in a realistic manner. The description of the design is embodied in the media in which it is presented.

In working on theatrical soundscape composition I have created rain on a Queensland verandah, a clock that evolved into an ocean, an elaborate royal divorce and a foreboding tour through a nuclear devastated wasteland. These sonic creations imply vast visual terrain.

As a recording engineer and musician I am able to listen to music and appreciate both the overall sculptural context of the tones and structure of music, but also listen to the individual components that contribute to the overall production. This provides me with great enjoyment each time I listen to a piece of music, understanding the composition, the instrumentation, the quality of players, the subtleties of rhythm and the techniques of playing that make each interpretation of a piece a unique experience of its own.

I enjoy listening to a passage of a Paganini composition played by Salvatore Accardo over and over to embrace the unique interpretation of the piece and to try to comprehend the technique that creates such a unique tonal structure from his instrument. Likewise Pink Floyd offer the same sonic interest.

Likewise with a room, I am able to focus on each component of the experience and relate that to a feature of the room.

This does not make my hearing any better than anyone else's, it is a quality of comprehension that is learned through experience.

---

[1] Refer to Background Appendix p44-47
[2] Refer to Background Appendix p4-5

How machines listen

The terms “good” and “bad” really have no meaning when referring to the sonic quality of a space. The perceived quality of a space depends upon the response to its intended function and occupation. This is one of the difficulties of mechanical analysis of space. Without application, sonic space has no measure. An unoccupied space has no sonic requirement.

I was once presented with a set of absorption coefficient data and, without any context for the application, asked the question “do you think this is ok?”. This is the equivalent of asking whether the colour 121, 22, 37 is ok. While I can recognise the sonic colour of the surface from the numeric description, and may have a personal preference for that colour over others, without understanding how it is applied and it’s relationship to the other design elements in the space any comment would be entirely meaningless.

While these criteria have recently been recognised as industry standards[1], their derivation dates back many years, to a time before computers were capable of the intensive calculations and simulations possible with modern devices. The simplicity of their derivation conceals a great deal of information within the impulse response that is effectively discarded by these methods of assessment.

In spite of their age and relative simplicity, these criteria have become a method where engineers convey a computer’s perspective of subjective impression to designers.

Beranek’s book, Music, Acoustics and Architecture[2] presents his impression of a series of halls throughout the world. The original work was prepared following his investigations of precedent spaces to assist in the development of Philharmonic Hall[3] in New York. The book ends as the “tuning” concerts were underway in the hall. There is an ominous reference to flaws in the design in the final passages of the book.

“The first adjustments of the canopy over the stage was promising, but the results fell short of the desired goal - the musicians still complained of being unable to hear each other and some string-brass imbalance was still noted. Also, some deficiency in the bass was noted and a slight echo was observed in several parts of the hall.”[4].

---

[1] ISO 2009. ISO 3382:2009-1 Acoustics - Measurement of room acoustic parameters Part 1: Performance spaces.

[2] Beranek, L. 1962. Music Acoustics & Architecture

[3] Refer to Background Appendix p20-21

[4] Beranek, L. 1962. Music Acoustics & Architecture p534

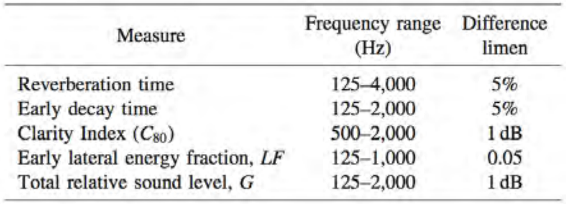
Clarity $C_{80} = 10\log(\int_{0}^{0.08} p^2(t)\mathrm{d}t \Big/ \int_{0.08}^{\infty} p^2(t)\mathrm{d}t)\mathrm{dB}$

Centre time $T_S = \int_{0}^{\infty} tp^2(t)\mathrm{d}t \Big/ \int_{0}^{\infty} p^2(t)\mathrm{d}t$

Spaciousness $J_{LF} = \int_{0.005}^{0.08} p_L^2(t)\mathrm{d}t \Big/ \int_{0}^{0.08} p^2(t)\mathrm{d}t$

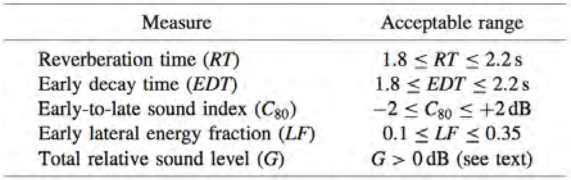
Loudness $G = 10\log(\int_{0}^{\infty} p^2(t)\mathrm{d}t \Big/ \int_{0}^{\infty} p_{10}^2(t)\mathrm{d}t$

Figure 14: Example criteria from ISO 3382-1 (2009)



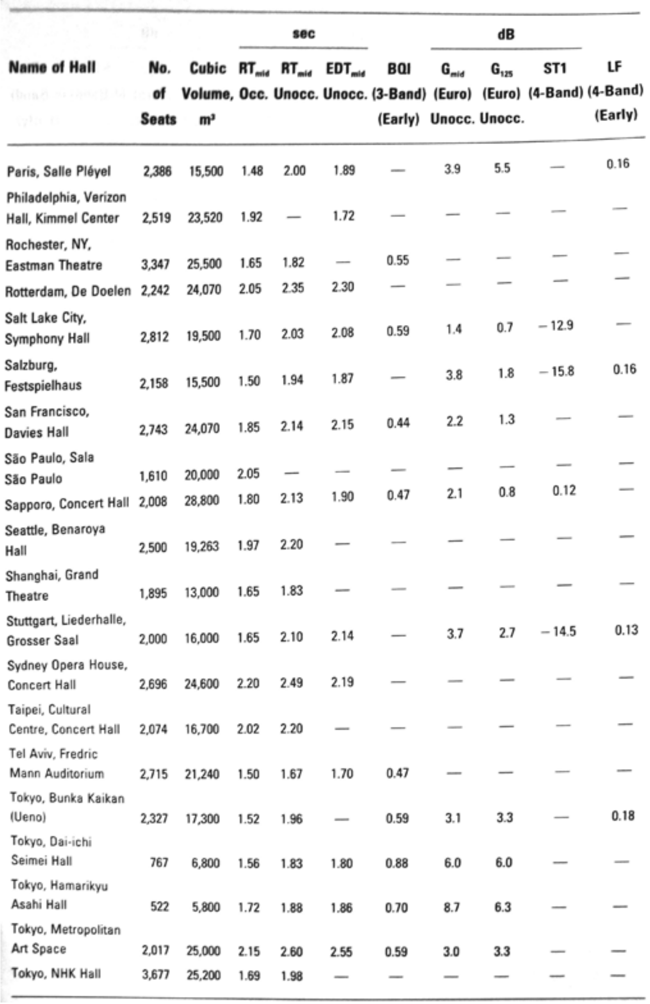
Measure	Frequency range (Hz)	Difference limen
Reverberation time	125–4,000	5%
Early decay time	125–2,000	5%
Clarity Index (C_{80})	500–2,000	1 dB
Early lateral energy fraction, *LF*	125–1,000	0.05
Total relative sound level, *G*	125–2,000	1 dB

Figure 15: ISO 3382-1 Objective criteria difference limen



Measure	Acceptable range
Reverberation time (*RT*)	$1.8 \le RT \le 2.2\,\mathrm{s}$
Early decay time (*EDT*)	$1.8 \le EDT \le 2.2\,\mathrm{s}$
Early-to-late sound index (C_{80})	$-2 \le C_{80} \le +2\,\mathrm{dB}$
Early lateral energy fraction (*LF*)	$0.1 \le LF \le 0.35$
Total relative sound level (*G*)	$G > 0\,\mathrm{dB}$ (see text)

Figure 16: Recommended design criteria



Name of Hall	No. of Seats	Cubic Volume, m³	sec RT_{mid} Occ.	 RT_{mid} Unocc.	 EDT_{mid} Unocc.	BQI (3-Band) (Early)	dB G_{mid} (Euro) Unocc.	 G_{125} (Euro) Unocc.	ST1 (4-Band)	LF (4-Band) (Early)
Paris, Salle Pléyel	2,386	15,500	1.48	2.00	1.89	—	3.9	5.5	—	0.16
Philadelphia, Verizon Hall, Kimmel Center	2,519	23,520	1.92	—	1.72	—	—	—	—	—
Rochester, NY, Eastman Theatre	3,347	25,500	1.65	1.82	—	0.55	—	—	—	—
Rotterdam, De Doelen	2,242	24,070	2.05	2.35	2.30	—	—	—	—	—
Salt Lake City, Symphony Hall	2,812	19,500	1.70	2.03	2.08	0.59	1.4	0.7	−12.9	—
Salzburg, Festspielhaus	2,158	15,500	1.50	1.94	1.87	—	3.8	1.8	−15.8	0.16
San Francisco, Davies Hall	2,743	24,070	1.85	2.14	2.15	0.44	2.2	1.3	—	—
São Paulo, Sala São Paulo	1,610	20,000	2.05	—	—	—	—	—	—	—
Sapporo, Concert Hall	2,008	28,800	1.80	2.13	1.90	0.47	2.1	0.8	0.12	—
Seattle, Benaroya Hall	2,500	19,263	1.97	2.20	—	—	—	—	—	—
Shanghai, Grand Theatre	1,895	13,000	1.65	1.83	—	—	—	—	—	—
Stuttgart, Liederhalle, Grosser Saal	2,000	16,000	1.65	2.10	2.14	—	3.7	2.7	−14.5	0.13
Sydney Opera House, Concert Hall	2,696	24,600	2.20	2.49	2.19	—	—	—	—	—
Taipei, Cultural Centre, Concert Hall	2,074	16,700	2.02	2.20	—	—	—	—	—	—
Tel Aviv, Fredric Mann Auditorium	2,715	21,240	1.50	1.67	1.70	0.47	—	—	—	—
Tokyo, Bunka Kaikan (Ueno)	2,327	17,300	1.52	1.96	—	0.59	3.1	3.3	—	0.18
Tokyo, Dai-ichi Seimei Hall	767	6,800	1.56	1.83	1.80	0.88	6.0	6.0	—	—
Tokyo, Hamarikyu Asahi Hall	522	5,800	1.72	1.88	1.86	0.70	8.7	6.3	—	—
Tokyo, Metropolitan Art Space	2,017	25,000	2.15	2.60	2.55	0.59	3.0	3.3	—	—
Tokyo, NHK Hall	3,677	25,200	1.69	1.98	—	—	—	—	—	—

Figure 17: Measured objective rating for a range of venues

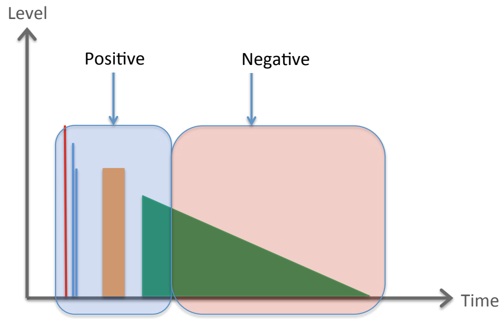


Figure 18: C_{80} Derivation

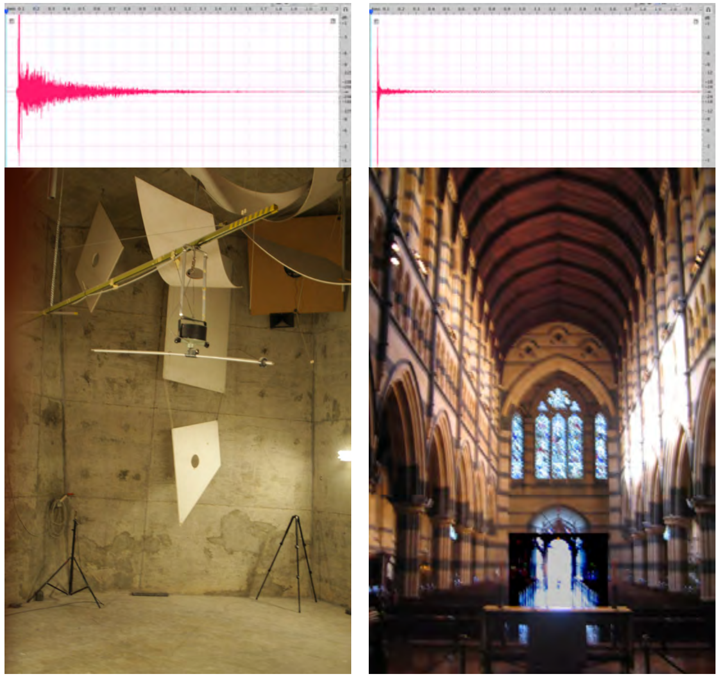


Figure 19: RMIT Reverberation chamber and St Pauls Cathedral

Parameters

The quantification of subjective sonic experience has gained acceptance through a series of objective acoustic parameters that have been developed and refined over a period of more than 100 years.

Wallace Sabine developed the parameter reverberation time to allow the significant design flaws with the Fogg Lecture Hall to be quantified. Harvard University had hoped to rectify the conditions to make it suitable for speech. Documentation indicates that this outcome was not achieved[1].

Reverberation time remains a key measure of the sonic performance of a space. It is reliable, and relatively simple to measure and predict to a reasonable degree of accuracy.

However, reverberation time alone does not provide an informative assessment of the subjective qualities of a room. For example, measurements of the Reverberation Chamber at RMIT and St Pauls Cathedral, Melbourne indicate that the two rooms have a similar reverberation time. Standing in each space it would be apparent that they are not remotely similar either visually or aurally. Listening to sound in these two spaces would reveal significant differences in the aural character that is not exposed by the reverberation time. The paucity or density of sonic reflections indicates the proximity and reflective qualities of the bounding surfaces of the space. This is not reflected in the reverberation time.

Various groups have investigated the subjective qualities concealed within an impulse response to derive simple, measureable quantities that allow comparison and classification of spaces.

In 1997 a selection of these criteria were included an international standard, ISO 3382-1[2]. At best, these ISO parameters provide a vague description of subjective experience. The mathematical derivation of some of the criteria in ISO 3382-1 is provided in Figure 14.

These criteria are scientific instruments for the automated assessment of subjective impression. The accuracy and relevance of their application is dependant upon the currency of the research and technology from which they are derived. In the case of Clarity (C_{80}), the derivation is based on Reichardt, Abdul Alim and Schmidt, Acustica, 32, 1975, p126. (Jordan, 1980). Reverberation time dates from 1937, Early Decay Time (EDT) from 1968, Centre time (T_S) from 1969. These reductionist criteria provide a simple summary of a complex, subjective response.

Unlike concert hall design, studio design does not use these criteria. The scale of a room dramatically affects its response to sound. The measurement criteria provided in ISO 3382-1 were developed for concert halls. These rooms are single volume spaces of relatively large dimensions compared to the wavelength of sound, and generally conform to the diffusion characteristics required for simple reverberation calculations that provide a realistic estimate of their response to sound.

---

[1] Soundscape of Modernity, Thompson 2004.

[2] ISO 2009. ISO 3382:2009-1 Acoustics - Measurement of room acoustic parameters Part 1: Performance spaces.

Complexity $C = T(10 - H), 0 < C < 100$

Harmony $H = H_1 + ... + H_5, 0 < H < 10$

Temperature $T = T_1 + ... + T_5, 0 < T < 10$

Life $L + C = 10T$

Figure 20: Architectural criteria - Salingaros (1997)

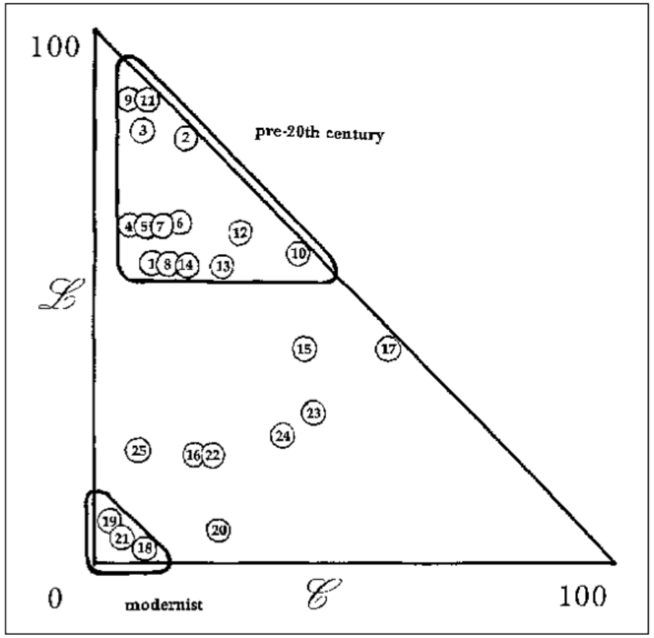


Figure 21: Architectural objective rating, Salingaros (1997)

No.	Building	Place	Date	*T*	*H*	*L*	*C*
1	Parthenon	Athens	-5C	7	8	56	14
2	Hagia Sophia	Istanbul	6C	10	8	80	20
3	Dome of the Rock	Jerusalem	7C	9	9	81	9
4	Palatine Chapel	Aachen	9C	7	9	63	7
5	Phoenix Hall	Kyoto	11C	7	9	63	7
6	Konarak Temple	Orissa	13C	8	8	64	16
7	Cathedral	Salisbury	13C	7	9	63	7
8	Baptistry	Pisa	11/14C	7	8	56	14
9	Alhambra	Granada	14C	10	9	90	10
10	St. Peter's	Rome	16/17C	10	6	60	40
11	Taj Mahal	Delhi	17C	10	9	90	10
12	Grande Place	Brussels	1700	9	7	63	27
13	Maison Horta	Brussels	1898	8	7	56	24
14	Carson, Pirie, Scott	Chicago	1899	7	8	56	14
15	Casa Batlló	Barcelona	1906	8	5	40	40
16	Fallingwater	Bear Run	1936	4	5	20	20
17	Watts Towers	Los Angeles	1954	10	4	40	60
18	Corbusier Chapel	Ronchamp	1955	1	2	2	8
19	Seagram Building	New York	1958	1	8	8	2
20	TWA Terminal	New York	1961	3	2	6	24
21	Salk Institute	San Diego	1965	1	6	6	4
22	Opera House	Sydney	1973	4	5	20	20
23	Medical Faculty	Brussels	1974	7	4	28	42
24	Pompidou Center	Paris	1977	6	4	24	36
25	Foster Bank	Hong Kong	1986	3	7	21	9

Figure 22: Derived objective ratings

Objective criteria

> “Creating equations is easy; creating equations that relate to perception is more difficult...” - Blesser (2007), p232

Architectural design criteria

In 1997, the mathematician Nikos Salingaros proposed a series of objective measures to assess the intrinsic qualities of a building.

These mathematically derived criteria allow a consistent evaluation to be determined for geometric composition in the same manner as the international standard applies evaluation criteria to the sonic environment.

I often use the analogy that this is similar to walking through an art gallery and assessing the quality of the works using a computer system that is able to measure the relative balance of red, green and blue in each of the paintings.

The assessment process would be simple and the quality of the entire collection could be quantified by averaging the results for all of the works, or a representative sample.

Extending this technique, new works could be commissioned on the basis of improving the overall numeric balance of the gallery’s objective rating. I am not recommending that this be adopted as a new curatorial model, however, it implies a certain degree of absurdity in a process based on numeric averaging of objective criteria for assessing and commissioning works with a strongly subjective outcome.

In conclusion Salingaros states: “With the help of this model, new structures can be designed that have a dramatically increased feeling of life, yet do not copy existing buildings”[1].

Salingaros’ method of proposing design criteria to direct architectural design is similar to the currently accepted design approach for auditorium acoustics where unachievable objective criteria are included in the project brief and these become the primary measures of success. While this process may be used to review the completed design, it is not clear how the methodology contributes to the conceptual design process.

The Sonosentio project researches a conceptual sonic design process that is not reliant on computationally derived criteria, but simulates the interactive sketching process in a sonic context.

---

[1] Salingaros, N. 1997. Life and Complexity in Architecture From a Thermodynamic Analogy. Physics Essays, 10, p165-173

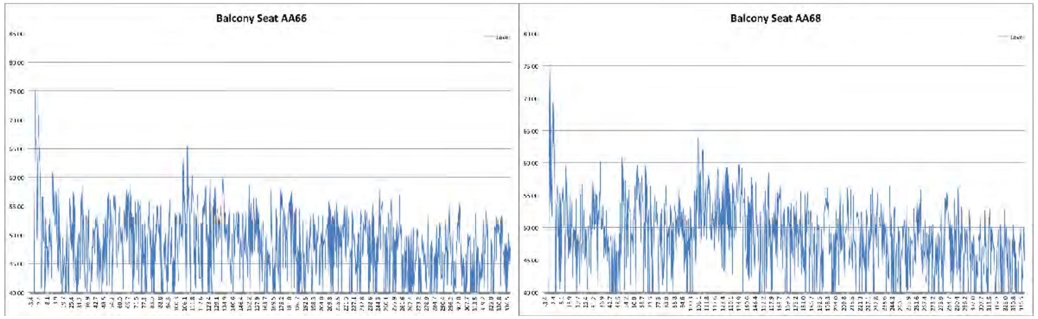


Figure 24: Melbourne Concert Hall - Balcony seat AA66 and AA68

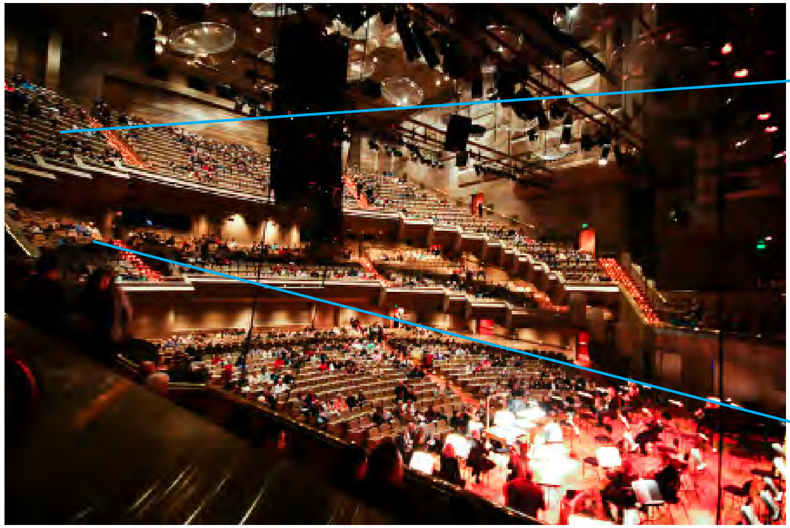


Figure 23: Melbourne Concert Hall

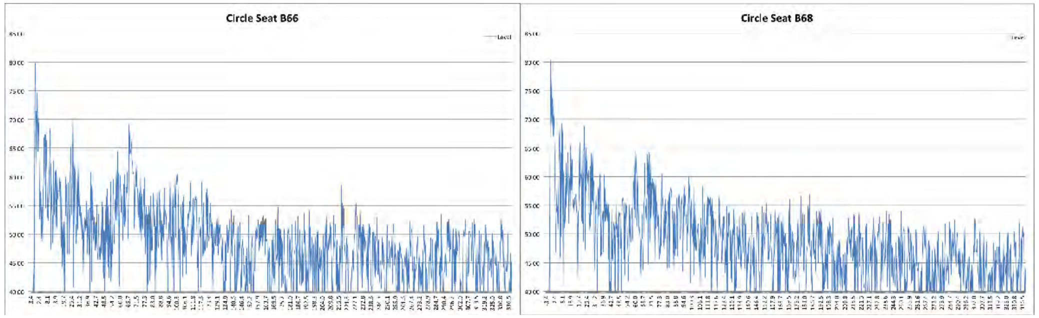


Figure 25: Melbourne Concert Hall - Circle seat B66 and B68

Objective criteria

Investigating the criteria

In 1994 I had the opportunity to conduct room acoustic measurements in the Melbourne Concert Hall (renamed Hamer Hall). I had been involved in numerous performances and recordings in the hall and therefore had the opportunity to experience the room from various perspectives over a number of years.

I had subjectively experienced a significant variation in the acoustic conditions throughout the hall and was keen to develop an understanding of how this was related to the measured sonic response.

I did not consider that a few measurements from each level would adequately convey the distribution of the sonic qualities of the room. Therefore, I conducted an extensive sequence of measurements that included each second seat in each second row. To reduce time, the measurements were only conducted on the prompt side (PS) of the centreline of the hall to exploit the symmetrical design of the hall.

I derived the reverberation time (RT) and clarity (C_{80}) for a number of locations to consider their relevance to my subjective personal experience. The measurements illustrated three main points:

- the reverberation time is relatively consistent
- the Clarity (C_{80}) varies significantly
- major surface features are clearly illustrated by the impulse response measurements.

The significant differences in C_{80} indicated that deriving an "average" for the room was extremely difficult. The ISO 3382-1[1] standard recommends a minimum of 10 measurement positions for a room of 2000 seats.

I chose 27 positions in the circle and balcony and calculated an average C_{80} of 2.3. However, the standard deviation of these 27 measurements was 3.8! By selecting the seats more carefully I could achieve a lower or higher average. This also allowed me to reduce the standard deviation.

However, by graphing the individual responses I was able to see the individual reflections that indicated the proximity of surfaces to that location and the sequence of reflections that provided the sonic perspective.

While I was able to provide a cautious validation of the relationship between the measured C_{80} values and my subjective impression of the area in which it was measured, it did not provide any detail regarding the design composition that contributed to the experience. As with Salingaros' [2]criteria for architectural design, they allow assessment of completed designs against subjective impression, but do not inform the design process.

A design could be informed by the reverberation criteria, where the volume and absorptive characteristics of an enclosed volume will generally be predicted within a reasonable tolerance ad be relatively consistent throughout the space. However, an averaged C_{80} could not inform the design process and would not provide useful design data for preparing geometries.

---

[1] ISO 2009. ISO 3382:2009-1 Acoustics - Measurement of room acoustic parameters Part 1: Performance spaces p19-20

[2] Salingaros, N. 1997. Life and Complexity in Architecture From a Thermodynamic Analogy. Physics Essays, 10, 165-173.

