

# THE ARCHITECTURAL MANIPULATION OF SOUND:

ARCHITECTURALLY ARTICULATING URBAN SPACE TO PROTECT AND ENHANCE THE  
OUTDOOR ACOUSTIC ENVIRONMENT

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## ABSTRACT

To date, 'Urban Design' has seldom accounted for the *quality* of the acoustic environment. The significance of sound in the urban environment is understated. This is evident in design attitudes towards Urban Acoustics, which are essentially objective; based on 'Noise Control Methodologies', limited by quantitative values and void of sonic variety. The aim of this thesis is firstly, to determine whether an acoustic agenda could be successfully introduced into the urban design process, and secondly, to assess the aesthetic impact of imposing such an agenda on the built environment.

To explore these ideas, the thesis combined research from three fields; Urban Design ('Public Places, Urban Spaces' by CARMONA ET AL.), Urban Acoustics ('Urban Sound Environment' by JIAN KANG), and Soundscape Philosophy (founded by R. MURRAY SCHAFER). A series of experiments were then conducted using noise propagation software 'CadnaA', which studied the acoustic performances of different Street and Open Space Layouts. Conclusions drawn from these experiments and the analysed literature provided the framework for an Urban Design Proposal located in central Wellington, which was used as a means to assess the viability of this design approach.

The results of the design-research process suggest that an acoustic agenda can be integrated into the urban design process with relative ease and little conflict, and that many of the Soundscape philosophies inherent in Urban Acoustic Design actually complement well-established Urban Design Principles. Additionally, while this approach is most effective in acoustically challenging areas, the intrinsic design principles can be adopted to enhance both the acoustic and visual aesthetic of any urban design.

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# 1. INTRODUCTION

## 1.1 Problem Statement

To date, 'Urban Design' has seldom accounted for the quality of acoustic experience. Design solutions for the acoustic environment are largely based on Noise Control Methodologies, limited by quantitative values and void of any sonic variety. While there is a large field of research into source-based noise reduction and barrier attenuation, little knowledge has developed on how 'Urban Acoustic Design' can be used to enhance the urban soundscape.

To Schafer (founder of soundscape philosophy), 'Acoustic Design' meant discovering the principles by which the aesthetic qualities of the acoustic environment may be improved. These principles could include elimination or restriction of certain sounds through noise abatement, the preservation of sounds that give character or sense of place to a location ('sound-marks' as the acoustical equivalent of visual landmarks) or imaginative placement of sounds to create attractive and stimulating environments. These approaches are described by Muhar & Brown as: (a)'defensive', protecting the sonic environment from acoustic pollution; (b)'offensive', consolidating the acoustic milieu and; (c) 'creative', composing the sonic landscape (2004, p. 828).

This thesis is an investigation into how Sound-based Urban Design methods can be combined with Urban Design Principles to acoustically enhance the urban environment. An Urban Design proposal located in the Harbour Quays Precinct of Wellington, New Zealand, will be used as a trial for the implementation of design strategies

established in the research phase of this thesis. This site presents particular acoustic challenges including bordering operational port, freight rail and a major traffic thoroughfare. Currently, Harbour Quays is subject to a degree of noise-based reverse sensitivity (see Appendix 1) with regards to future development. The effectiveness of the design strategies used in the proposal will be evaluated from both an acoustic and urban design point of view.

### **1.2 Aims and Objectives**

The aim of this thesis is to explore how Architectural Acoustics can be used positively in conjunction with Urban Design Principles to protect and enhance the urban acoustic environment. During the course of this thesis, I endeavour to answer the following questions;

- Does the value of acoustic design warrant its inclusion in the urban design process?
- How does this approach effect the aesthetic of the built environment on which it is imposed?

### 1.3 Research Approach

To achieve these aims, **Chapter 2** summarises the fields of research in question in a Literature Review. These include Urban Design, the fundamentals of Outdoor Acoustics, and areas where these fields intersect. Early research focuses on Urban Acoustic. In a broad sense, this area of research explores;

- Sound behaviour in external space (e.g. Traffic noise, reverberation times).
- Natural methods of sound absorption/diffusion, etc. (this research niche provides a technical understanding of sound behaviour in urban space)
- Outdoor sound attenuation techniques.

In conjunction with Urban Acoustics I discuss Urban Design Principles. This review primarily looks at the book 'Public Places, Urban Space' (CARMONA, HEATH, OC, & TIESDELL, 2010), which provides a holistic overview and general guide to good urban design practice. Following this, I discuss readings on Soundscape; these provide an additional perspective on how to address the urban acoustic environment. Soundscape research covered includes;

- Positive Sound Articulation Techniques.
- Human Perception of Acoustic Environments
- Precedents for sound mapping and case studies utilising Soundscape theory in design.

**Chapter 3** establishes the principles of Soundscape Design through the analysis of a series of anecdotal case studies. These range from Existing Area Analysis, to Early Stage Urban Planning.

These case studies;

- Provide a set of practical tools and techniques for the protection and enhancement of the urban acoustic environment, and
- Help to clarify when, and to what degree an acoustic agenda can be properly implemented into the design process.

After discussing the basic concepts in the fields of Urban Acoustics, Contemporary Urban Design Principles and Soundscape Design, **Chapter 4** explores the intersection of these fields. In this chapter, using an acoustic propagation software (Datakustik's CadnaA), a series of experiments is conducted that study the acoustic performances of different Street and Open Space Layouts. The conclusions drawn from these experiments lay the foundations for a set of Urban Acoustic Design principles to be implemented in the Design phase.

**Chapter 5** introduces the selected site, provides a comprehensive analysis of its existing conditions, and further elaborates on Chapter 4 with a series of abstracted site-based acoustic experiments that look at different building/street layouts within a simplified version of the site (again using CadnaA). A design brief is then consolidated using experimentation results from Chapters 4 and 5, coupled with the established Urban and Soundscape Design Principles from Chapters 2 and 3. The design process and results are then summarised.

Finally, **Chapter 6** is used as a reflection on the successes and shortcomings of the experimental urban design proposal and a final discussion of the thesis findings.

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## 2. LITERATURE REVIEW

### 2.1 Introduction

Historically, the urban ‘Soundscape’ was considered a by-product of necessary urban activity. Beyond the quantitative considerations of noise levels, there has been little attempt to address the quality of one’s Acoustic Experience in the urban environment. While recent theories on sound perception are beginning to establish a more holistic understanding of the Acoustic Environment, little knowledge has developed on how the application of Urban Acoustic Design could be used to enhance the urban ‘Soundscape’.

This literature review establishes the context in which attitudes towards the acoustics of urban open space have been formed and critiqued. It then summarises theory on Urban Sound Propagation and Principles of Urban Design. An overview of the recent philosophies of ‘Soundscape’ and its relevance to the modern Urban Design is then presented.

The purpose of this chapter is to outline the technical concepts of Urban Acoustics and Sound Behaviour, and to provide a basic knowledge of Contemporary Urban Design Principles and Soundscape Design Strategies. This facilitates the identification of areas of cross-over between the fields of research, and thus also the development of a holistic framework to situate the experimental Urban Design Proposal.

## **2.2 Noise in Context**

### **2.2.1 The Industrial/Electrical Revolution**

Preindustrial communities were aware of the concept of noise, but it was not until the industrial revolution and the birth of new architectural materials and transportation that the concept of ‘noise’ was viewed as problematic. The growth of urban infrastructure from the mid-19th century resulted in an urban landscape that held fundamentally new acoustic qualities. Street canyons formed of hard, acoustically reflective materials perpetually reflected traffic sounds of the newly appearing vehicular transportation (combustion engine). Industrial sounds became sonic background rather than isolated foreground sonic events.

By the turn of the century, residents were commenting about the high level of background noise in the city and complaining about the difficulty of getting one’s bearing acoustically (PAYER, 2007, pp. 774-776).

With the rapid growth of the city requiring regulation, ‘Urban Planning’ became an important discipline. Segregating residential areas from business zones and industrial areas became a primary solution for the rapidly growing city. Public requirements for greater mobility lead to enormous increases in traffic volumes and thus a multiplication of traffic noises (PAYER, 2007, pp. 789-790). At this time, the assessment of noise still remained a highly personal matter that people found difficult to discuss in a factual and objective manner (science did not find the means to measure sound quantitatively until the 1920’s.) (PAYER, 2007, p. 782).

### 2.2.2 Establishment of Soundscape Philosophy

It wasn't until the second half of the 20th century that academics began to view the sonic environment as an ecological field in need of protection and preservation. This attitude was brought on by a wave of ecological movements that grew through the 60's and 70's, in response to contemporary environmental problems related to important technological innovations (PAQUETTE, 2004, p. 5).

It was during this time that Murray Schafer founded Soundscape Philosophy and helped launch the 'World Soundscape Project' (WSP). The WSP proposed a 'global' approach to the problem of noise pollution, in contrast to the growing specialisation of traditional disciplines dealing, for instance, with acoustics and acoustical engineering. The view taken by the WSP was not to solve the problem of noise pollution through negative processes used in noise abatement, but to take a positive approach.

In this approach they established five specific objectives;

- To undertake an intensive interdisciplinary study of contrasting acoustic environments and their effects on people.
- To suggest ways of changing and improving acoustic environments.
- To educate students and field workers in acoustic ecology.
- To educate the general public in acoustic ecology.
- To prepare reports as guides to future studies.

(TORIGUE, 1982, p. 15)

## **2.3 Urban Acoustics**

While there are well established theories for the behaviour of sound waves in general terms, the scientific application of these theories has been largely restricted to fields of more controlled, interior environments (Performance Space Design/Acoustic Engineering). However, there has been some recent progress in the scientific analysis of sound behaviour in the more volatile outdoor environment. In order to determine a more holistic criterion for Urban Design Proposal, it is important to establish a scientific basis for which design interventions can be measured. Kang's book, 'Urban Sound Environment', provides extensive information in this field, and is my primary source of research into Urban Acoustics.

### **2.3.1 Sound Waves. Propagation and Intensity**

#### **Wave Transmission**

Sound waves can be transmitted through solid, liquid, or gaseous media in the form of vibrations. The vibrations displace particles in the direction of propagation creating a 'longitudinal' wave. The physical properties of a sound wave are listed below;

- The time for completing a full circuit by a displaced particle is called the period (T).
- Oscillations are repeated, and the number of repetitions per second is defined as the frequency (f).
- The distance of displacement between particles is called the wavelength ( $\lambda$ )
- The velocity of sound (c) is approximately  $340\text{ms}^{-1}$



These variables are related using the formula

$$f = 1/T = c/\lambda$$

### **Sound Levels**

From audibility threshold to pain threshold, the ratio of sound intensity is measured at a scale of '10'. Because the human ear does not respond linearly to sound pressure and intensity, it is necessary to use a logarithmic unit to measure sound intensity and pressure, decibels (dB).

### **Frequency Range**

Most sounds are complex, containing many frequencies. A sound can be measured in a series of frequency intervals called frequency bands. An octave band's upper limit frequency is exactly twice that of its lower limit frequency. Therefore the centre frequencies of octaves have been standardised into acoustic measurements of 31.5Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz and 16 kHz. Frequencies in human auditory range are from 20Hz to 20 kHz. With an increase in age the upper frequency hearing limit drops continuously.

### **Loudness**

The auditory range of human hearing is again noted when measuring loudness. A sound of 10-15dB is barely audible, whereas 130-140dB will risk irreparable nerve damage. It is generally understood that an increase of 10dB is an approximate doubling of the strength of sound sensation on the human ear (KANG, p. 3). It is noted that in many cases, loudness and annoyance are two separate, and distinctly perceived attributes.

## Masking

Masking occurs when a signal is rendered unintelligible or inaudible by a simultaneous sound that exceeds a certain level. In other words, it is the process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound. With pure tones, the masking effect is more significant when the signal frequency is close to the masking sound. Low frequency sounds have considerable masking ability over high frequency sound. The frequency range of the masking sound increases depending on the Sound Pressure Level of that sound (KANG, p. 5). Masking sounds provide an opportunity for the introduction of preferred sounds into the urban environment to disguise those considered irritating.

The most prevalent sounds found in the city are those of traffic and people. These sounds are a by-product of activity, and thus do not communicate information of value. They also demand the most attention, and therefore act as a mask for those intentionally designed; sounds like bells, signals, speech or music (SOUTHWORTH, 1969, p. 56).

## Urban Sound Sources

While there are numerous sound sources, these can be categorised into point, line and plane sources. Typical point sources include valves and fans, line sources include trains and continuous traffic, and plane sources include playgrounds and industrial building facades (KANG, 2007, pp. 6-8). As an example, Figure 2.1 illustrates the relative sound power levels of vehicular transport.

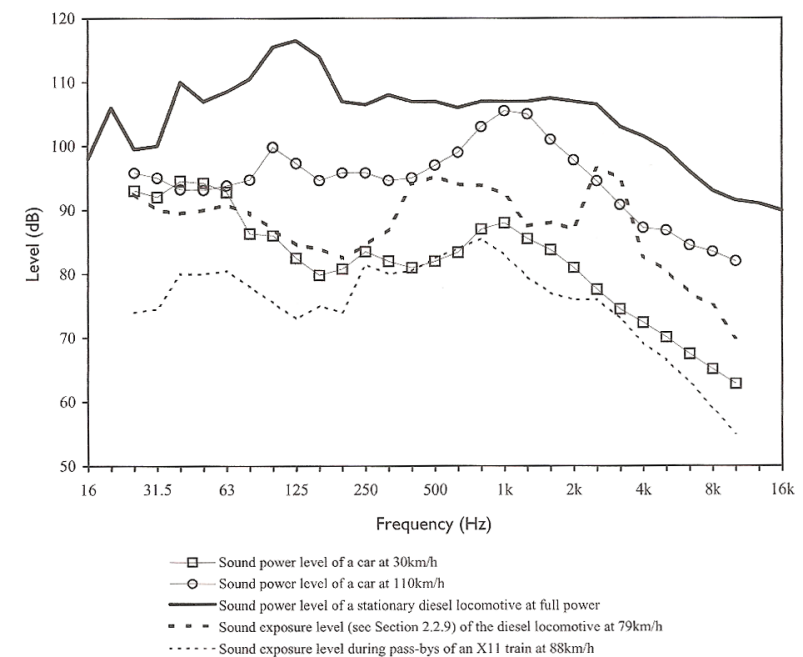


Fig. 2.1 Typical spectra of car and train noise.

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### 2.3.2 Reflection/Diffusion/Absorption/Reverberation

#### Acoustic Materials

When sound falls on a boundary, it is partially reflected, partially absorbed and partially transmitted through the boundary. Sound absorption, transmission and reflection coefficients are all frequency dependent, and can take on any numerical values between 0 and 1.

#### Reflection/ Diffusion

If a boundary is rigid, smooth and considerably greater in length than the wavelength of a sound, it will reflect that sound at an angle equal to the angle of incidence. If there are irregularities on a reflecting boundary, sound energy may be scattered or diffused. A diffusive surface disperses reflections both temporally and spatially. Typical diffusers include simple curved surfaces, irregular geometric structures, periodic geometric structures and a mixture of absorptive and reflective materials from wood, to concrete, metal, brick and glass (KANG, 2007, pp. 10-11).

#### Absorption

Sound Absorbers include porous absorbers, single resonators, perforated panel absorbers and panel and membrane absorbers. When sound waves impinge on porous materials, part of the sound energy is converted into thermal energy due to viscous flow losses caused by wave propagation in the material and internal frictional losses caused by motion of the material's fibres. Characteristics are dependent on thickness, density, porosity, flow resistance and fibre orientation. Because absorption is best when the par-

ticle velocity is at its greatest, it is better to have a thicker wall that covers a wider range of frequencies (i.e. 20Hz sound with a wavelength of 17m) (2007, pp. 9-10).

The use of vegetation is also an effective method of reducing sound in street canyons. While its effects as an attenuator are limited, it can be useful where multiple reflections occur (i.e. street canyons). Ground attenuation can be achieved using a range of different materials (i.e. grass, bark etc.).

### **Reverberation**

Spatial acoustics can amplify a target sound using reflections. When nearby surfaces reflect sound back to a receiver shortly after the direct sound wave, the two waves perceptually fuse, increasing the loudness of the sound without increasing reverberation. A spatial geometry that produces the intensity of these reflections can increase the 'acoustic arena'. However, late arriving reflections will become noisy echoes and reverberations, effectively shrinking the arenas (BLESSER & SALTER, p. 23).

### 2.3.3 Urban Acoustic Design Methodologies

Chapter 6 of Kang's book focuses on noise mitigation using urban design techniques. This is directly relevant to my thesis as it discusses solutions that aren't directed at source-based noise reduction.

#### Urban Geometry

Kang begins by discussing building arrangement techniques for noise mitigation (of which modern buildings are often monolithic reflective surface in cities). These include;

- Using reflective facades to direct sound into less sound sensitive areas.
- Ensuring Concave facades are not having an adverse effect by increasing noise level.
- Distancing buildings from sound sources (effectiveness is limited, however. Unhindered sound loses little intensity over small distances)

Design strategies used to reduce noise levels of streets to upper levels of buildings include podium building, step backs, balconies and walled courtyards. All of these methods reduce sound by screening the source from the receiver. While these strategies reduce noise at the upper levels of buildings, ground floors still experience high sound intensity. Kang describes this design approach as 'Self-protective building'.

A built buffer that absorbs sound can be used to protect sensitive areas behind. Kang describes this method as 'Acoustic Enclosure' (KANG, 2007, pp. 178-179). Generally made of a solid material to minimise transmission, a porous material can be added to absorb some of the sound. Combinations of wall types are also very good at limiting sound transmission.

Barriers are discussed by Kang in length. Barriers of all kinds of material are implemented to reduce/diffract sound away from areas. Sound refraction is achieved using gas filled barriers (as sound passes through a medium of different density, its speed changes and therefore the angle at which it exits that medium is different from its entry). Figure 2.2 illustrates the degree of sound transmission through different boundaries.

Alternatively to built attenuation, 'Strategic Architectural Landscaping' can be used; This is largely about source management through road alignment. By elevating or dropping roads, areas of acoustic shadow are created, cantilevered barriers can also be implemented to attenuate and diffract traffic noise.

### 2.3.4 External Discrepancies

Unlike the controlled environment of a Performance Hall, the urban acoustic environment is exposed to numerous external variables. Kang discusses these variables and how they affect sound propagation outside. Outdoor characteristics include ground and air attenuation, wind speed and direction, temperature and relative humidity, barrier attenuation, acoustic screening, and surface reflections (KANG, 2007, pp. 13-16).

Kang then discusses the basic equation for the propagation of sound in a free field from a point source. Where the intensity (I) of the sound at any point is inversely proportional to the square distance(d) from the source, commonly referred to as the inverse square law, i.e., sound intensity is reduced by 6dB (halved intensity) for every doubling of distance from the source. (W) represents the sound power level at any given time.

$$I = W/4\pi d^2$$

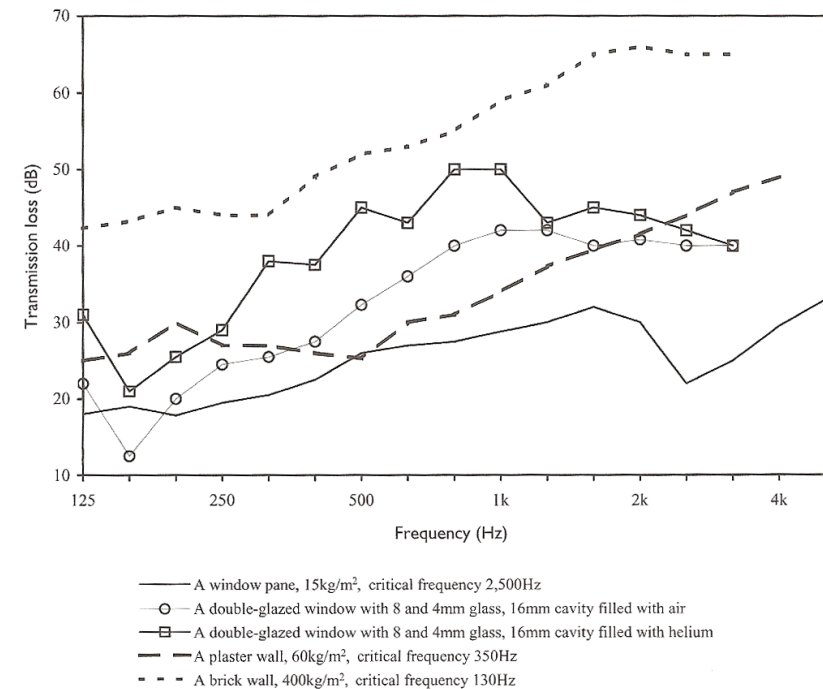


Fig. 2.2 Transmission loss of typical boundaries.

## 2.4 Urban Design

Employing knowledge of contemporary Urban Design Principles, I will establish crossovers between these principles and those of Urban Acoustic/Soundscape Design. The primary text I have used to cover Urban Design Principles is 'Public Place, Urban Spaces', by Carmona, Heath, Oc and Tiesdell. The text provides a holistic guide to urban design.

### 2.4.1 Brief History of Urban Spatial Evolution

There have been countless theories as to how the urban grid has evolved, Hillier extensively theorised the relationship between movement and the evolution of the urban grid. His central proposition was that movement dictates the configuration of urban spaces, and is in itself largely determined by spatial configuration. While Buchanan argued that it was the movement network, the services buried beneath it, and the monuments and civic buildings within and adjacent to it that formed the relatively permanent parts of the city (as cited in CARMONA ET AL., 2010, pp. 84).

The modernist movement towards freestanding buildings as opposed to the building defined streets was fuelled by the ideas that it would create healthier living conditions, be more aesthetically pleasing and better accommodate cars (2010, pp. 22). However, this theory did not perform as originally conceived. Large urban public spaces became impossible to maintain and keep safe, and afforded no legibility to pedestrians.

Many contemporary urban design projects are now conceived of as urban blocks defining space rather than individual buildings. This is generally received positively as it

promotes positive urban space while not micro-designing the entire city. Block sizes are commonly established using existing linkages and connection (2010, p. 93).

### 2.4.2 Understanding Context

Context is considered as both site, and the area immediately outside its boundaries. The unique qualities that context affords are possibly the most precious design resource, requiring designers to work within established, complex, delicate situations.

One must understand the Economic, Social and Cultural differences of space to ensure that urban space is understood and maintained by its users. Good urban design has to adhere to the sensitivities of cultural diversity. Figure 2.3 provides an example of the array of fields that should be considered in the urban planning process (2010, p. 48).

### 2.4.3 Urban Morphology

Urban Morphology is the study of form and shape of settlements, considering several different elements; Land Uses, Building Structure, Plot Pattern and Street Pattern are among the most important.

- Land Use; Pertains to the temporary nature of land use. How they are redeveloped, subdivided, adapted and converted.
- Building Structure; Refers to the progression of building development within the context in question.
- Plot Pattern; Pertaining to the plot boundary and its change over time. This could either be amalgamation or subdivision of plots.
- Street Patterns; Pertains to the layout of urban blocks and the spaces be-

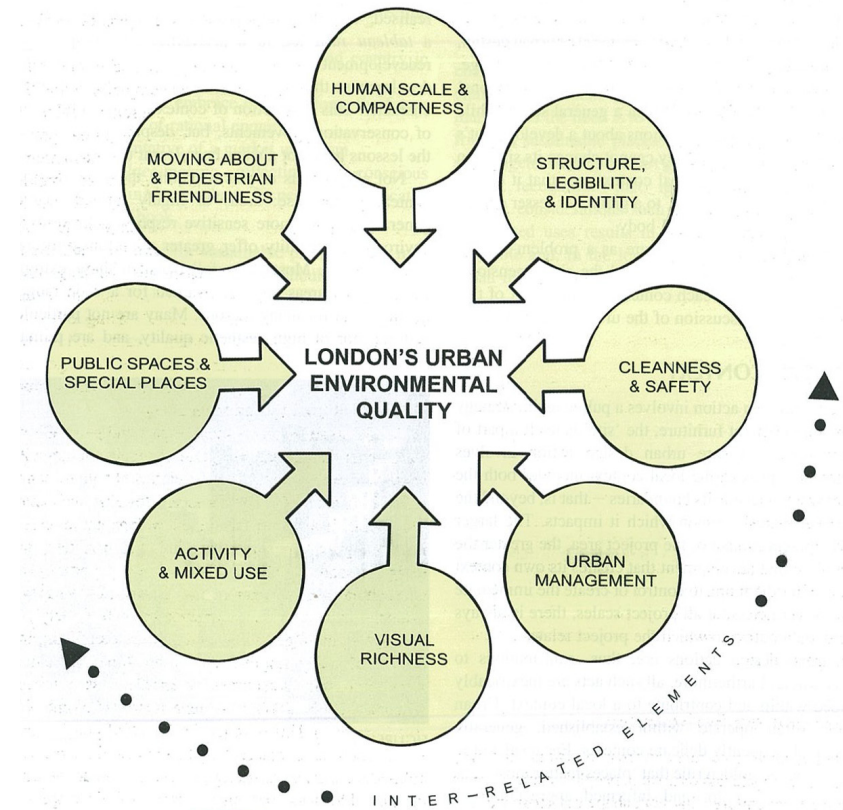


Fig. 2.3 London's Urban Environmental Quality.



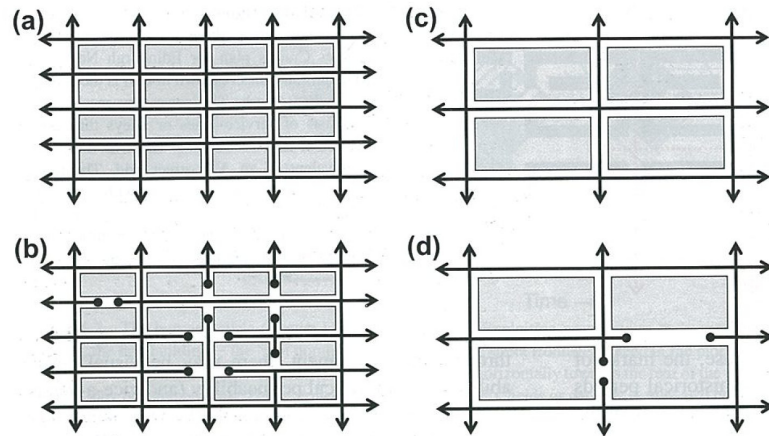


Fig. 2.4 Street Grid Permeability Comparison, (a) Fine continuous grain, (b) Fine discontinuous grain, (c) Coarse continuous grain, (d) Coarse discontinuous grain.

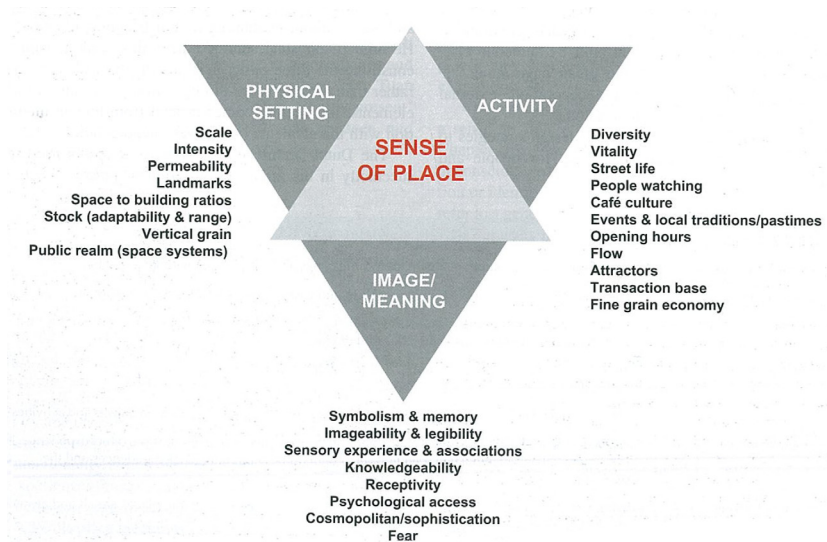


Fig. 2.5 (Image adapted from Montgomery 1998) This diagram illustrates how urban design actions can contribute to, and enhance sense of place.

tween them or the 'public network' of spaces. This is probably the most historically significant element of morphology as it can include fragments of street patterns from different eras. Street patterns also contain a number of important urban design elements that include Accessibility, Permeability (visual and physical and sonic), and Urban Grain (Fig. 2.4).

#### 2.4.4 Social Requirements

Rather than designing to determine human actions or behaviour, urban design can be seen as a means of aiding the perpetuation of certain activities or behaviours. The maintenance of existing social and physical environments is the driver for successful Identity-Based Urban Design. Figure 2.5 illustrates how these urban design drivers contribute to sense of place.

Carmona discusses the requirement for 'safety and security' in the urban environment. While natural threats are generally managed, human threats (i.e. crime, pollution) are on the increase. A sense of security is a prerequisite for successful urban design. Crime can be tackled through many measures, but a few urban design techniques include:

- Control of Space; clear demarcation between public and private, controlling access
- Surveillance; eyes on streets, public thoroughfare, routine property use
- Activity; sufficient numbers, mixed-use to promote continuous activity

(2010, pp. 151)

### 2.4.5 Aesthetics

Jack Nasar identifies five attributes of preferred aesthetic environments;

- Naturalness; predominance of nature over built environment
- Upkeep/Civilities; environments that are looked after/cared for
- Openness/Defined Space; blending open space with vistas
- Historical Significance/Content; favourable associations
- Order; organises, coherent, legible, clear

(as cited in CARMONA ET AL., 2010, p. 169)

Carmona argues that a degree of 'enclosure' is important in providing a positive space for pedestrians. This is achieved primarily using surrounding buildings. However the degree of enclosure must also be balanced with connectivity and permeability to prevent Closure, a state perceived uncomfortable for pedestrians.

Squares fall into this category, generally framed by buildings; these are designed as people places for public function. Figure 2.6 presents the range of square types, the spaces which form the social environment of urban space (2010, pp. 175-180).

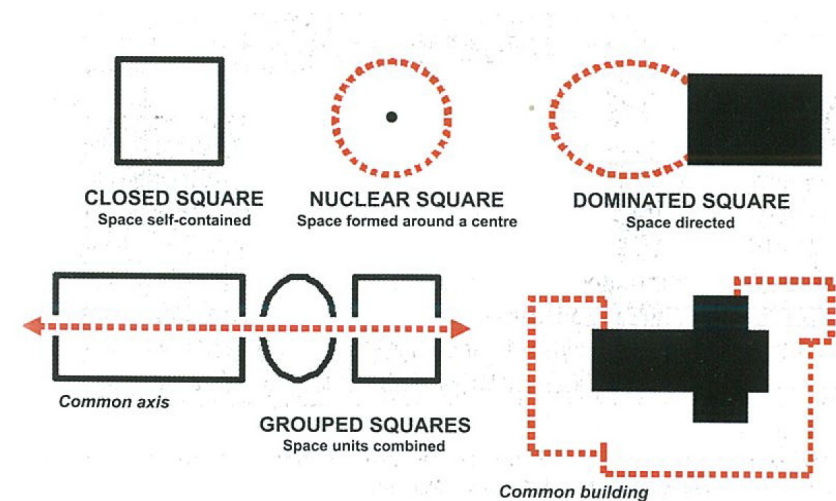


Fig. 2.6 Paul Zucker's Typologies of Urban Squares.

Streets do not refer to roads, primarily for vehicular use, but tend to be one of the most image-able spaces in the urban environment; creating enclosure, encompassing life, and facades, all of which contribute to the character of streets. Ratios of building height to street width are also important in determining the character of the street. Figure 2.7 illustrates the perceived effect of different street width to building height ratios.

### 2.4.6 Urban Architecture

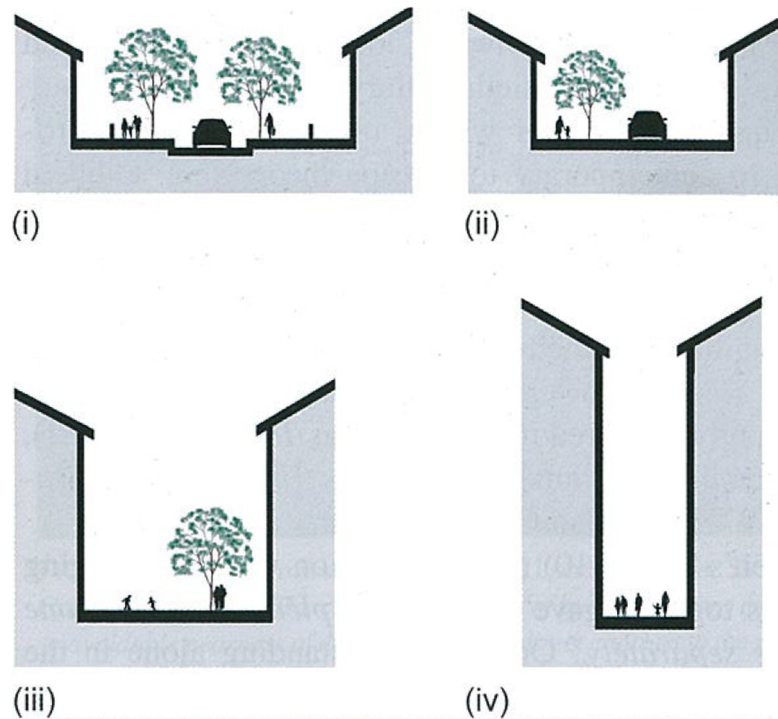
‘Public Places, Urban Spaces’ gives an example of 6 criteria set out by the Royal Fine Arts Commission (RFAC) in the United Kingdom. These include;

- Order and Unity (symmetry, balance, repetition etc.),
- Expression (of use, significance, hierarchy, creating legibility),
- Integrity (in terms of design principles, architectural context, morality),
- Plan and Section (self-explanatory, considering the building’s three dimensionality),
- Detail (both visual interest and elegance of the façade), and
- Integration (how the building harmonises with its surroundings)

(2010, pp. 186)

### 2.4.7 Landscape & Floor-scape

While landscaping is often considered as an after-thought in urban design, its visual and ecological importance should make it an integral part of the urban design framework. ‘Greening’ of towns and cities is a key sustainability objective. ‘Floor-scaping’ also has many functions, emphasising traffic flows of certain paths, to separating road from pavement, illustrating ownership, directing etc. Landscape and Floor-scape should adhere to the same conditions of the urban architecture (2010, pp. 193-199). These principles also have an important influence on the acoustics of Urban Space.



**Fig. 2.7** Height to Width ratios of Street Enclosure. (i) 1:4 ratio; with low walls in relation to street width, views are not sufficiently contained to provide a sense of enclosure. (ii) 1:2 ratio; equal amounts of visual fields devoted to street wall and sky providing better enclosure. (iii) 1:1 ratio; often considered the minimum for a comfortable urban street. (iv) ratios greater than 1:1 reduce light penetration into street spaces and may be claustrophobic.

#### **2.4.8 Function**

The Functional Dimension is made up of multiple factors, a series of texts identify five primary necessities of satisfactory public space;

- Comfort; The length of time people stay is an indicator of the comfort of a space. This could be acquired in a number of ways like relief from environment factors such as sun and wind, sufficient comfortable seating, psychological comfort, etc.
- Relaxation; This may include providing natural elements like trees, water features, or providing sanctuary from visual access.
- Passive Engagement; Things like the ability to people watch, viewing buskers etc.
- Active Engagement; Creating opportunities for contact with known people.
- Discovery; Desire for new spectacles

#### **2.4.9 Movement**

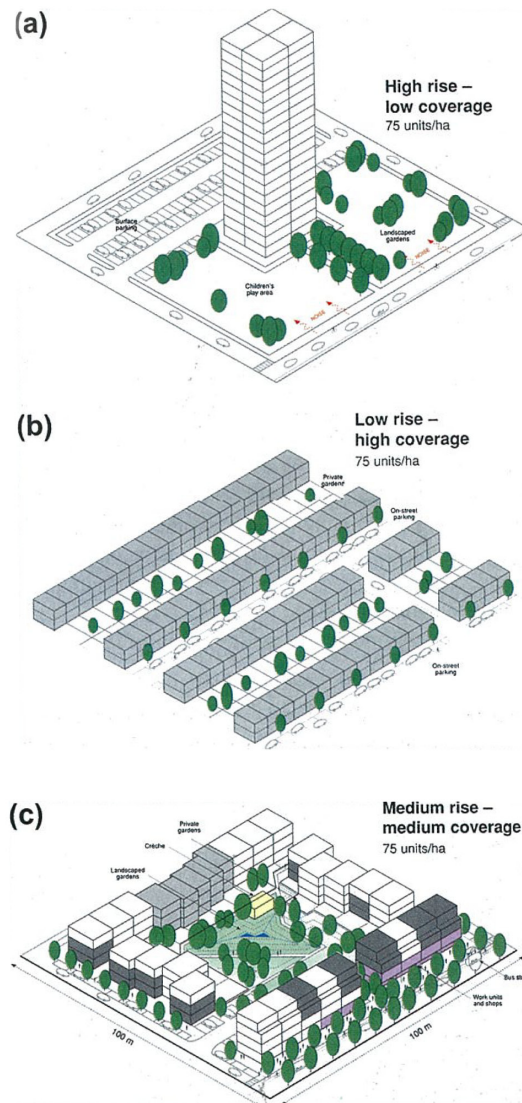
At the heart of the urban experience is movement; created by implementing worthwhile destinations that are easily accessible by foot. The social experience of the journey is less important in a car and is therefore unimportant in this context. Pedestrian journeys are seldom single purpose, Hillier terms the potential use of space as the by-product of movement (as cited in CARMONA ET AL., 2010, pp. 202).