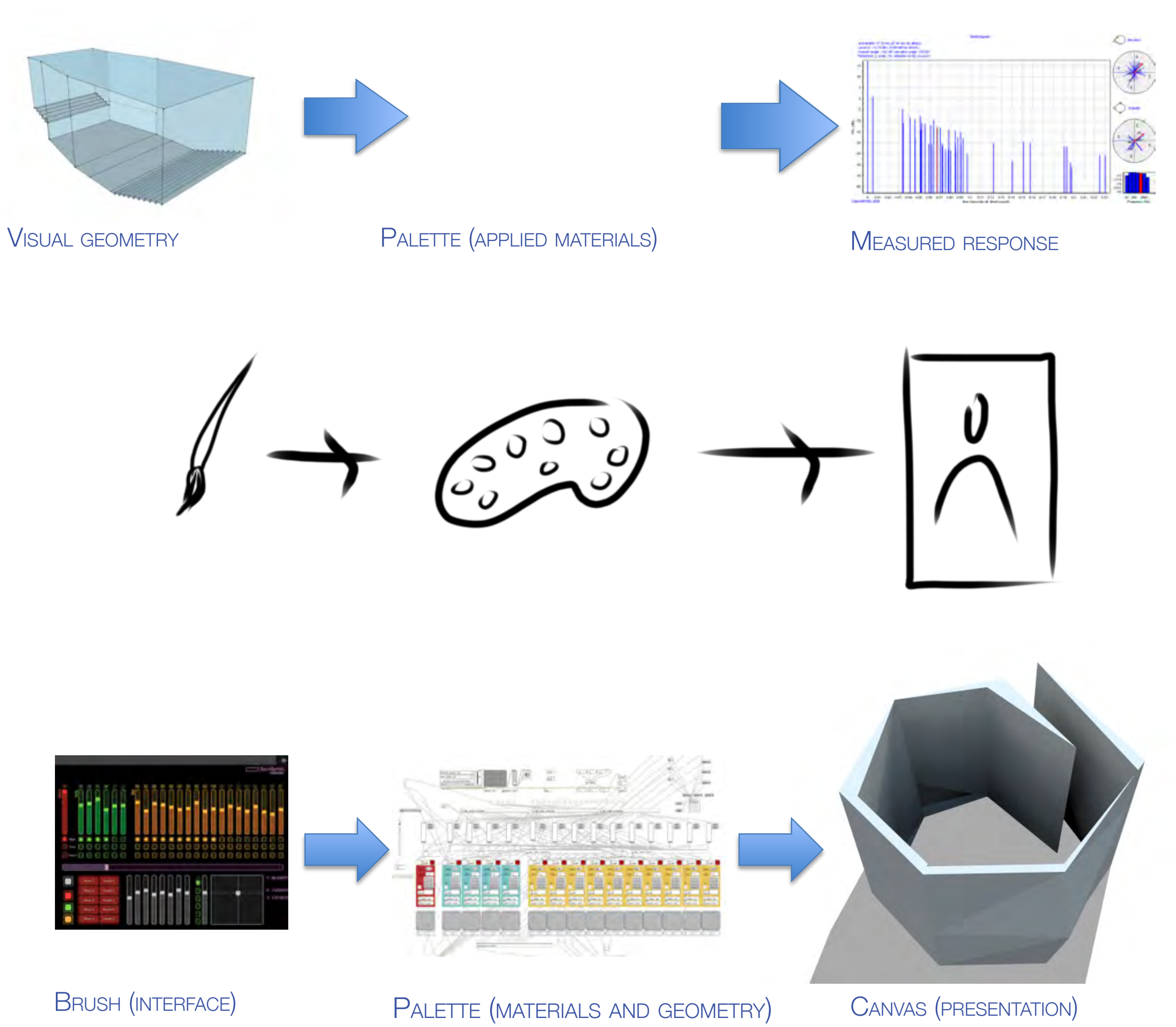


Figure 26: Brush, palette canvas paradigm

Sonosentio

Concept

PROJECT DEVELOPED TO CONSIDER THE FORM OF A SONIC SKETCHPAD FOR GEOMETRIC DESIGN

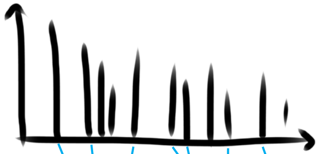


Figure 27: Sonic composition

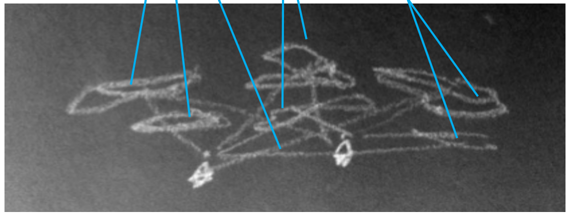


Figure 28: Geometric composition

Interactive sonic sketch

In essence, this project reverses the existing geometric design process to enable designers to interactively “sketch” a desired sonic response which is used to derive an associated geometric composition.

The genesis of this project was formed during the design of the Federation Square South Atrium[1]. The project required a unique approach to sonic design to allow a glass room to function as a multipurpose performance space. The question was:

“If a building is deconstructed into it’s sonically critical components, what would the resultant composition be and how could it be derived?”

While attempting to research the deconstructed form, it became apparent that the existing design tools were limited in their application. Thus, a second research project was born to investigate the initial proposition - researching a method to realise the geometric form of a sonically derived design composition. The two projects are intertwined, with one providing the basis for development of the other.

Due to the difficulty in developing the original investigation of minimal geometries to establish sonic environments, this became a secondary project. The trial and error method proved extremely cumbersome and time-consuming for this approach to design. What I really required was the ability to sketch sparse geometry sonically and then mathematically derive a realised geometry. Thus a new project, Sonosentio became the primary research project and the sparse geometry became a method for validation.

Sonosentio is a sketchpad for sonic design of geometric compositions. The core of Sonosentio is a parametric representation of the sonic qualities of the model being constructed. It is unique in that the design is conducted in the sonic domain.

The project is a combination of sonically designed enclosure, sound reinforcement system, software and hardware for computer simulation. The ray tracing technique is best applied as a review of completed enclosure. Sonosentio has bee developed to interactively compose partial geometries. This project does not replace or dismiss the application of ray tracing in the role of design review.

While a sketch is being made the feedback is immediate. Changes can be made by enhancing or erasing components to improve the composition.

The design research explores the influence of scale on the sonic performance of a space. The wavelength of audible sound is within the range of approximately 17mm (20kHz) to 17m (20Hz). When a room’s dimensions are related to the wavelength of sound the characteristics change.

This relationship between wavelength and the physical scale of enclosure provides a natural imbalance to sound reproduced in enclosed spaces.

This project uses a unique enclosure design to provide a more neutral response within the space to extend the range of realistically reproduced sounds without the low frequency limitations of typical, enclosed small rooms.

---

[1] Refer Background Appendix p30-31

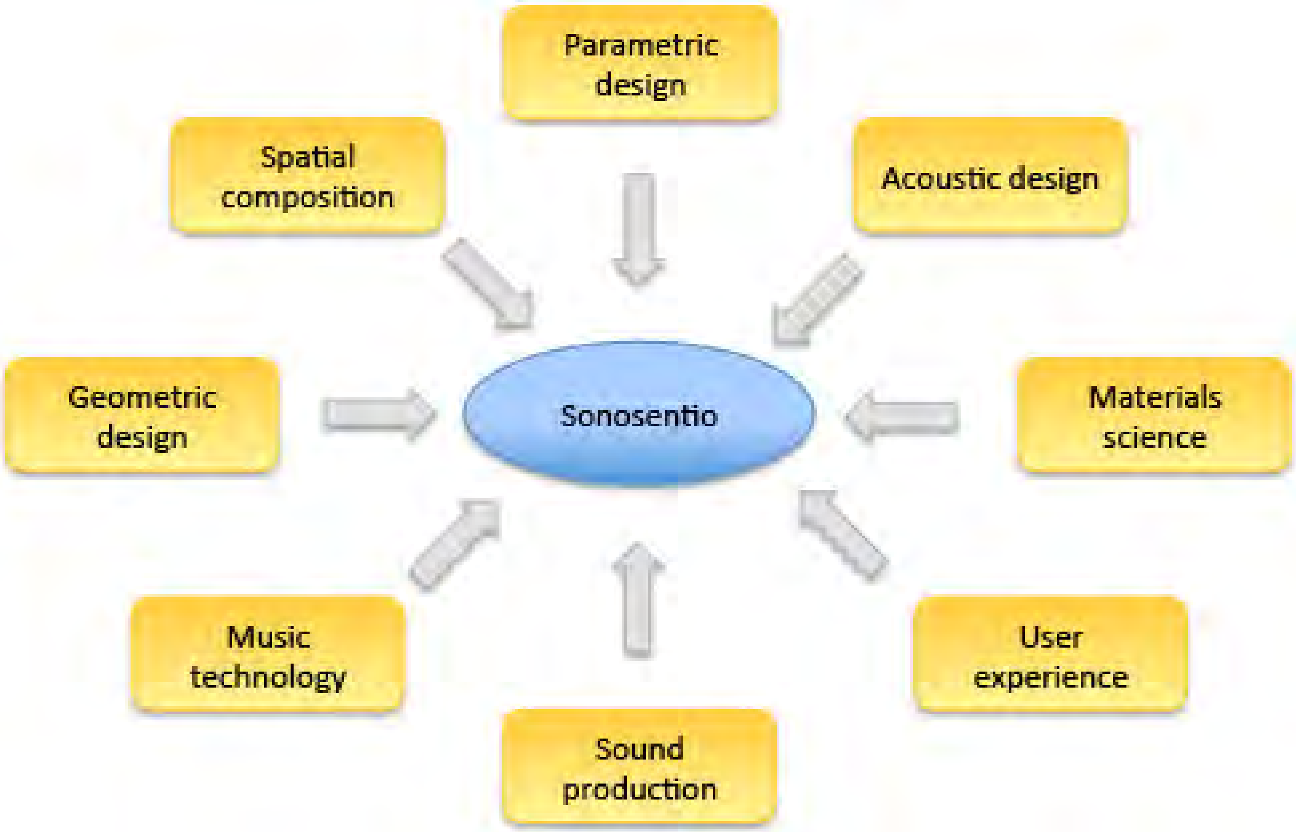


Figure 29: Contributions from various fields of design

Sonosentio

Overview

Sonosentio is a research project exploring unique geometries using sonic response as the primary design medium. It conducts this research through the design of an interactive aural design environment.

Unlike acoustic modelling and auralisation systems that estimate the aural implications of visually derived geometries, Sonosentio allows designers to develop a spatial composition of sonic responses and to realise the composition in unique geometric forms.

The Sonosentio environment proposes a new paradigm for spatial design of sonically critical spaces. It is an interactive, sonically responsive space that allows its occupier to directly create spatially realised geometry in an interactive design environment.

The sonic response designed within Sonosentio is not derived from a predetermined visual geometry.

The response can be manipulated in real time to develop a space that is either real, or unreal depending upon the sonic requirements of the occupier. In this way, Sonosentio is a drafting system for sonic designers who are able to manipulate and interpret their ideas at both coarse and fine scale.

It creates a sonically responsive architecture that interacts with it's occupiers to provide a space that is flexible in multiple dimensions allowing development and refinement of models responsive to sound.

This space is derived from a series of previous projects involving concepts of communication of sonic concepts to a diverse range of project team members.

Sonosentio is a combination of interactive software, multimedia hardware and spatial sound reproduction.

The space has been designed to create accurate spatial images and spatial placement in four dimensions while reducing the localisation[1] effect of close proximity to the loudspeaker array.

The basic room uses minimal components to establish the spatial image. The locations have been determined based on the sensitivity of listeners to surrounding spatial sound fields. The envelope is designed to be broken down for setup in project spaces. Sonosentio is designed for a single occupation position.

Sonosentio is therefore a cost effective, spatial simulation environment that allows designers to share and experience sonic designs in its native spatial context. The space and equipment is designed to be easily erected in a project space and provide an extremely high quality environment for exhibition and demonstration of concepts to project team, clients and interested parties.

This is a prototype system developed to demonstrate proof of concept. While it has many restrictions, it is presented to exhibit the fundamental operational paradigm that would be used in a model refined by future research.

---

[1] Localisation is a term used to describe the ability to accurately define the source of a sound.

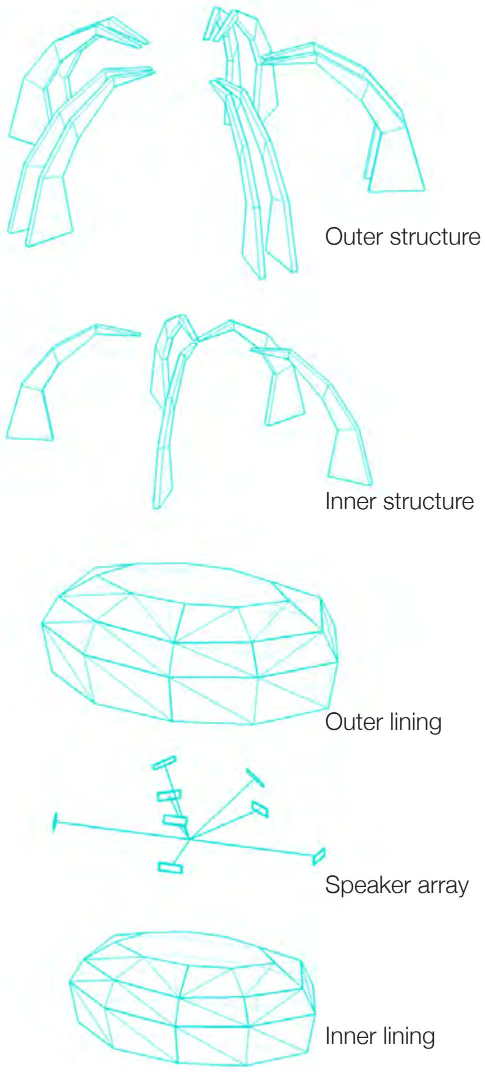


Figure 30: Canvas composition

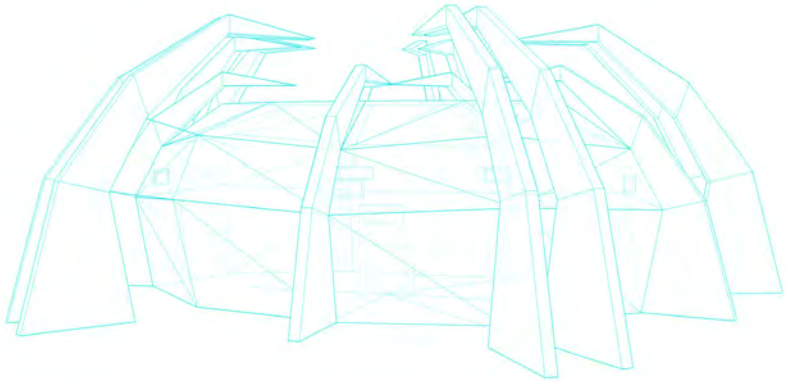


Figure 31: Overview of structure and enclosure

Design principles:

- Cost effective
- Relocatable
- Sonic design precedes visual design
- Intuitive, interactive user experience
- Integration with interdisciplinary design process
- Platform for future research

Design principles

Sonosentio is an immersive environment for design. It comprises a spatial reproduction array installed in a sonically neutral environment controlled by an iPad application that manipulates materials and geometry to form unique spatial compositions. The design principles describe the foundation of the conceptual design of the environment.

The design has been conducted within the sonic domain. The software and physical environment have been developed from principles that are specifically derived to achieve the sonic design goals within a design paradigm that is familiar to designers working with sound.

As with all "real world" projects, cost effectiveness is a primary concern. Common materials are used for the structure and linings of the space. The construction is best described as a tent within a tent. Canvas, polyester, rope and pine are the materials. The entire environment is intended as a temporary structure within an existing building. Naturally, it embodies a philosophy of environmental consciousness.

The enclosure and its support structure are designed to be relocatable. It is envisaged that it would be set up for the duration of a design project and then dismantled for relocation. The support structure is simple and provides the minimum bracing required to support the reproduction array elements and the inner and outer enclosure linings.

The user interface has been developed to be intuitive for designers with an understanding of audio systems technology. The operational paradigm is not complex and any designer could quickly become competent with the interactive environment. However, this system does not provide designs, Sonosentio is like any other computer aided design (CAD) system, it merely provides an interactive method of documenting design. Autocad does not design buildings. Photoshop does not enhance photos. Likewise, Sonosentio does not design sonic experience.

This research is primarily focussed upon the design process. It reviews existing sonic design processes and proposes an alternative method that is interactive in the media in which the design is occurring. This ability to directly interact with the design medium provides a greater opportunity to share the experience/design with other design professionals.

The project described by this research is an indication of a possible design that will enable a new process of design for sonic geometries. The realisation is developed as a proof of concept, outlining the components that would enable a new sonic design paradigm. Each aspect of the system offers the opportunity for considerable refinement and provides a significant path for future research.

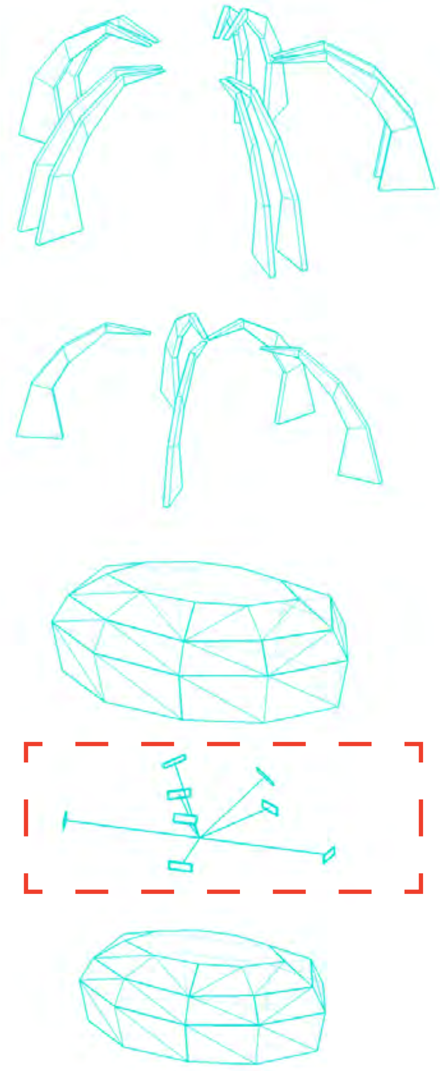


Figure 32: Canvas composition

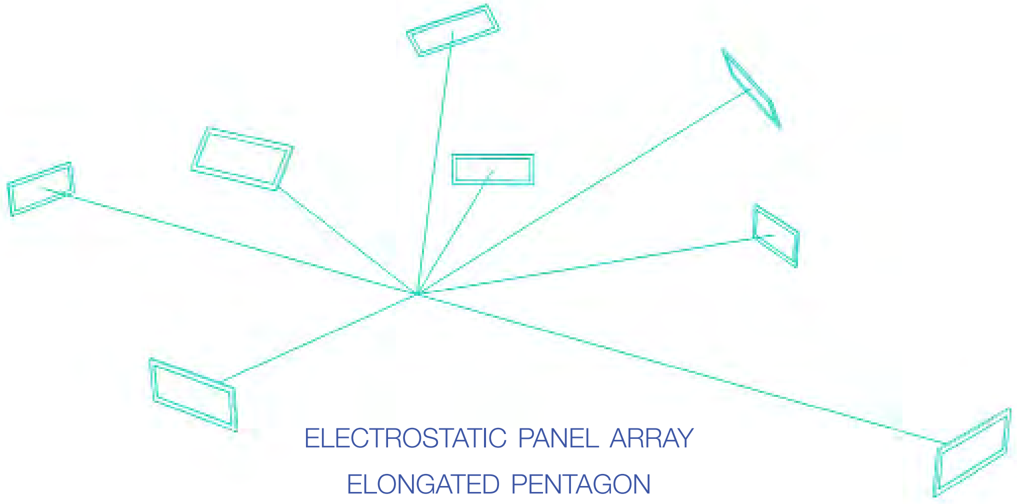


Figure 33: Spatial reproduction array configuration

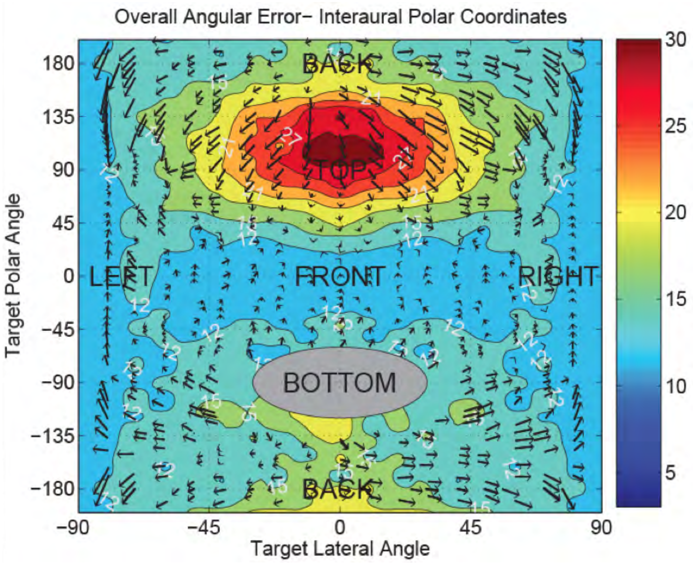


Figure 34: Positional errors in spatial hearing

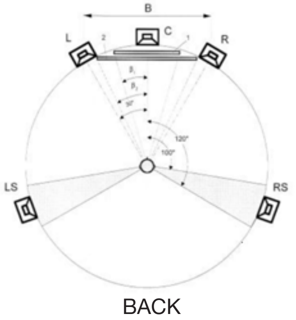


Figure 35: Dolby 5.1 array

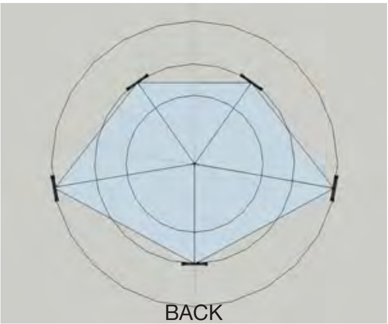


Figure 36: Sonosentio primary array

Spatial reproduction array

The spatial sound reproduction array is the display media for the sonic geometries developed in the Sonosentio environment. The array allows the spatial distribution of the reflection sequence to be interactively composed by the designer within the space.

The key design parameters for the array are:

- accurate spatial imaging in 3 dimensions
- sonically accurate radiation elements
- minimal components with ability to expand

The arrangement of the array components has been designed to minimise the number of components by optimising their position in relation to the spatial sensitivity of human hearing. This optimisation is informed by the research conducted to map auditory localisation accuracy as a function of location of the sound source[1].

The minimal reproduction system is based on an array of eight primary components. Eight has been chosen as the most cost effective number as sound interface is typically available with eight outputs. The reproduction system can be expanded to improve the performance of the experience

As the number of elements increases, the accuracy of the spatial location will improve. A further consideration for a fully enclosing array, ie. one that creates a lower design hemisphere is being considered, but is not included in this project.

Electrostatic loudspeakers have been chosen as the principal sound radiators. Unlike magnetically driven cone speakers, electrostatic loudspeakers use a high voltage electric field to move a large, flat diaphragm. In my experience, they provide a more realistic sound than traditional cone loudspeakers and more accurate sonic imaging.

The most common experience of spatial sound is the Dolby 5.1 format that is used in cinema and home entertainment systems. This configuration includes a centre speaker for “grounding” speech to the centre of the screen. This location is redundant in the Sonosentio array as each component has equal status and function.

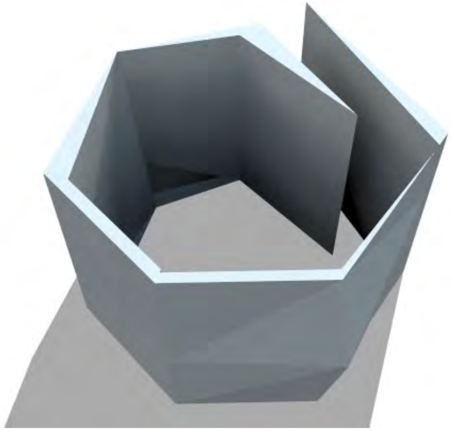
The Sonosentio loudspeaker array may be described as an elongated pentagon. The front speakers are in a typical left and right position. The side speakers are slightly behind the designer’s seating position. These speakers are set back to provide a greater path length from the front to the side speakers. A single speaker is provided directly behind the designer’s position. This loudspeaker draws the image directly behind where our sensitivity to spatial location is low. The three upper speakers are located at the two front and one rear position at an elevation of 1.8m.

The loudspeakers are mounted on the inner support structure of the enclosure. The elongated pentagon shape of the primary loudspeaker array establishes the fundamental shape of the enclosure and the position of the primary structural supports.

---

[1] Best, V. E. A. 2009. A meta-analysis of localization errors made in the anechoic free field. International Workshop on the Principles and Applications of Spatial Hearing. Zao, Miyagi, Japan.