**Fig. 2.8** A comparison of urban form configurations with the same density level (75 dwellings per hectare);

(a) High rise development standing in open space; No private gardens, poor amenity, no direct relationship to surrounding streets and buildings, large open spaces requiring management and maintenance.

(b) Street layout with 2-3 storey houses; Front and rear gardens, continuous street frontages defining public and private space well, high site coverage minimising the potential for communal spaces.

(c) Urban Perimeter Block; Variety in surrounding building heights and configurations, buildings arranged around landscaped community-based open space, Potential for commercial and public activities on ground floors.



#### 2.4.10 Privacy

The edge of the public network needs to both interact and mediate between public and private space. In urban space, privacy is usually defined by selective access, but it can be obtained in a number of ways. Visual and Aural control are the two primary methods of gaining privacy. Rather than a duality of public/private, there is a spectrum of privacy needs. Softer, more permeable screening between the two domains is often more desirable. In terms of undesirable sound, measures like distancing, sound insulation, screening and barriers can be used to remedy such a situation.

#### 2.4.11 Mixed-Use and Density

Sufficient density of activity and people is essential for the vitality of an urban area, and for creating necessary mixed-use. Jane Jacobs describes 300 to 500 dwellings per hectare as an ideal density for the optimum urban environment.

It is the overlapping of activities and the mixtures of uses that cultivate diversity within city streets and districts. To blur the lines of the city, zones should not be separated by roads but overlap (2010, pp. 225).

Figure 2.8 illustrates examples of varying dwelling densities achieved in a single hectare.

## 2.5 Soundscape

### 2.5.1 Conception/ Philosophy

The formation of Soundscape Philosophy and Acoustic Ecology is directly linked to the wave of ecological movements that grew through the 60's and 70's, in response to emerging environmental problems related to recent technological innovations (PAQUETTE, 2004, p. 5).

With noise pollution of the public arena becoming a global problem, new motivations for the invention of soundproofing arose (BLESSER & SALTER, 2007, p. 106).

*“In a quiet world, built acoustics flourished as an art of sonic invention. In a noisy world it becomes merely the skill of muting internal shuffles and isolating incursions from the turbulent environment beyond” (SCHAFER, 1993, p. 222)*

The philosophy underpinning Acoustic Ecology/Soundscape is straight-forward: its founder - R. Murray Schafer, a musician, composer and former Professor of Communication Studies at Simon Fraser University (SFU) in Burnaby, BC, Canada - suggested that we try to hear the acoustic environment as a musical composition and further, that we own responsibility for its composition. Schafer notes that there is an incredible dominance of the visual modality in society - ‘eye culture’ as it has been termed elsewhere (WRIGHTSON, 2000, p. 10).



To Schafer, 'Acoustic Design' meant discovering the principles by which the aesthetic qualities of the acoustic environment may be improved. These principles include the elimination or restriction of certain sounds through noise abatement, the preservation of sounds that give character or sense of place to a location ('Sound-marks' as the acoustical equivalent of visual landmarks), or imaginative placement of sounds to create attractive and stimulating environments.

In Schafer's book 'The Soundscape: Our sonic environment and the tuning of the world', he categorises environmental soundscapes into two separate fields, hi-fi and lo-fi soundscapes;

- A hi-fi system is one possessing a favourable signal-to-noise ratio. The hi-fi soundscape is one in which discrete sounds can be heard clearly because of the low ambient noise levels. The country is generally more hi-fi than the city; night more than day; ancient times more than modern. In the hi-fi soundscape, sounds overlap less frequently; there is perspective; foreground and background...
- A lo-fi system obscures individual acoustic signals in an over-dense population of sound. Sound becomes something that the individual tries to block, rather than to hear; the lo-fi, low information soundscape has nothing to offer. As a result, individuals have tried to shut out the soundscape using methods such as noise abatement, or acoustic perfume; MP3 music etc.

(WRIGHTSON, 2000, pp. 11-12)

### 2.5.2 Science vs. Perception

The literature is split between the physical and psychological problems sound creates for people, and it is this ambiguity that has prolonged a holistic solution to problem. In Blesser and Salter's book 'Spaces Speak, are you Listening?', they consider how contemporary terms of sound have become a method of quantification rather than experiential;

- Acoustics; Originally derived from Greek pertaining to hearing; now refers mostly to the behaviour of sound waves in solids, liquids and gases.
- Aural; Parallels visual, refers exclusively to the human experience of a sonic process.
- Hearing; To detect sound.
- Listening; To active attention or reaction to the meaning, emotions, and symbolism of sound.

(BLESSER & SALTER, 2007, p. 5)

Early literature on Soundscape admits that it is difficult to determine a solution to a problem that is perceptual and therefore unique to individual cultures and situations. However, it was the introduction of perception as a variable that stood 'Soundscape Philosophy' apart from historic conventions of noise abatement. Additionally, as a relatively young field of research, 'Soundscape' confesses a necessity to integrate these differing perspectives into the solution.

*"From a psychological perspective, we don't so much hear sound as perceive sonic events; sound transports those events into our consciousness. Where a landscape might sometimes appear static, a soundscape is defined as never static."* (Blesser & Salter, 2007, p. 15)



### 2.5.3 Sound Classification

Schafer talks about the classification of sound and its current lack of integration (1993). Currently sound is classified in several ways;

- Physical Characteristics (acoustics)
- Perceptual (psycho-acoustics)
- Function and Meaning (semiotics and semantics)
- Emotional or Affective Quality (aesthetics)

Historically these classifications have been treated separately. The isolated nature of these studies, however, yields limitations to their wealth of information;

*“To split a total sound impression into its component parameters appears to be a skill that must be learned; and while it is probably one that is necessary for acoustic design, a soundscape cannot be understood merely by a catalogue of such parameters, even if that were possible, but only through the representation formed mentally that function as a basis for memory, comparison, grouping, variation and intelligibility” (SCHAFFER, 1993, p. 133)*

As Schafer stipulates, for the study of Soundscape to develop, there has to be a synergy between isolated disciplines. Integrative Sound Classification will play an important role in a more holistic approach to the Urban Design of acoustic environments.

#### **2.5.4 Urban Design Application**

To best determine what constitutes a high quality soundscape in an urban environment, the function of space must be defined as a whole. This approach is highly contextual, and will often result in a biased reading of the sounds around us and their significance, resulting in the creation of a 'Place-based Identity'.

Schafer proposed an ecological model to deal with growing problems of noise and the way we should design our environment. Paquette further clarifies; when Soundscape is studied under the realm of architecture and urban design, the emphasis shifts from the ecological expressions of the natural environment, to social expressions of the built environment, the way it is fabricated, and then experience of it's inhabitants (2004, p. 3).

Schafer states that sounds of a particular locality can express a community's identity (keynotes, sound signals, sound marks). Unfortunately, since the industrial revolution, an ever increasing number of unique soundscapes have disappeared completely or submerged into the cloud of homogenised, anonymous noise that is the contemporary city soundscape, with its ubiquitous keynote – traffic (WRIGHTSON, 2000, p. 10).

## 2.6 Perception/Psycho-acoustics

Aural Perception, as field of research, is considered to have originated from the foundation of Soundscape Philosophy. This section first reviews literature based on general perceptions of the urban environment (including aural perception of the sonic environment), and then presents a review of literature that looks at more specific examples of the effects of aural perception on ones individual acoustic environment.

### 2.6.1 Urban Environmental Perception

Vision is widely regarded as the dominant sense orientating us in space; as it is the only sense that is active. We look for things, but sounds and smells come to us. These senses might appear less informative, but can provide people with far more emotional richness.

Perception is more than just cognition. It involves;

- Cognition; making sense of the environment by organising information.
- Affect; involving our feelings which influence and are influenced by our surrounding environment.
- Interpretation; considering meaning or associations derived from the environment.
- Evaluation; incorporating personal preference, determining whether the environment is 'good' or 'bad'.

(CARMONA ET AL., 2010, p. 112)

Lang argues that concern for the 'sonic environment' should - in specific settings - focus on increasing the positive sounds of an environment's soundscape, and that this can be treated in much the same way as its visual qualities by the choice of materials used on surfaces and the nature of objects within it (1994).

In Lynch's book, 'The Image of the City' (1960), he argues that the ease with which one can navigate a city is determined by how one perceives certain frames of reference within a city's fabric. These can be described in terms of Identity, Structure and Meaning. From his research he derived five key elements;

- Paths; where major paths lack identity imagery is less clear.
- Edges; important organising features, visually prominent, impenetrable.
- Districts; an area of thematic continuity in a certain area.
- Nodes; concentrations of junctions of functional and physical significance.
- Landmarks; points of reference to the external observer, typically 'seen' from many angles. Uniqueness and Singularity define a landmark.

To develop a contextually appropriate identity, places must;

- Be responsive to and based on environmental features crucial to their identity.
- Participate in future uses.
- Be modifiable and adaptable to cater for the need of individual identity.

(as cited in CARMONA ET AL., 2010, p. 113-116)

Southworth regards sound as an important asset in the urban environment. Locations with quiet foregrounds allow sound views to other parts of the city. Elevation enhances this effect.

One should also consider how the soundscape of space varies depending on the time of day. Settings tend to have more clarity during the early morning, evening and weekends. Traffic can, however, dominate the sound environment during peak times and mask informative sounds.

Through individual accounts during Southworth's study of the Boston Soundscape, it was concluded that the ability to identify individual sounds (especially those of other people) was an asset to public spaces. Conversely, ambient noise that hinders sound identification (i.e. low traffic roar) weaken a space's acoustic environment (SOUTHWORTH, 1969, p. 59).

### **2.6.2 Visual Relationship to Sound Perception**

The functions of sound in the urban environment are to both enrich and protect. Many designed informational cues appeal to both sound and vision (i.e. crossing signals). A place that is pleasing has to appeal to more than the eye. In Southworth's study of Boston, it was found that the most identifiable places were those that contained visible external activity and had unique spatial characteristics such as tight narrow hard street spaces. Spaces seemed more meaningful and could be perceived more clearly when one could hear echoes of their own sounds (SOUTHWORTH, 1969, p. 55).

Human perception is by nature multi-sensorial. An 'Urban Sound Scene' is rarely perceived in isolation, but rather apprehended fully with additional information from other sensory modes such as vision and touch. Together, these various sources of information give rise to a mental representation of the perceived environment (VIOLLON, LAVANDIER, & DRAKE, 2002, pp. 493-494).

In an experiment conducted by Viollon et al., people's visual preference with regards to the aesthetics of a traffic noise barrier was examined. It was found that perception of road traffic noise transmitted through barriers varied according to the visual degrees of pleasantness and efficiency (as cited in KANG, pp. 196-197).

Kang, in 'Urban Sound Environments', also alludes to an experiment conducted by Aylor & Marks (1976), in which they determined that perception of loudness is significantly affected by line of sight. When a sound source is partially obscured by a sound barrier, noise level is perceived as reduced, whereas when the source is fully obscured, noise level is perceived as increased. Therefore total visual shielding from sound sources could potentially render a noise more intense/annoying.

### **2.6.3 Demographic Disparity in Sound Perception**

Regardless of how well an Urban Soundscape is designed, you cannot cater for the sonic preference of all users all the time. In order to ensure that a range of demographics are catered for in the Urban Design Proposal, it is necessary to understand how demographics prefer different sounds.

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### **Cultural differences**

In a cross-culture soundscape study of five countries in Europe, it was determined that all countries had a similar tendency to prefer nature and culture-related sounds, and to reject construction and vehicle sounds (YANG & KANG, 2003).

However, there were significant differences in preference of other sounds between cities. Over 50% of interviewees in Kritis Square (Greece) rated surrounding speech as 'annoying', whereas in Kassel (Germany) less than 1% rated the sound annoying, and in Sesto San Giovanni (Italy) nearly 45% rated the sound as 'favourite'. The study suggested cultural preferences of certain sounds may be due to long term differences in environmental conditions.

### **Age based differences**

In a further study on two squares in Sheffield (UK), it was shown that the acoustic preferences between age groups differ significantly. This suggests that young and old people evaluate sounds in fundamentally different ways. Generally speaking, with an increase in age, people are more favourable to, or tolerant of, sounds relating to nature, culture or human activities. By contrast, younger people favour, or are tolerant of music and mechanical sounds (YANG & KANG, 2005, pp. 77-78).

## **2.7 Conclusion**

This chapter has established the context in which my design-research takes place. The success of this design-research thesis lies in comparing existing 'Urban Design Principles' and recently developed 'Soundscape Design Principles'. By finding areas of contradiction and crossover between the two disciplines, an evaluation of their compatibility can be conducted. The results of this analysis will be reflected in the 'Urban Design Proposal' results, and the subsequent discussion that takes place.



### 3. ESTABLISHING SOUNDSCAPE PRINCIPLES AND ANALYSING ANECDOTAL CASE STUDIES

#### 3.1 Introduction

The notion of Soundscape is still relatively young. Its principles are closely tied to those of the ecological/sustainable movements of the seventies. This adolescent stage of field development is reflected in Soundscape's lack of presence in government policy and design regulations today. It is also reflected in both the limited number, and restricted range of case studies typically found on the subject, be it 'early stage planning' or 'analysis of existing areas'. Finally its youth is reflected in the convoluted nature of the language used in recent Soundscape research, as a consensus on field terminology has not yet been established (refer to Appendix 1 for terms).

In this chapter, case studies from the field of Soundscape Analysis/Design are evaluated to establish key principles and issues that are present in urban acoustic design today. The effectiveness of Macro-level Soundscape Planning and Micro-level Design Strategies are also discussed.

## **3.2 Soundscape Principles**

The first section of this chapter outlines the well-established principles of Soundscape Design and the typical acoustic design tools used to uphold these principles.

### **3.2.1 Siebien et al. : Defining an acoustic palette for Urban Design**

In a Soundscape study undertaken for the 13th International Congress on Sound and Vibration, an acoustic palette for Urban Design interventions was developed. The paper outlines design strategies that included reducing, buffering and mitigating undesirable existing sounds; preserving and enhancing desirable existing sounds; and introducing elements that bring with them new sounds and activities that are designed to enhance the acoustical, architectural and social life of a district (SIEBEIN, KWON, SMITTHAKORN, & GOLD, 2006). The following section summaries these strategies in detail.

#### **Reduction Techniques**

Firstly, reducing noise at the source is investigated. The transportation network generates the majority of irritating urban noise (i.e. cars, rail, air, etc.), and while cars are getting quieter, urban design methods of reducing traffic noise should be considered. By designing the street environment to encourage lower speeds (speed bumps, on-street parking, pedestrian crossings, vegetation, etc.), noise from traffic can be significantly reduced. These noises can also be masked using desirable sounds like flowing water/fountains or active play areas.

### **Masking/Buffering Techniques**

Masking plays a role in buffering public spaces from noise sources. By using positive sounds to mask areas for public activities, more comfortable gathering spaces can be created. Buffering is accomplished by separating spaces through distance or topography, adding landscaping buffers (rises and falls) or noise barriers. The use of buildings to buffer public space from noise sources should also be noted as a very efficient method.

Where the above techniques are unable to be implemented, more drastic measures may need to be used such as completely enclosing pedestrian or vehicular routes (i.e. Tunnelling or bridging sources or receivers). This could be considered a severe form of buffering.

### **Sound Preservation**

If desirable sound-marks exist within an area, it is important to preserve them to maintain a sense of place and identity. Unique sounds are evident all over the world, some of which are noted below;

- In Rotorua (New Zealand), fields of boiling sulphur, spread over acres of ground, are accompanied by underground rumbling and gurgling.
- In Melbourne (Australia), the sound of leather straps on the trams as they twist around long horizontal support poles, squeaking richly.
- In Paris (France), the brilliant slam of the doors of the old carriages of the Paris Metro.

(SCHAFER, 1993, pp. 26, 240)

Preserving these worthwhile sounds can be achieved by zoning various activities that can use and/or enhance the sound-marks. For example, bicycle and pedestrian paths, dog-parks and sports fields can be located adjacent to natural areas rather than locating transportation arteries in these areas (SIEBEIN ET AL., 2006).

### **Sound Insertion**

Adding new acoustical elements to the soundscape that are not present in the existing community may complement Architectural and Urban Design objectives. These could include; importing natural sounds into areas (e.g. Fountains, flowing water, textured walking and driving surfaces, wind sculptures, trees for bird life), allowing sounds from gathering activities to propagate encouraging participation, or importing specific sounds of social significance like clock towers or background/foreground music. Designed areas of quiet repose where people can retreat from urban cacophony could also be inserted (SIEBEIN ET AL., 2006).

### **3.2.2 Summary**

The preceding section has clearly defined the tools and strategies used to realise those principles. In order to create an acoustically rich environment, unwanted sounds must be reduced, mitigated or buffered, and desirable sounds should be preserved, maintained and potentially introduced. Inclusion of these design strategies will not only enrich the urban acoustic environment, but yield a far more desirable social environment for public use.