Figure 39: Conceptual sketch for spiral enclosure



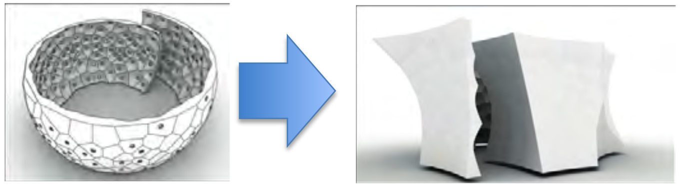


Figure 38: SIAL FabPod enclosure

Figure 40: Support structure concept

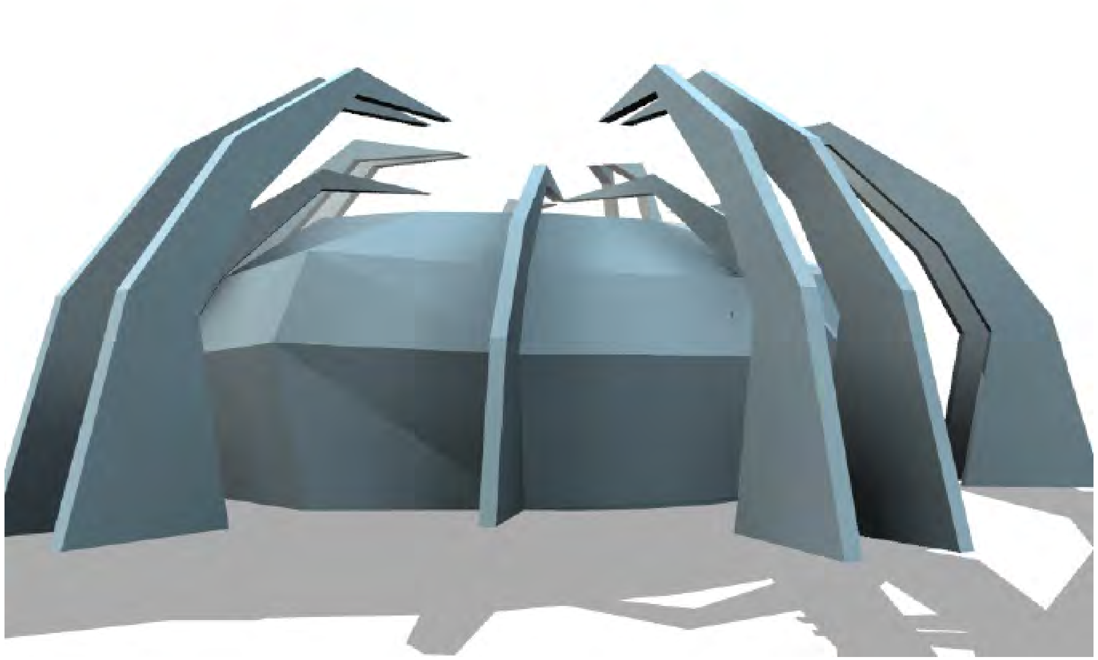


Figure 37: Enclosure derivation

Figure 41: Frei Otto

Figure 42: Ernesto Neto

Figure 43: Zumthor & Bourgeois

Figure 44: Louise Bourgeois

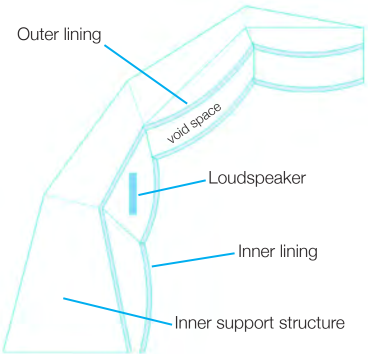


Figure 45: Lining configuration

Enclosure

The configuration of the enclosure has developed from a number of small studio and critical listening room projects. These include the Arup SoundLab[1], RMIT Pod[2] and Music and Effects post production studios[3].

The design process for the enclosure is entirely derived from the sonic context. The geometric composition and materiality is entirely derived from the sonic design process. The design precedence follows the following sequence:

1. derivation of the reproduction array locations
2. design of the transmissive exterior skin
3. design of the absorptive inner layers
4. location of the array support structures
5. location of the interim support structures.

The boundaries of small rooms result in sonic properties that create inconsistencies in the consistent, balanced sound quality throughout the space, particularly at low frequencies. The interference of air pressure fluctuations result in standing waves, referred to as room modes, that affect the balance of the spectral qualities of the sound[4].

To overcome these issues the boundary surface of the Sonosentio enclosure has been designed to be effective in three different frequency ranges provide a more balanced spectral response within the space. These ranges are:

- High Frequency - interior material absorptive
- Mid Freq - interior and exterior combined
- Low Freq - transmission through the skin

The enclosure design consists of a tent within a tent. The outer layer has been designed to be sonically transmissive in the frequency range below the Schroeder frequency[5]. This layer consists of a heavy canvas layer and a layer of sound insulation to absorb sound within the wall cavity.

The inner layer is made of sound absorbing polyester. It serves two main functions:

- as a high frequency sound absorptive layer to suppress reflections within the space
- to conceal the loudspeaker locations from visual reference within the room

While the inner layer reduces the visual localisation of the loudspeaker components by concealing them from view it must also not adversely affect the quality of the reproduced audio.

All support structure for the enclosure is exterior to the outer skin to reduce reflections from support members that may provide false images or reduce the accuracy of spatial placement for the occupant. While a nominal tower structure is illustrated, the tent could be tied to the existing structure of the building in which it is located.

---

[1] Refer to Background Appendix p50-51
[2] Refer to Background Appendix p52-53
[3] Refer to Background Appendix p48-49
[4] Refer to Component Appendix p9

---

[5] Refer to Component Appendix p9

Kid Neon Images

Figure 46: Sonosentio enclosure with support structure

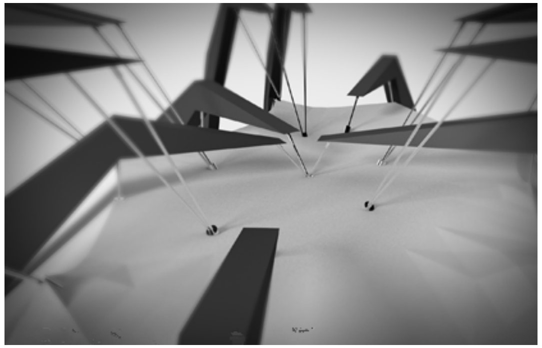


Figure 47: Structure connections

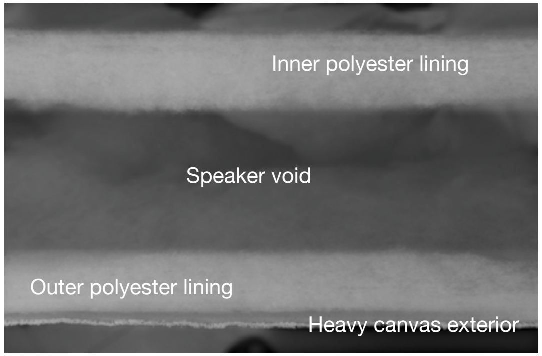


Figure 48: Lining composition

Composition

The shape of the enclosure reflects the elongated pentagon speaker array that is fixed to the main internal support structures. A secondary array of supports structures, between the primary supports is employed to draw the enclosure into shape.

The enclosure design comprises a tent-in-tent construction supported by an external structure. This arrangement reduces the potential for reflections that may confuse the sonic imaging within the space

The support connections for the linings pass through the outer layer to also pick up the inner layer.

The tent-in-tent technique was chosen to provide the following benefits:

- neutral sonic character
- speakers concealed within the inner lining
- reduction of reflections from exposed structure
- minimised cost

The support structure was developed to minimise the number of required components and allow them to be built out of readily available, low cost materials. As described earlier, the five inner supports are located at the primary loudspeaker positions and form mounting structure for these components. The secondary, outer supports draw the linings in to shape between the primary supports.

The linings are supported by rope bindings to the junctions of the support members. Attachment points are provided for attachment of the rope fixings. The inner lining is also connected to the attachment points by short lengths of rope that provide the spacing between the two layers.

The major difference between this space and previous spaces I have designed is the sonic transparency of the boundary of the room.

Previous spaces have been designed to provide a high degree of sound insulation between the auditioning space and adjacent spaces.

The Sonosentio project is designed to allow sound to penetrate the linings, thus increasing the apparent absorption of the interior linings, particularly at low frequencies where modal issues occur.

In this way, the room in which the Sonosentio enclosure is located becomes a major contributor to the environment within the space.

This approach allows the room to be far more sonically neutral allowing greater clarity and tonal accuracy for sound reproduced within the space.


Figure 49: A room within a room

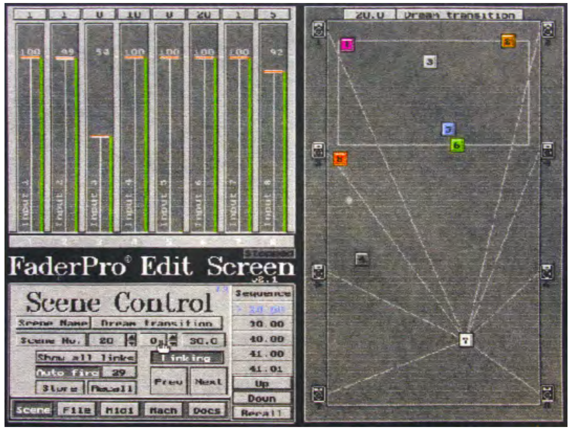


Figure 52: Faderpro interface screen

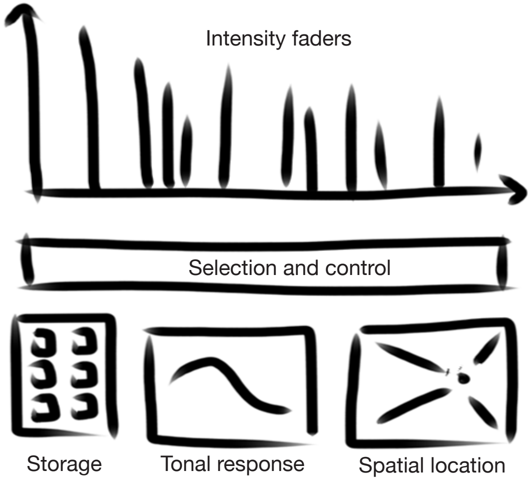


Figure 51: Audio mixing console interface

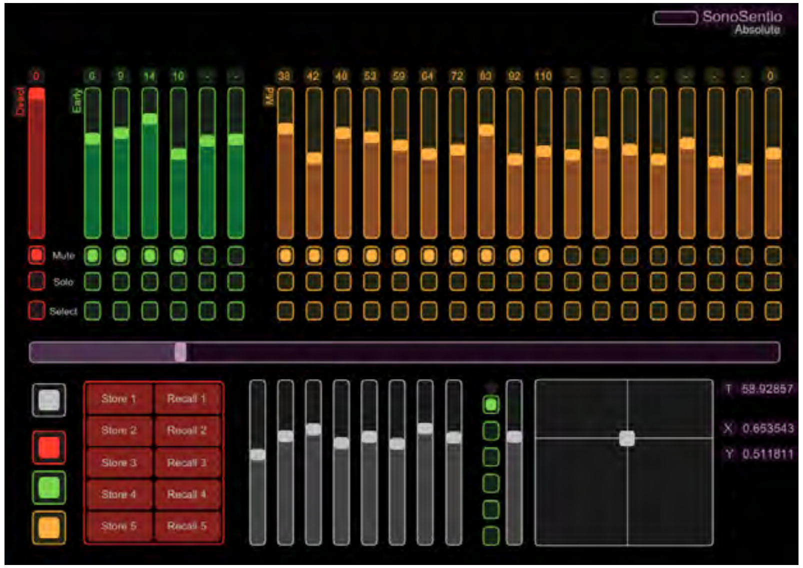


Figure 50: Brush application UX design

INTERFACE TO ENABLE USER TO INTERACT IN A NATURAL MANNER.

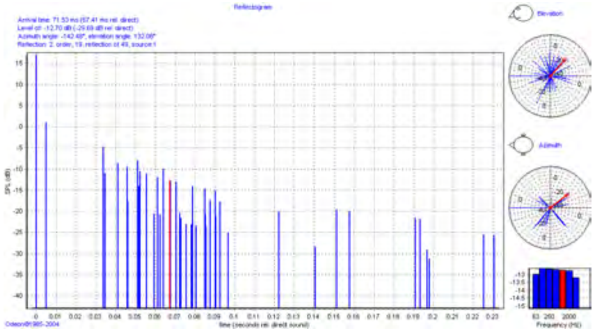


Figure 53: Reflection diagram (From ODEON)

Designing sonic response

The brush is the user interface to the sonic geometry system. It allows a spatial design to be conceptualised aurally using an interface paradigm that the majority of sonic designers would be familiar with.

The primary goal of the brush application is to allow the impulse response to be used as a three dimensional sonic design medium. Each of the intensity faders represents a repetition of the original sound. The spatial location and tonal balance of each of these repetitions is manipulated to form and overall response that represents the geometric form of the spatial composition. This form may be realised passively by an arrangement of physical surfaces, or actively using a sound reinforcement system.

As discussed, a ray tracing program provides the capability of examining an individual reflection within an impulse response. The location and tonal character of that surface can be reviewed. However, there is no ability to hear the individual response or to interactively relocate or colour the tone without redesigning the visual geometry and repeating the ray tracing process. Even then, the auralisation will only allow the entire context of the room to be heard. It does not allow individual reflections to be considered sonically, only as a visual representation (Figure 53).

The brush application allows any individual impulse or any combination of the impulses within the overall response to be examined sonically. An individual impulse can be silenced or heard by muting its control in the brush application.

This allows the context of each component of the overall impulse response to be interactively manipulated in time, space.

For the proof-of-concept presented in this project, the brush application has been developed using the TouchOSC[1]. The user interface layout, based on the digital audio mixing console paradigm, has been realised using this modular user interface development tool. These controls generate OSC[2] control messages that are transmitted wirelessly to the palette program via WiFi.

The application runs on an Apple iPad tablet computer. The brush application is presented as a proof of concept and offers the opportunity for significant research to refine it's operation.

The use of gesture control systems such as Leap Motion[3] or the Thalmic Labs MYO armband would enhance the experience for designers working within the Sonosentio design environment. This would provide a more intuitive interface for the spatial placement of impulse responses within the three dimensional environment.

---

[1] A modular interface design environment developed by Hexler.net. (http://www.hexler.net/)

[2] Open Sound Control is a multimedia communication protocol developed by UC Berkeley Center for New Music and Audio Technology. (http://opensoundcontrol.org/)

[3] Leap Motion is a computer interface for providing contact free control for three dimensional gesture tracking (https://www.leapmotion.com/)

Figure 54: Impulse reponse

Figure 57: Selection and control

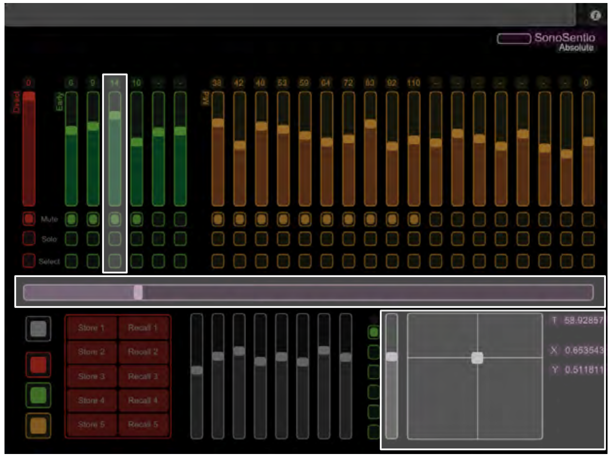


Figure 55: Distance and spatial position

Figure 56: Material properties

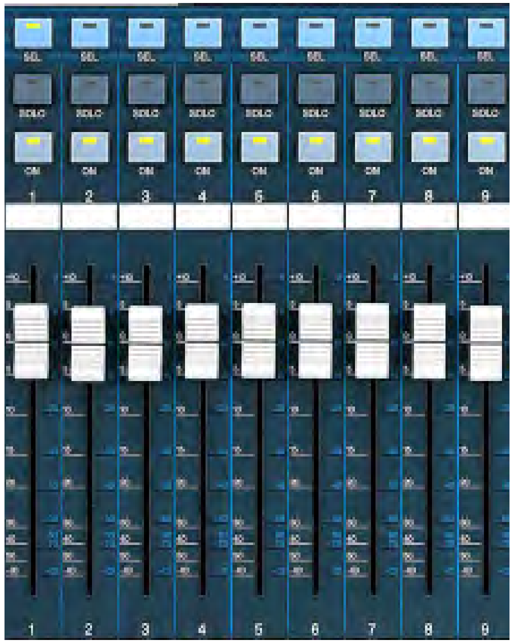


Figure 58: Audio mixing console interface

User experience design

The control functions of the audio mixing console have been adopted as the operational paradigm for the brush application to create a familiar environment for experienced sound designers. While the function of the impulse faders is considerably different to that of their mixing console counterparts, functions such as select, mute, solo, equalisation and spatial panning operate in a familiar manner.

The Brush interface incorporates the fader and channel control features of a typical audio mixing console combined with the spatial manipulation controls of the Faderpro[1] system.

For the brush application, the relative intensity faders provide the level reduction of impulses within the response. In a typical reverberant response, the faders would be configured in as reducing in level from left to right.

Each intensity fader has an associated time display. This indicates the delay from the direct sound (the leftmost, red fader). The structure of the reverberant response is a combination of the time and relative intensity of each of the impulses. In the brush application the delay is represented by the distance slider in the middle of the screen.

The impulse faders are grouped in two parts, early and late. This segregation of early, green faders, and late, orange faders, allows the groups to be activated and deactivated to hear the effect of early and late sections of the response.

The control section consists of a series of buttons that allow selection, muting and soloing of each impulse.

When selected, the lower controls, spatial position (xy panner and adjacent z fader), distance and equalisation are active on the selected impulse. Each impulse may be selected individually to adjust these parameters. The sonic influence of the control manipulation is represented by the spatial sound array in real time.

The solo button under each impulse allows an individual reflection to be heard with all others muted. This allows the detailed position and tonal response of each reflection to be considered individually and then recombined with the entirety of the impulse response. By selecting multiple solo impulses, a number of impulses can be considered together.

The mute buttons allows individual reflections to be silenced. This can be used to highlight individual characteristics in an overall impulse response such as echo or harsh response.

The materials section allows absorption and diffusion to be applied to each impulse. A unique sonic texture can be applied to each impulse within the overall response. The characteristic can be applied from a common set of materials, or individually designed using the equalisation controls.

---

[1] Refer to Background Appendix p44-46

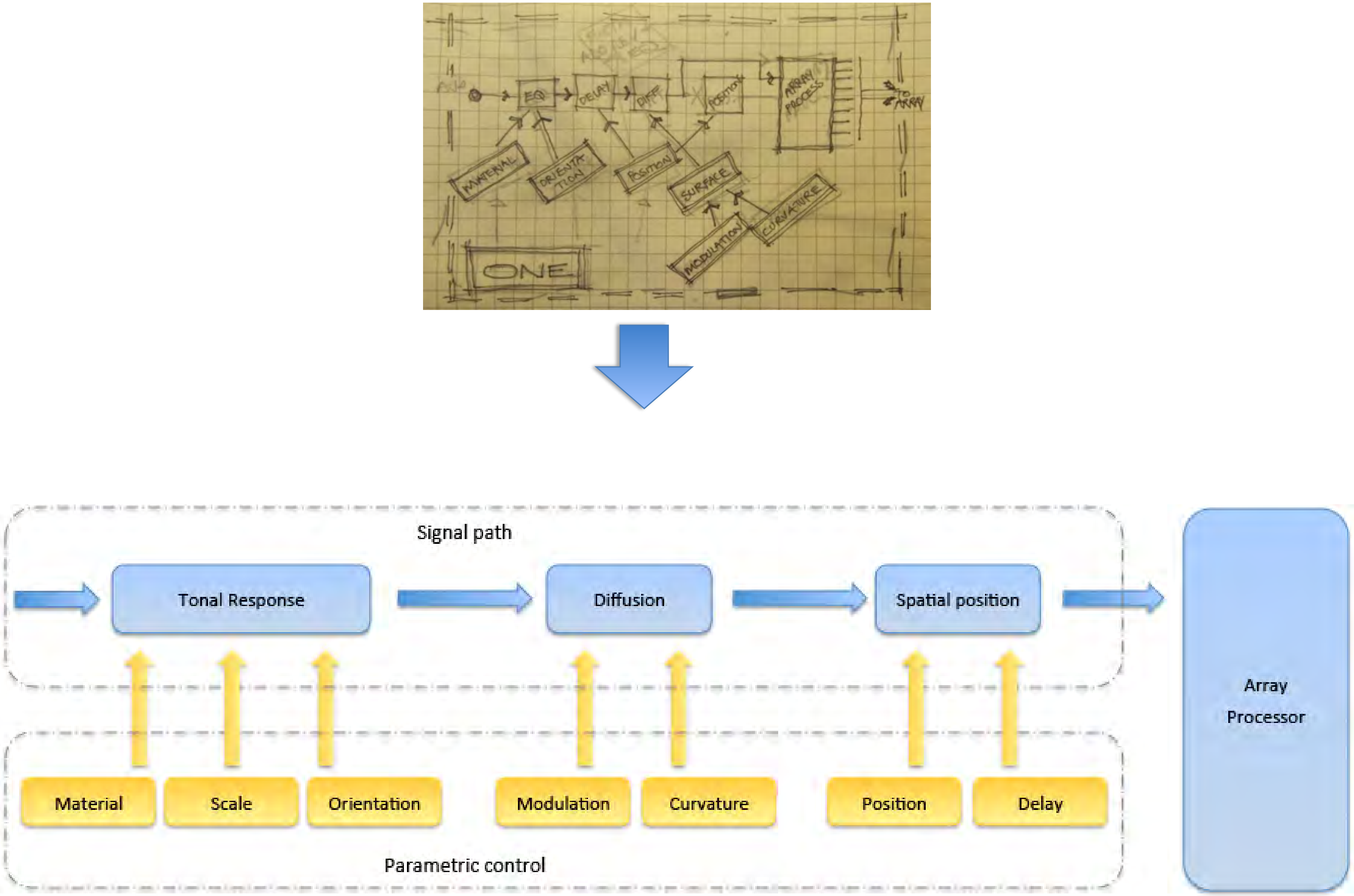


Figure 59: Palette program derivation

Palette

Parametric system to simulate the performance of geometry and materials. This is first stage of concept development. Future research required.

Interaction of sonic and geometric form

The Palette is a parametric program that uses geometric and material property data from the brush application to produce a spatially realised sonic response that interactively reflects the evolving design.

The Palette is the mathematical heart of the Sonosentio environment. It provides the sound field in which an experienced designer can manipulate the geometric response in real time. Concurrently, the palette program calculates the geometric representation of the sonic texture that is being designed. This dynamic relationship between sonic response and geometric composition provides a new context for design within the Sonosentio environment.

The Palette program consists of three basic modules:

- tonal response
- diffusion
- spatial position (in time and space)

The Brush application allows the parameters used by these modules to be adjusted for each impulse within the overall response.

The tonal response affects that balance of frequencies within the selected impulse. This balance may be selected from standardised materials or tailored by the individual frequency controls in the brush application. For custom responses, equivalent materials could be retrieved from a database, through the design of custom materials or by electronic reinforcement.

The scale of the surface and the subtended angle to the incident sound also effects the tonal composition of the reflected sound.

The sonic image is presented as the real time design environment. The visual domain is derived from the dynamic parametric model.

This real-time response is one of the major discriminating factors between this process and the typical design process.

Typically, visual design is performed in real-time and sonic design is in the same project position as render engines.

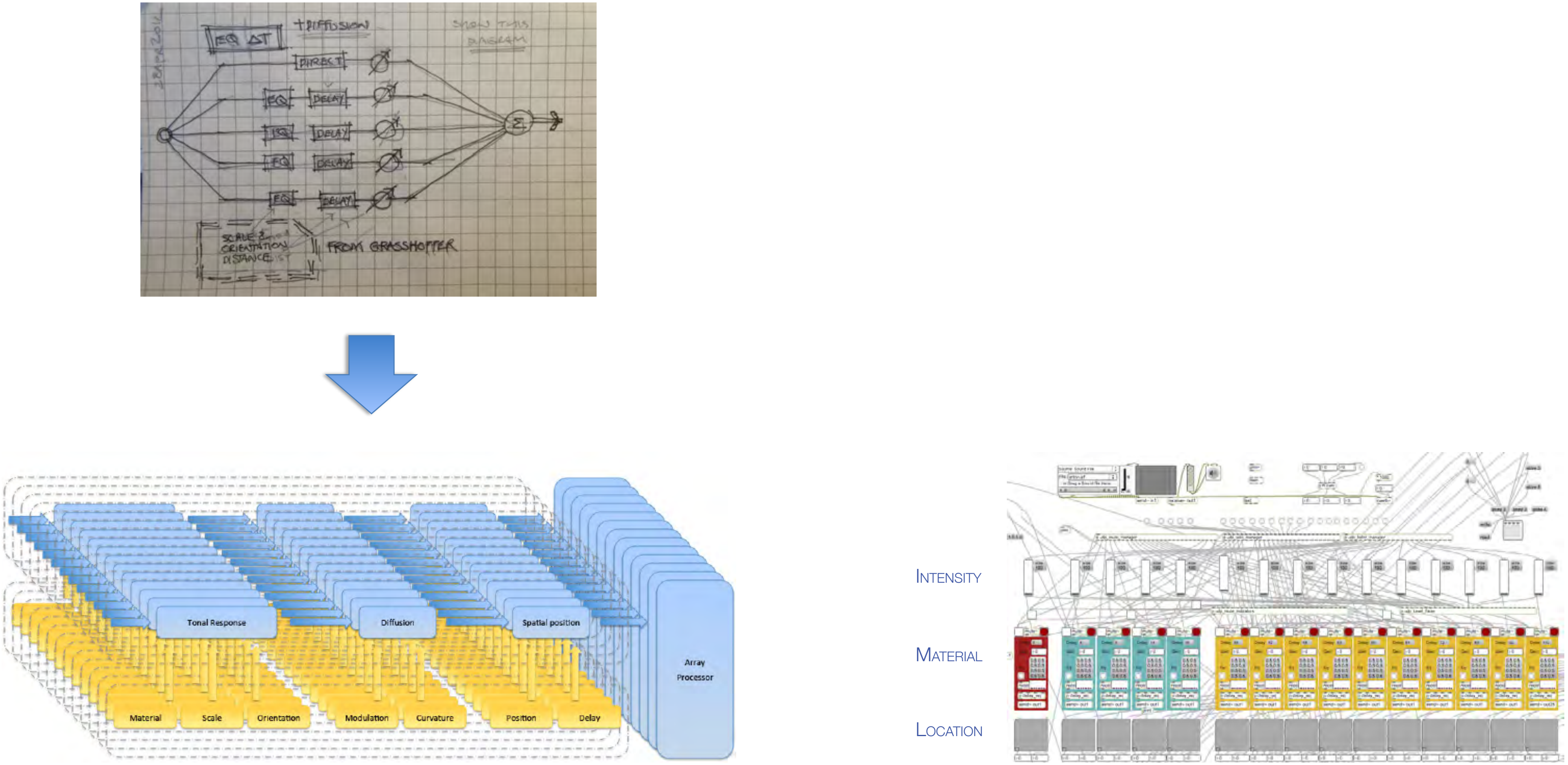


Figure 60: Palette program impulse mixing

The contribution, tonal quality and spatial position of each individual impulse is combined to provide the composite impulse response. This is then presented to the spatial reproduction array to provide the sonic response within the Sonosentio environment.

For example a natural increase in intensity would imply a focussing of reflections from one, or a number of surfaces. Alternatively, it would be achieved by electronic reinforcement.

The palette uses the following characteristics to describe the geometry being simulated:

- Scale of surface
- orientation
- absorption
- diffusion
- curvature
- spatial location
- distance

Unlike modelling and auralisation tools that apply broad estimates to geometric forms, the Sonosentio environment enables the sound of these characteristics to be experienced in real-time.

Each surface defined in the brush program is spatially modelled and the characteristics of the surface can then be derived. Where a surface cannot be realised physically, then the location within the overall compositions could be achieved using a loudspeaker, or array of loudspeakers. In this way the Sonosentio palette is providing the ability to creatively define space that is physical surfaces or electronically enhanced compositions.

Each component of the impulse response can be individually controlled by the brush application. The palette program then combines them to create the overall response.

The interaction of the palette program and the brush application allows complex responses to be developed and refined in real time using sound as the interactive design medium.

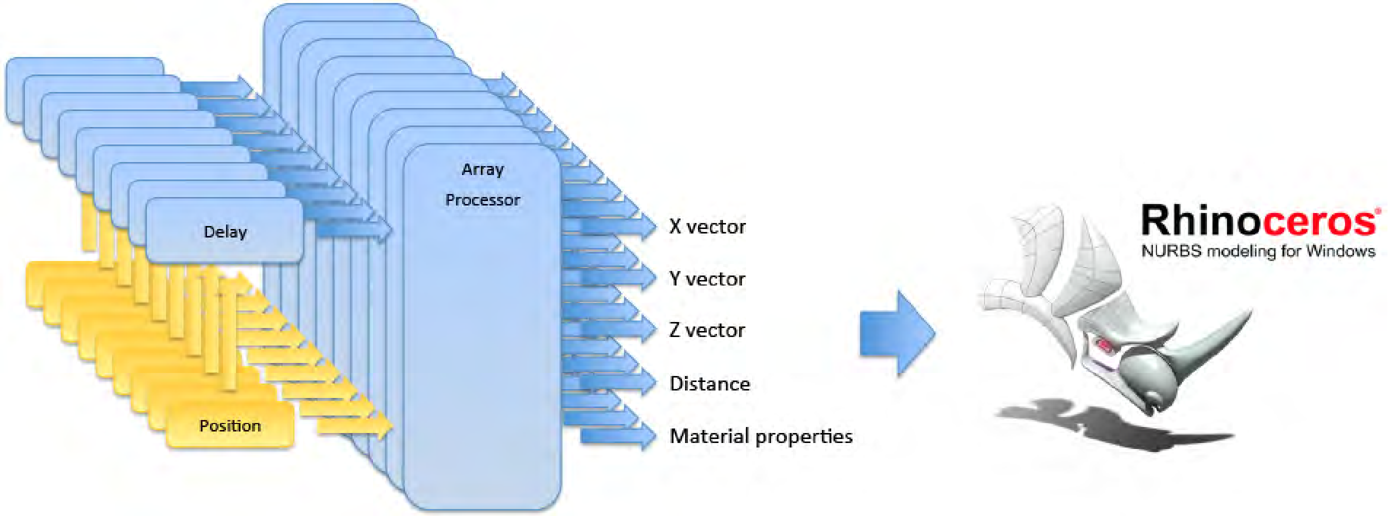


Figure 61: Palette program - export geometry and materials

Export geometry

The spatial location and distance information established in the brush application and subsequently interpreted by the palette program can be directly exported as geometric components. In reality, this geometric composition could be dynamically created and modified as the sonic composition is manipulated by the designer.

This direct relationship between sonic composition and the spatial geometry can be exported from the palette program to describe the geometry represented by the spatial impulse response established in the Sonosentio space.

The palette program builds a dynamic model of all of the geometric components and material data required to realise the sonic design in physical space. This provides significant potential for interactive design in a dynamic visual and aural environment.

The scope of this research is limited to the sonic representation of the space under design.

The spatial array processor within the palette program collates this information and provides a sonic image for each impulse an reflects that image in three dimensional space. This space is constructed beyond the confines of the enclosure by the various time delays modelled within the palette.

Material properties may be derived by either looking up the best fit within a standard database of existing materials or as technical data that specifies a material composition that can be constructed from a composite arrangement of materials. The Palette program does not design materials or geometry, it provides an interactiv environment to design sonic response.

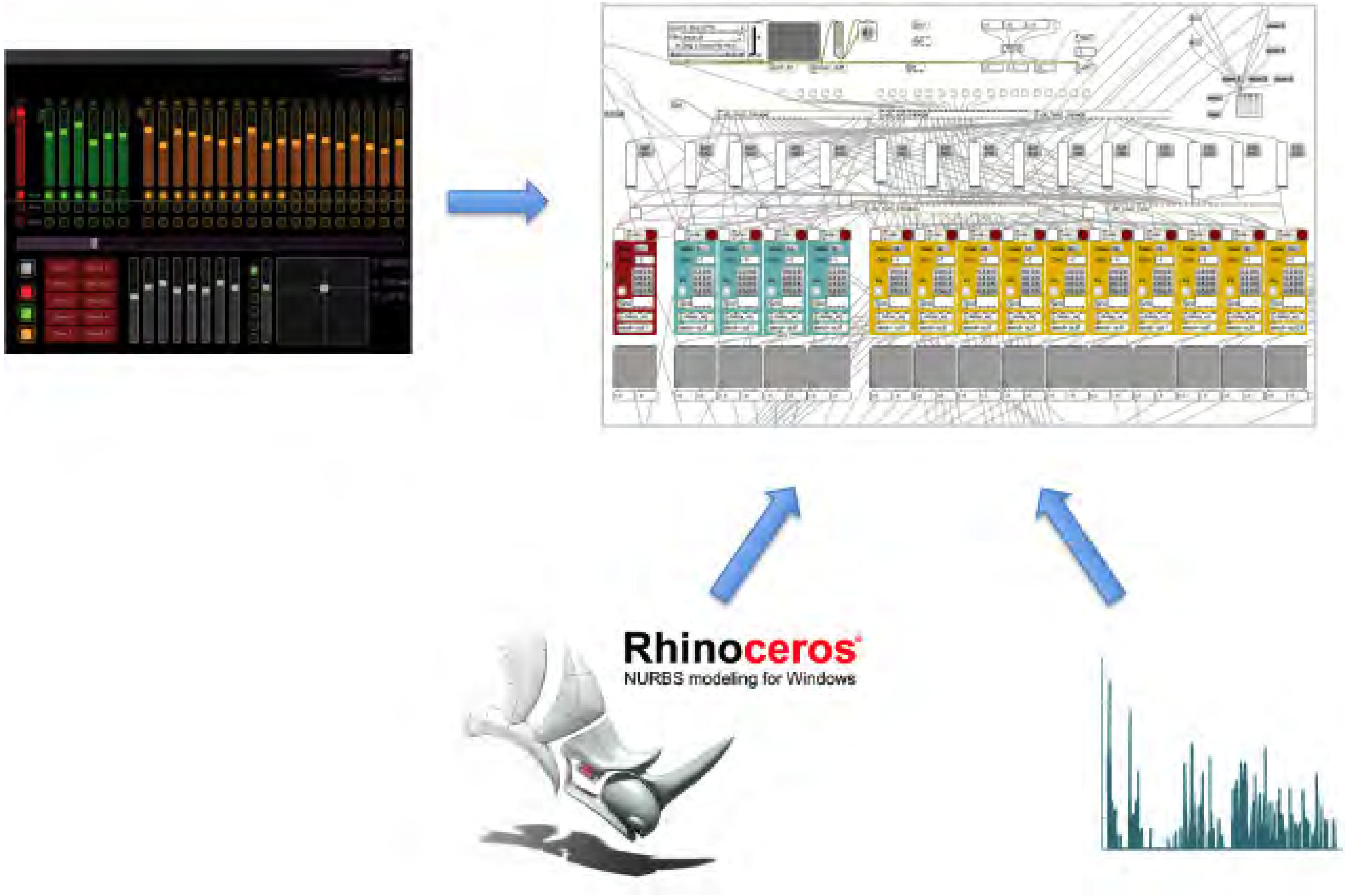


Figure 62: Palette program - potential alterate parameter input methods

Import geometry

The scope of this research is limited to the development of the proposition of a sonic sketchpad for geometric design. The concept has been developed as a proof of concept to demonstrate a potential realisation of this approach for sonic design. The proposed design environment offers significant potential for future research and for application in design.

There is potential for future research to develop the palette program to provide a path for importing impulse and geometric data from various sources.

Essentially, the palette program can be considered as a two way translator between geometry and sonic response. It is able to accept sonic response data and present that as a spatially realised sound or as geometric data that located specific fragments of three dimensional space.

In addition to the interactive design application presented in this work, the palette program could also accept impulse response data from a measurement or modelling program and allow interactive modification of that data to investigate the implications of various design changes.

For example, an impulse response measurement conducted in a real space could be imported into the palette program for manipulation in the brush application. The influence of individual impulses within the response could be reviewed and the spatial location varied to create a similar reverberation within a revised spatial context.

Likewise, the geometry from a visual CAD program could be imported into the palette program for sonic review and manipulation.

Extending this interaction further, a session with a program such as Rhino could interact directly with the palette program to allow live geometric design and sonic response to be experienced concurrently.

The interaction of the programs was demonstrated in a earlier GRC[1] session indicating the potential for this form of interaction. While it is possible for Rhino to have brief discussions with Max/MSP via the Open Sound Control protocol, it is a long way from having a meaningful, interactive dialogue regarding complex geometries. However, this is only a matter of conceptual design and programming.

Sonosentio proposes a new paradigm for sonic design and its interaction with visual geometry. While it does not replace ray-tracing and hybrid design review software, it proposes a new model for interactive design that is complementary to these existing systems.

---

[1] The Global Research Conference (GRC) is a forum for presentation and review of postgraduate research.

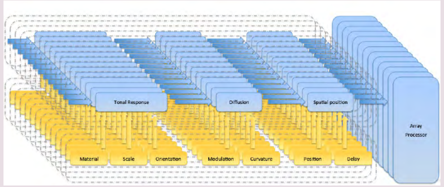
Stimulus - For example a hand clap

A stimulus is used to activate the sonic geometry synthesised by the Palette program. This could be an impulse, handclap, music, speech or any other appropriate signal.

Visual design concept

Brush: Interactive concept development

The designer manipulates the spatial sound field using the Brush application to interactively control the characteristics of the impulse response while listening to the field within the Canvas enclosure.



Palette: Impulse response synthesis

Spatial field created in brush application is synthesised for reproduction in the Canvas. Concurrently, geometric data representing the spatial field is derived for presentation in visual simulation software providing a simultaneous representation of the sonic architecture.

Sonosentio
design process
(Scope of research)

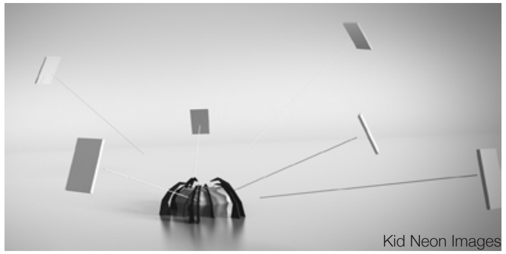
Canvas: Interactive spatial sound environment

Spatial field reproduced by sound system within acoustically inert space providing an interactive environment for design.

Mathematical interaction of spatial geometry

Polar (Degrees)	Elevation (Degrees)	Distance (metres)
58	16	22.2
93	27	11.7
135	41	16.1
201	24	14.0
255	33	20.0
291	62	10.0
301	12	17.5
352	24	13.9

Geometric data is used to interactively communicate spatial information between sonic and visual models.



Kid Neon Images

Spatial geometry (sonic)

The spatial design created in the Brush application and synthesised in the Palette program is presented as a geometric model.

Measured Impulse response:
An artifact of the design process

Figure 63: Sparse geometry design using interactive Sonosentio process

Interactive design process

Figure 64: Sparse geometry sketch

Figure 65: Sparse geometry design

This research explores the process and precedence of design and proposes a new approach that applies the creative sketching method inherent in drawing tools to a sonic context. This proposition allows creative design for geometry to be conducted in an interactive sonic environment.

This research has reviewed the existing techniques currently employed by engineers to evaluate the sonic properties of visually conceived geometries.

This research proposes a unique design process where conceptual design of geometries can be conceived and evolved interactively in both a sonic and visual context.

As discussed the current design review practices provide a cumbersome interaction process between creative design disciplines. This has created a tension that is generally resolved by the visual design being the creator and sonic design then conducted as an engineering review. This often results in sonic designs where the outcome is constrained by the existing, cumbersome engineering interaction process.

The Sonosentio design process uses sonic response as the foundation of interactive conceptual design.

In order to contextualise the sonic design process proposed by this research project, I return to the original concept of deconstructed geometries.

In my original proposition, I considered the deconstruction of existing space to identify the elements that contributed to the perceived sonic qualities. As discussed, this premise again placed existing spaces as the foundation of the proposition and sought a method to deconstruct and reinterpret their form into new geometric configurations.

My sketch of the proposed sparse geometry, shown in Figure 64, proved extremely complex to realise using the measurement and review approach of existing sonic design processes.

I reinforce that the research is specifically directed toward the process of creative design. The design outcome and the assessment of design quality is not the focus of this work.

The project, Sonosentio, demonstrates one potential implementation that realises the proposed design process. Sonosentio has been developed using currently available, off-the-shelf hardware. It also uses a modular software environment and spatial sound processing algorithms developed for a previous project - Faderpro.

The implementation of the Sonosentio process exhibited as part of this research represents the minimum possible configuration of components capable of providing the proposed interactive design environment. Additional funding would allow a much more complex technical implementation to be realised.

Using the Sonosentio environment, the sonic response can be interactively “sketched” in the brush application. The resulting sound is directly related to its geometric architecture resulting in a three dimensional physical representation of the sonic response. This approach releases the design process from the cycle of trial and error by providing an interactive, creative development approach. Existing processes that require conversion of the model for trial in acoustic modelling software and the subsequent calculations can occupy hours awaiting a sonic representation of the proposed geometry.

The Sonosentio environment makes this interaction immediate, with no lag between the sonic model and representation of the associated geometry.

Figure 63 provides an overview of a simple geometric design process for a sparse array. This project has been considered in the context of a public art installation.

The impulse response is developed using the Brush application on an iPad. The Palette program provides a spatially realised synthesis of the Brush interface for interactive reproduction through the spatial array. The geometry of the design is calculated and presented as coordinates in three-dimensional space. The resulting spatial design can then be combined with the visual concept to create an integrated visual and aural design.

This research has highlighted the impediments of pursuing a philosophical analysis of geometric design in a sonic context. The realities of design can be disregarded by practitioners who derail conceptual discussion by prioritising precise engineering detail. This often stifles the prospect of rational discussion of more conceptual elements of design in the field of sound and acoustics.

This project reviews the existing design process employed on the majority of creative projects relating to geometric design for sound where the “acoustic” design becomes a review of a visually derived concept. This design is undertaken using computationally derived measures of subjective impression. The majority of these measures were developed well over 30 years ago.

This research describes an interactive conceptual design process that uses directly experienced spatial sound to derive geometric form. This process allows design to be undertaken in the medium in which the design is focussed.

This sonic design can then interact directly with the visual design via geometric data shared within the Palette program and drawn in three-dimensional CAD software.

Using this process a visual geometry can be derived from a sonic sketch and vice-versa. This new technique has significant potential to change the design process for sonic spaces.

Future research opportunities

The project provides significant potential for further research opportunities in each aspect of its design.

- The configuration and composition of the spatial reproduction array to provide more realistic and accurate spatial location.
- The enclosure materials and structure. The “leaky exterior” approach and it’s application in various external enclosures requires a significant amount of development. This approach to critical listening space design is unique.
- The brush application is currently restricted by the environment in which it has been developed. There is significant scope to develop a new program that provides a more interactive and realistic user experience.
- The palette program offers the greatest opportunity for development. The data required, particularly diffusion, texture and shape parameters is limited and each aspect could be enhanced by further research.
- Perhaps the most significant area of future is the overall concept of sonic response in the design process and the manner in which the sonic design interacts with other design disciplines. The ability to design both geometry and sonic response simultaneously at a conceptual stage of project development would offer substantial security to project teams and client groups.
- Interaction with other sources of palette data including importing geometry from CAD and importing measured 3D impulse responses.
- The use of a gesture control interface such as Leap motion to control the spatial location within the Sonosentio space.

Conclusion

The traditional process for sonic design is typically characterised as a review and rectification process rather than as creative composition of deliberately conceived spatial impression.

The tools have been created to support this process of design review.

The process is heavily reliant upon the use of objective criteria to communicate the subjective impression of the sonic characteristics of the space.

The communication language consists of mathematically derived, reductive parameters to quantify subjective experience for communication to the design team and client.

The majority of these objective criteria, now incorporated into the International standard ISO 3382: 2009, are based upon research and technology that predates 1975.

These criteria are specifically intended for concert halls consisting of a single volume space of typical size and shape, with the performers and audience within the same space.

The averaging of these parameters across venues further reduces the quality of the assessment and discounts valuable information regarding the consistency and quality of the space. These are measurement parameters, not design parameters.

The recommended ranges for the parameters are not within the typical range of reality for the rooms being assessed.

This project proposes a new design philosophy based on the principle of design within the medium of interest.

For painting this would represent paint upon canvas, for architecture composition of geometry and materials for functional outcome. For sonic design this represents sound interactively composed within a spatial listening environment.

The proposed composition tool allows space to be composed as temporal, material and spatial impulses within the overall context of a sonic signature of a space (impulse response).

This work does not propose to replace existing processes, but offers to enhance the processes and techniques available to designers by proposing a new paradigm in which composition could be developed at preliminary stages of the project and shared with team members in the language of sound rather than mathematics.

This research proposes a method for geometric composition using sonic response as the design media. It is envisaged that this would be used collaboratively with visual designers to create responsive architectures that cannot be explored using existing techniques.

The research has developed a system to illustrate the concept. The system requires further funding to develop beyond concept stage. The operation of the system has been demonstrated at the PhD exhibition and output of the system has been presented in this document.

The process and system described in this work are considered as predominately research tools in their current state of development. Future development of this research would allow application in a number of fields of creative design including:

- Research in subjective response to spatial environment
- Creative interactive sculptural design
- Architectural design
- Research in sonic design

It is my intention to develop this project to commercial realisation.

Potential users include:

- Researchers in sonic and acoustic design
- Venue design consultants
- Creative sound designers
- Artists

Bibliography

Cycling 74, ‘Max MSP’.

Barron, M. (1993), Auditorium Acoustics and Architectural Design (E & FN Spon).

Barron, M. (2005), ‘Using the standard on objective measures for concert auditoria, ISO 3382, to give reliable results’, Acoustics, Science and Technology, 26, 162-69.

Baume, M. (1967), The Sydney Opera House Affair (Thomas Nelson).

Beranek, L (1962), Music Acoustics & Architecture (John Wiley & Sons).

Beranek, L (2004), Concert Halls and Opera Houses: Music, Acoustics and Architecture (New York: Springer-Verlag).

Best, V. et. al. (2009), ‘A meta-analysis of localization errors made in the anechoic free field’, International Workshop on the Principles and Applications of Spatial Hearing (Zao, Miyagi, Japan).

Blesser, B. and Salter, L. (2007), Spaces speak, are you listening? (MIT Press).

Blundel Jones, P. (1997), Hans Schauron (Phaidon Press).

Bruel, P. (2008), ‘Of Acoustics and Instruments’, Sound and Vibration, (February 2008), 10-24.

Cahill, T. (1897), ‘Art of and Operation for Generating and Distributing Music Electrically’, in United States Patent Office (ed.), (USA).

Charles M. Salter Associates Inc (1998), Acoustics: Architecture, Engineering, The Environment (William Stout Publishers).

Christensen, C. L. (2011), ODEON Room Acoustics Software Version 11 (2nd edn.: Odeon A/S).

Dictionary, Macquarie (2009), ‘Macquarie Dictionary’, in Susan Butler (ed.), (Fifth Edition edn.).

Dictionary, The New Shorter Oxford (1993), ‘The New Shorter Oxford English Dictionary ‘, in L. Brown (ed.), (Clarendon Press).

Fairfax, V. (2002), A Place Across the River (Macmillan Art Publishing).

Forsyth, M. (1985), Buildings for Music (Cambridge University Press).

Forsyth, M. (1987), Auditoria, Designing for the Performing Arts (The Mitchell Publishing Company Limited).

Hall, P. (1990), Sydney Opera House: The Design Approach to the Building with Recommendations on it’s Conservation (Peter Hall).

Hexler ‘TouchOSC’, (Hexler.net).

Holmes, Peter (1994), ‘FaderPro’, (Peter Holmes).

Hunt, F.V. (1978), Origins in Acoustics (Yale University Press).

ISO (2009), 'ISO 3382:2009-1 Acoustics - Measurement of room acoustic parameters Part 1: Performance spaces'.

Izenour, G. (1997), Theatre Design (Yale University Press).

Jordan, V. L. (1980), Acoustical Design of Concert Halls and Theatres (applied Science Publishing).

Katz, B. and Wetherill, E. (2005), 'Fogg Art Museum Lecture Room, A calibrated recreation of the birthplace of Room Acoustics', Forum Acusticum (Budapest).

Loyrette, H. (1985), Gustave Eiffel (Rizzoli International Publications).

Makrinenko, L. (1994), Acoustic of Auditoriums in Public Buildings, trans. R.S. Ratner (Acoustical Society of America).

Mallgrave, H. F. (1996), Gottfried Semper, Architect of the Nineteenth Century (Yale University Press).

Millais, M. (2009), Exploding the Myths of Modern Architecture (Frances Lincoln Limited).

Murray, P. (2004), The Saga of the Sydney Opera House (Spon Press).

Palllasmaa, J. (2009), The Thinking Hand (John Wiley & Sons Ltd).

Rindel, J.H (2011), 'Echo Problems in Ancient Theatres and a Comment to the 'Sounding Vessels' Described by Vitruvius', The Acoustics of Ancient Theatres Conference (Patras, Greece).

Saint, A. (2007), Architect and Engineer: A Study in Sibling Rivalry (Yale University Press).

Salingaros, N. (1997), 'Life and Complexity in Architecture From a Thermodynamic Analogy', Physics Essays, 10, 165-73.

Somerville, T. Gilford, C. L. S. (1963), 'Tonal Quality in Concert Halls', (BBC Research).

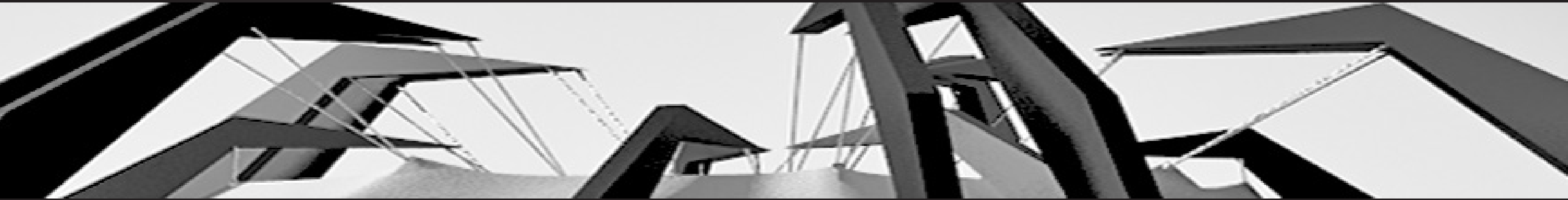
Thompson, E. (2004), Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933 (The MIT Press).

Treib, M. (1996), Space Calculated in Seconds, The Philips Pavilion (Princeton University Press).

van Schaik, L. (2005), Mastering Architecture (John Wiley & Sons).

Vitruvius, M. (First Century BC), Ten Books on Architecture, trans. I. Rowland (Cambridge University Press, 1999).

Woolley, K. (2010), Reviewing the Performance (The Watermark Press).



Sonosentio

BACKGROUND

TABLE OF CONTENTS

Contents

LIST OF FIGURES

Table of Figures

LIST OF FIGURES

The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny ...' Isaac Asimov

HISTORY

Introduction

This document provides a selection of historic references that have influenced the concept and design of the Sonosentio project. It includes various historic spaces and presents selected projects of my own experience.

As with any practitioner, the evolution of my ideas is the result of a cyclic process of progression and reflection. I believe I have a reputation for not accepting status quo, but continually challenging conception and boundaries to better understand and improve my practice and the field.

The field of sonic design is often characterised as a review process that ultimately results in “design” being reduced to remedial application of concepts and technologies to achieve the best possible outcome under the prevailing circumstances. This is often the result of late involvement in the planning and conceptual phases of the design process. This approach to sonic design as applied acoustic decoration constrains its development as a design discipline.

The historic references contained in this volume represent a small sample of the projects and experience in the field. However, they provide a useful foundation for comprehension of the pitfalls of existing processes and assist in assessing the design of the Sonosentio environment as a new paradigm for the sonic design process that reflects both the creative design aspects as well as the technical foundations within which the project is founded.

History demonstrates that collaboration is one of the major defining characteristics of multi-disciplinary design. Where each discipline is approached as separate, independent, design components with independent goals and applications, the quality of the integrated outcome typically becomes compromised. Collaboration is often defined by the quality of the question, not of the answer.

The Sonosentio project proposes a pause for reflection of the accepted design processes and parameters, and proposes an alternative methodology that reverses the accepted normality of design review as a design methodology and considers a new process where the outcome is initially directed by sonic goals.

One of the most graphic historic references in this regard is the development of the Sydney Opera House. It is presented in this document as an historic project with a turbulent and well documented history and also in terms of my personal experience while working on the proposed redevelopment of the Opera Theatre, and other projects within the building.

The reader should draw from the few examples presented within this volume an appreciation of some of the key concepts in project development:

- Brief development
- Context and conceptual planning
- Purpose and functional requirements
- Key performance criteria and their influence
- Importance of collaboration

The main point to draw from these references is the permanence of failure when design flounders with well intentioned, but misguided priorities.

This document presents a series of projects and experiences that have influenced my development over time either through their historic relevance to the field, or their direct influence on my work within my practice.