### **3.3 Integrating Soundscape Principles into Urban Design**

The following case studies provide a number of precedents for the integration of Soundscape Principles into the urban design process. These case studies will help to establish a framework under which my Urban Design Proposal will take place.

#### **3.3.1 Hedfors : Early Stage Urban Planning and Design**

Research in the field of environmental psychology has highlighted the need for varying levels of complexity within our environment, but with ever increasing global urbanisation, a vast array of unique local soundscapes are being lost. While auditory design has not been a conscious part of the planning and design phase to date, by adopting it we can take a step towards avoiding acoustic homogeneity (HEDFORS, 2003, p. 59).

The variety and contrast provided by existing unique sounds needs to be promoted in the planning and design process, establishing/maintaining the identities of different places. It is diversity and complexity that both sustains public engagement, and contribute to a sense of place-based identity. Hedfors outlines a couple of Urban Acoustic Design strategies that seek to retain that sense of place and variety/complexity;

- ‘Auditory Refuge’; defined as a place where listeners perceive themselves to be in control of their acoustic environment. The expression ‘refuge’ in his research is used to describe a place which offers an alternative and often contrary acoustic environment to that of the surroundings. In a broader sense, the expression ‘Auditory Refuge’ refers to the development and protection of squares, walkways, parks and landscapes with various acoustic qualities.

- Isolated refuges can be connected by 'Acoustic Corridors/Paths'; The concept of such corridors is prominent in urban design practice with regards to park networks or 'Green Corridors', and can be easily appropriated to accommodate an auditory element.

These design strategies align well with good urban design practice, and could easily be implemented into the planning process of a new urban development.

### 3.3.2 Coensel et al. : The Soundscape approach to Early-Stage Urban Planning .

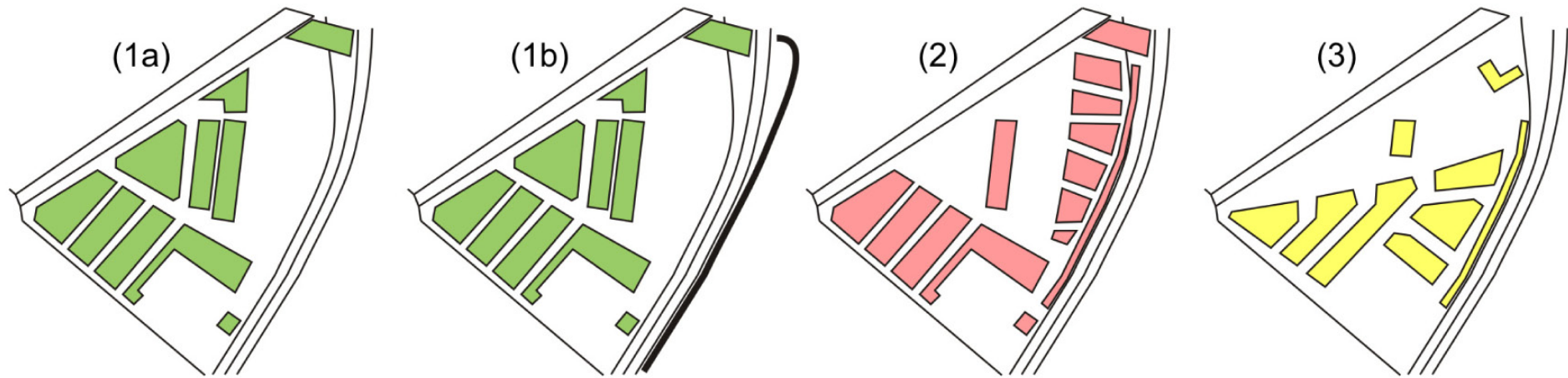
This conference paper provides a comprehensive model for integrating Soundscape Principles into the Early-Stage Urban Planning process. The case study is located in the south-eastern part of the 19th century city belt of Antwerp, Belgium. The area is enclosed by an elevated railway to the north, a residential area with minor roads to the south, and a major road and a freeway to the east. Figure 3.1 illustrates the site and its architectural character.

The area is to be redeveloped into a residential area, with room for an urban park and an elementary school, with roads but without through traffic. The Acoustic Planning Methodology was carried out in two stages, differing in their level of detail;

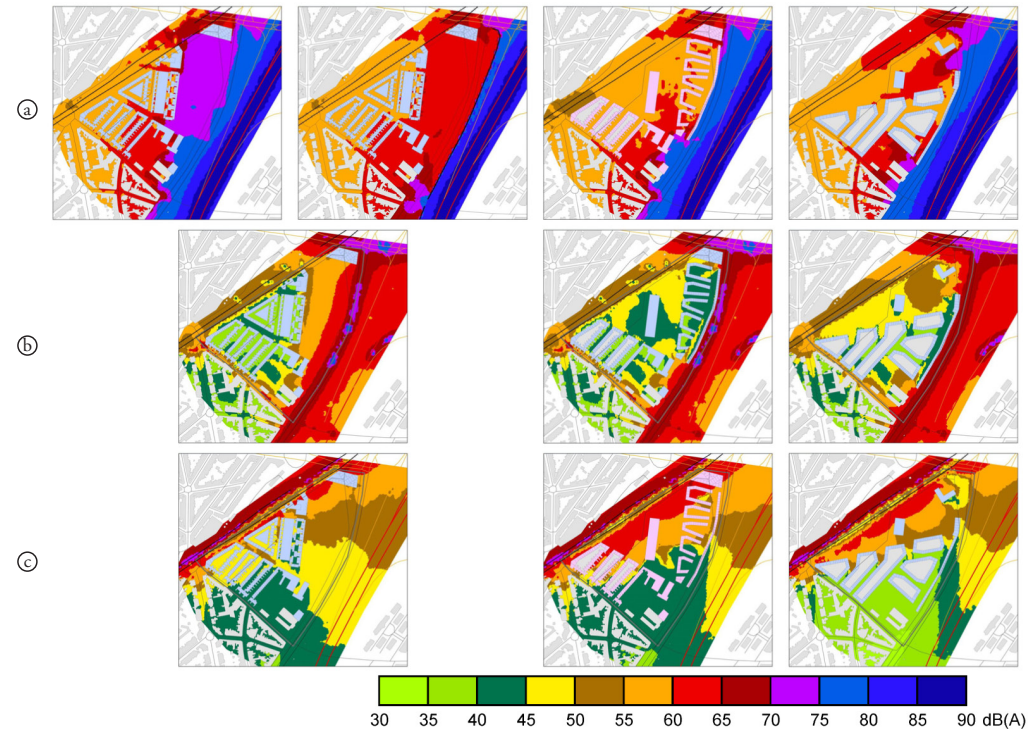
- Stage one consisted of giving advice on the placement of buildings blocks and the park. The main concern for this stage was that all acoustic objectives were met, i.e., Sound Pressure Levels (SPL) for dwellings met local guidelines. The park in question had to be of a SPL low enough to permit creative potential for soundscape design, ‘providing a place of psychological restoration.’
- In Stage two, advice was given on the detailed acoustic design of the public space, which extends beyond mitigating noise. The goal was to shape an acoustic environment ideal for the intended use of the space, integrating sound from local activities. This would entail creating a diversity of acoustic conditions on site from lively to quiet areas, natural to urban.



Fig. 3.1 (left)Antwerp, site for the Urban Planning Proposal, (right) Contextual photos of the existing site .



**Fig. 3.2** Varying Urban Planning Scenarios. (1a) urban park situated on western edge, (1b) same as 1a with the addition of a noise barrier along the freeway, (2) park situated in the centre of the site and the freeway lined with buildings, (3) park forms a peg from western to eastern edges with artificial mounds on the western edge.





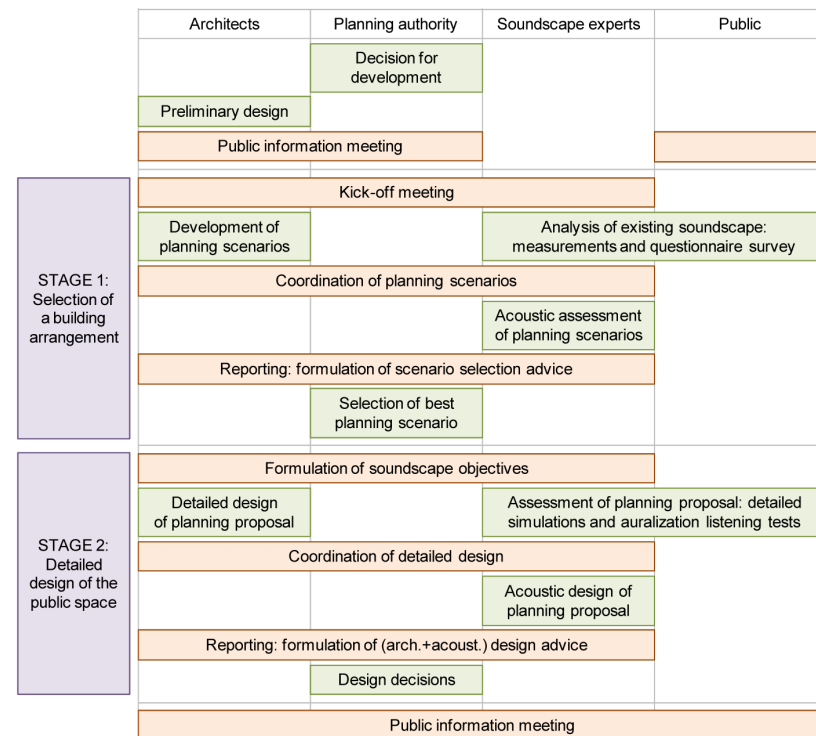


Fig. 3.4 Urban Soundscape Planning Process.

The stages of this urban design approach are diagrammed in Figure 3.4. In order to develop a comprehensive recommendation for the two stages of the planning process, the site was surveyed from a number of angles, including;

- A quantitative analysis of the existing acoustic environments through long and short term noise measurements,
- A Questionnaire Survey conducted on current neighbourhood residents, who listed pros and cons of their existing living situation, and what they would like to see from a new park,
- Advice sought from Architects, Soundscape Experts and the Planning Authority.

After the completion of the survey process, a series of building layouts were modelled and noise maps constructed. Figures 3.2 and 3.3 display the series of urban layout iterations and the results from the noise mapping exercise. These results were then compared to find the iteration that performed best in terms of residential noise exposure.

Stage 2 of the planning process, 'Advice on a detailed design of public space', assumes the building layout is now fixed. Areas of acoustic opportunity are worked out in detail, including a variety of acoustic environments, and integration with local activity. This paper was, however, printed as a work in progress and only the first stage was finalised.

This conference paper provides a great precedent for implementing Soundscape Principles into the Urban Design Process. Figure 3.4 also outlines the people involved and the degree of input they have. Elements of this paper begin to lay the foundations for my design methodology.

### 3.3.3 Ryden : Applying Architectural Acoustic Design to Railway Stations

As with all types of urban space, we use both visual and auditory cues to understand our surroundings and inform our actions. Good urban design seeks to optimise these cues for the comfort and safety of its inhabitants. To date, the design of auditory cues has been underutilised.

For the 12th International Congress on Sound and Vibration, a paper by Leif Ryden looked at the application of Architectural Acoustic Design in the 'City Line' train station in Stockholm, Sweden. The acoustic consultancy company 'Ingemansson Technology AB' investigated a number of general questions;

- What types of activities take place within the different spaces (e.g. Entrance, passage and platform)?
- What relationships are there between sounds and activities?
- What criteria are desirable within the different spaces – in regard to acoustic and architectural design, information, communication, orientation and aesthetics – and how can these criteria be fulfilled by acoustic design?

(RYDÉN, 2005, p. 2)

The first spatial typology analysed was the 'Path/Transitional Space'. With the sole function of movement and no variety of activity or facilities, these spaces create an atmosphere of discomfort and unpleasantness. It is therefore important that these environments are designed to be as comfortable as possible.

The established criteria in this spatial typology involves;

- Breaking the monotony,
- Slowing down the fast tempo,
- Creating a dynamic atmosphere, and
- Establishing a safe and secure environment.

These criteria are then articulated through the acoustic design of space. The design strategy discussed in this case study is one of creating a longitudinal rhythm for long passages by varying acoustic conditions.

This is achieved through a shift between absorbent and reflective materials along the passageway, weakening and enhancing sound reflections (creating an acoustically dynamic space). A series of spatial nodes where the rhythm shall be articulated are determined; the material in these nodes consists of reflecting materials, such as enamelled steel sheet or tempered glass. To intensify the spatial and dynamic effects, the variation of acoustics could also be synchronised and supported by lighting design (RYDÉN, 2005, pp. 3-4).

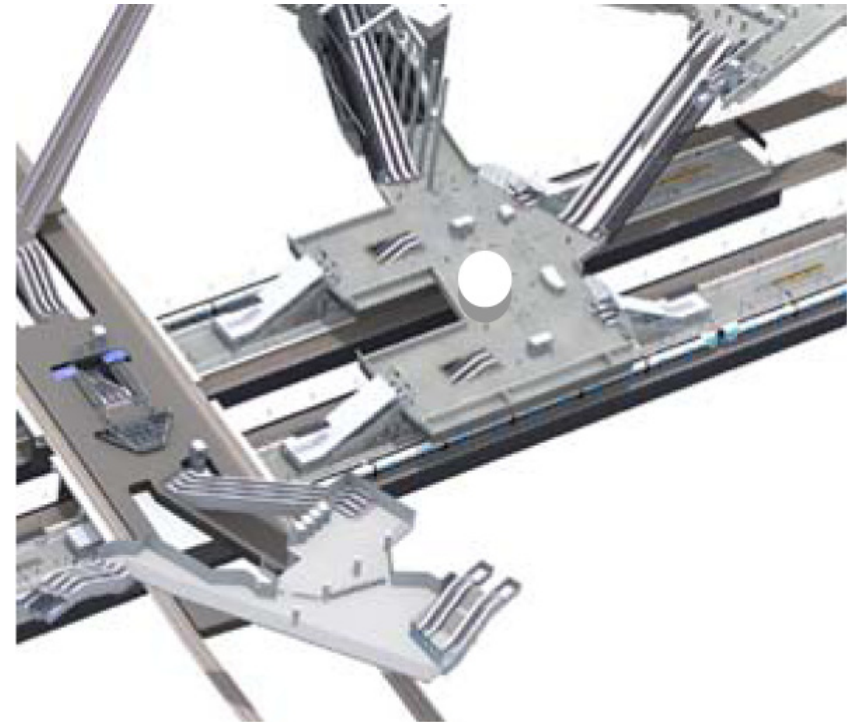
Another intervention method noted in this case study (one I will not pursue), is the introduction of electronic sound into the urban environment. 'Entrance Hall/Platform' environments can be very stressful, especially during rush-hour traffic. In this respect, there is a need for private spaces. Such private spaces are often created by the distribution of music and sounds via loudspeakers, i.e. by creating a qualitative sonic space, which differs from the surrounding sound environment and which has a relaxing effect on people.

This approach often fails. For instance, some metro stations in Paris play ‘Muzak’ on the platforms (e.g. Magenta and St Lazare station). The intention is to create a qualitative sonic ambience, a ‘sound perfume’ that makes people feel comfortable. Yet, it has the opposite effect. Instead of enhancing qualities, the music adds to the public hubbub, reducing the subtle borders between public and private spaces.

Finally, the case study focuses on the ‘Central Atrium’ of the station. As the meeting point for a number of passage ways, the central atrium needs to display an acoustic spectacle. Large domes function as the type of semi-spherical cupolas one finds in cathedrals and churches, often with a huge reverberation time. Figure 3.5 displays the City-line Train station plan.

Hence, a sound dome may execute a well-defined sonic space, differing from the surrounding sonic space. The spatial sonic effects within the radius of the dome are articulated by its specific acoustic qualities; reverberation time, intensity and propagation. The particular geometry within the radius also produces different focal points, which may strengthen the transmission of sounds to certain spots.

Acoustically speaking, sound domes could provide favourable open and enclosed spaces; the dome acts as a well-defined sonic space that contrasts with surroundings. What the dome provides is not a precedent for atrium design, but an example of how a contrasting acoustic environment can create spectacle, and therefore interest. Where a dome is not practical, elements like reverberation, propagation and focal point can be designed using simple architectural curves.



**Fig. 3.5** Plan view of the City Line Train Stations. The Central Atrium is illustrated as a white dome in the centre of the plan.



Fig. 3.6 St Paul's Cathedral, upper level whispering gallery.



Fig. 3.7 Barossa Reservoir, South Australia, the sweeping curved dam surface acts as a whisper gallery.

An interesting acoustic phenomenon that occurs in several places around the world is that of a whispering gallery (Fig. 3.8). The whispering gallery effect occurs when a sweeping curved surface reflects multiple sound waves from a source sound to a receiver point, amplifying that sound. Examples of this include;

- St Paul's Cathedral, London - Inside the upper level of the cathedral dome, a whisper from any point along the gallery (diameter of 30m) can be heard from any other point with an ear to the wall (Fig. 3.6).
- Barossa Reservoir, South Australia - Here, the sweeping curved surface of a water dam allows words whispered from one side to be clearly heard more than 100m away (Fig. 3.7).
- Temple of Heaven, Beijing - The Echo Wall surround the temple can transmit sounds over large distances.

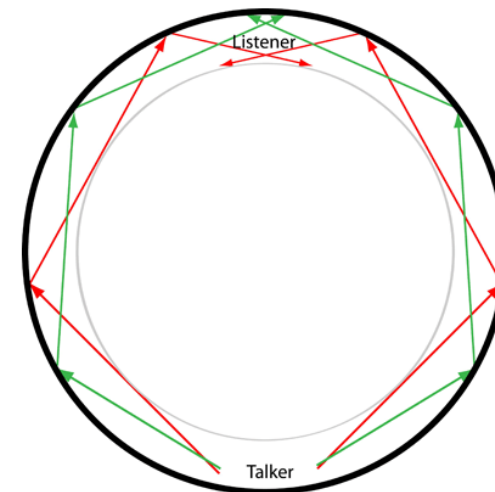


Fig. 3.8 Whispering Gallery Acoustics; multiple reflections from the source (talker) reach the listener, thus amplifying the source sound level.

### **3.4 Effects of Hierarchy and Morphology on Urban Acoustics**

Transportation hierarchy is particularly significant to the urban acoustic environment. The following case study evaluates the effects of Urban Morphology on the sonic environment of two cities (Eastern and Western) in an attempt to find patterns.

#### **3.4.1 Wang et al. : Effects of Urban Morphology on Noise Distribution: A Comparison between the UK and China**

This 'International Congress on Acoustics' (ICA) study observed the relative noise distribution of traffic over urban areas of similar character in the cities of Sheffield (UK) and Wuhan (China). The method for this study takes place in three stages;

- Sampling of typical urban areas,
- Noise mapping (using CadnaA noise propagation software) and,
- Determining indices for characterising noise distribution and urban morphology.

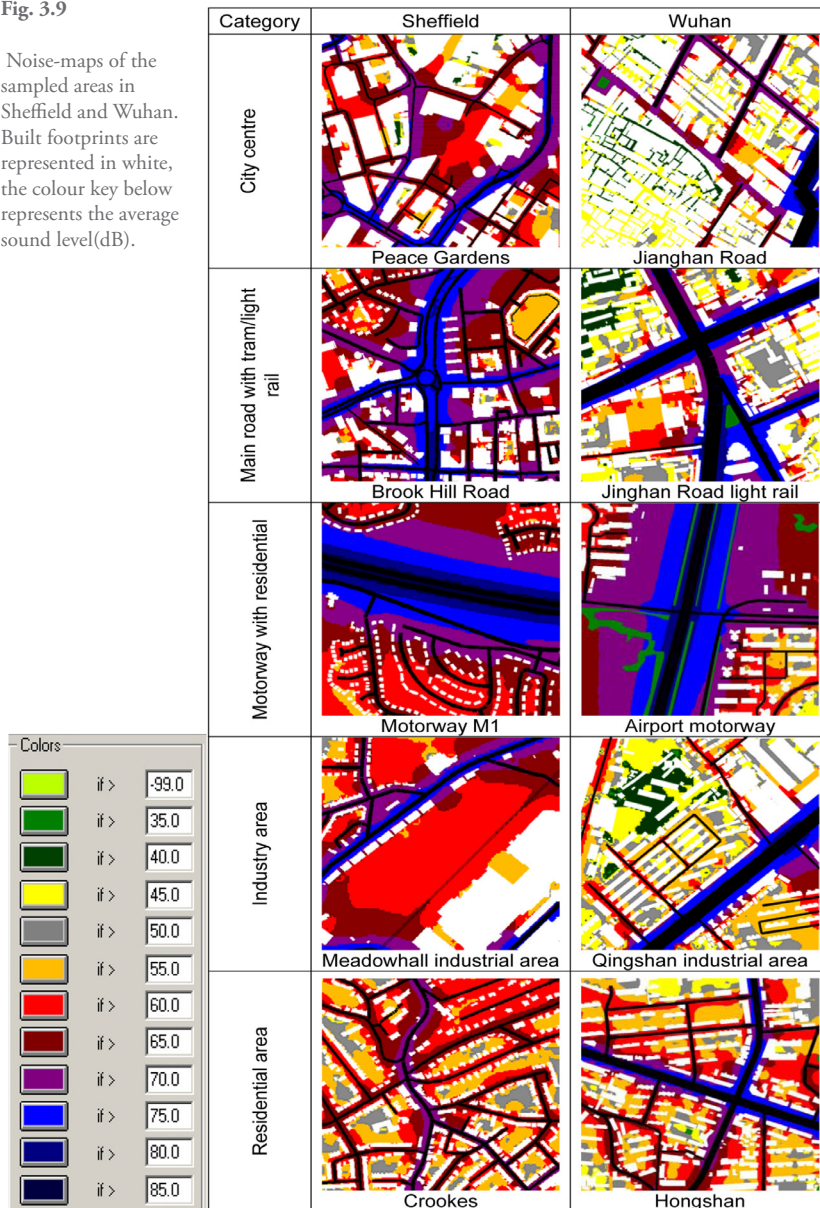
In each city, five 500m<sup>2</sup> areas were sampled including; the city-centre pedestrian area with surround streets, a main road with light rail, motorway with adjacent residential buildings, an industrial area with some residential buildings, and a typical residential area.

In order to create a comparable study, the calculations for both cities were based on British International Standards, with most parameters set to standard values. Building heights were estimated from on-site observation and traffic flow was based on on-site surveys. Figure 3.9 shows the resultant noise maps of the 10 sample areas.



Fig. 3.9

Noise-maps of the sampled areas in Sheffield and Wuhan. Built footprints are represented in white, the colour key below represents the average sound level(dB).



Conclusions were drawn from the comparisons of  $L_{\max}$  and  $L_{\text{avg}}$  (refer to appendix 1) between the two city space samples.

The comparisons between Sheffield and Wuhan demonstrate the significant effects of Urban Morphology on the noise distribution. In Sheffield, most roads are accessible by all vehicles and thus, the average noise level is generally higher than Wuhan, by 2-11dB. Conversely, in Wuhan some major roads take a large proportion of traffic, causing high SPL on the road sides, about 5-10dB higher than that in Sheffield, while also creating quiet areas of very little traffic flow (further aided by tall buildings acting as noise barriers along arterial routes). From this we could conclude that Sheffield is noisier than Wuhan, but we must also note other urban morphological factors in the overall results (WANG, B., Kang, J., Zhou, J. 2007, p. 6).

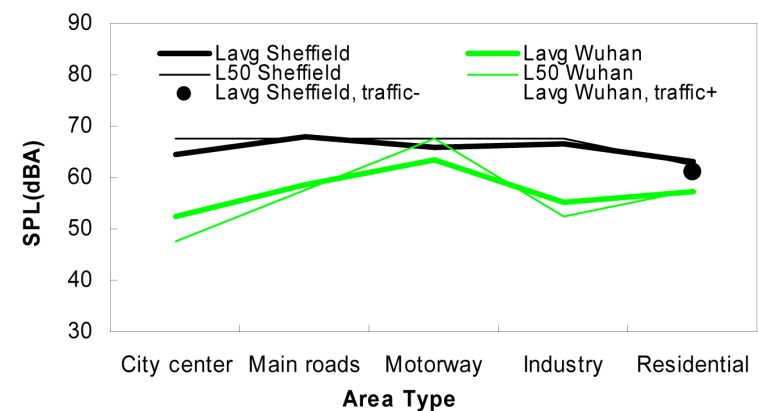


Fig. 3.10 Comparison of SPL between Sheffield and Wuhan in the sampled Urban Areas (Showing  $L_{\text{avg}}$  and  $L_{50}$ )

The distribution of roads in the two cities; Sheffield has a relatively evenly distributed street network, providing vehicular access to a wide range of roads. Contrastingly, Wuhan’s major arterial roads are typically spaced 350-500m apart, taking a heavy traffic load and producing high SPLs, while simultaneously creating large quiet zones between them. This is further assisted by the nature of the residential areas in Wuhan, where vehicle access can be limited to residents and visitors only. Figure 3.11 compares the morphological features of each city.

The negative implications of the Wuhan Street hierarchy are seen in two areas; The acoustic environment of the street canyons created by large arterial roads, where SPL is disproportionately high, and where these high SPL routes meet large public spaces like Hongshan Square, where sound is allowed to propagate over large expanses (see Fig. 3.12).

The comparison demonstrates the significance of urban morphology on noise distribution. Both street hierarchies have their trade-offs. Perhaps the answer is finding a balance between Eastern and Western practices.

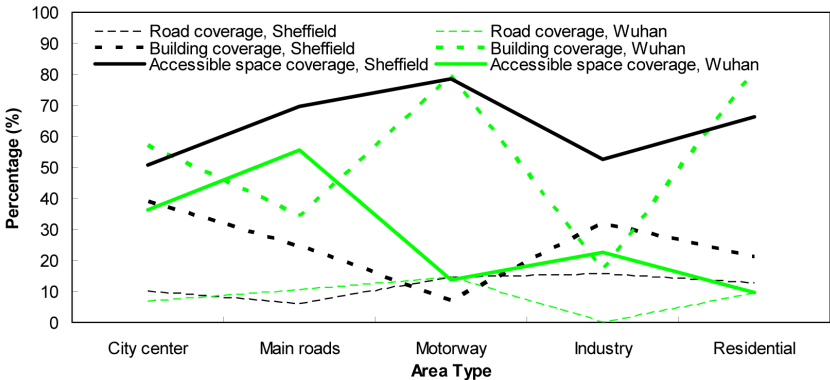


Fig. 3.11 Graph showing a comparison of three morphological indices between Sheffield and Wuhan.

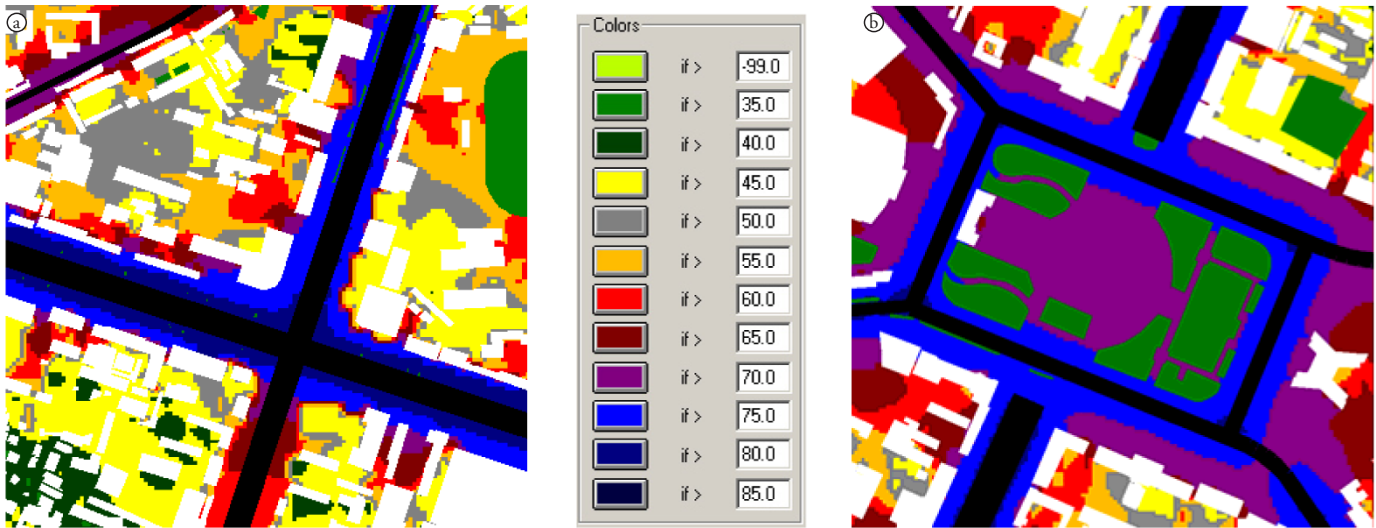


Fig. 3.12 Noise-maps in (a) the Jiedaokou Cross and (b) the Hongshan Square.



### 3.4.2 Hedfors on the Acoustics of Street Hierarchy

Hedfors champions the hierarchical systems used in Wuhan, exclaiming that;

*“Traffic must be increasingly concentrated along well-defined routes to ensure that the enclosed areas will have room for other purposes. If this does not occur then the soundscapes in the cities may converge... concentration therefore serves to avoid that extreme which is known as monotony...” (HEDFORS, 2003, p. 62).*

He then provides a series of reasonable guidelines for traffic arrangement;

- Traffic should not be directed along water or parks, for example, if the purpose is to enable other sounds to be noticed. Water is an effective sound distributor: it causes traffic murmurs to be heard from much greater distances.
- Buildings should be located in between strong flows of traffic and water or parks. A traffic route is an unsuitable demarcation for a recreational area, but well-designed buildings along a path can prevent sounds from spreading to such an adjacent area. The noise damping function of a building should be integrated with its architectural execution, while maintaining its visual aesthetics.

The concept of street hierarchy is well supported in urban design, but to what degree vehicular flow should be concentrated remains to be seen. Designers need to seek a balance between good pedestrian and vehicular accessibility/permeability (privileging ease of movement), and the concentration of vehicular traffic down arterial routes (privileging acoustic diversity between arteries) without creating ‘traffic sewers’.

### **3.5 The Perceptual Element of Soundscape**

The complexities of human perception is an area of research that is heavily investigated and constantly challenged in the field of Psychology (among others). The following case studies don't seek to provide an answer to how people perceive their surrounding environment, but instead provide a small insight into a few Soundscape-specific examples of human perception in urban space.

#### **3.5.1 Hiramatsu describes Old town Kyoto and the Gion Festival**

Hiramatsu provides an example of the cultural and contextual interpretation of Soundscape in the Japanese city of Kyoto. Through questionnaire, survey and interview, the inhabitants of the Yamahoko-cho province portray a tolerance and ownership of the annual change in Soundscape that the Gion Festival brings to Old Town Kyoto. Truax defined 'Soundscape' as the perceptive interpretation of sonic environment by the individual, or by a society (1978).

'Soundscapegraphy' (coined by the author) is a description of soundscape which consists of physical, mental and social factors of sonic environments; noises, sound events, people's attitude toward sound sources, history of the community, images of sounds heard and/or having been heard by inhabitants, and many other aspects and factors related to life-histories of inhabitants in the area (HIRAMATSU, 1999).

The authors initial analysis observes the Objective Soundscape, which includes;

- The physical sonic environment, conventionally measured using sound level meters or recording devices.
- Noise mapping using GIS software.

Objective Soundscapes can be described without obtaining any information from the inhabitants of an area. In most cases, the objective soundscape is described by external sources.

Secondly, the author measures the Subjective Soundscape, which essentially involves a description of the sonic environment by an individual or community, obtained by survey, questionnaire or interview. This measure integrates experience, memory, history and associations of the local inhabitants into the general analysis of the Soundscape. The methods used to obtain information in this case were;

- Measurement of sound level and recording of environmental sounds to observe physical properties of the Soundscape,
- Collection of printed matters on the 'Gion Festival' and 'Yamahoko-cho' to obtain historical information about the area, and
- A questionnaire survey and interview of local people to understand the 'internals' impression and opinion on the soundscape and grasp the relationship between inhabitants and sounds. The questionnaire asked about the sounds they heard on various occasions related with seasons, time, nature, weather, ceremonies, business, distress, annoyance and so on.

This inquiry provided data for two distinct temporal soundscapes in the area, the ‘Ordinary Day Soundscape’ and the ‘Festival Soundscape’ of the Yamahoko-cho district.

The ‘Ordinary Day Soundscape’ consisted largely of traffic noise, like any other urban area. It is interesting to note, however, that contrary to the common (western) outlook, inhabitants did not associate this with annoyance, but considered it an indicator of commercial activity within the area. Annoying sounds were restricted to reckless driving sounds during the night.

This description is also limited, as it only takes into account the experience of the main street, while the majority of inhabitants live in the adjoining alleyways, where sound levels can be 10 to 20 dB lower than those streets. The Urban Fabric of the Yamahoko-cho district is modelled on 8th Century Chinese cities, where inhabitants built their houses in dense and small spaces to protect from traffic, outsiders and vandalism. This model creates a sonic community within a block, where traffic noise is scarcely heard, and neighbouring family sounds, wind, birds, and temple bells are prolific. The residential area of Yamahoko-cho portrays the same qualities discussed in the Sheffield/Wuhan case study, where a more compact/densely built area actually aids in the development of a quieter, more comfortable acoustic community. Figure 3.13 illustrates this layout.

The ‘Festival Soundscape’, on the other hand, drastically changes the makeup of Yamahoko-cho’s sonic environment for the month of July every year. The district becomes engulfed in festival sounds, including music from bands atop tall festival floats marching around the area, and sounds from an influx of locals and visitors shopping and enjoying the festivities.

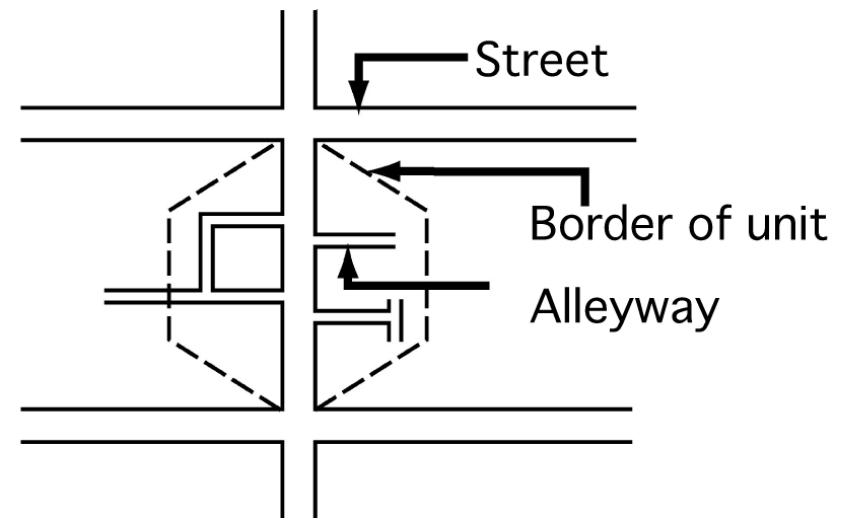


Fig. 3.13 A typical residential block in the Yamahoko-cho district.