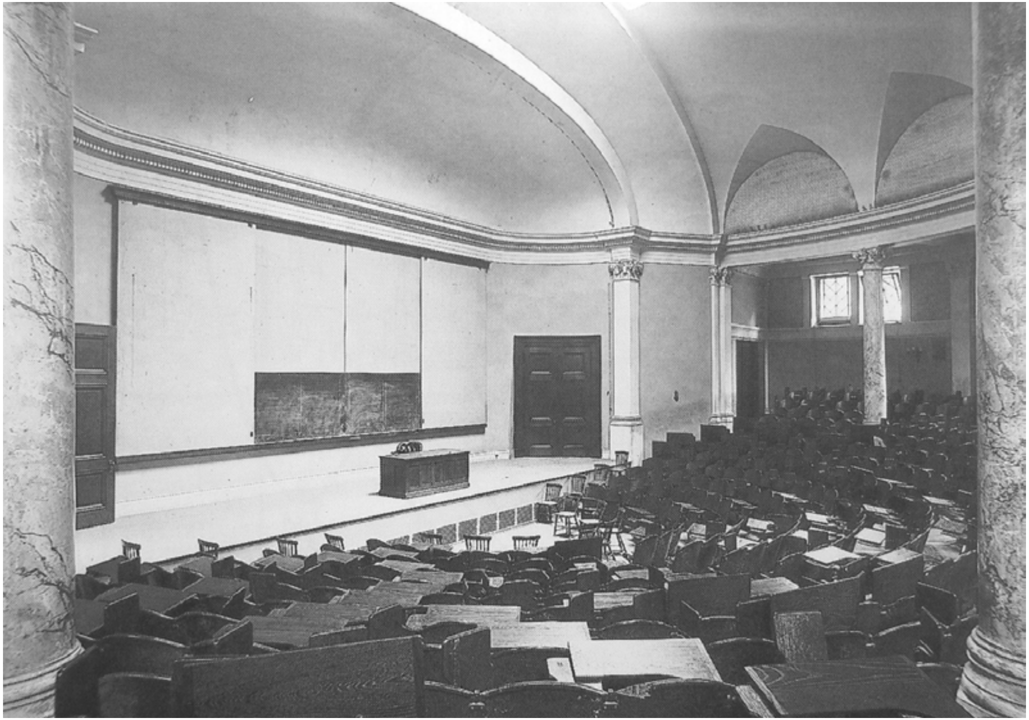


Figure 1: Fogg Art Lecture Hall

Brief history

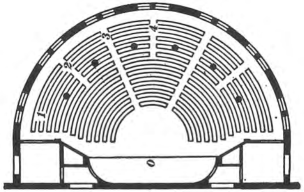


Figure 2: Fogg Art Lecture Hall Plan

Figure 3: Tacoma Narrows bridge

This section of the work draws on various sections of Blesser (2007), Millais (2009) and Thompson (2004).

In 1895 Harvard University constructed a new lecture hall at the Fogg Art Museum, shown in Figure 1. Upon opening, it was apparent that lectures in the room were almost incomprehensible. Each utterance persisted in the space to mask the clarity of following phrases. An assistant professor of physics, Wallace Sabine, was given the task of improving the design so that the lecture hall could be used as......a lecture hall.

With little preceding research to draw upon, Sabine developed measurement techniques to determine the sonic influence of various materials in a room. From his measurements he composed a mathematical solution for the prediction of reverberant decay based on the room volume and the sound absorptive properties of the materials present in the space.

In 1898 Sabine added some absorptive materials to reduce the reverberance of the room. Modest treatment brought modest success. One museum director commented that “We hope for a roof that does not leak and a medium-sized lecture hall instead of a large one in which you cannot hear.”[1]

- In 1912, the audience capacity was halved and the volume of the hall reduced
- In 1930’s more absorptive panels were added to the space.
- In 1965 the room was carpeted
- In 1972 a canopy was installed above the lecturers position.

Following the final modification, a student reported: “... the hearing conditions have been drastically improved. A speaker anywhere to the front of the room can be heard clearly throughout the hall.”

In 1973 the lecture hall was demolished.

The Fogg Art Lecture Hall demonstrates the process of design-after-construction that characterises poorly integrated design processes that are unfortunately still evident in many projects today. Design teams often undertake complex projects without adequate skill and experience in the field, often on the flawed premise that ignorance inspires creative outcomes.

When sonic issues begin to be recognised, remedial work is undertaken to develop creative solutions to achieve the fundamental project objectives. This work is often undertaken when the allocated budget has been exhausted thereby limiting the potential for an integrated design approach that would provide decisive benefit. Thus the failure of the design process becomes a permanent legacy for the client and patrons of the facility that is ultimately resolved by additional funding for refurbishment or replacement.

The succession of modifications that followed the construction of the Fogg Art Lecture Hall clearly demonstrates that modest solutions after the fact cannot rectify poorly conceived design.

The Lecture Hall inadvertently contributed to the understanding of the physics of sound in the same manner that the spectacular collapse of the Tacoma Narrows bridge[2] (Figure 3) due to wind generated resonance advanced structural design. However, while the catastrophic failure of the bridge cleared the way for a replacement with improved performance, the difficulties with the Fogg Art Lecture Hall were subjective issues of quality and integrity and persisted until its demolition almost 80 years after its construction.

---

[1] Katz, B.et al (2005), Fogg Art Lecture Room, a Calibrated Recreation of the Birthpllace of Room Acoustics p 2191-2196

[2] Also known as “galloping gertie”. Opened to traffic in 1940 and collapsed due to wind generated oscillation in the same year.

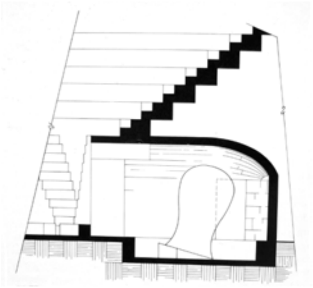


Figure 4: Izenour's sketch of Vitruvian urns

Musicians, actors, architects, scientists and philosophers have struggled to comprehend the response of sound to enclosure for thousands of years. Composers had often developed their work to be complemented by the available venues. In fact, many instruments are recognised by their character in an appropriate room. e.g. a pipe organ with a reverberant space that enhances its power and resonance.

Documentation of sonic design philosophies often refer to the texts of Marcus Vitruvius Pollio (Vitruvius) in the first century BC. In the Ten Books on Architecture[1], Vitruvius describes the use of resonant urns (echea) in Greek amphitheatres[2]. He implies that these urns were introduced to enhance the performance from stage, and provides a music-based methodology for the placement and tuning of the vessels. It is not clear from the text whether he experienced the application of these vessels.

Much of Vitruvius' understanding is derived from the work of the Greek architects and musical philosophers from an earlier period[3]. Book five of the Ten Books on architecture provides a description of the use of these urns and the musical derivation following the work of the Greek music theoretician and philosopher Aristoxenus of Tarentum.

Heinrich Helmholtz (1821-1894), a German physiologist and physicist, was a master of numerous fields of human perception. His treatise "On the sensation of tone as a Physiological Basis for the Theory of Music" was published in 1863. In this work, he developed a mathematical formula for the resonance of vessels. His work describes the relationship between the volume and shape of vessels and the resulting tonal characteristics that forms the foundation of many sonic devices in use today.

Helmholtz's work also provides a fundamental basis of understanding that tends to dispel Vitruvius' theories of resonating vessels for enhancing performance in theatre. In fact, following a review of the concepts Per Bruel[4], declared that: "In reality we have not found any evidence that suggests that the use of these vases in open theaters or the sound pots in churches improved the acoustics in any manner.".

Likewise Jens Holger Rindel[5], also conducted research on similar vessels and concluded "The sounding vessels could not possibly make any improvement to the acoustics in practice".

The architectural concepts proposed in Vitruvius' books may be beneficial to the field, however, the musical theories applied to theatre architecture appear more mythical than scientific.

A clue to the musical derivation of the work is provided in Book 5, Chapter 3 which states:

"just as musical instruments achieve the clarity of their sounds by means of bronze panels or horn sounding boxes added to the sound of strings, so, too, the calculations for theatres were established by the ancient harmonic principles to amplify the voice."[6]

---

[1] Vitruvius (First Century BC) translated by Rowland, I. Cambridge University Press (1999)

[2] Vitruvius M. Ten Books on Architecture, Book 5 ,Chapter 5.

[3] Vitruvius M. Ten Books on Architecture, Book 5 ,Chapter 4.1.

[4] Bruel, P. (2008), Journal of Sound and Vibration, February 2008, p21

[5] Rindel, J. (2011), The Acoustics of Ancient Theatre Conference, Patras, Greece

[6] Vitruvius M. Ten Books on Architecture, Book 5 ,Chapter 3


Figure 5: Telharmonium console


Figure 6: Telhamonium mechanism


Figure 7: Telharmonic Hall

This application of the principles of resonance of instruments to room design continues to be a source of confusion and myth today. In reality a musical soundboard, which radiates the sound from the strings of a piano or guitar, becomes a sound absorber when suspended in a room.

While building my own classical guitar I spent a considerable amount of time scraping and sanding the soundboard to make it thin and responsive to generate a strong, rich tonal response. In my practice I have spent considerable time convincing designers to make walls thick and rigid to ensure a strong, rich tonal response. This apparent contradiction is understandably confusing.

The description and placement of resonant vessels in Vitruvius' text is testament to the poor understanding of the behaviour of sound in the built environment. This defines the tentative relationship between science, sound and architecture.

Oddly, there seems to be little research investigating the application of ash filled vessels located under the seating in ancient theatres for the thermal comfort of patrons. Or possibly even as some form of musical device to summon audience members.

In about 1660 Robert Boyle (1627-1691), noted physicist and chemist, conducted an experiment using a stopwatch placed inside a glass vessel to investigate the media of sound transmission. As air was evacuated from the vessel the sound of the ticking watch reduced indicating that air was required for the propagation of sound.

Sometime before this, around 1640, Marin Mersanne (1588-1648) had used a timekeeping device to record the time taken for an echo to be returned[1]. He used his observations to determine the approximate speed of sound.

Isaac Newton (1647-1727) had concluded in his Pricipia (published 1686):

"As to sounds, since they arise from tremulous bodies, they can be nothing else but pulses of the air propagated through it."

Newton also related the speed of sound to temperature of air and concluded that it would "go forward at about 1088 feet in one second of time".

In February 1896, while Sabine was investigating the sound of the Fogg Art Lecture Hall, Thaddeus Cahill[2] applied for a patent for a machine that promised to not only revolutionise the production of music, but also it's distribution to a wider audience[3]. The patent described the "Art of and apparatus for generating and distributing music electrically". This electrical device for music-making, the Telharmonium, allowed sound to be distributed to numerous locations simultaneously. His plans were eventually realised as a 200 ton behemoth that generated music by a series of dynamos, each using a slotted wheel to generate tone. Cahill's patent states that:

"the apparatus is wholly electrical and bears little, if any, real likeness, either in structure or mode of operation, to the instruments now known in the musical art as the 'pianofortes' and 'orgaus'

---

[1] Hunt, F. V. 1978. Origins in Acoustics, Yale University Press, p94-99

[2] Thaddeus Cahill (1867-1934) American Electrical Engineer and inventor. http://www.ieeeghn.org/wiki/index.php/Thaddeus_Cahill

[3] Cahill, T., Art and Application for Generating and Distributing Music Electronically, Patent No. 580-035, 6 April 1897.


Figure 8: Becquerel's image


Figure 9: Koenig's Flame apparatus


Figure 10: Paris Opera House

The Telharmonium console (Figure 5) was used to control the mechanism (Figure 6) that generated the sounds which were then exhibited in the room (Figure 7).

The Telharmonium represented the full force of the industrial age brought to bear on music. It proposed a new relationship between players and audience which was not truly realised until the later invention of radio.

While Sabine struggled to comprehend the sonic qualities of historic venues, Cahill developed previously unimagined musical systems of the future. Three were built, none remain. But the genesis of a new form of musical instrument was born.

The late 19th century was a tremendous time for discovery.

Concurrently, in Paris, Henri Becquerel had been researching the properties of x-rays by exposing phosphorescent rocks placed on photographic plate wrapped in thick black paper to sunlight (Figure 8). He proposed that the resultant image on the plate was the result of the glow of the rock sample stimulated by the sunlight.

In late February 1896, the sun was obscured by cloud so he stored the plates that he had intended to expose. When he developed the stored plates, he found that the image was as clear as his other samples. He abandoned his original hypothesis and concluded that his images were the product of spontaneous radiation by the rocks. Thus atomic radiation was observed.

Visualising the effects of radiation was more illusive for the pioneers of sound. A scientific instrument maker, Rudolph Koenig (1832-1901), developed techniques for demonstrating the presence and composition of sound using a modulated flame. Koenig's Manometric flame apparatus (Figure 9) applied sound from an acoustic phone to a membrane that caused fluctuations in the gas supply to a burner providing a visual representation of the sound.

Initially, Sabine had “employed a variant of Rudolph Koenig's ‘dancing flame’ device to study the sound in the Fogg Lecture Room, but there was no useful way to interpret the results. Sabine thus abandoned all attempts to look at sound, and instead chose the seemingly obvious, but long neglected, alternative of listening to it.”[1]

Listening to sound, as Sabine had concluded, had generally resulted in the greatest leaps of understanding in the field.

In 1875 the Paris Opera House, designed by Charles Garnier, opened. The opera house is highly regarded for its fine sonic performance. However, Garnier maintained a cautious pessimism to science, engineering and sound in his work. He commented:

“..nowhere did I find a positive rule to guide me,” “I must explain that I have adopted no principle, that my plan is been based on no theory, and that I leave success or failure to chance alone.”[2]

In fact, Garnier based the Paris Opera House on the precedence of numerous traditional horseshoe theatres. The venue represents an evolution of form rather than a unique design. He was also fortunate that massive construction techniques, lavish ornamentation and opulent furnishings were standard features of the day (Figure 10).

Garniers “chance” outcome was informed by historic design

---

[1] Thompson, E. Soundscape of Modernity (2004), p35

[2] Forsyth, M. 1985. Buildings for Music p179

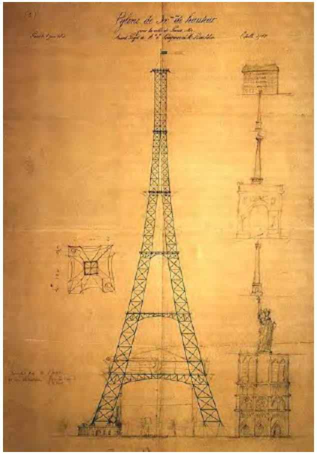


Figure 11: Hateful column of bolted steel


Figure 12: Munich Opera House

precedence and used construction techniques whose fundamental qualities were appropriate for performance venues.

Garnier was suspicious of many fields of science and engineering. In 1887 he joined a group protesting the erection of an exhibit for the world fair. He was signatory to a petition proclaiming: “We, writers, painters, sculptors, architects and passionate devotees of the hitherto untouched beauty of Paris, protest with all our strength, with all our indignation in the name of slighted French taste, in the name of the threatened art and history of France, against the erection, right in the heart of our capital, of the useless and monstrous Eiffel Tower ...” “for twenty years ... we shall see stretching like a blot of ink the hateful shadow of the hateful column of bolted sheet metal”[1] (Figure 11).

In response to the petition, Eiffel provided the following defence: “Is it because we are engineers that we do not pay attention to beauty? Do not the laws of natural forces always conform to the secret laws of harmony?”[2]

The schools of architecture and engineering, once integrated, were now diverging. One considered itself concerned with beauty and the other with functionality.

Not long before Sabine began scientifically exploring the mystery of spatial design, a new type of opera theatre was being developed in Bavaria. Richard Wagner (1813-1883) considered opera to be the ultimate form of performance and desired a new type venue. Unlike Garnier’s traditional Paris Opera House, Wagner demanded a more radical design to properly showcase his works. His productions were designed as overwhelming storytelling, providing strongly integrated sonic and visual textures and he considered the venue to be an integral foundation for performance.

Wagner’s great supporter, Ludwig II of Bavaria, proposed the construction of a theatre for the presentation of Wagner’s opera masterpieces. On Wagner’s recommendation, Ludwig commissioned Gottfried Semper[3] to design a new opera theatre in Munich for Wagner’s works. In 1864 Wagner wrote to Semper:

“My young patron deeply believes in the truth of my ideal regarding a dramatic work of art, which is essentially and fundamentally different from a modern play or opera.”[4]

Semper had designed the Dresden opera house[5] which was, and remains, highly regarded for its sound quality. His proposal for Munich was a grand palace, which was to be the finest in Europe had it proceeded (Figure 12).

Wagner was less impressed than the King and, given various constraints, suggested the development of a smaller venue inside Munich’s Glass Palace[6].

Semper’s opera house did not proceed and the trio fell out. Ludwig was also obsessed with the development of his great castles of Linderhof and Neuschwanstein as the new backdrops for his Wagnerian visions. That part of this story did not end well.

---

[1] Loyrette, H. 1985. Gustave Eiffel, Rizzoli International, p174-176

[2] Loyrette, H. 1985. Gustave Eiffel, Rizzoli International, p176

[3] Forsyth, M. 1985. Buildings for Music p180

[4] Mallgrave, H. F. 1996. Gottfried Semper, Architect of the Nineteenth Century, Yale University Press.p252

[5] Original opened in 1841 - destroyed by fire. Rebuilt 1878.

[6] Modeled upon London’s Crystal Palace and ultimately suffered the same fate as its counterpart in 1931.

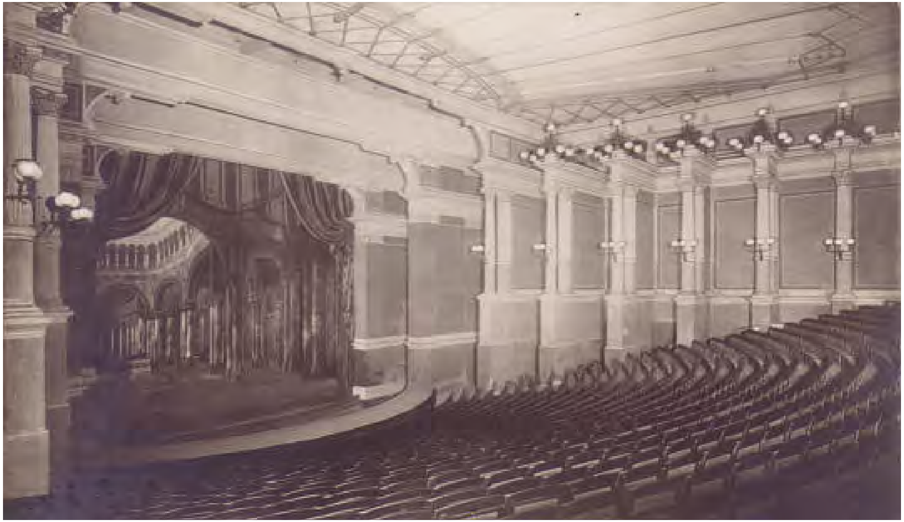


Figure 13: Bayreuth Festpielhaus

But Wagner's vision for a new form of venue proceeded in 1865 when he began development of an opera theatre that was not a derivative of the traditional horseshoe shaped auditoria. His theatre, the Bayreuth Festpielhaus, placed all patrons in front of the proscenium with a direct view of the stage. The large, covered orchestra pit allowed his grand orchestrations to be played confidently without overwhelming the singers on the stage.

The design and construction of the Festpielhaus was directly overseen by Wagner. The clear and forthright vision of Wagner, and his comprehension of the outcome from a multi-sensory perspective ensured that the venue was designed with a clear functional goal that was not compromised or overwhelmed by the facade of the building.

The pit is deep and covered by a hood that conceals the musicians from view. Forsyth wrote that:

"The sound reaching the liistener is entirely indirect (that is, reflected), and much of the upper-frequency sound is lost. This gives the tone a mysterious, remote qualityand also helps to avoid overpowering the singers with even the largest Wagnerian orchestra. The sound then reverberates in the lofty volume of the auditorium itself, with its uncarpeted floor and wooden seats, blending with the singers'voices."[1]

The design of opera houses requires the carefully considered integration of three spaces; stage, pit and auditorium. The Bayreuth Festpielhaus reconsidered this arrangement and reinterpreted opera theatre design with the specific goal of presentation of Wagner's own monumental works.

In 1896 while Sabine was investigating the functional adequacy of the Fogg Lecture Hall, Lois Sullivan wrote in his article, The Tall Building Artistically Considered:

"It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the heart, of the soul, that the life is recognisable in its expression, that form ever follows function. This is the law. " [2]

This principle was embodied in the design of the Festpielhaus. It represented a new form of venue directed to Wagner's concept of fusing the arts[3] (a concept that would be today referred to as multimedia).

---

[1] Forsyth, M. 1985. Buildings for Music p187

[2] Sullivan, L. The Tall Office Building Artistically Considered, Lippincott's Magazine #57 (March 1896) pp 403-409

[3] Forsyth, M. 1985. Buildings for Music p193

Figure 14: Phillips Pavilion at the Brussels Expo

Architect: Le Corbusier (coll. Iannis Xenakis)

and Edgard Varese

Consultant: Phillips

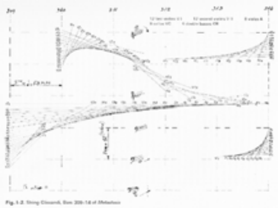


Figure 17: Musical score, Metastsis, Xenakis 1955

Figure 15: Interior of pavilion

Figure 16: Application of asbestos sound absorption

In 1958, the world gathered at the exposition in Brussels to celebrate postwar achievements. The Dutch electronics manufacturer Philips commissioned Le Corbusier to develop a pavilion to showcase their technologies.

When commissioned for the project Corbusier stated: “I will not make a facde for Philips, but an electronic poem. Everything will happen inside: sound, light, colour, rhythm. Perhaps, a scaffolding will be the pavilion’s only exterior aspect.”[1] He commissioned Edgard Varese to develop a spatial sound composition as part of the audio visual presentation for the pavilion. The team, including Edgard Varese and Iannis Xenakis developed a major spatial composition which united the architecture, music, mathematics and projection in one gesture to showcase Phillip’s technologies.

The design of the pavilion, created by Iannis Xenakis under the direction Le Corbusier was based on a series of hyperboloid panels constructed from precast concrete panels suspended from a tensioned wire grid. The shape was based on the musical score of Xenakis’ composition Metastasis (1955). The glissando structure of the musical piece was structured on mathematical codes derived from Corbusier’s Modulor proportions[2]. The architecture of the pavilion’s facade was, therefore, derived from musical score rather than sonic requirements. In fact, the sonic environment within the pavilion was subdued by spraying a layer of asbestos on the interior of the concrete panels.

THIS IS NOT AN EXAMPLE OF FORM FOLLOWING FUNCTION.

While sound is used as a visual descriptor for the facade, it does not relate to the actual sonic composition or integrity of the design. The pavilion integrates the elements of a scoring style of music composition and architectural facade. The sonic design is not integrated into the building itself. Varese believed that art and science are inherently linked and that “music has it’s place in the company of mathematics, geometry and astronomy”.[3]

The sonic experience is provided by the dynamic spatial movements integrated into Varese’s score and the technical aspects of the relationship between the sonic and visual performance that provide the overall experience.

While the nominal exterior facade is derived from a musical score, it does not represent a sonic design intention. None of the intensive mathematics of the form relate to sonic understanding or outcome.

This project highlights the misconception that visually derived geometries have a sonic basis. While the shape of this structure is derived from a musical context, and it has been conceived by an architect who was also a composer of contemporary music, the shape of the building was not been derived from the perspective of its sonic response.

The treatment of the walls with asbestos is provided to reduce the influence of the shape of the enclosure on the critical aspects of the spatial sound composition being reproduced in the pavilion. Although typically assumed to be an integrated sonic and architectural composition, it is presented as an example of form independent of function.

---

[1] Treib, M. 1996. Space Calculated in Seconds, The Philips Pavilion, p9

[2] Treib, M. 1996. Space Calculated in Seconds, The Philips Pavilion, p16

[3] Treib, M. 1996. Space Calculated in Seconds, The Philips Pavilion, p175

HISTORIC VENUES

Figure 18: Royal Festival Hall

Royal Festival Hall

Architect: Sir Robert Matthews and Dr Leslie Martin

Consultant: Hope Bagenal et al

Opened: 1951, refurbished 2005-2007

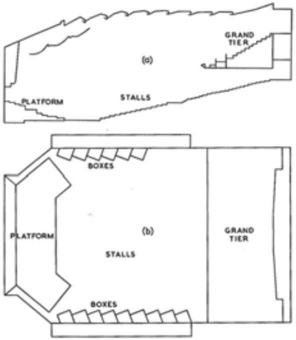


Figure 19: Plan and Section

Rectification by technology

The Royal Festival Hall is a purpose built concert hall located on the South bank of the Thames River, London. It was completed in 1951 and has an audience capacity of approximately 3000.

Referring to Royal Festival Hall, the BBC[1] indicated that:

“This hall has the characteristic deficiencies of recent designs since, in addition to the short reverberation time, the blend is poor and it is not possible to hear all the instruments in tutti. The tonal quality is hard and there is no singing tone.”

The design of the hall incorporated multiple side boxes either side of the stalls and ceiling was designed to direct sound into the audience seating. While these factors could contribute to reduced reverberance in the space, the BBC report also indicates that the volume per seat is approximately 7.3m^3. This is 2-3m^3 per seat less than typically recommended.

Beranek indicates that: “The primary cause was the lack of technical infomation on how much sound an audience absorbs when seated in modern theatre chairs”

The University of Salford Website indicate that: “The problems reportedly arose as some of the original specifications for room surfaces determined by the acoustic consultants were ignored in the building process. This led to the introduction of a new electronic system of ‘assisted resonance’, the first time that the acoustics of a concert hall had been improved electronically.”[2]

The use of electronic reverberation enhancement is considered an unappealing aesthestic for orchestra players and audiences. It indicates a significant failure in the fundamental design of the room and a barrier to the traditional relationship between the orchestra and their environment. The artificial reverberation system was decommissioned and the hall was eventually refurbished and reopened in 2007.

The Royal Festival Hall represents an early example of modern concert hall design. It demonstrates that the traditional, rectangular room form does not guarantee a sucessful result.

The commentary on Salford University’s website indicates that there were communication difficulties between the architect and the acoustic consultant that ultimately led to the inappropriate design of the room. While some advantage could be achieved by modifying the surfaces of the room, the overall volume is clearly insufficient to achieve the requirements for orchestral concerts.

The design of the Royal Festival Hall was certainly adventurous and the audience capacity was greater than the majority of traditional halls. The acoustic issues with the completed hall imply that the design team were not experienced in the design of concert halls, or that fundamental design issues were not clearly communicated and understood by the design team.