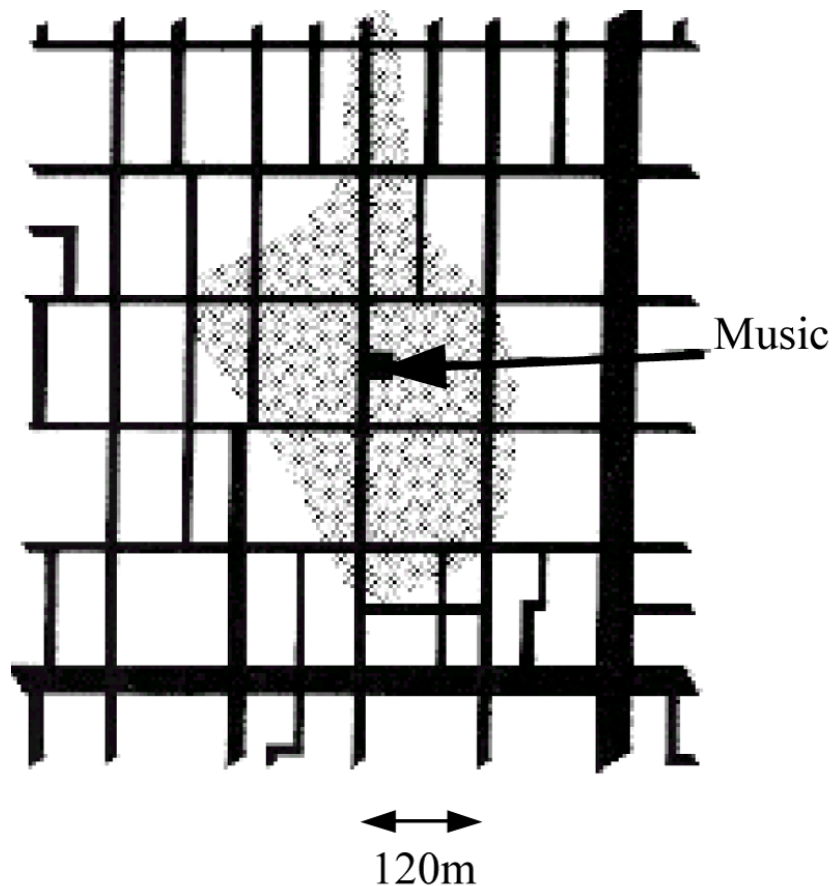


Fig. 3.14 Audible area of music from festival floats

For the inhabitants of this district, the sounds of the festival are not only tolerated, but embraced. Many accounts from interviews in the district regarded the music played in various areas of the town during the festival indelibly as their own sound, and although the music level atop the floats may reach 100dB, the historic significance and cultural value of the festival sounds is accepted (Fig. 3.14 diagrams the propagation of sound from a festival float). Hiramatsu finally concludes,

*'For external workers to avoid their work being superficial, it is essentially important to interview those internal to the studied space, for their historical experiential knowledge.'* (1999)

Kozo Hiramatsu, using 'Soundscapegraphy', shows great insight analytical power'. While the subjective analysis sheds light on the complexity of the contextual soundscape with regards to cultural and historical experience, the objective analysis allows us to step back and look at the urban fabric of the site, and how that fabric influences the day to day acoustic environment of the Yamahoko-cho province. This provides a great precedent for acoustic site analysis in an established areas.

### **3.5.2 Anderson et al. : Perceptual responses to Vegetation**

The effects of vegetation on human response to sound are discussed in a journal article written by Anderson, Mulligan and Goodman. They determined that in addition to trees and shrubs beautifying the urban environment, they can also reduce the level of unwanted sounds like traffic and other sources in residential areas, schools, and workplaces (1984, p. 45). Noise abatement can be achieved through a combination of forest elements;

- Soft forest floors reduce the intensity of low frequency sound by absorbing energy.
- Leaves and stems help to reduce noise levels by scattering high frequency sound waves.

They emphasized, however, that for these methods of abatement to appreciably affect the transmission of sound, a significant width of area must be planted (at least 5m wide). In terms of spatial practicality, an alternative measure is conceived; when there is too little land area, constructed barriers, perhaps beautified with trees and shrubs, can provide more significant noise relief (1984, p. 45).

Of greater interest is the article's reference to people's perceptual experience of vegetative screens that have little detectable influence on actual sound intensity. The article refers to a series of tests conducted on the psychological aspects of Noise Abatement. As alluded to in the Literature Review's perceptual analysis section, the authors discuss how visual screens alter sound perception;

*“Studies showed that if a sound source was completely screened from view, its noise was described as louder than when the source was either partially or completely visible. The noise was described as even louder if the observer was blindfolded, although the sound intensity at the observer’s ears was the same in all cases.” (1984, p. 46)*

The explanation of this contradiction comes from people’s expectations, and the effects they have on perceiving the information at hand. People learn that the intensity of a sound is reduced by obstacles, and by distancing oneself from a sound source. When a screen blocks the observer’s view of a sound source, the observer expects the sound to be of lower intensity. This meant that if the screened source is as loud as the unscreened, the observer may report that screened source as louder, as it would have to be if the source were further away or if the screen were truly effective in reducing noise levels.

Like the ‘Visual Screen’ effect described above, the influence of vegetation on the perceived sound environment may be an increase in loudness. People learn to expect reduced sound levels in more vegetated settings like wooded areas, at least in comparison to highly developed urban settings. Conversely, this expectation that a city street will be noisy leads people to use lower standards to judge sound level, and so sounds are not found to be as loud. This effect is prominent in all walks of life. Merely travelling in a car at 100km/h can produce a sound level of 70dB+, a level that would be a constant annoyance in almost any other situation.

Vegetative additions to Urban Design may not directly improve the acoustic quality of space, but can make a difference to people’s evaluation of that space, by substantially improving perceived visual quality.

### **3.5.3 Gidlof-Gunnarsson & Ohrstrom : Modifying noise perception through the provision of Attractive ‘Quiet’ Courtyards**

Contrary to the previous case study, this study looks at the regenerative qualities of vegetation in an urban courtyard setting (GIDLOF-GUNNARSSON & OHRSTROM, 2010, p. 3359). The study featured data obtained from the multi-disciplinary field of ‘Soundscape Support and Health’. The study was conducted in four urban-residential areas of in Stockholm, Sweden. Special care was taken to ensure a good range of residential areas, including;

- Variety of traffic flows.
- Similar acoustic conditions.
- Different residential aspects.
- Similar building heights (3-5 storeys.)
- Differing courtyard outlooks.

Surveys on residents were conducted to determine the level of noise annoyance experienced due to traffic sounds over the array of residential buildings, and the results of these surveys were analysed and discussed.

The notion of a ‘Quiet Side’ is that a residential dwelling with multiple outlooks has a side exposed to traffic noise, and a quiet side which offsets the negative effects of the prior. Results from the survey suggested that access to a high-quality ‘quiet’ courtyard lowers the percentage of annoyed residents by 9 -13 percentage points depending on the sound level from road traffic at the most exposed side of the dwelling. An interpretation of this is that a high-quality courtyard with an attractive outlook increases inhabitant’s



satisfaction of their home environment, therefore modifying their annoyance level.

The authors assert that visually aesthetic scenes containing natural elements are able to restore depleted attention capacity caused by overexposure to noise. Kaplan found that the view from one's home over a garden, flowers etc. strongly increased resident's neighbourhood satisfaction and wellbeing. Thus, a 'quiet' courtyard may assist in shifting noise-exposed residents' attention from traffic to tranquillity (as cited in GIDLOF-GUNNARSSON & OHRSTROM, 2010, p. 3371).

This case study makes clear the positive influence of a 'quiet side' (See 'Acoustic Refuge'). High-quality courtyards can function as attractive, restorative environments, providing residents with a positive soundscape, opportunities for rest, relaxation and play, as well as social relations that potentially reduce the psychologically adverse effects of noise exposure. Contrary to the previous case study, the perception created by a vegetative environment does not alter one's expectation of the surrounding sound environment, but instead transfers focus from negative sound sources to a perceived tranquillity.

### 3.5.4 Prochnik : The remedial qualities of Paley Park

In Prochnik's book 'In Pursuit of Silence – Listening for meaning in a World of Noise' (2010), he alludes to a local pursuit of silence within his working vicinity. In the early stages of his pursuit he refers to the pocket park known as 'Paley Park' (Fig. 3.15). The concept of the pocket park only really took off in Post-War Europe - London and Amsterdam in particular - where staggering numbers of bombed out building sites provided opportunities for an array of small parks at less cost than reconstruction (2010, p. 119). 'Paley Park' rests in a small gap between two tall buildings on Fifty-Third Street. To enter, one must ascend a few steps from the footpath into the park. With either side flanked by ivy covered walls. Prochnik notes that almost instantly;

*“The waterfall at the far end of the park – twenty feet high and running 1800 gallons of water per minute – entirely drowns out the street noise... like other pocket parks in the neighbourhood, there's no real quiet. Water masks the grinding city sounds. It works: the effect on the spirit is one of silence.” (2010, p. 118)*



Fig. 3.15 Paley Park, New York.

As referred to by Prochnik, the effectiveness of this park as an 'acoustic refuge' is not based on the lowering of sound intensity (dB level), but rather the peace of mind created by providing an environment that acoustically contrasts that of the dominant Soundscape. It is in the act of drowning out the "grind of the city" with a more desirable sound like water-flow that creates a sense of refuge. This interpretation of Paley Park leans towards the argument discussed in the previous case study, where natural elements don't create an expectation of lower sound levels, but provide a perceived tranquillity.

### 3.6 Conclusions

This Chapter has;

- Established the major principles and ideologies of Soundscape,
- Recognised the design strategies used to realise these principles, and
- Explained how these acoustic design elements are perceived by their users.

It was interesting to note that from the case studies analysed, none provided an example of built works that actively employed Soundscape Design techniques (with the possible exception of Paley Park). The studies instead provided an insight into how existing urban structures have passively shaped the acoustic environment, for better or worse.

With such a large portion of Soundscape literature leaning towards micro-design strategies like buffering and masking, it is easy to lose sight of the important role macro-design plays in the protection and enhancement of the urban acoustic environment.

**‘Building Density’** is a major contributor to the acoustic condition of the urban environment. In two separate case studies, both referring to Eastern Asia, the tightly packed, high-density morphology of residential districts performed particularly well acoustically. This may come at the cost of public accessibility or permeability, but it cultivates a sense of community and place within those residential areas.

**‘Street Hierarchy’** also featured heavily in this chapter. The Sheffield/Wuhan case study illustrated the effect of differing street hierarchies well. With a more permeable street network, better access is available, but the overall sound levels of a city can be elevated. Concentrating more traffic along arterial routes reduces flow in internal areas

creating arguable better acoustic environments for residential development, but at the cost of poor acoustic environments for those buildings and spaces along arterial roads. The solution therefore falls to balance. For street hierarchy to successfully complement both Soundscape and Urban Design criteria, equilibrium needs to be met between the sheltering of residential areas through traffic concentration and good accessibility/permeability in more public districts.

Maintaining '**Contextual Identity**' is another important element in the macro-design stage. As in a number of the case studies, questionnaires and surveys were conducted on site to determine what made them acoustically unique. Analysis from Kozo Hiramatsu's Kyoto case study showed that there is no public consensus as to what constitutes noise, as inhabitants demonstrated an embrace of loud festival sounds for a month every year. It is therefore essential for site inhabitants/users to participate in the design process, providing designers with insight into the acoustic identity of place, which sound-marks to preserve, and what future activities to cater for.

The case studies emphasised the importance of affording spatial opportunities for micro-level Soundscape Design at an early stage. This is possibly an area where Soundscape and Urban Design Principles clash, as affording that opportunity can mean isolating such spaces from major traffic routes, therefore reducing their accessibility and overall use.

The Soundscape Design of parks, again, falls on a (user-informed) plan of park 'activity', whether it be a quiet park for rest and reflection, a vibrant space for conversation and play, an amphitheatre for performance, or a space for just appreciating surrounding sounds.

**‘User Perception’** ranked highly in the concerns of micro-scale soundscape design. The vegetative perception case study (see 3.5.2) showed that altering people’s expectations of noise could have a negative effect on the overall experience of the acoustic environment. Conversely, in the quiet courtyard case study (see 3.5.3), natural elements were introduced into open space without altering user expectations, and regardless of their acoustic performance, had an acoustically restorative effect.

It seems the most important thing is to manage the user’s expectations of their surrounding acoustic environment. This could be achieved by maintaining a visual connection to noise sources, moderating the degree of vegetation in public space, or utilising elements that bring with them an inherent level of assumed noise (like Paley park’s heavy-flow waterfall).

Conclusions drawn from this chapter will be integrated into the Urban Design strategies implemented in the following Design Chapter of this thesis.



## 4. URBAN FORM EXPERIMENTATION USING CADNAA SOFTWARE

### 4.1 Introduction

As established in previous chapters, measuring annoyance due to noise is largely a subjective matter. The previous chapter analysed case studies that address the perception of sounds and their desirableness. This chapter focuses on a more objective analysis of the relationship between annoyance and noise exposure through the experimental analysis of continuous sound levels ( $L_{eq}$ ).

A series of urban form configurations are tested using CadnaA acoustic analysis software. While research in this field of acoustics is prevalent, I have yet to find an in depth investigation into relationships between built form and urban sound sources.

## **4.2 Software Application**

### **4.2.1 Present Application**

CadnaA is a software used for the calculation and assessment, prediction and presentation of noise exposure and impact of air pollutants. In recent years it has proven very successful as an industrial tool. Its uses, however, extend beyond mere industrial assessment.

The CadnaA software has the ability to calculate and assess a multitude of urban environments, including mall complexes with parking lots, new road or rail schemes or even of entire towns and urbanized areas. Some examples of its current commercial use include;

- Calculation and Assessment of Industrial Noise for various facilities.
- Maintaining of Emission Data for Industrial plants, assessing the impact of any modifications to plants and the resultant noise emissions.
- Modelling, Calculation and Prediction of Road and Railway Noise.
- Traffic Planning, calculating the effects of modifying or introducing newly planned roads or railway routes adjacent to sound sensitive areas (i.e. residential, natural).
- Rating of Measures - If permissible values are exceeded, necessary measures like walls, noise reduction surface or other measures carried out on the buildings themselves can be modelled and evaluated.



#### 4.2.2 My Application

Where my application of the software differs is in its use as an experimental tool. It is currently used primarily for the analysis of existing urban environments and upcoming changes to those environments. I implement the software in the conceptual phase of Urban Design, testing variations of street and open space layouts in order to determine how well they function acoustically. Tested layouts include;

- Single and Dual Street Layouts,
- Urban Block Layouts, including internal squares, pedestrian corridors and other open space configurations, and
- A Street Canyon analysis of 'Self-Protective Building' and 'Terrain Manipulation' techniques.

Conclusions drawn from the analysis of these experiments will lay the foundations for a set of design tools used to create and preserve favourable acoustic environments.

#### 4.2.3 Software Limitations

While the CadnaA software is an extremely useful tool for the calculation of noise propagation in urban environments, there are some variables it cannot account for that may have a substantial effect on the urban acoustic environment.

The software works primarily with continuous noise and average SPL. This approach is suitable for calculations of traffic noise or industrial noise, but may not be accurate when there are intermittent or sporadic noises that significantly exceed the averages modelled in the software. Port noise, for example, may have a continuous ambient

sound level over an area, but events such as loading and unloading container ships or logging create louder sporadic sounds associated with residential annoyance, especially at night.

These high decibel sporadic noise events are perhaps better dealt with using source based noise reduction techniques rather than larger urban intervention. Unfortunately, source based noise reduction is often not considered as a viable solution. In a European report on rail-freight noise, the current situation is well summarised;

*“Despite the fact that retrofitting has very good cost effectiveness, the most commonly used noise abatement strategy is noise barriers... reasons for this range from legal to political, but mostly are based on the fact that there is no incentive for a whole system fix, limiting solutions to those that are locally isolated, i.e., Noise barriers.”*

*(OERTLI, 2007)*

Noise barriers can be effective, reducing noise by 5-15dB depending on height, but the negative effect they can have on the landscape makes them a less desirable solution. The far more cost effective and holistic solution to the problem involves retrofitting parts like composite brake blocks, wheel absorbers and track absorbers to freight trains.

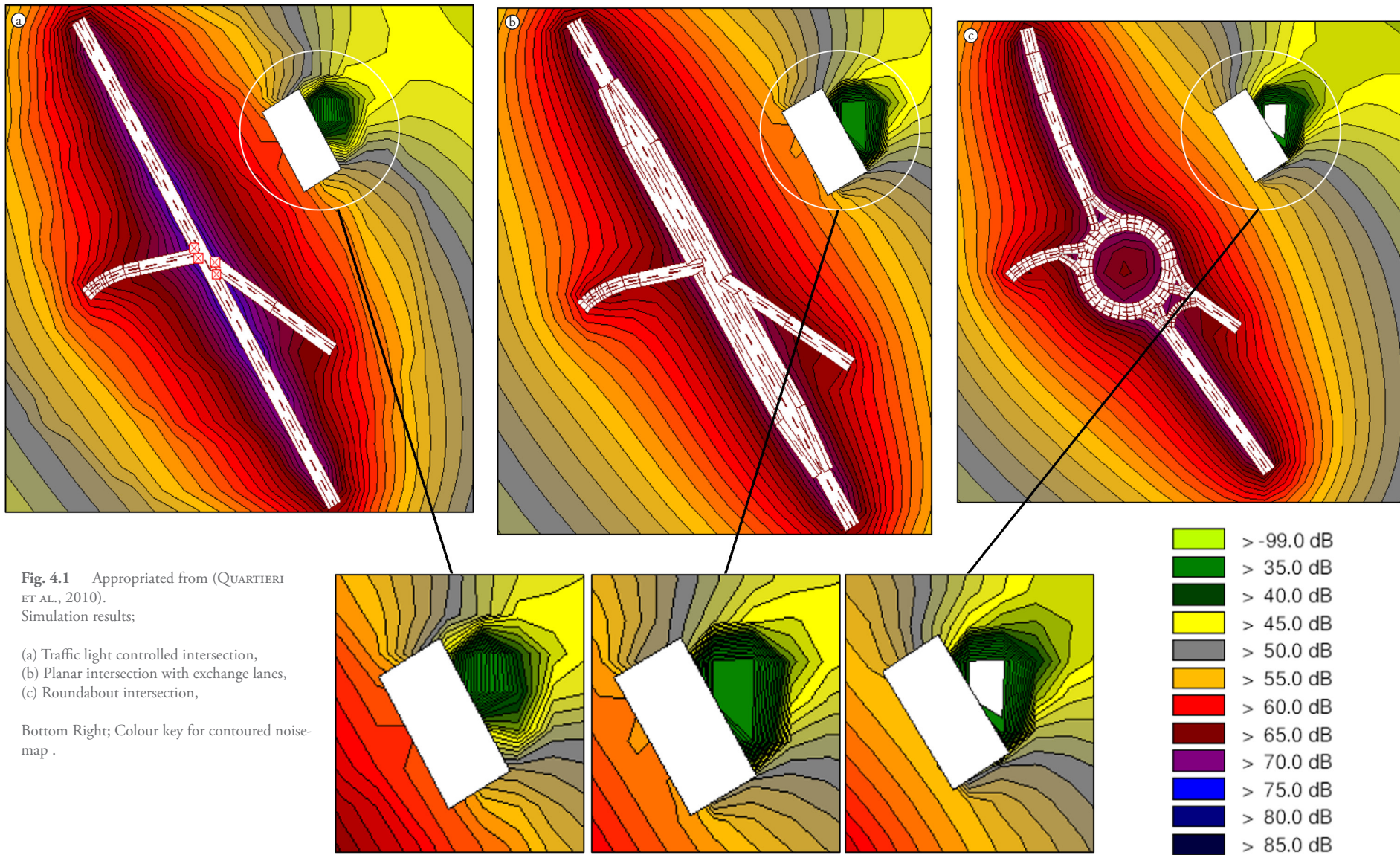
#### **4.2.4 CadnaA Application precedent : Traffic noise impact on road intersections**

In this case study, the authors review the designs of three different intersection typologies, and then investigates the noise impact of these variations using software-aided performance analysis (QUARTIERI ET AL., 2010). The three intersections the authors consider for their study are;

- Traffic light controlled
- Linear Planar
- Roundabout

Each intersection typology is analysed thoroughly in a written review, then, using CadnaA, is analysed for its acoustic performance. The study considers a single building in close proximity to an intersection between a principal road, and two local connections. The principal road is characterized by a design velocity ranging from 60-100 km/h and by a single carriageway 7.50m wide, with double lanes, each of them 3.75m wide, with 1.50m of external path. Finally, the calculation model is arranged with the following parameters;

- Road and Intersection geometry.
- Traffic flow data; primary roads - 400 vehicles/h, local roads - 200 vehicles/h, accelerating and decelerating features.
- Road surface, chosen as smooth asphalt.
- Speed limits, chosen as 60 and 100 km/h for the principal road, respectively for heavy and light vehicles, and 50 km/h for the local ones.
- Heavy vehicles percentage, fixed at. 20% of the overall daily traffic flow.



## Results

The simulation was performed with three different types of intersection: traffic light controlled intersection, roundabout, and linear planar intersection with exchange lanes. The calculation is performed inside a suitable grid formed by 10 x 10m receiver cells, and the height of the receivers is fixed at 1.5m from the ground. Figure 4.1 presents the simulation results.

Observing the noise maps, it is easy to observe that the traffic light configuration results in a higher equivalent noise level (Fig. 4.1 (a)), while the roundabout gives the best result (Fig. 4.1 (c)), with a significant lowering in the noise evaluated on the building façade facing the highway. CadnaA has a constant penalty built in for traffic light intersections that accounts for the required acceleration/deceleration in proximity to intersections.

## Conclusions

In the Authors' opinion, the primary issue here is the inability of the designer to easily predict the noise impact of a project under development. A tool like CadnaA, implemented early in the design process enables designers to analyse the noise impact information of different types of intersection, and thus optimise the acoustical environment of an urban development in addition to other practical requirements.

### 4.3 Introducing the Experimental Process

Using a similar method to the previous case study, I conduct a series of experiments that map the acoustic efficiency of various urban configurations. Through these experiments, I aim to;

- Give designers the ability to consider the acoustic environment when planning new areas of urban fabric,
- Provide some general Urban Acoustic Design Principles that could be used to reduce the adverse effects of noise pollution.

The guidelines determined in this chapter are not intended to dictate the design and layout of streets and buildings. Rather, they are experimental conclusions drawn from the acoustic analyses of the relationship between street network and built form.

Urban form and detailing can greatly affect the acoustic environment, and with some appreciation of the mechanics of sound and the means of alleviating negative noise, designers can create liveable environments in the most acoustically challenging of areas. This is an especially important consideration for public areas, i.e. Pedestrian Corridors and Parks. With the aid of a predictive modelling tool such as CadnaA, these new considerations can be incorporated into the urban design process.



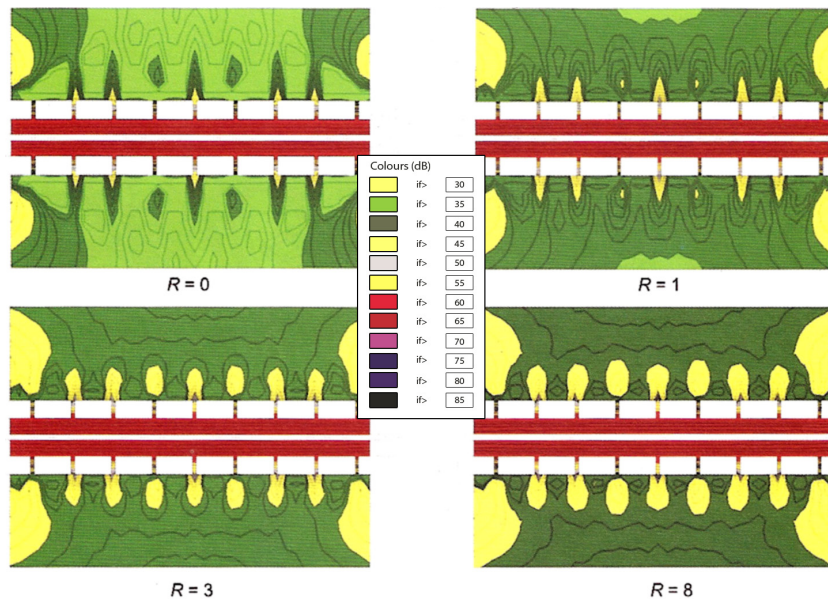


Fig. 4.2 Comparison of different reflection orders on a single street layout.

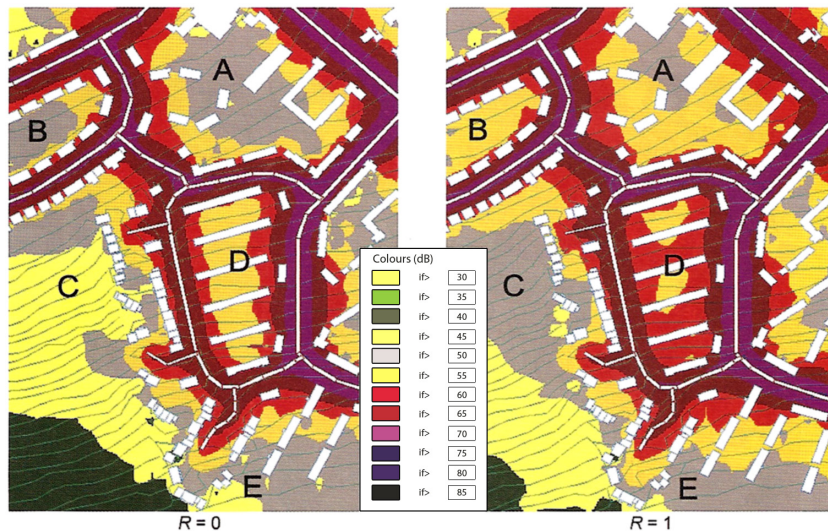


Fig. 4.3 Difference between Reflection order of 0 and 1 when mapping noise in a Sheffield suburb.

#### 4.3.1 Software Mechanics

The software is based both on ‘ray-trace’ and ‘angle scanning’ principles (see Appendix 1). For my CadnaA experimentation, I will primarily be using the ‘Calculation Area’ tool.

**Calculation Area** - This is a user defined receiver grid over a certain area. The grid is made up of lots of equally spaced receivers (the height and density of these receivers is user defined). Essentially, the receivers release rays in every direction with 360 degree coverage. Each ray, after few or many reflections, intercepts the noise source. The path length of the single ray from receiver to source describes the attenuation of said sound wave (Figures 4.2 and 4.3).

**Reflections** - The number of reflections taken into account within a calculation can be altered (Reflection Order). Increasing the reflection order increases the accuracy of the calculation, but exponentially increases the calculation time.

In a study conducted in Kang’s ‘Urban Sound Environment’, he tests a simple street and building layout at a Reflection order of 0, 1, 3, and 8. He notes that there is a significant difference between  $R=0$  and  $R=1$ , the difference between  $R=3$  and  $R=8$  is negligible. A second test is conducted on a larger urban area between  $R=0$  and  $R=1$ , resulting in an average Sound Pressure Level difference of 2.4dB. For both accuracy and efficiency, Kang suggests the use of a Reflection order between 1 and 3 (2007, pp. 162-163). I have therefore adopted a Reflection order of 1 for all modelling in this thesis. (Figures 4.2-3)

**Building Absorption** - The level of reflection loss can be set for each building. A series of façade absorption options are presented in CadnaA from ‘Mirror reflector’ (no loss) to ‘Highly absorptive’ (8dB loss) facades. I have elected to use the ‘Structured Façade’ option with a reflection loss of 2dB for buildings within my experimentation as a typical façade type. This means that any ray that reflects off a building will lose 2dB upon impact.

**Wind Correction** - CadnaA also incorporates a correction tool for wind speed. Despite Wellington’s reputation as a notoriously windy city, the purpose of this correction tool is to determine the altered directivity of major industrial sound sources (i.e. Industrial chimneys/stacks). I have therefore decided not to use this tool in my calculations.

### Typical Sound Levels

Again, it isn’t the mean Sound Pressure Level, but the high decibel sporadic noise events that create the most annoyance. This, however, is a factor that cannot be tested using this model. Figure 4.4 shows some established reference SPL measurements for urban sound sources and environments.

Lambert divided the daytime traffic noise annoyance into three levels: <55dBA, no annoyance; 55-60dBA, some people annoyed; and >65dBA, definite annoyance (as cited in Kang, 2007, p. 21). The majority of my experimentation lies between SPLs of 35-70dB, which would constitute a typical urban outdoor area.

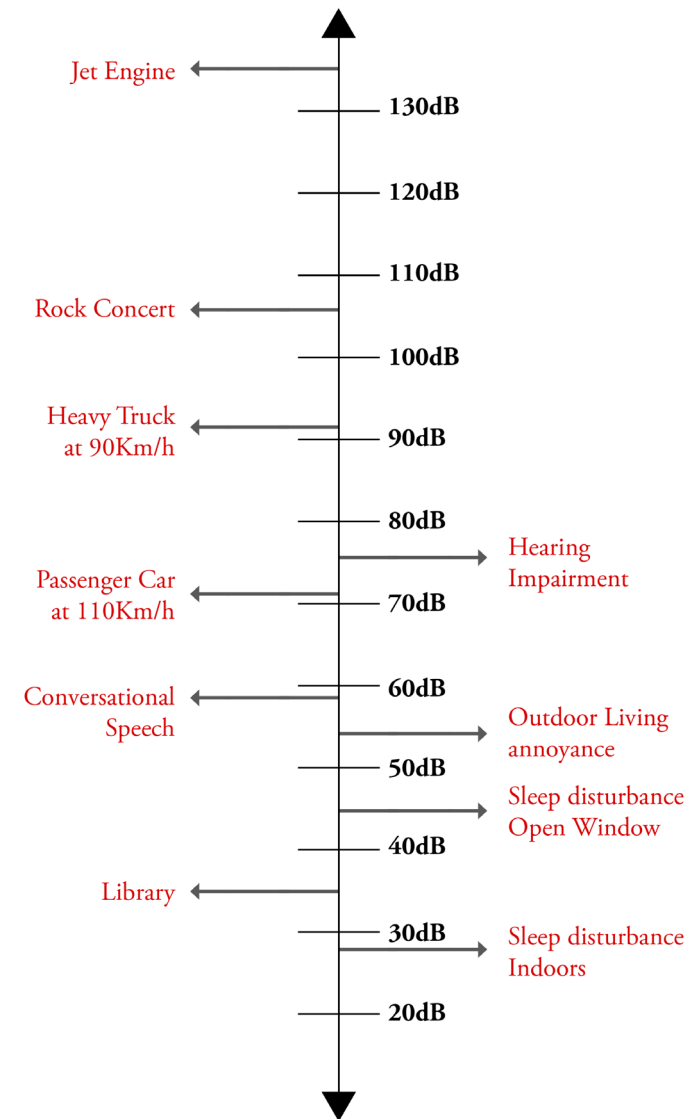


Fig. 4.4 Decibel Scale, illustrating some established reference SPLs for Urban Sound Sources and Environments.





## 4.4 Single Street Experiment

The Study looks at the acoustic environment around and behind buildings on a single road. This street configuration would not occur in an urban environment as intersecting streets would inevitably have an effect on the environments behind the building line. Also, any perceived patterning effects are caused by the continuous nature of the road sound source used in the acoustic model, and in reality would seldom occur. The following Interpretations of this study should be understood in this context.

### 4.4.1 Test Configuration (Fig. 4.5)

- Type
  - Isolated Single Street, lined with buildings of equal size
- Sound Sources
  - 10m wide Single Street producing 66dB at centre
- Variables
  - Building Width, Building Depth, Gap Width
- Analysed area
  - Space around and behind building envelope

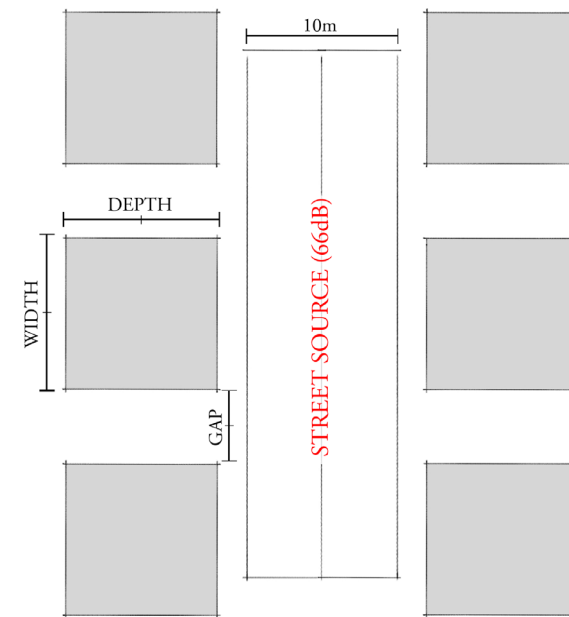
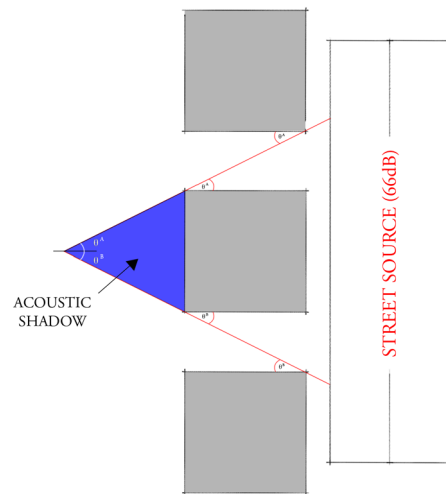


Fig. 4.5 Single Street Test Configuration.

#### 4.4.2 Study Interpretations



**Fig. 4.6** Acoustic Shadow Formation; the acoustic shadow is formed as a result of the angles determined by the front and rear corners of adjacent buildings.

Note – The angles created by building edges will not generate a perfect shadow, a degree of sound diffraction will always occur, blurring the edges of the shadow. What is presented here is an exaggerated observation under specific modelling parameters. An increase in reflection order will further reduce the area of a shadow as seen when comparing Figure 4.8 (a) and (b).

**Acoustic Shadows** – An Acoustic Shadow is the resultant area of quiet created when an object or objects obstruct the direct propagation of sound. In this case, its presence is a result of the angle created between the front edge and rear edge of adjacent buildings, and the relative dimensions of those buildings in question. The single street experiments provided acoustic shadow results for a variety of building arrangements along a single street. Interestingly, those tests emulating more urban conditions (buildings of widths of 20 and 40 metres along the street edge (Fig. 4.9)) showed acoustic shadows of significant depth and width, potentially providing acoustic conditions conducive to the creation of acoustic corridors and internal squares behind built street edges. In later single street tests, building positions and type were varied within single experiments (Fig. 4.10).

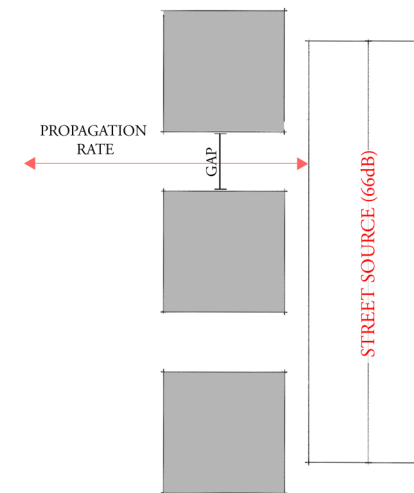
When a building is moved further from the road, not only does road noise propagate further, but the acoustic shadow of the adjacent buildings can be greatly reduced (due to angle change). At the ground floor, the dB level on the street side facades is generally high, and it would be impractical to increase this distance from the road far enough to reduce the dB level to a reasonable level for residential development. With a 10m difference in distance from the road there is only a 5dB reduction in sound level. This would have to be dealt with using some form of noise barrier technique. (e.g. Noise absorptive/reflective facades like double glazing or heavier walls like masonry.)