---

[1] BBC Report No. B-079 1963/52, Tonal Quality in Concert Halls (1963), p4-5

[2] http://www.acoustics.salford.ac.uk/acoustics_info/concert_hall_acoustics/?content=rfs

Figure 20: Berlin Phihamonic Hall

Berlin Philharmonie

Architect: Hans Schauron

Consultant: Lothar Cremer

Opened: 1963

Figure 21: Philharmonie Plan

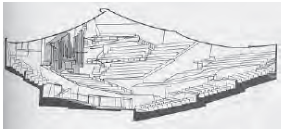


Figure 22: Philharmonie Section

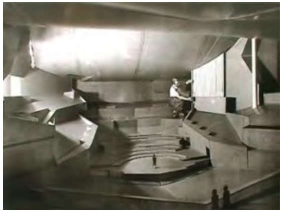


Figure 23: Acoustic model

Collaboration and direction

The Berlin Philharmonie is a 2400 seat concert hall designed as the principal performance venue for the Berlin Philharmonic Orchestra.

The Berlin Philharmonie was designed by Hans Scharoun. The concept was based on a circus tent with the performers in the centre of the room surrounded by the audience members. This approach to the design provided a more intimate experience for audience members by shortening the maximum distance to stage. Scharoun considered:

"Can it be an accident that wherever improvised music is heard people tend to gather around the performers in a circle? The psychological basis of this natural process sees self-evident to all; it had only to be transposed into a concert hall."[1]

The concept was as far from a rectangular hall as could have been considered. The acoustic consultant, Lothar Cremer, worked with Scharoun to develop a hall divided into terraces of varying levels. This arrangement allowed interim walls to be introduced that provided reflections into each of the seating areas. In this way, the surrounding reflections that characterise the rectangular halls were reimagined into a unique spatial distribution.

"After years of struggle and disappointment, Scharoun in his seventieth year had finally proved his ideas both valid and technically realisable and this turned the tide." "Scharoun refused to diverge from his main idea, but promised to accommodate Cremer in every other way." [2]

Cremer said that "Scharoun was the most accommodating architect for whom he had ever worked, always able to fulfil the acoustician's demands without violating his own conception."[3]

"This comes from a working method in which everything is adjustable, which is evident in the geometric complexity of the result. Such complexity does not, as often thought, indicate formal wilfulness. In fact the opposite can be claimed , the more open ended the planning geometry, the more good reasons could be found for each decision."

"The Berlin Philharmonie was opened to great public acclaim on 15th October 1963"[4]

This complex project strove to break the traditional relationship between audience and performers in concert halls. The success of this design is a tribute to the collaboration of the Scharoun and Cremer for achieving excellent results.

The complex shaping of the hall achieved a unique geometry that sonically implied the response of the traditional rectangular form, but with little visual similarity.

Where the Royal Festival Hall demonstrated that the traditional rectangular form does not guarantee a successful outcome, the Berlin Philharmonie demonstrates that radical design by a collaborative team, with clear design goals and good communication can realise successful results in non-traditional building forms.

---

[1] Hans Scharoun, (1995), p179

[2] Hans Scharoun (1995), p182

[3] Hans Scharoun (1995), p182

[4] Hans Scharoun (1995), p196

Figure 24: New York Philharmonic Hall

Architect: Harrison and Abramovitz

Consultant: Leo Beranek

Opened: 1962, reconstructed 1973

New York Philharmonic Hall

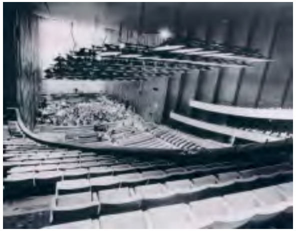


Figure 25: Original Hall


Figure 26: Early Rectification works


Figure 27: Avery Fischer Hall

Engineered to “perfection”

Philharmonic Hall was a 2600 seat concert hall constructed as part of the New York’s Lincoln Centre. It was conceived as a replacement for Carnegie Hall which was scheduled for demolition[1].

The plan of the hall is unusual, being fundamentally rectangular, but with concave side walls. The result is that the walls near the stage fan out. This means that reflections from these surfaces are directed toward the rear of the auditorium rather than in the seating near the stage. The surface was faceted to try to return these reflections, however, this is not as effective as large surfaces in the early part of the room.

The side balconies of the hall swept down toward the stage. This meant that the reflections that would typically be provided by the underside of the balconies in Shoebox halls are not present.

To achieve intimacy, the principal design goal in his subjective rating scheme, Beranek used a series of hexagonal reflector panels to direct sound into the audience plane. The timing of this reflection established the degree of intimacy for the performance.

The overhead panel array consisted of two layers; a lower layer that extended from above the stage to almost halfway along the room, and an upper layer above the stage. Figure 24 shows the view from the stage in the original design

Panel arrays of this type are often used to improve stage support and to direct early reflections into the seating closest to the stage. The array has three significant acoustic qualities that can provide a detrimental influence on sonic performance; the relative timing of the reflections within the room response, the tonal composition of the reflections from the array and the complexity of the combined contribution of multiple reflections from the elements.

Barron indicates that: “Schroeder et al. (1966) listed as faults: ‘a poor frequency response affecting audibility of cellos and double basses, a lack of reverberation, echoes from the rear, inadequate sound diffusion and poor hearing conditions for musicians on stage’”[2]

The hall was designed as a classic rectangular room with a formal relationship of performers addressing the audience. The requirement for a larger audience capacity than historic venues, coupled with modern requirements for egress and comfort increased the scale of the room and therefore the remoteness of the reflecting surfaces consequently reducing the intimacy of the venue.

Leo Beranek had conducted a significant amount of research to develop his own understanding of concert hall acoustics during the design of the Philharmonic Hall. His work is well documented in his book Music, Acoustics and Architecture[3]. However, his research and experience were not sufficient to guide the original design of a fundamentally traditional rectangular room to success.

The overhead reflector array, introduced to improve acoustic intimacy is also regarded as one of the contributing factors that limited the low frequency performance of the room. This illustrates that sonic design must be considered in more holistic context with the influence of each design decision being understood in the overall context of the space.

This project also highlights the permanence of failure. The remedial rectification works did not achieve success and the entire hall was eventually demolished and rebuilt as Avery Fischer Hall in 1976 (Figure 27).

---

[1] Barron, M. 1993. Auditorium Acoustics and Architectural Design, p101

[2] Barron, M. 1993. Auditorium Acoustics and Architectural Design, p104

[3] Beranek, L. 1962. Music Acoustics & Architecture

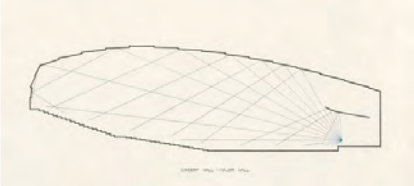


Figure 29: Major Hal - concert mode

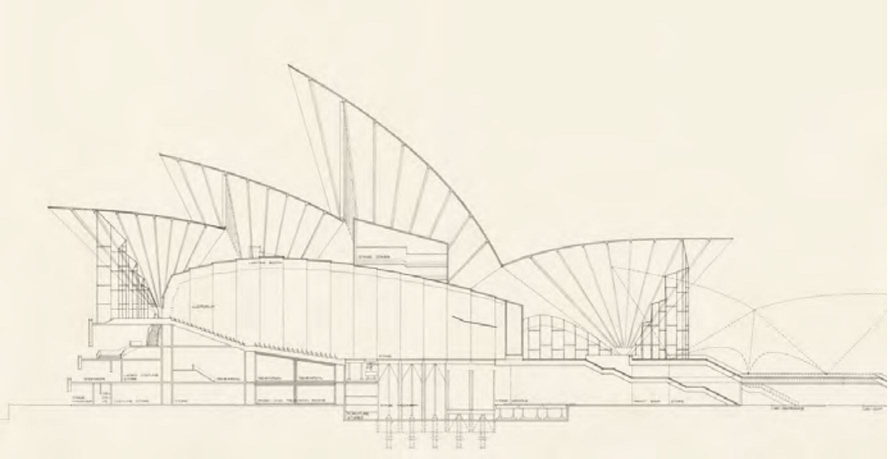


Figure 28: Long section through Major Hall (Concert Hall Mode) from Utzon’s Red Book

Figure 30: Major Hall - opera mode

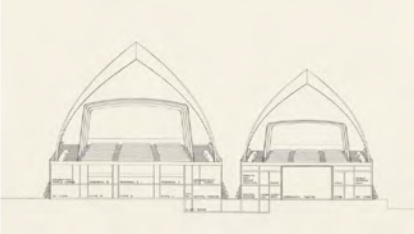


Figure 31: Cross section through both Halls

Architect: Utzon (1957-1966), Hall Todd and Littlemore (1966-1973)

Consultant: Lothar Cremer and Vilhelm Jordon

Opened: 1973

Sydney Opera House

Quality of briefing

The turbulent development of the Sydney Opera House is well documented. While the building is a masterpiece of modern architecture and an iconic symbol of not only Sydney, but also Australia, the difficult resolution of its construction is legendary. Many of the issues regarding its functional adequacy for its core clients remain unresolved. The interdisciplinary design team that created a satisfactory, construct-able interpretation of the original proposal following the departure of Jorn Utzon, achieved an outcome that is a triumph of ingenuity and perseverance.

The solution to the issues of constructing the external shells was elegant. However, the resolution of the venues and their interiors was more problematic and was a significant contribution to the conflict between the architect, Jorn Utzon, and the client. Upon resumption of the project following Utzon's departure, the brief was revisited and an alternative configuration of the venues was undertaken to resolve various technical and managerial issues inherent in the original project.

Utzon had been working with the acoustic consultant Vilhelm Lassen Jordan. But, "Utzon had been very impressed by the interior of the Philharmonie in Berlin designed by Hans Scharoun, which was then under construction, where the audience surrounded the orchestra. At the same time, he was not keen on Jordan's 'shoe box' approach and wanted something more in keeping with the rest of the architecture of the Opera House. So he consulted Lothar Cremer, Director of the Institut fur Technische Akustik in Berlin and Werner Gabler."[1]

The solution for the Opera House design had many facets. The many acoustic consultants that were involved developed opinions regarding the potential for achieving a multi-purpose venue in the Major Hall. This provided a considerable distraction from the actual briefing and design issues.

The operation of a single venue to house the two competing requirements should have been perceived as a significant financial restriction on the long term viability of the centre. Apart from the acoustic differences, there were considerable staging and logistics issues with the proposed scheme.

Although considerable effort was expended to explore the proposed multipurpose Opera Theatre/Concert Hall, ultimately the pursuit was abandoned.

In the epilogue to Michael Baume's book, The Sydney Opera House Affair[2], Peter Hall wrote: "Professor Cremer described it as a mistake in the original programme that it should have been required in Sydney - and none of the best concert halls or opera houses is multipurpose..." "Cremer's admission, after six years work, that he could not put the two together satisfactorily was a major blow to the possibility of delivering a dual-purpose auditorium."[3]

However, the engineers were looked upon to provide a yes or no answer to the viability of the shared venue. The inevitable response was a cautious yes, with a number of provisos. It appears to be Hall who finally presented the inevitable statement to the trust which appears to have been met with a hostile reception.

---

[1] Murray, P. 2004. The Saga of the Sydney Opera House, p37-38

[2] Baume, M. 1967. The Sydney Opera House Affair

[3] Murray, P. 2004. The Saga of the Sydney Opera House, p120


Figure 32: Sydney Opera House Concert Hall

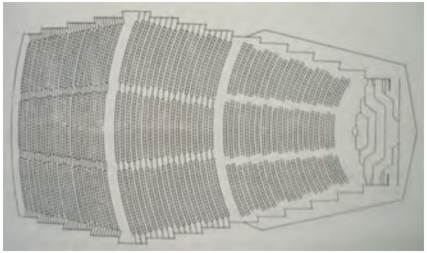


Figure 33: Original design for Major Hall - Concert mode

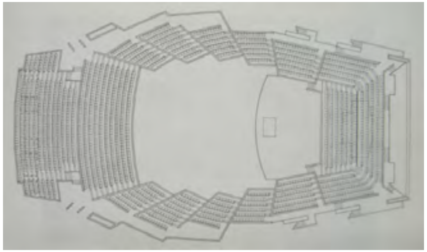


Figure 34: Concert Hall as constructed


Figure 35: Concert Hall ceiling construction

Quality of briefing

The requirements for the concert hall were explicitly stated by the Australian Broadcasting Commission in their letter of 7 June 1966[1].

Dr. Cremer responded that - "It is a pity that (the) ABC has not stated these requirements before the competition in 1957. This would have avoided the principle difficulties of the project which arise from the panning of two multipurpose halls of different capacity only instead of planning one concert hall with a very large capacity and one auditorium with stage for opera and theatre with a smaller capacity"[2]

The sequential solution of design issues during construction of the three phases; plinth, shells and interiors, rendered the venues themselves as the last priority. The design process meant that the functional and operational requirements of the venues were not resolved until completion of the construction of the boundaries of their enclosing volume. The optimistic planning had made little concession to the shape of the shells, the thickness of the structure, or the fundamental requirements of the venues.

Peter Hall wrote: "The volume available was limited by the shells, as was the plan area available for seats. The inward taper of the shells, which are ogival arches in cross section, limited the scope for galleries and ruled out the possibility of a rectangular cross section. The design process to be followed was the reverse of normal, in which area and volume would be determined before the design of the outer envelope. At the Opera House, it amounted to definition by subtraction."[3]

The most stress was placed on completion of the auditorium and stage, the finances were tightening and the program under pressure. The design of the venues also requires the greatest coordination and attention to detail.

There are a great many lessons to be learned from the development of the Sydney Opera House. The most critical relate to the importance of planning, briefing and conceptual design. These elements must be approached with the same collaboration and coordination as the ultimate realisation of the project.

The appearance of a clear brief from the ABC in 1966, 9 years after the announcement of winner of the design competition indicates the depth of uncertainty in the original program.

The design sequence, which placed the realisation of the exterior prior to resolution of the interior resulted in significant time and cost issues with the project.

It is a tribute to both architectural firms involved and their consultants that the building is an international landmark.

One of the critical points that this raises in my opinion is that the quality of design is not entirely realised by providing the correct solution. To embark on the solution, one must first ask the right questions.

The quality and success of a project is defined by attention to detail during the briefing and concept stages, as much construction and commissioning.

---

[1] Letter from T.S. Duckmanton, ABC General Manager 7 June 1966.

[2] Letter from Dr. L. Cremer, 30 August 1966

[3] Hall, P. 1990. Sydney Opera House: The Design Approach to the Building with Recommendations on it's Conservation

Figure 36: Bregenz Outdoor Opera Stage - Verdi’s A Masked Ball, 1999-2000

Bregenz Opera

Technology as enclosure


Figure 37: Spatial location console

As part of a venue tour with a client from South Korea, I visited the Staatsoper and Musikvereinsaal in Vienna. During my discussion with the staff of the Staatsoper they described the spatial sound system that had been developed for the Bregenz Festival[1] outdoor opera productions. The festival features an outdoor stage that is located on Lake Constance facing an audience seated on the shore of the lake. I had seen the production of Verdi's opera, A Masked Ball, on television and was impressed by the scale and design of the production.

The complex spatial sound system provided reinforcement and foldback for the performers and simulated reverberation for the audience members. A dynamic spatial location system had been developed to track the position of performers to allow the sound system to provide a sonic image to assist the audience by reinforcing the position of the performers on the vast stage.

The spatial sound mixing console was developed by Fraunhofer Institute for Digital Media Technology[2] in cooperation with the Bregenz Festival and Lawo AG[3].

I visited Fraunhofer IDMT at the 2006 Audio Engineering Conference in Paris to discuss the system with their staff. They demonstrated the basic operation of the console and described the operation of the spatial sound location system.

One of the most critical aspects of its operation was the ability to interact with the performance using both automated cues and also live controls to follow the inevitable inconsistencies of live performers.

The Bregenz Opera represents the state of the art in large scale spatial sound control for live productions. It illustrates the potential using spatial sound to elevate an audience's engagement with performance.

In addition to the spatial imaging, the Bregenz system provides the audience with artificial reverberance to provide a sense of enclosure in the outdoor environment. This allows the realisation of a virtual space that is independent of the physical environment and whose spatial sound field and sense of intimacy are derived entirely within an array of loudspeakers

The dynamic spatial location system is a significant advance over my modest efforts in the development of the Faderpro[4] system.

The combination of sonic architecture and dynamic spatial positioning demonstrates the potential for spatially realised audio technologies for live performance and artistic applications

This represents an application for artificial reverberance that is creatively integrated with performance rather than remedial. This would allow greater creative potential for systems that do not just replicate existing spaces, but create whole new environments that respond to the performance dynamically.

---

[1] The Bregenz Festival is an annual performing arts festival in Bregenz, Austria - http://www.bregenzerfestspiele.com

[2] The Fraunhofer Institute of Digital Media Technology conducts research in the field of audiovisual media - http://www.idmt.fraunhofer.de

[3] Lawo AG is a supplier of audio mixing and routing systems for the broadcast and entertainment industries - http://www.lawo.de

[4] Refer to Background Appendix p44-47

EXPERIENCE

1988-1995	Victorian Arts Centre Sound Engineer
1995-2002	Marshall Day Acoustics Senior Consultant
2002-2006	Arup Acoustics/Venue Senior Consultant
2006-2010	Marshall Day Entertech Associate

Figure 38: South Atrium wall and ceiling model

Federation Square

Architect: Lab + Bates Smart

Client: Major Projects Victoria

Consulting with: Marshall Day

Opened: 2002

Figure 39: Visual render

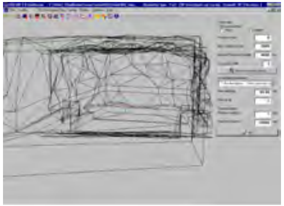


Figure 40: Acoustic model

Signs of a flawed process

My involvement with Federation Square was predominately within three areas of the project:

- Cinemedia Cinemas (now ACMI)
- Outdoor Plaza sound
- South Atrium (now BMW Edge).

Each of these areas required a different approach to the design of the sonic environment.

The Cinemas were to be designed to achieve the certification requirements of the THX[1] cinema standards. This specification was originally prepared for the release of the Star Wars film Return of the Jedi (1983) to insure consistent quality of reproduced sound in screening venues. The cinemas may be characterised as low reverberance spaces directed to the accurate reproduction of cinematic surround sound. Their design involved the placement of a range of sound absorptive treatments to reduce reflections that reduce the quality of the spatial experience.

The outdoor plaza included a performance stage located at the foot of the western building of the square. A sound system installed into the facade of the building would support the video screen on the Eastern facade and announcements from the stage. The buildings surrounding the plaza produced a reverberant environment within the plaza. Two large speaker arrays were specified for the building facade. Two smaller arrays of loudspeakers were provided on poles approximately 20m from the stage to improve the intelligibility of the system and reduce the overall sound level required from the main loudspeaker arrays.

The South Atrium (now renamed the BMW Edge) had been designed with vertical glass walls on three sides. The void between the inner and outer glass walls created a thermal shaft for natural convection to create airflow through the atrium.

However, the South Atrium was intended as a multipurpose performance and presentation venue and the reflective glass walls would have resulted in a cacophony of acoustic reflections that would be detrimental to the function of the space. An acoustic model was prepared and the resulting auralisation demonstrated the difficulties of proposed design. An alternative interior in which the inner glass layer was folded into the structure of the atrium was adopted to diffuse the sound. This was combined with a significant area of sound absorption concealed behind the partially perforated ceiling to reduce the buildup of reverberance in the space.

These three sections of Federation Square were a lesson in design process and coordination. The cinemas, with a well defined brief that was embraced by the client and the design team achieved their intended purpose in a collaborative and unique manner.

This project highlighted that conceptual design should incorporate all critical aspects that potentially introduce significant requirements on building scale, finishes, services and technical systems and other areas requiring significant design/cost consideration.

Interrupting the process and introducing conceptual design issues that have not been considered in the initial briefing and concept design typically has two outcomes:

1. Significant design, cost and time implications
2. Compromised spatial planning and operational performance due to inadequate site conditions, time and budget.

---

[1] Design standards and certification process for sound reproduction equipment and sonic environment for cinema.

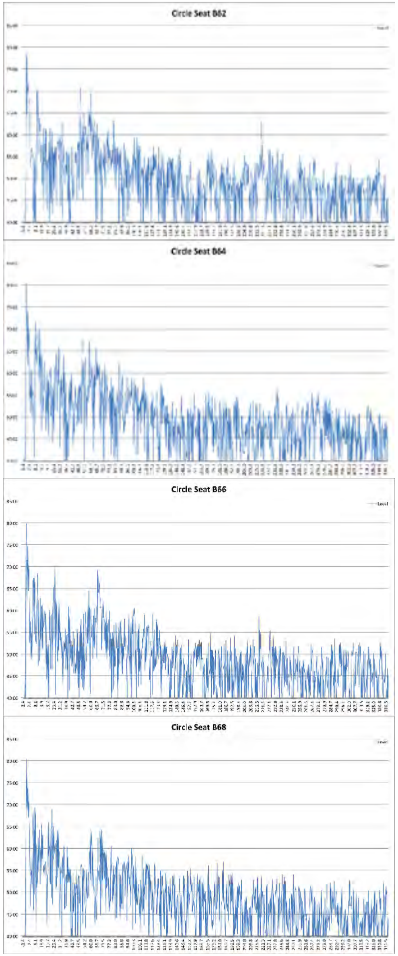


Figure 41: Measurements in Circle B62, B64, B66, B68

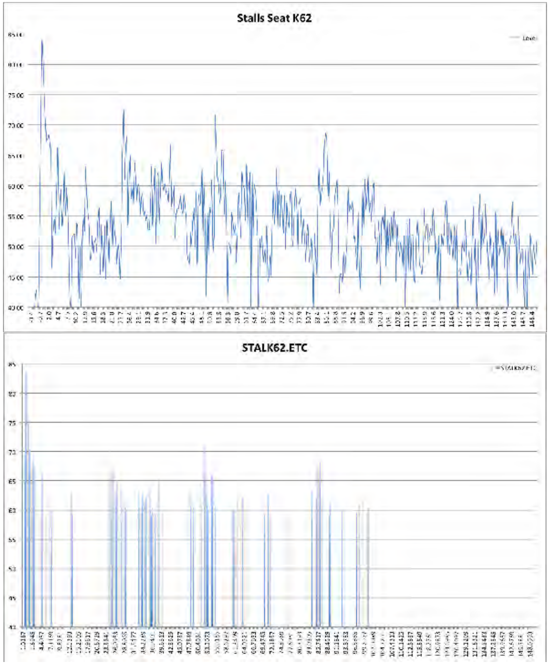


Figure 42: Stalls seat K62 - Impulse response and derived reflection diagram

Architect: Sir Roy Grounds

Client: Victorian Arts Centre Trust

Acoustic consultant: Bolt Beranek Newman

Opened: 1982, refurbished 2012

Melbourne Concert Hall

Experience versus formulaic perception

This work represents a personal investigation to determine the consistency and reliability of room acoustic measurements and the association of the derived criteria to experience.

I was fortunate to experience the sound of the Melbourne Concert Hall for a considerable number of performances over many years. I was also able to attend numerous rehearsals and listen to the same performance from various locations throughout the hall. In July 1994 I was able to conduct an extensive series of measurements of the hall. I was hoping to investigate the relationship between these measurements and my subjective impression of the sound at each location.

Barron, referring to Bolt Beranek and Newman's concert hall designs following Philharmonic Hall, indicates:

"Three are of interest: Louise M. Davies Symphony Hall, San Francisco (1980, 3000 seats), Victorian Arts Centre Concert Hall, Melbourne (1982, 2600 seats) and Roy Thomson Hall, Toronto (1982, 2812 seats). All three used the Old Massey Hall, Toronto, as a model and have two levels of balcony. Hall widths next to the stage are modest, widening substantially beyond the stage front. The coverage of suspended reflecting panels is now limited to above and a little beyond the stage, which is much less than Philharmonic Hall."[1]

As part of my investigation I visited Davies Hall, San Francisco, Roy Thomson Hall, Toronto and the Old Massey Hall, Toronto to gain an appreciation of the design history and influences.

As the capacity and therefore scale of concert halls increased therefore the balance of time and space that resulted in the sonic success of smaller spaces with massive surfaces was compromised. Beranek equated the impression of spatial intimacy to the time between the sound from stage arriving at a listener in the audience to the next most significant reflections that were heard at that location. This intimacy was referred to as the initial time delay gap (ITDG).

"He (Beranek) generalised from the observation that halls with a good sense of acoustic intimacy have surfaces not too distant from the audience. This suggested a crucial design parameter: initial-time-delay-gap, that is the delay of the first reflection. Beranek considered that for the best acoustics the delay gap should not exceed 20ms."[2]

To achieve the intimacy that Beranek had identified as being of great importance to the subjective preference of spaces these large venues introduced overhead reflector arrays. These were similar to those installed in the New York Philharmonic Hall, but limited to above the stage.

However, while they improve stage conditions for the performers and provide the early reflections suggested by Beranek, their contribution is from above and they do not contribute to the spaciousness of an auditorium. In essence, they do not make up for the breadth of these halls and the reduced influence of reflections from the side and rear that contribute to the sense of engagement with the performance.

My own listening experience in the hall left me with the impression that each level of the room had a character that was related to the relationship between the geometry of the surfaces and the large volume at the upper levels of the room.

---

[1] Barron, M. 1993. Auditorium Acoustics and Architectural Design,

[2] Barron, M. 1993. Auditorium Acoustics and Architectural Design,

Figure 43: Melbourne Concert Hall above stage reflector array (prior to renovation)

Architect: Roy Grounds

Client: Victorian Arts Centre Trust

Consuting with: Arup

Melbourne Concert Hall

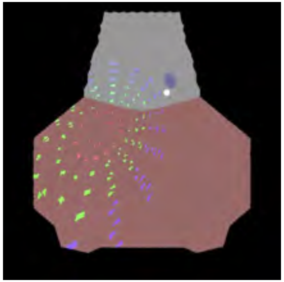


Figure 44: Panel reflections (2003)

The stalls sounded relatively dry and the source was precisely located at the stage with little impression of breadth or spaciousness. The majority of the circle was overhung by the balcony and appeared dry and lifeless. The balcony, exposed to the upper reverberant volume provided a sense of spaciousness and reverberant depth to the sound.

My analysis of the measurements was conducted in two parts. I derived the reverberation time, clarity for sample locations and compared the results with my listening experience. Figure 41 shows the measured impulse response for a number of locations in the concert hall. While I was able to associate the criteria with my impression, I was not able to obtain enough information from the criteria to review or modify the space. However, by examining the impulse responses I was able to relate surface features to the peaks and troughs in the graphs. Further analysis of the impulse responses allowed me to extract individual impulses within the response to provide a clearer image of the individual contributions of each component (Figure 42).

In 2003 I was involved in a study with Arup to investigate the performance of the reflector array. Over time, the angle of the reflectors had been varied to either improve conditions on stage, or to clear space for the movement of technical systems that regularly travelled between the reflectors. We undertook the study using Radiance[1], a ray tracing program designed for illumination engineers. Radiance was able to provide a much clearer image of the reflection from the array than we were able to achieve with acoustic ray tracing software. As the sound reflection from the dishes is predominately high frequencies, this method provided a reasonable estimation of the path of sound for this project. Figure 44 shows one of the radiance images for the stalls of the concert hall.

My listening experience in the venue provided the opportunity to relate the mathematically derived acoustic criteria with my impression of the room at the measured locations. My concern was that, provided with the acoustic data for a room without reference to its measurement location or information about the venue in which is was measured, it is unlikely I could derive the any sonic impression of the space from the measurement alone. My conclusion was that the measurements can confirm subjective impression, but not blindly inform a listener as to aural character of the sound defined by the data.

The measured responses were, in essence one dimensional. They indicate the energy arriving over time at the measurement location, but not the direction of arrival. The technology to make measurements in three dimensions has advanced considerably since I undertook these measurements.

This measurement process provided a considerable image of the overall sound of a concert auditorium. However, as I realised at the time, measurement is not design and it was not clear how this process could be applied to a creative design process founded in sonic response.

This experience demonstrated the limitations of assessment using acoustic measurement criteria to categorise subjective experience. The application of these criteria, particularly when averaged across a number of locations, conceals the detailed sonic information that is provided by the impulse response. The spatial variance of a hall, particularly complex rooms such as the Melbourne Concert Hall, can only be comprehended by a combination of extensive measurements and listening experience.

---

[1] Visual ray tracing software - http://radsite.lbl.gov/radiance

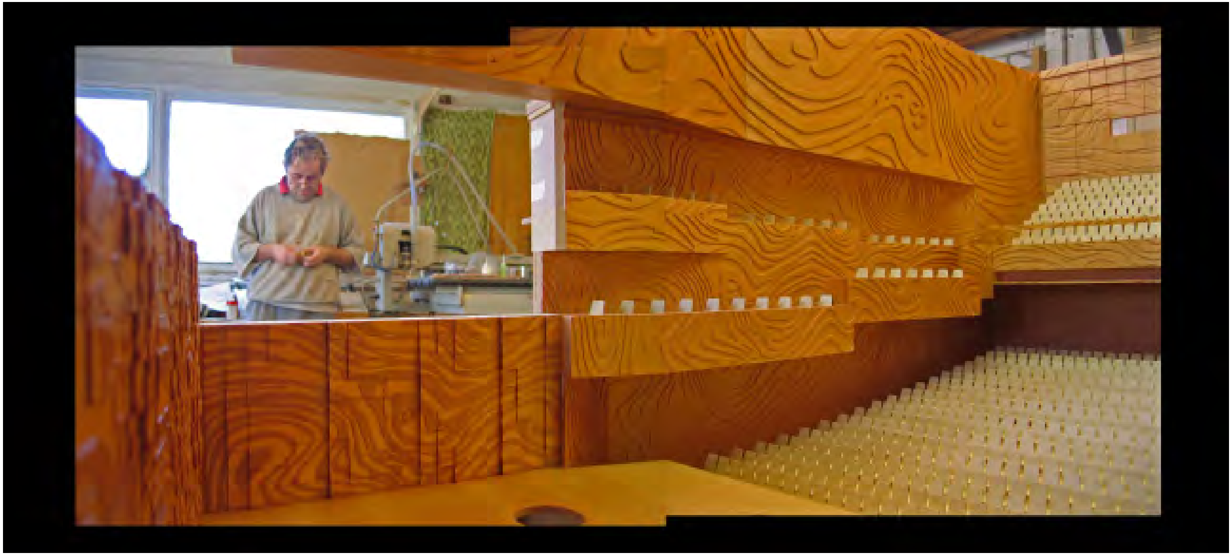


Figure 45: Melbourne Recital Hall interior scale model

Architect: ARM Architecture

Consulting with: Arup/TheatrePlan

Opened: February 2009

Melbourne Recital Centre

Figure 47: Model of stage

Figure 46: Construction of test sample

Secure foundations

The Melbourne Recital Centre is a facility for the presentation of a broad range of recital and chamber music. The centre is located in Melbourne's Arts Precinct and provides performance spaces that complement the nearby concert hall, opera and ballet theatre and drama theatres.

There are two venues within the centre, the Elisabeth Murdoch Recital Hall, a 1000 seat performance venue for chamber music and recital and the Salon, a multipurpose space for more intimate performances and experimental music.

The brief for the Recital Hall outlined the requirements for a traditional, "shoebox"shaped hall specifically designed for chamber music. While the final shape is fundamentally rectangular, the configuration of the balconies and the materials used for the interior are less traditional.

One of the key design considerations for any performance space, but most particularly recital venues is performer communication. This implies both visual and acoustic intimacy where subtle gestures can be used to communicate tempo and timbre to allow precise performance of the ensemble. The hall was crafted to provide excellent on stage communication through the design of surfaces surrounding the stage that support performers.

The entire interior of the venue is lined with plywood panelling. The panel incorporated modular stepping raised contours to provide acoustic diffusion that is integrated with the interior design of the room.

Musicians often indicate a preference for timber room lining as it is related to the resonance that an instrument soundboard provides. However, the reality is that the this timber that provides a resonant foundation for a violin string becomes a sound absorbing device when it is used as a wall lining. In order to achieve the rich sound that supports performance, the wall linings must be composed of relatively massive materials.

To increase the mass of the timber panelling in the recital hall, a number of layers were laminated together to form a thick, solid wall surface.

There are three basic wall lining types in the Recital Hall; the stage surround, ceiling and side walls. The Salon walls and ceiling represented a fourth wall type for testing

A sample of each of these wall types was constructed in the reverberation chambers at RMIT. To insure that the test wall represented the composition of the installed walls, the entire structural support system as well as the linings were constructed for the tests. These test walls also allowed construction techniques to be tested including details such as resilient panels joints and fixing methods.

Figure 47 shows the partial construction of the ceiling panel sample in the reverberation chamber. Note that the sample is constructed in an open doorway with a large cavity behind to replicate the arrangement of the final installation in the Recital Hall. The steel beams of the support structure are visible above the three installed panels.

The development of the Recital Hall interior made use of both computer modelling and scale modelling techniques to conduct acoustic testing of the developing design. Once the results of

Figure 48: Salon interior scale model

Architect: ARM Architecture

Consulting with: Arup/TheatrePlan

Opening: February 2009

Melbourne Recital Centre

Secure foundations

the reverberation room tests were available, the data was used to refine the computer models. The information was also used as a reference for preparing the materials that would simulate the acoustic performance at scale dimensions for construction of the physical model of the Hall.


Figure 49: Salon panels in test chamber

The Recital Hall and Salon also incorporate variable acoustics to adjust the room to accommodate a diverse range of performances. A double layer drape system is used to achieve a high degree of variability in the spaces. This is particularly effective in the Salon, where, at their maximum extension the drapes cover the majority of the wall surfaces on all sides. I once presented a brief talk to students in the Salon and the staff were kind enough to lower the drapes while I was speaking. The gradual change from reverberant to relatively dry provided the students with a clear example of the effectiveness of this form of surface treatment.

There were many lessons from the design process of this centre.

It is important that teams members ask the right questions!

While the shoebox hall is considered a safe configuration for a concert performance venue, shape alone does not guarantee success.

Material absorption and diffusion require considerable future research to develop techniques that provide more reliable results. This results in rules of thumb being used for major decisions.

Existing modelling techniques are not responsive to creative design. The turnaround time is long compared to the sketching systems of visual design.

The modelling techniques are reactive rather than proactive making contribution to the design process through aural experience lag behind a fluid and rapidly changing design environment.

Existing methods that use octave band data limits the performance of modelling software.

The low frequency response of existing modelling and auralisation systems does not provide tonally realistic response.

For modern design processes, which are conducted in relatively short time frames, physical modelling, that must represent the detail of a room at scale, introduce as many issues due to their inconsistencies as they solve. The ability for refinement is limited at this stage.

The use of design parameters in the project brief and as design communication tools should be reviewed. The criteria for concert halls are not appropriate for chamber spaces. The investigation of differences in derivation technique can be more profound that the actual measurements.

Modern fast tracked processes do not provide luxury of numerous design studies.

Figure 50: Sydney Opera House Opera Theatre

Sydney Opera House

Opera Theatre Refurbishment

Architect: Johnson Pilton Walker/Utzon Architects

Consulting with: Arup/TheatrePlan

Completed: 2004 (Design study)

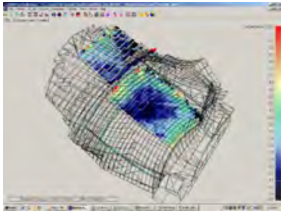


Figure 51: Acoustic model

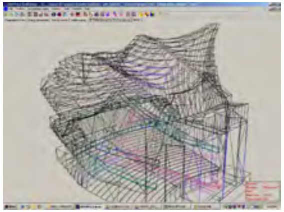


Figure 52: Acoustic model ray trace

Function following form

In 2003 I was involved in the review of the Sydney Opera House Opera Theatre. The review considered the constraints of the existing venue and developed recommendations to improve the facilities for repertory Opera productions.

One of the principal difficulties with the venue was the configuration of the orchestra pit. It had been expanded over the years to increase the capacity. Part of the stage machinery, a large revolving platform with integrated lifts, had been decommissioned to allow the pit to be extended into its structure. The pit was therefore deeply overhung by the stage and the shape of the downstage edge was constrained by the curvature of the original drama theatre pit that had been cast into the plinth structure.

Our initial investigation considered improving the conditions in the pit by extended it into the auditorium and reducing the curvature of the downstage edge substantially to create more comfortable conditions for the musicians. Implementation of this scheme would result in a significant reduction in audience capacity and required extensive structural modification to the building.

In addition to the improvements required for the pit, the acoustics of the venue itself required improvement and the staging and other technical facilities required upgrade,

One of the complications of reconfiguring the orchestra pit was that the downstage edge formed part of the structural triangulation of the shells. The constraints imposed by the building envelope restricted the space available to expand the Opera Theatre.

A major study was undertaken to develop a scheme for the venue that would provide a major improvement in all aspects of its operation.

To maintain the capacity of the venue while improving the pit and venue acoustics it was proposed that the entire venue be lowered 4m. This allowed the stage to be improved, the pit to be reconfigured, improved audience capacity and a more appropriate configuration for the internal volume of the space to improve the acoustic conditions for Opera Productions.

Over 40 acoustic models of various configurations of the Opera Theatre were prepared to review design options for the venue. The general consensus of the acoustic modelling supported the propositions that an open orchestra pit would reduce the intensity of the sound buildup in the pit and that increasing the volume of the room would improve the reverberant conditions within the theatre. The modelling incorporated a number of ceiling options to consider profiles that were adapted from Jorn Utzon's original scheme of a sculpted radial ceiling emanating from the proscenium.

The review of the existing Opera Theatre was one of the most enlightening experiences I have had in my career. The difficulties with the original design and construction process are immediately apparent in the materials and geometry of the auditorium, stage and orchestra pit. It is a space that evolved within the confines of an existing enclosure, rather than one conceived from a unified design concept. In theatre, these are often referred to as "found spaces".

I am a great proponent of the concept of logical review of inadequacy rather than repeated reflection upon perfection. There are far greater lessons in the failure of design than in it's triumphs. And these lessons are not always in the intricacies of minor geometric proportions or subtle selection of materials.

Architect: Johnson Pilton Walker/Utzon

Client: Sydney Opera House Trust

Consulting with: Arup/TheatrePlan

Sydney Opera House

OPERA THEATRE REFURBISHMENT

Function following form

As with the New York Philharmonic Hall project, the opera theatre is a product of poor design communication. The design team did a remarkable job to create the venue, but the many flaws are apparent and offer lessons However, their work was undertaken to achieve the best outcome within a significantly constrained volume bounded by the seating steps cast into the plinth and the completed shells above.

The venues acoustic quality is poor. This is a result of numerous factors including:

- shape of the orchestra pit
- deep overhang of the pit by the stage
- high ceiling above the pit and stalls seating
- lightweight construction of wall and ceiling panels
- serrated wall panelling
- isolation of upper balcony

Earlier studies had considered the installation of acoustic reflectors to improve the sound quality in the venue. However, installation of a reflector would affect the ability to provide theatrical lighting from the bridges above the auditorium.

As with the Fogg Art Museum Lecture Theatre and the New York Philharmonic Hall, small improvements to the venue could not resolve the fundamental issues that constrain it's performance.

The scheme proposed by Johnson Pilton Walker, in association with Jorn Utzon increased the enveloped of the theatre by projecting it 4m down into the foundation plinth. This provides a substantial improvement in the volume of the auditorium and above the stage that is currently constrained by the curved inclination of the shells. The orchestra pit was relocated forward of its current position to place the majority of the orchestra member in the uncovered section. This reduces the intensity of the sound for the players and improves the sound in the auditorium. The larger volume allows the improved acoustic conditions for the audience.

As mentioned, this project was particularly illuminating. The original competition for the Opera Theatre provided a brief for a multipurpose venue. In my experience, for acoustic venues of significant status, multi-purpose should be interpreted as single purpose with variation to complementary functions. The requirements of a national opera house and an orchestral concert hall would not be considered complimentary.

In many accounts it appears to be the acoustic designers that were establishing the defining characteristics of the multipurpose space. Finally admitting that it was not possible to reconcile these incompatible functions.

This project reinforced the critical importance of briefing and planning to successful venue development. It is still common for these processes to be poorly conceived resulting in consequential failure. Inexperience, or inappropriate experience at the critical early stages of a project conception can stifle success before the design has even begun.

It is testament to the power of the Sydney Opera House that an alternative opera theatre in another location is not an option that could be contemplated.

Figure 53: FaderPro in operation at the Fairfax Studio, Victorian Arts Centre

Personally initiated and produced project

Completed: 1995

Faderpro

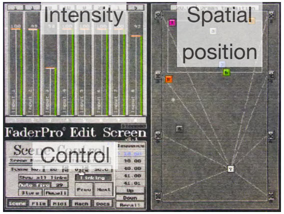


Figure 54: Faderpro main screen

Spatial control

I developed the Faderpro system in response to the requirement for automated, spatially realised sound effects for theatrical productions. While theatrical lighting had long been the domain of computerised systems for storage and replay of theatrical cues, sound effects typically required a dedicated operator to replay and mix the effects as required by the director. The operator typically worked from notes written on a script and responded to timing cues provided by the Stage Manager.

The Faderpro system allowed sound effect to be plotted in the same manner as lighting cues. The Faderpro console was located at the production desk and the operator responded to the requirements of the director in real time. Once the cues were plotted they could be repeated to create the same effect as the director had experienced during the technical production sessions.

The system selected the track from Minidisc[1] players and waited for a go button press. When triggered the tracks selected would be played and the spatial panning system would locate and, if required, dynamically move the sound around the stage and audience.

The system consisted of:

- computer controlled audio matrix hardware
- remote operation of sound replay devices
- custom software for recording and replay of sound cues

The development of the system was undertaken in 1994 in consultation with the Melbourne Theatre Company who trialed the system and used it on numerous productions. The key design criteria were simple operation, responsive to production requirements and high reliability. All hardware and software was custom designed to achieve a fast, responsive system that achieved the requirements of the theatre production environment.

The system automated the selection of sounds for replay and the dynamic spatial position of those sounds during production. Therefore the system could play the sound of a carriage starting from upstage right, moving across the upstage wall and then driving out past the audience and through the rear wall of the venue. The entire action could be achieved by the stage manager pressing a single “Go” button. The system would then set up for the next cue and await the stage managers next cue.

Three processes are running; user interface, control sequencer and matrix control. The matrix control is an interrupt driven routine that runs at preset intervals to constantly manipulate each of the matrix cross-point controllers. .

There were five major design criteria for the Faderpro system:

- Ease of use
- Fast response to production and direction
- Repeatability
- Reliability
- High audio quality

---

[1] Re-writable magneto-optical audio recording and replay disk developed by Sony in 1992.

Faderpro

There were few other systems available to perform the functions of Faderpro. The other systems also tended to be directed toward larger productions that had significant production times and budgets. The Faderpro system was developed for repertory theatre, where the setup and production time in the performance venue is limited. The system was simple enough that technical staff could learn the operation in an hour. Spatial audio was dynamically reproduced interactively allowing directors to develop a scene during rehearsal and record the spatial movements for replay during the season of the production.

The Faderpro system was first trialed in the Fairfax Studio at the Arts Centre, Melbourne. The design of the Fairfax Studio incorporated a significant surround sound speaker system that surrounded the venue on all sides and extended across the ceiling. As part of the venue upgrade I was working on, the surround sound system was upgraded to improve sonic performance and make it more flexible for true surround effects.

The new patching system allowed the Faderpro system to address each of the speakers individually and therefore to create moving sound images that could encapsulate and absorb the audience.

Previously sound had been operated from a position at the rear of the auditorium. However, the Faderpro system allowed the technical staff to sit at the production desk with the director, stage manager and lighting operator to modify the sound playback and dynamic spatial location and create a sequence of cues that could be replayed in the same manner as a lighting desk replays a series of lighting states. This new freedom provided a more responsive production experience and more consistent performances and more financially viable productions.

By using an interface paradigm that was familiar to the sound designers they were able to develop a familiarity with the system without reading manuals or significant periods of training. The system was intuitive to operate for operators and designers familiar with the general systems that they used on a daily basis.

The Faderpro system provided useful lessons in developing interactive spatial sound systems for theatrical productions. It clearly demonstrated the improved communication and creativity that could be realised by presenting spatial sound movement in real time to develop sound effects for theatre.

The system also assisted in developing an understanding of the barriers that could develop where description of sonic requirements was conducted using notes or diagrams. Using spatial sound to illustrate sonic concepts significantly reduced the time required to develop communication between operators, sound designers and directors.

Figure 55: Music and Effects Main Mixing Studio

Architect: Bill Jacobs Pty Ltd
Client: Music and Effects
Consulting with: Marshall Day

Music and Effects

Strong brief as foundation for successful outcome

Music and Effects is a cinema sound editing and post-production facility located in South Yarra. The facility incorporates a main mixing cinema, editing rooms and a foley recording suite.

I was involved in the design of the main mixing studio, designed to achieve the Dolby Laboratories specification for cinema sound production. These standards provide guidelines for the design of sound systems for reproduction and the acoustic requirements for the mixing studio.

The main studio is located on the top floor of a warehouse building. The building is directly opposite the South Yarra railway station that is a route for both suburban electric trains and also diesel freight locomotives.

To achieve appropriate dimensions for the mixing studio the bracing for the main roof trusses spanning the studio was removed and a new support structure was added and the roof structure strengthened to increase the effective height of the space.

The main studio was designed to simulate the environment of a high end commercial cinema. The room response needed to be well balanced to allow sound designers, operators and other production staff to develop high quality soundtracks that create, a sense of reality or hyper-reality for reproduction in a range of commercial cinema and, ultimately home cinema rooms.

Custom sound absorption panels were designed to reduce the reverberation in the room and control reflections to allow accurate spatial sound placement within the cinema surround sound environment.

Two basic panels were designed:

- a dual function panel with a high density, bonded fibreglass panel fixed to a timber panel mounted over a hollow cavity
- a resonant absorber with high density polyester filling.

The combination of these two panels was carefully designed to result in a smooth frequency response at the main mixing location.

When the room was completed, there was a noticeable resonance to the response. This response was unacceptable for the operation of the room and would effect the quality of sound produced by the studio.

The panels were tested in a laboratory and the resonant absorbers were not functioning as designed. The high density polyester insulation was removed to test its performance. It was immediately apparent that the density of the polyester was inconsistent. It appeared to be melted solid on one side which significantly reduced the flow resistivity of the material. A replacement material was found and the panels then tested and performed as intended.

This highlighted the importance of the performance of materials for room design. This room was created for accurate spatial sound reproduction. The scale, proportions, geometry and materials were specifically designed with a well defined brief and a clear client vision.

Figure 56: Arup SoundLab, Author with Arts Victoria Director Penny Hutchinson and Dame Elizabeth Murdoch

Client: Arup
Builder: Connellan Industries
Consulting with: Arup

Arup SoundLab

Toward sonic presentation

The Arup SoundLab, Melbourne is one of a suite of proprietary audition rooms located in offices throughout the world. The rooms are used for collaborative design and client exhibition of various aspects of room acoustic design.

This form of collaborative consultancy space follows the model that I first saw during a visit to Salter Associates, San Francisco.

The reproduction consists of a spatial sound array and custom computer software to present pre-composed auralisations from either room acoustic modelling software or measurements in existing spaces.

The Melbourne SoundLab was constructed in the Arup offices at the Orica Building in Nicholson Street Melbourne. A high degree of sound insulation was required to allow the room to be operated while the office space was occupied.

As the room was constructed in an existing space, the proportions were not ideal. However, the cube shaped loudspeaker array was pushed to one end of the room which offset the listening position from one of the main modal resonance points in the centre of the room.

The technical equipment for operation of the SoundLab was concealed within the wall. The only visible equipment is the keyboard monitors and mouse that control the software.

The SoundLab uses visual images as well as sonic replay to present the reproduced space in context. The video projector is located above the ceiling behind a glass plate to ensure that noise does not effect the reproduction within the room.

The sonic response is composed of B-Format[1] recordings from software or measurements that provide a simulation of the room geometry being presented.

Sound absorptive panels are provided to reduce audible reflections within the room. The screen surface, which is painted onto the plaster wall, was particularly problematic due to the strong reflection from its surface.

The SoundLab is an excellent tool for sharing the sonic experience with clients and other design team members. It also allows international teams within Arup to share room models and measurements.

---

[1] Four channel sound recording that incorporates spatial information for the sound field.

Figure 57: RMIT Pod

RMIT Pod

Architect: Paul Morgan Architects
Client: RMIT
Consulting with: Arup

Figure 58: Ellipsoidal Computer Lab

Figure 59: 2001 Pod

Soundscape space

The RMIT Pod is a high performance listening space for the composition and presentation of soundscape compositions. The room was constructed in an historic building that was formally a chemistry laboratory. The Pod is one of a suite of classroom spaces for students of soundscape composition.

The conceptual design for the Pod was based upon it's namesake from the motion picture 2001: A Space Odyssey[1]. The challenge of the project was to take an ellipsoidal room, renowned for inherent sonic inconsistency due to focussing and mould it into a high performance listening space. In fact RMIT had one other ellipsoidal room in the School of Computer Science and I.T. When we inspected that room, prior to embarking on the Pod design, it was used as a storage space as its uncomfortable acoustic made occupation undesirable.

It is interesting to note that in his review of the Pod for Architecture Australia Magazine Conrad Hamann wrote:

“For the core's form, Morgan takes his cues from acoustic requirements and the need for a balanced or curved shape, with internal convex faceting, and the flaring of ducts to reduce background noise.”[2]

In fact the shape was an architectural concept. As with Vitruvius[3], beware Architecture writer's commentary on issues of sound. While the shape offered significant challenges for a critical listening space due to the focussing of the ellipsoid form it was considered that if a good result could be achieved it would highlight the potential to develop new forms. Never one to shy from a challenge, I approached the concept with enthusiasm.

The original interior developed with Paul consisted of a “landscape” of various modular absorbers and diffusers that could be adjusted to optimise the space. These panels were concealed behind a mesh lining that rendered the visual appearance of an ellipsoidal shaped interior. However, this approach was considered cost prohibitive and a new interior was designed incorporating a multilayer sound absorptive surface for the majority of the interior.

The shape of the inner structure was modified to reduce some of the focussing effects of the ellipsoid. The result is a very dry acoustic with minimal focussing and some minor residual modal effects.

Working with Paul during the development of the Pod was a pleasure. His creative vision and commitment to quality were in good balance with his pragmatic approach to success in both the sonic and visual integrity of the space.

As a high performance listening space the Pod has been a great success. Visitors are struck by the dry acoustic and the extreme isolation of the room. It allows composers to work precisely with the subtle nuances of sound and spatial placement.

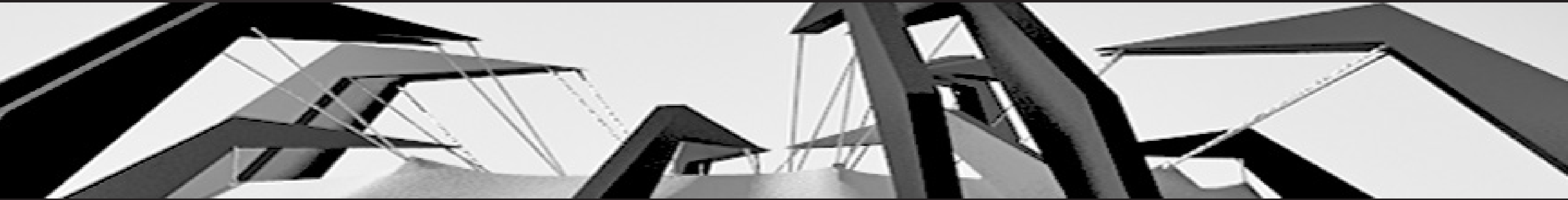
The Pod is testament to good collaboration with the Architect and client. It achieves the external perspective that provides a strong physical presence that is integrated with its principal sonic performance requirements.

---

[1] 1968 film directed by Stanley Kubrick.

[2] Architecture Australia, March/April 2005 Issue (http://www.architecturemedia.com/aa/aaissue.php?issueid=200503&article=8&typeon=2)

[3] Refer to Background Appendix, p6



Sonosentio

COMPONENTS

TABLE OF CONTENTS

Contents

LIST OF FIGURES

COMPONENTS

Introduction

This PhD research considers the sonic design process and proposes a new approach that is based on a creative model in place of the existing reflective model[1]. This process places a priority on the role of sound and listening in sonic design in place of the computational analysis and objective criteria currently used for developing and communicating design concepts.

The research is conducted through the design of the Sonosentio project which explores a new paradigm for sonic design based on a process of interactive "sketching" conducted within the sonic domain to realise responsive geometric compositions.

The Sonosentio environment[2] has been developed as a prototype system to demonstrate the concept of operation of one possible implementation of this new sonic design process.

This document provides an overview of each of the three basic components of the Sonosentio environment described in the Research Catalogue.

The Sonosentio environment, using the brush, palette and canvas paradigm, owes as much to Thaddeus Cahill's invention of the Telharmonium[3] as it does to Wallace Sabine's pioneering work at Harvard University[4]. Although presenting itself as a pioneering development in musical instruments, the true nature of Cahill's ingenuity was the broadcasting of music to a wider audience.

As with the Sonosentio sketching paradigm, the palette of the Telharmonium was the monstrous dynamos[5] that used the advances in the developing field of electricity to generate the array of musical tones. The brush was the console[6] that provided an interface that allowed the skilled musicians to operate the machine using traditional techniques that they were familiar with. The canvas was the Telharmonic Hall[7] that housed both the reproduction system and an appropriate environment for Cahill to present the sound of the Telharmonium.

The Sonosentio interactive design environment is not intended to replace existing computer modelling and auralisation techniques. These design review systems provide an informative review of developed designs. Sonosentio is a primary design tool, designed as a sketchpad for experienced sonic designers to enable creative design concepts to be explored and shared interactively using sound as the design media.

---

[1] Refer to Research Catalogue p12
[2] Refer to Research Catalogue Figure 5
[3] Refer to Background Appendix p7-8
[4] Refer to Background Appendix p5

---

[5] Refer to Background Appendix Figure 6
[6] Refer to Background Appendix Figure 5
[7] Refer to Background Appendix Figure 7

Spatial Reproduction Array

There are many examples of the use of loudspeaker arrays in low reverberance rooms for spatial sound reproduction. These specialised rooms may be used for creative sound design, engineering or research. Examples include:

- Music and Effects Studio[1]
- Arup Soundlab[2]
- RMIT Pod[3]

The spatial array requirements for these spaces vary depending upon their function. For example, Music and Effects produce sound for cinema and their spatial sound system is designed to replicate the standard sound system configurations used in commercial cinema.

In cinema, the principal sound occurs on the screen and is produced by loudspeakers mounted behind the screen to locate the primary spatial image with the visual image. This configuration includes a central loudspeaker to place dialogue centrally on the screen for a distributed audience. The surround loudspeakers are predominately used to provide supplementary sound effects that support the activity on the screen.

The derivation of the cinema arrays, now common in home theatre sound for DVD replay is defined by the screen location.

The RMIT Pod uses an octagonal array to reproduce a spatial image for soundscape composition. This for of array places loudspeaker in a cube about the listening position.

The Arup Soundlab uses a spherical array of loudspeakers to provide three dimensional spatial imaging for auralisation.

Each of these configurations places the loudspeakers equidistant from the listening position. With a dense loudspeaker array equidistant array of speakers can provide good imaging for localisation of sound sources. However, these arrangements do not consider the spatial sensitivity of human hearing to the location of the source. Therefore, as the number of loudspeakers is reduced, the ability to provide realistic images between the locations reduces.

The Sonosentio environment is designed to be transportable. The intent is to design a high quality, low cost system that provides interactive spatial environment for sonic designers.

The of the spatial sound array considers the following:

- Minimal components to reduce cost
- Optimal placement by review of aural sensitivity
- Smooth spatial placement using both level and time
- Smooth panning algorithms
- A view toward a 360 degree spherical array in the future

In order to minimise the number of loudspeaker components required for the spatial array it was necessary to understand the sensitivity to the directional location of sound. This would allow optimal placement of the components. The design is undertaken with a view that increased funding could allow a denser array of more components that would increase the accuracy of spatial sound placement within the array.

---

[1] Refer to Background Appendix p48-49

[2] Refer to Background Appendix p50-51

[3] Refer to Background Appendix p52-53

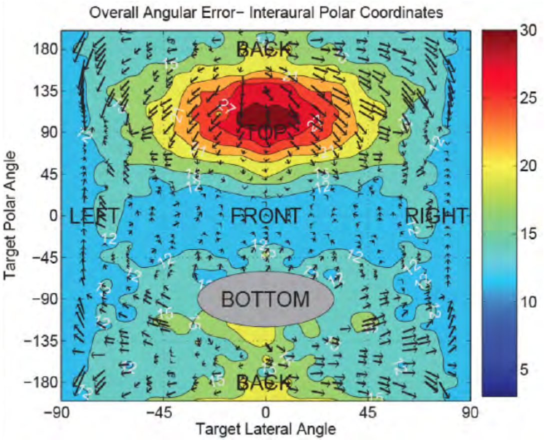


Figure 1: Positional errors in spatial hearing

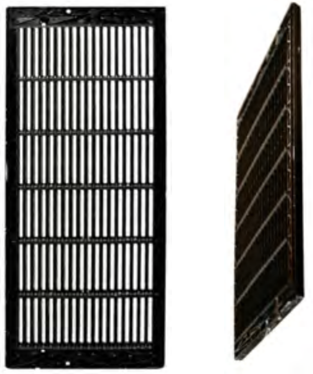


Figure 2: Flat panel loudspeakers

Spatial Reproduction Array

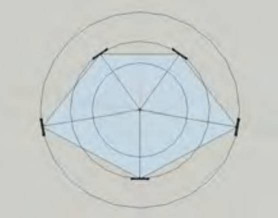


Figure 3: Primary speaker locations

A significant study had been undertaken to investigate the sensitivity to the spatial position of sound in an anechoic free field by an international research group[1]. The study used either a large spherical array of loudspeakers, or a single speaker on a moving arm to produce a sound source that could be placed at any location in a 360 degree sphere. This study produced a polar coordinate graph, shown in Figure 1, indicating the three dimensional errors made for sound localisation.

The angular error is greatest in the zone directly above the listener and it is least in front of the listener. The arrows indicate the direction that the error is displaced from actual source.

I related this map to my own experience in various high quality listening environments. While developing the Faderpro[2] program I had identified the increased localisation that occurred at the loudspeaker locations. This created inconsistencies in the spatial panning that could be corrected by modifying the speed of transitions as they passed the loudspeaker locations.

Likewise the phantom position of sound in arrays such as those in the Arup Soundlab and RMIT Pod created specific points at the loudspeaker locations that were prominent. These prominent positions can be reduced by the addition of numerous elements into the array, or by spatial image algorithms and elongated arrays.

Using the localisation error diagram and my own listening experience I developed a loudspeaker array that utilised the minimum number of loudspeakers placed at optimal locations[3].

A five sided array, in the form of an elongated pentagon was selected to minimise the number of elements in the array. The centre front loudspeaker, common in many configurations has been deleted. While a strong element in cinema surround sound it is not required for the Sonosentio array as localisation is most accurate between the left and right locations.

A centre rear loudspeaker is provided to provide a clear image directly behind and to either side. The rear left and right loudspeakers are displaced to provide a longer path for spatial panning to the sides and rear where localisation is not as accurate.

A custom software algorithm provides consistent spatial panning in the array by using both time and intensity to define the location of spatial images. This is a combination of time and level variations allows smoother movement close to the array components and provides more defined image placement in phantom locations.

The spatial reproduction array uses flat panel, electrostatic radiators as the primary sound source (Figure 2). My own listening experience indicates that these loudspeakers provide more accurate spatial imaging than conventional loudspeakers. All of the array elements are identical. The Sonosentio array must allow equal spectral content to be reproduced regardless of location.

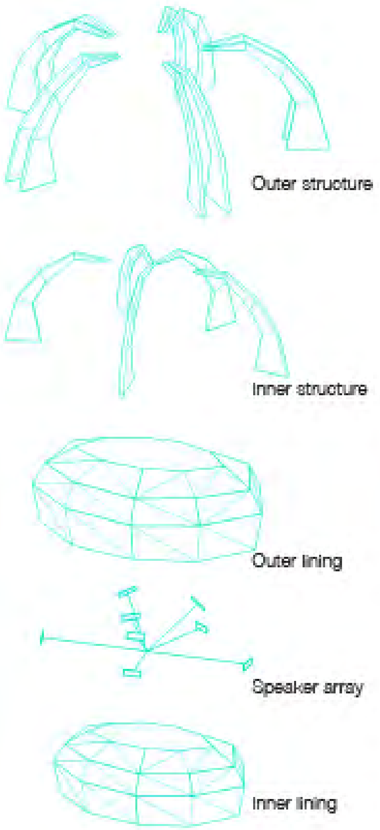
The loudspeaker components are concealed behind the inner lining of the room to reduce visual cues to their location.

---

[1] Best, V. et al 2009. A meta-analysis of localization errors made in the anechoic free field.

[2] Refer to Background Appendix p44-47

[3] This is a preliminary study and further research is required to optimise the location of the spatial array components.



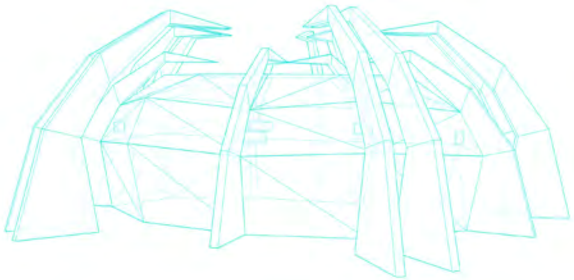


Figure 4: Sonosentio linings and support structure

Figure 5: Sonosentio lining

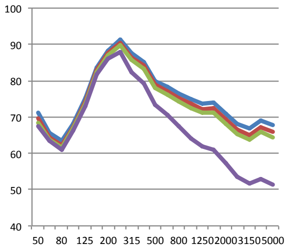
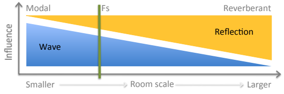


Figure 6: Lining insulation measurement



$$fs = 2000\ (\ RT\ /\ V\ )^{0.5}\ \ \mathrm{Hz}$$

Figure 7: Schroeder frequency formula

Enclosure

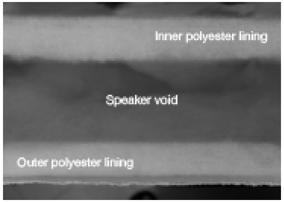


Figure 8: Photo of proposed linings

Figure 9: Frei Otto

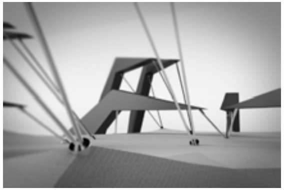


Figure 10: Sonosentio support structure

The Sonosentio enclosure is best characterised as a tent within a tent. While this implies the box-in-box construction that is typical of high performance production facilities, the Sonosentio enclosure does not share any of their design philosophies.

In a production facility the inner and outer linings provide an efficient method of achieving a high degree of sound insulation to prevent the egress of sound either in to, or out of the space. The inner and outer linings of Sonosentio are purposely designed to ensure that a component of the sound escapes the boundary of the room. This intentional leakage is designed to exploit the tonal imbalance of the transmitted sound to provide a more balanced environment within the enclosure.

The inner lining is a low-density polyester insulation material. This lining is the only material visible from the interior of the enclosure. It functions as the first level of sound absorption within the room. It absorbs high frequency sound and also provides a beneficial reduction in the direct sound from the loudspeaker components installed between the inner and outer linings.

The outer layer consists of low-density polyester insulation and an external layer of heavy canvas. The inner layer consists of low density polyester insulation. There is an airspace between the inner and outer layers of between 150 and 250mm (varying). The outer layer, in combination with the inner layer provides mid frequency sound absorption. The inner layer suppresses reflections from the loudspeakers and their support structure to reduce reflections that may affect accurate localisation with the room.

Low frequency sound is able to pass through both the inner and outer layers of the enclosure. In this manner, the three different approaches to sound absorption integrated into the design of the enclosure linings provide the potential for a highly absorptive surface with a well balanced tonal response across a very broad range of audible frequencies.

This approach to composite sound absorption design is a continued development of the sound absorptive panels designed for the Music and Effects production studio[1] and the absorptive lining of the RMIT Pod[2].

The balanced sonic performance of an enclosure is limited by the frequency at which the modal response becomes prominent. This is referred to as the Schroeder frequency (Figure 7). The Schroeder frequency of the Sononsentio enclosure is approximately 180Hz. The composition of the skin of the enclosure was tested at the RMIT Acoustic Laboratories. The measurements, shown in Figure 6, confirm that below 200Hz sound transmission is not significantly attenuated by the combination of the inner and outer linings.

The precise composition of the layers requires more research to achieve the optimal balance of sonic response that is relatively independent of the enclosure in which the room is located. I have worked with multilayer fabric constructions consisting of canvas, felt and insulation while investigating sound insulating stage curtains and approach the concept with a degree of confidence.

This enclosure design approach was also inspired by a swimming pool that I had visited some time ago. The interior sound was very harsh and highly reverberant. The tensile roof structure, reflected mid to high frequency sound, but provided no barrier to low frequencies that passed through the skin. This effective form of low frequency "absorption" is one of the primary design features of the Sonosentio enclosure.

---

[1] Refer to Background Appendix p48-49

[2] Refer to Background Appendix p52-53

Figure 11: Sonosentio enclosure and support structure

Enclosure

The fundamental shape of the Sonosentio enclosure is derived from the five primary locations of the spatial reproduction array. The five main inner supports carry the main loudspeaker elements of the spatial array and also directly support the outer linings of the enclosure. The outer support structures are used to suspend the linings of the enclosure in the span between the inner supports.

As discussed above the design of the enclosure is specifically designed to reduce the modal effects that constrain the sonic performance of small rooms.

I had experienced the low frequency influence of modal effects in room while working on a recording with the State Orchestra of Victoria[1]. Initial editing of the recording was conducted in the Dubbing Suite of the Melbourne Concert Hall. The Dubbing Suite was a recording room with a low ceiling and unusual floor plan. I completed the initial editing late at night and took a copy to listen to in my car on the way home. Although not an ideal listening environment, I was familiar with the sound of my car's stereo system. It was immediately apparent that there was a severe imbalance in the tonal quality of the recording; excessive low frequency response.

The next day I played the recording in the Dubbing Suite listening to the variations in sound quality as I walked around the space. I was able to find one location, in a corner of the room behind a storage cabinet where the true balance of the sound was reproduced. I did not make further tonal adjustments to the recording in that space.

This experience provided a useful lesson in the response of rooms where the scale of the room is within the wavelength of sound (ie. below the Schroeder Frequency - Figure 7).

When designing the Music and Effect Studio[2] and the Arup Sound Lab[3], these modal issues were reduced by the introduction of tuned sound absorptive treatments and locating the listening position, away from the centre of the room.

For the Sonosentio environment, the modal effects are reduced by allowing low frequency sound to permeate the skin of the enclosure. At the scale of the Sonosentio enclosure the Schroeder Frequency is approximately 200Hz. The composition of the skin of the enclosure was tested at the RMIT Acoustic Laboratories. The measurements confirm that below 200Hz sound transmission is not significantly attenuated by the combination of the inner and outer linings.

The design of the enclosure has been conducted with sonic requirements as the principal goals. The coordination of the loudspeaker locations and composition absorptive treatments provided the materials and geometry of the enclosure.

The tent linings are designed to be relocatable. This allows the room to be a temporary structure that is set up as required. The support structure allows the tent to stand independently within a larger space. It is intended that the supports could be removed and the tent supported by shock-rope from existing structure if preferable.

---

[1] CD Recording, Solitudo : alone in darkness, ABC Classics

[2] Refer to Background Appendix p48-49

[3] Refer to Background Appendix p50-51

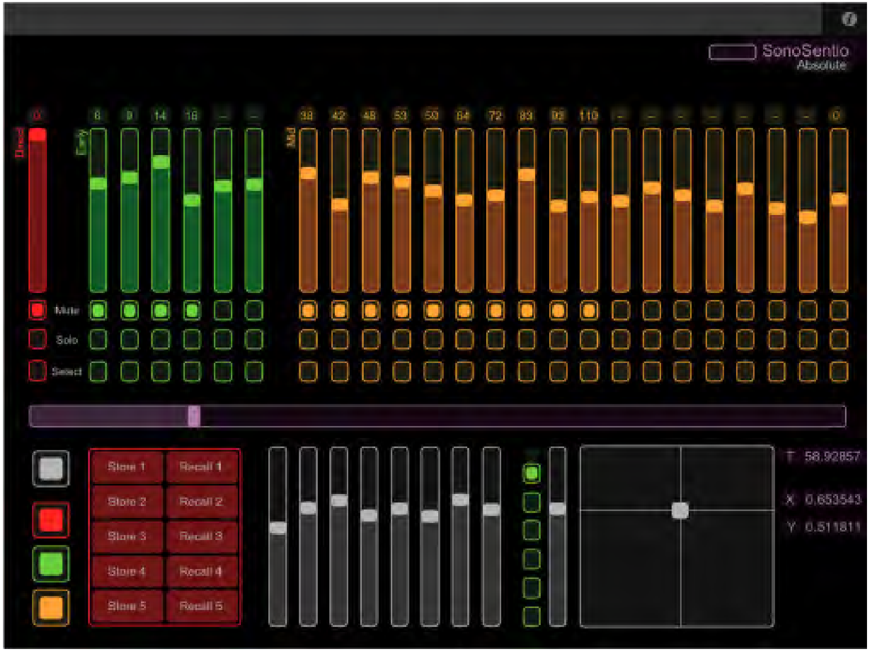


Figure 12: Brush Application Interface

Brush

The interactive, parametric modelling of Sonosentio is controlled by an iPad application that allows real-time manipulation of the sonic space. This is referred to as the Brush application, following the brush, palette and canvas paradigm of the design environment.

For an experienced sonic designer, the application allows the equivalent of visual sketching or sculpting to be performed of an imagined spatial environment. The sonic parameters of time, intensity, tonal response and spatial location become, distance, lighting, colour and geometry in the visual world. This translation occurs in real time in the palette program and is presented as sound via the spatial array within the enclosure.

The user experience of the brush application is similar to that of an audio mixing console with an array of sliders representing individual sonic impulses, tone and position controls for each impulse channel and the ability to “mute” and “solo” individual components to listen to the interaction of the design in detail. These control paradigms are familiar to the majority of sonic designers.

Unlike an audio console, where each channel controls an instrument level and position, the impulse channels in the Brush application controls the relative level of time related repetitions of the original sound. Figure 12 shows the user interface for the brush application. For this project, the application has been realised in TouchOSC[1] to demonstrate the concept.

For the brush application, the relative intensity faders provide the level reduction of impulses within the response. In a typical reverberant response, the faders would be configured in as reducing in level from left to right.

Each intensity fader has an associated time display. This indicates the delay from the direct sound (the leftmost, red fader). The structure of the reverberant response is a combination of the time and relative intensity of each of the impulses. In the brush application the delay is represented by the distance slider in the middle of the screen.

The control section consists of a series of buttons that allow selection, muting and soloing of each impulse.

When selected, the lower controls, spatial position, distance and equalisation are active on the selected impulse. Each impulse may be selected individually to adjust these parameters. The sonic influence of the control manipulation is represented by the spatial sound array in real time.

The solo button under each impulse allows an individual reflection to be heard with all others muted. This allows the detailed position and tonal response of each reflection to be considered individually and then recombined with the entirety of the impulse response. By selecting multiple solo impulses, a number of impulses can be considered together.

The mute buttons allows individual reflections to be silenced. This can be used to highlight individual characteristics in an overall impulse response such as echo or harsh response.

The materials section allows absorption and diffusion to be applied to each impulse. A unique sonic texture can be applied to each impulse within the overall response. The characteristic can be applied from a common set of materials, or individually designed using the equalisation controls.

---

[1] A modular interface design environment developed by Hexler.net. (http://www.hexler.net/)

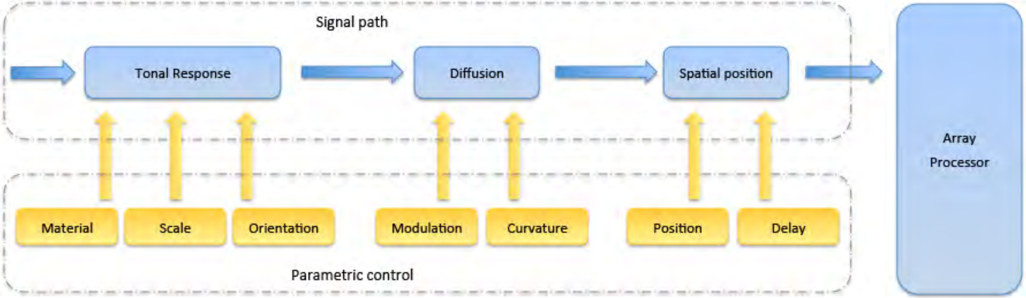


Figure 13: Palette impulse block diagram

Palette

The Palette program accepts the sonic and geometric characteristics being manipulated by the designer in the Brush application and represents them on the sonic canvas. This allows the designer to interactively manipulate the spatial and tonal characteristics of each impulse and to listen to either the entire response, or a subset of individual impulses to consider the interaction of various components of the design. This interactive control of individual impulses is one of the features that makes the Sonosentio environment a unique design tool.

As shown in Figure 13, the Palette program allows a number of material and geometric features to be sketched. Unlike auralisation programs, the Palette program does use material data to create the sonic image. The Palette program allows the designer to work with an infinite number of materials to derive the sonic image, in real time, in the same manner as a painter mixing colours. The derived material data is then used to select the appropriate combination of materials to realise the design.

Characteristics such as sound absorption, diffusion and curvature are sonically created in the Sonosentio environment and then the corresponding material and geometry design develops from this sketch.

Sound absorption refers to the amount of sound energy that is not reflected by the material. This can either indicate that the energy is absorbed by the material or the energy passes through the material.

As each surface responds to sound differently, the tonal balance of the reflections from the surface is typically not consistent across the entire spectrum of audible sound. This change in tonal balance, often referred to as colouration affects the perceived quality of the sound in the space. A simple analogy in light would be a red surface reflecting white light. The light is coloured by the tonal imbalance of the reflection from the surface.

Sound absorption is the most commonly used and easily measured material property. Manufacturers of many types of building materials maintain databases of the sound absorptive properties of their products. Where data is not available, the sound absorption can be measured in a reverberation chamber. The material is installed in the chamber and the variation of the reverberation between the empty chamber and the introduction of the material sample allows the absorption coefficient to be calculated. Refer to Background Appendix Figure 46 and Figure 49 which show the installation of material samples for the walls of the Melbourne Recital Centre installed in a reverberation chamber.

The scale of a surface affects the tonal range of the reflection from the surface. Small surfaces reflect high frequency sound, large surfaces reflect a broader range of frequencies. The tonal quality of the reflection is determined by its relationship to the wavelength of sound.

The orientation of the panel also affects the quality of the response. As the relationship between the panel and the listened becomes more oblique the tonal character changes depending upon the directivity of the reflection at various frequencies. The same effect is heard when a listener moves away from the front of a loudspeaker, where low frequencies, which tend to be less directional, maintain their presence, while high frequencies, which are more directional, tend to reduce in level as the listener moves further off axis.

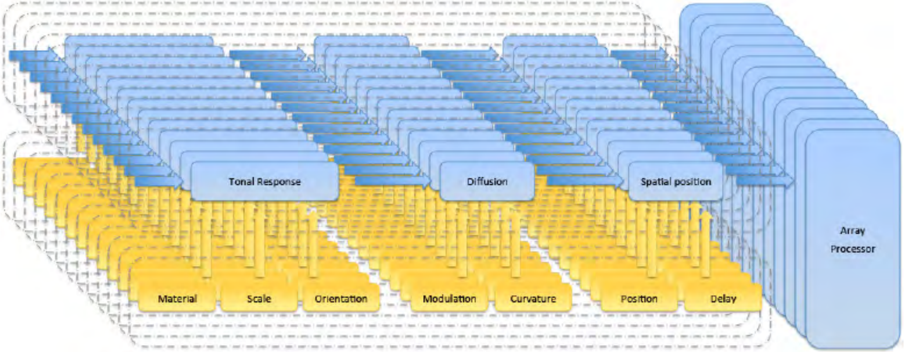


Figure 14: Palette impulse block diagram

Palette

The modulation and curvature affect the diffusion of the surface to sound. The scale of the modulations and curvature affect the range of audible frequencies differently depending upon their wavelength.

While the measurement of sound absorption is well defined, many of the other spatial characteristics are difficult to classify due to the large number of variables. One of the primary factors is the scale of the surface. As Beranek discovered at Philharmonic Hall[1], a large array of moderate sized panels responds to sound in an unpredictable manner. While the array provided reflections at mid and high frequencies, it also inhibited the reverberant buildup at low frequencies, reducing the richness of tone in the hall.

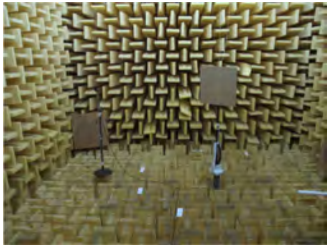


Figure 15: CSIRO panel tests

In order to investigate these effects, I conducted a series of measurements in an anechoic chamber at the CSIRO's Highett facilities (Figure 15). Two series of measurements were undertaken; the first to investigate the reflection of sound from an individual panel and, the second to investigate the interaction of multiple panels. The complexity of these measurements became apparent during the process and deriving a clear picture of the reflection from the single panel proved extremely difficult. Unfortunately this research was too complex to be undertaken as part of the Sonosentio project.

Room acoustic modelling software tends to use diffusion parameters from optics to estimate the absorption of surfaces[2]. These parameters provide a limited estimate of the actual behaviour of sound where the wavelength is greater than the scale of the object.

The spatial position affects our impression of the location of the sound source. In typical spaces, the main sound source represents the strongest signal we receive and other impulses (reflections) are reduced in level. For live performance, sound systems use a technique known as the Haas effect[3] to allow the loudspeakers to produce a stronger signal than the performer. However, the signal from the loudspeaker is delayed and, although louder, we perceive it as a secondary source and are not distracted by the displacement of the performers voice or instrument to the loudspeaker location. The location and trajectory algorithms were developed for the commercial Faderpro System[4] and are not a component of this research.

The delay and spatial location defined in the Brush application establishes the geometric location of each impulse in three dimensions within the overall response. This location can be extracted from the Palette program to provide a geometric composition for the sonic response derived in the Sonosentio environment.

The palette program combines all of the designed impulses into an overall response that represents the spatial response of the geometry. This spatial composition can become the foundation of a visual design process to establish a responsive physical geometry.

The Palette program allows the spatial and tonal characteristics of a space to be developed as a series of spatial repetitions of sound. The sonic composition is expressed interactively in sound in the spatial reproduction array. This allows the geometries to be developed and shared in real time.

---

[1] Refer to Background Appendix p 20-21

[2] Christensen, C. L. 2011, Odeon Room Acoustics Software p4-58

[3] Haas effect also referred to as the precedence effect. Refer to Blesser, B. et al. 2007. Spaces speak, are you listening?, p200

[4] Refer Background Appendix p 44-47