**Propagation rate** - The rate at which sound dissipates from its source through the atmosphere is always constant, but by changing the gap width between adjacent buildings, there is a reduction in the overall SPL between and beyond buildings. Essentially, with tighter gaps, less sound is allowed through, and any reflected sound waves are partially absorbed by the buildings facades. In almost all cases, regardless of building shape the propagation rate was a direct result of the gap width between buildings;

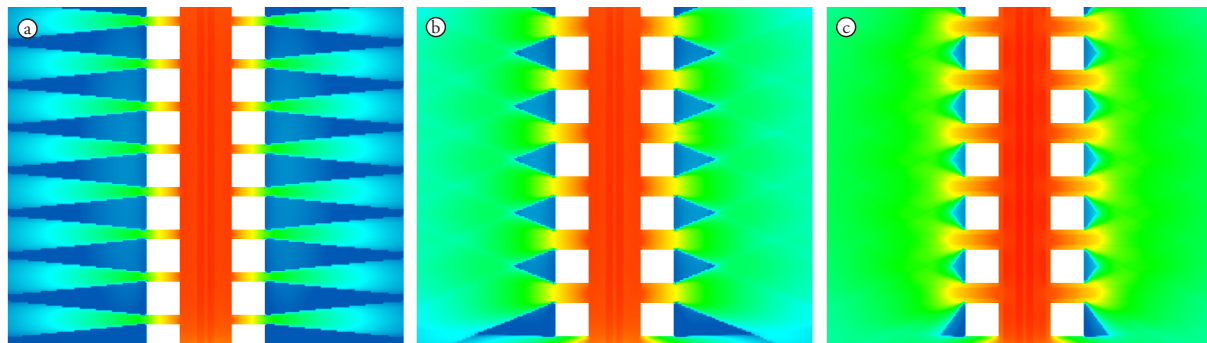
- 2m gaps – 16dB reduction after 14m
- 5m gaps – 16dB reduction after 19-20m
- 10m gaps – 16dB reduction after 26m

(16dB represents a reduction of 66dB to 50dB, a level suitable for quiet public space)

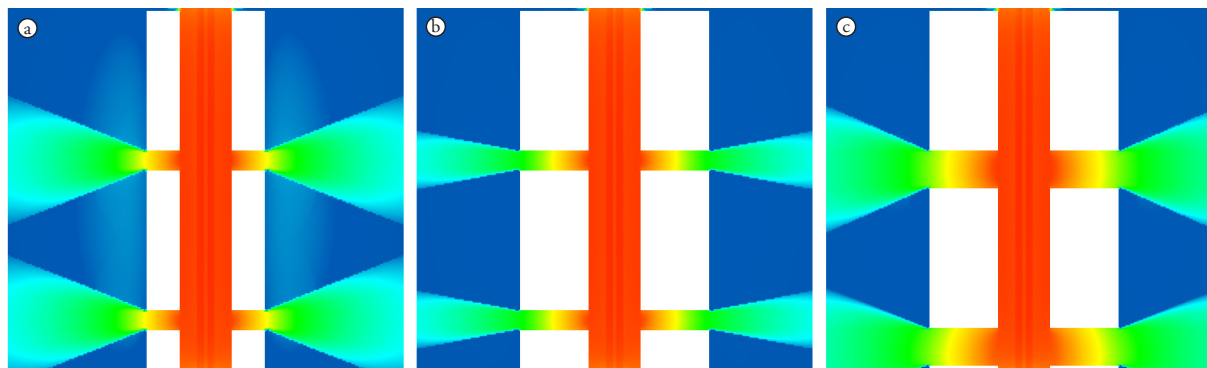
When deeper buildings were introduced into the test scenario, there was no change to the propagation rate, confirming that 'gap width' was the key variable.



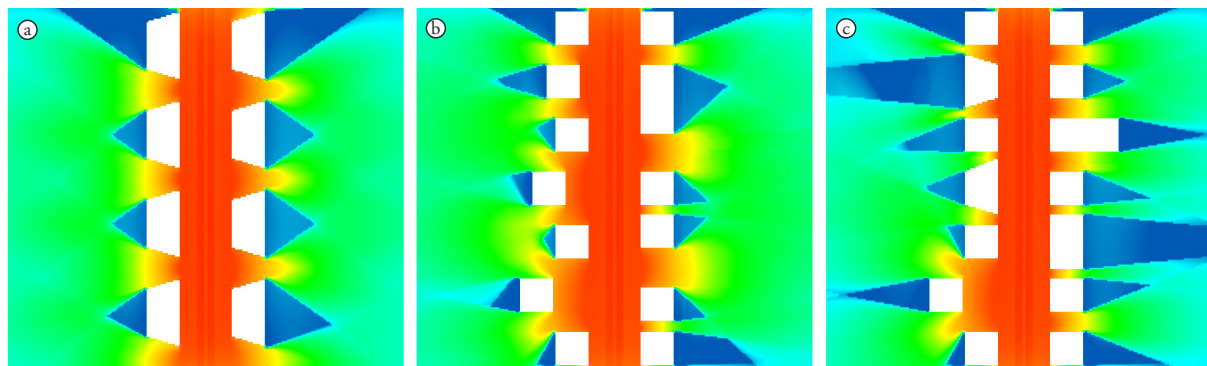
**Fig. 4.7** Propagation Rate through Building Gaps; this is determined by the amount of sound allowed through the gap between buildings.



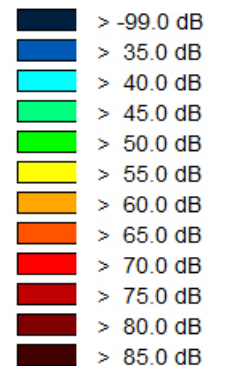
**Fig. 4.8** Single Street Analysis. 10m<sup>2</sup> buildings -  
 (a) 2m gaps,  
 (b) 5m gaps,  
 (c) 5m gaps with a reflection order of 2.



**Fig. 4.9** Single Street Analysis -  
 (a) 40 by 10m buildings with 5m gaps,  
 (b) 40 by 20m buildings with 5m gaps,  
 (c) 40 by 20m buildings with 10m gaps.



**Fig. 4.10** Single Street Analysis -  
 (a) 20 by 10m trapezoidal buildings  
 with 5m gaps,  
 (b) randomly placed 10m<sup>2</sup> buildings,  
 (c) random building size and placement.



#### **4.4.3 Urban Design Implications - Single Street Experiment**

For designers to make the most of their acoustic environment, they must first determine the use of space around newly proposed buildings and the respective acoustic environments those uses/activities entail.

If we consider a suburban situation (with a similar linearity to the building layout reflected early in this study (Fig. 4.8)), there may be a need to retain a sense of acoustic sanctuary in the back-yards of detached housing, and the best way to exploit the acoustic shadows of buildings may be to maintain a uniformity and closeness between adjacent houses, as opposed to randomly locating houses on ones property. In an urban situation, the importance of acoustic shadow is more likely to lie in the internal square or courtyard of a block.

If there is a requirement for quiet areas behind buildings, it is important that designers pay special attention to the gaps between buildings and the angles created by edges of adjacent buildings. If spaces between buildings are to be used as pedestrian pathways, sound could be minimised by having tight entry points that later widen, thus minimising sound propagation.

## 4.5 Dual Street Experiment

This experiment looks at the acoustic environment of an internal lane created between two building-lined parallel streets. Like study 4.3, this configuration would be unlikely to extend for any considerable length without being intersected by perpendicular streets in an urban situation. It does, however, begin to resemble a situation closer to that of an urban configuration. Any perceived patterning effects are caused by the continuous nature of the road sound source used in the acoustic model, and in reality would not endure uninhibited.

### 4.5.1 Test Configuration (Fig. 4.11)

- Type
  - 2 Parallel Streets 60m apart, Lined with buildings of equal size
- Sounds Sources
  - Two 10m wide Streets both producing 66dB
- Variables
  - Building Width
  - Building Depth
  - Gap Width
  - Offset Position of Opposing Building Sets
- Analysed area
  - Internal (Pedestrian) Lane Between Building Lines

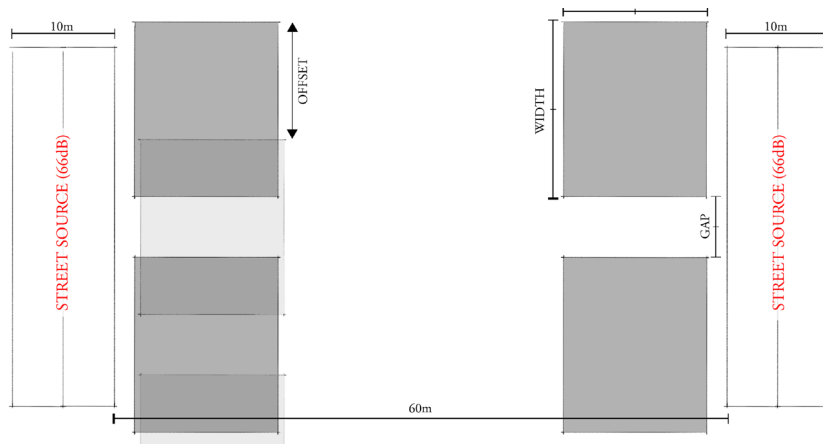


Fig. 4.11 Dual Street Test Configuration.

### 4.5.2 Study Interpretations

**Shadow Patterns** - The acoustic patterns created from this set of experiments were a result of the interaction between the acoustic shadows of opposing building sets. My initial experiments looked at smaller  $10\text{m}^2$  buildings with varying gaps. Again, more akin to suburban environments, these tests provided some interesting information, but did not reflect the urban conditions I sought to study. Additionally, with such shallow buildings ( $10\text{m}^2$ ), any gap of  $5\text{m}$  or greater allowed enough sound propagation into the internal lane to nullify any useful attenuation. Results of greater interest came when testing larger ( $20\text{m}^2$ ) buildings (Fig 4.14).

**Shadow Cancelling and Overlapping (Fig. 4.12)** - Offsetting buildings on opposing streets had a significant effect on the acoustic shadows cast. Any shadow cast can essentially be cancelled out by the noise propagation of the opposing roadway (Fig. 4.14 (a)). The degree of cancellation, however, is again a product of building sizes, positions and gaps (shadow angles). A partial overlap of acoustic shadows can create strips of quiet within the internal lane. Conversely, deep buildings with tight gaps can create a large shadow overlap, and instead of the quiet strip being the exception the channel of noise propagation between buildings becomes the exception (Fig. 4.14 (b) & (c)).

**Diamond Patterns and Quiet Spots (Fig. 4.13)** - Some of the most intriguing observations came from buildings placed parallel. Diamond patterns are created when the acoustic shadows of matching buildings overlap. The degree of the overlap is also interesting. If only the shadow tips overlap, a quiet spot is created in the centre of the corridor (Fig. 4.13). This isolated quiet zone has the lowest decibel level of the lane.

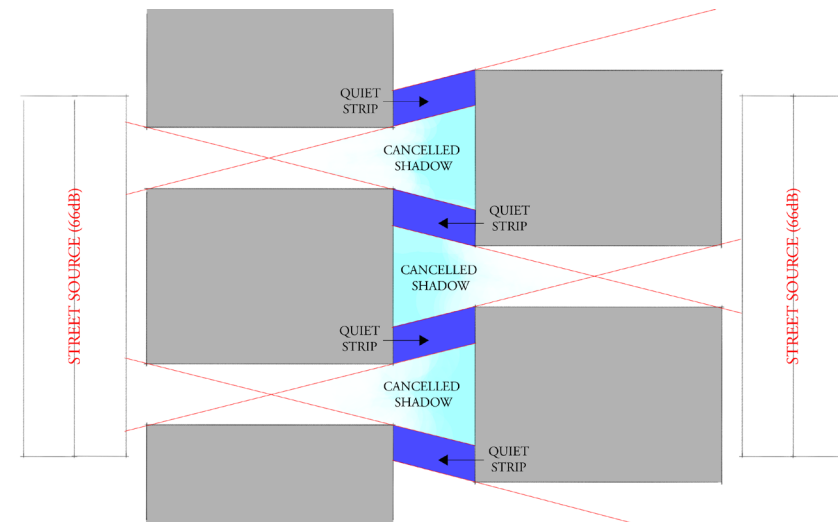


Fig. 4.12 Formation of Quiet Strips; In an offset building configuration, strips form as a result of overlapping acoustic shadows.

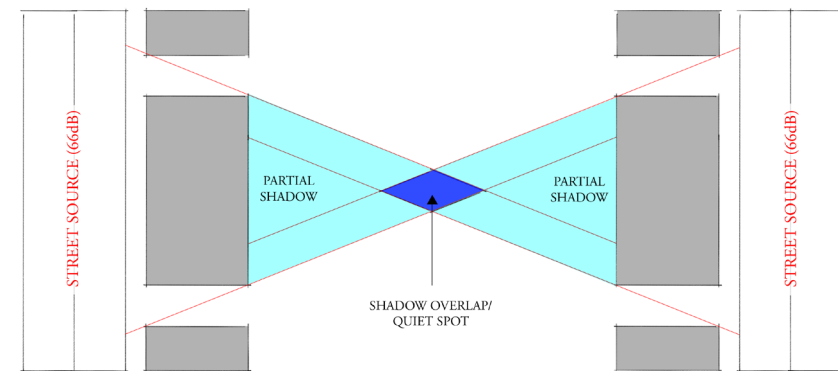
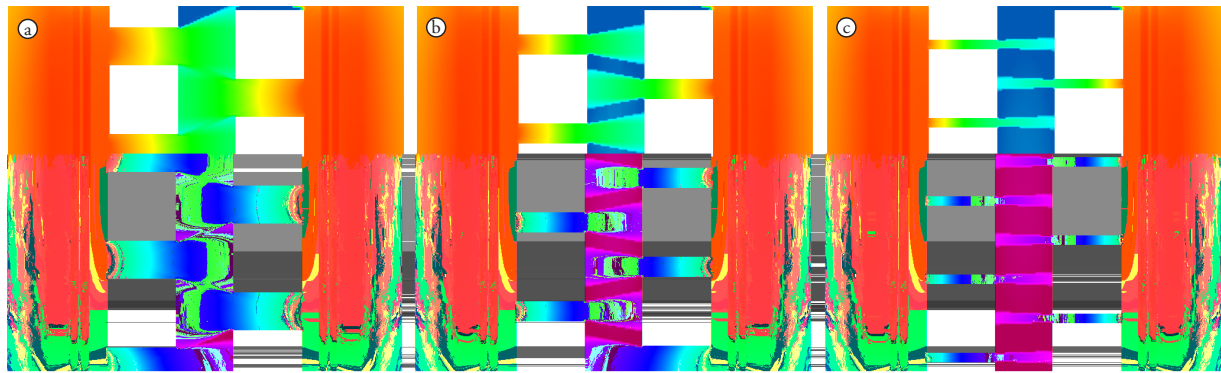
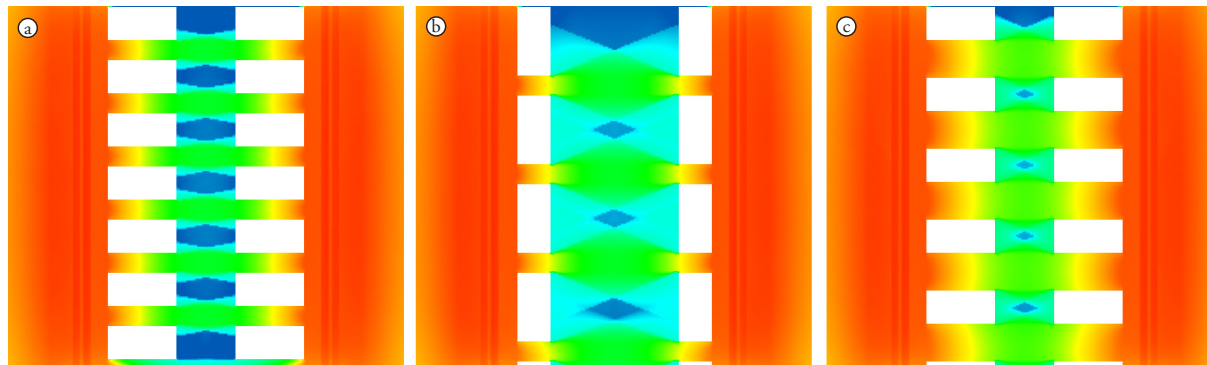


Fig. 4.13 Formation of a Quiet Spot; Again, as a result of overlapping acoustic shadows, however, the symmetrical overlap creates a central shadow zone.

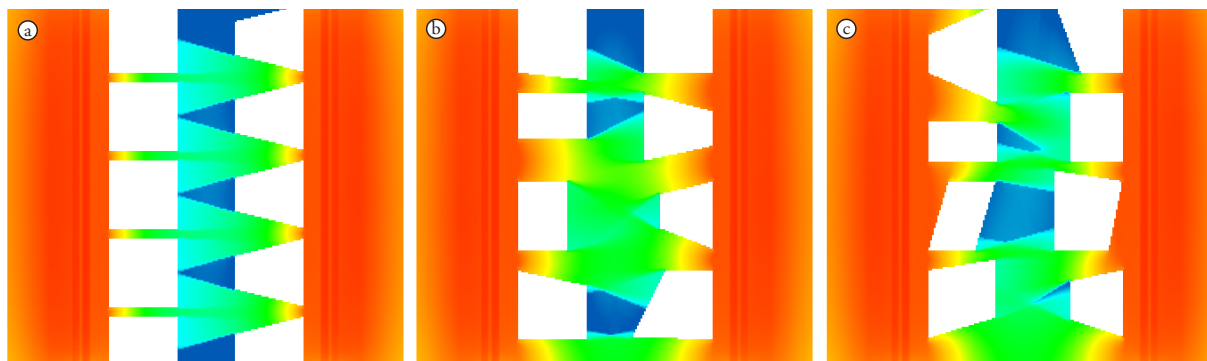




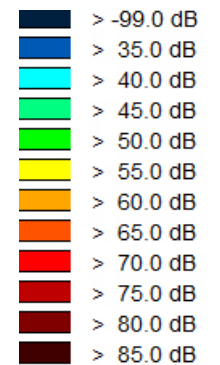
**Fig. 4.14** Dual Street Analysis of offset 20m<sup>2</sup> buildings -  
 (a) 10m gaps, complete offset,  
 (b) 5m gaps, complete offset,  
 (c) 2m gaps, complete offset.



**Fig. 4.15** Dual Street Analysis of parallel buildings -  
 (a) 20 by 10m buildings with 5m gaps, parallel,  
 (b) 10 by 20m buildings with 5m gaps, parallel,  
 (c) 20 by 10m buildings with 10m gaps, parallel.



**Fig. 4.16** Dual Street Analysis -  
 (a) 20m<sup>2</sup> buildings with parallel trapezoidal buildings, 2m gaps,  
 (b) randomly placed building set 1,  
 (c) randomly placed building set 2.



#### **4.5.3 Urban Design Implications of Dual Street Experiment**

As an experimental set, the above study gives some insight into the acoustic environment of an internal lane between parallel roads. The design significance of this study becomes evident when actively designing such a lane for the benefit of pedestrian use.

The Soundscape Design of such a lane may include elements of contrast, rhythm, complete quiet or constant noise. As referred to in the 'Railway Design' case study from the previous chapter (see 3.3.3), providing a sense of acoustic intrigue in transitional spaces is vital for mitigating feelings of discomfort or unpleasantness. These experimental set goes some way to providing potential tools for creating a more acoustically dynamic internal lane, be it through adding rhythm with quiet strips or noise channels, or just providing a little contrast. It is unusual to think that one could design such a space to have the quietest area in the centre of an internal lane.

## 4.6 Block Experiments

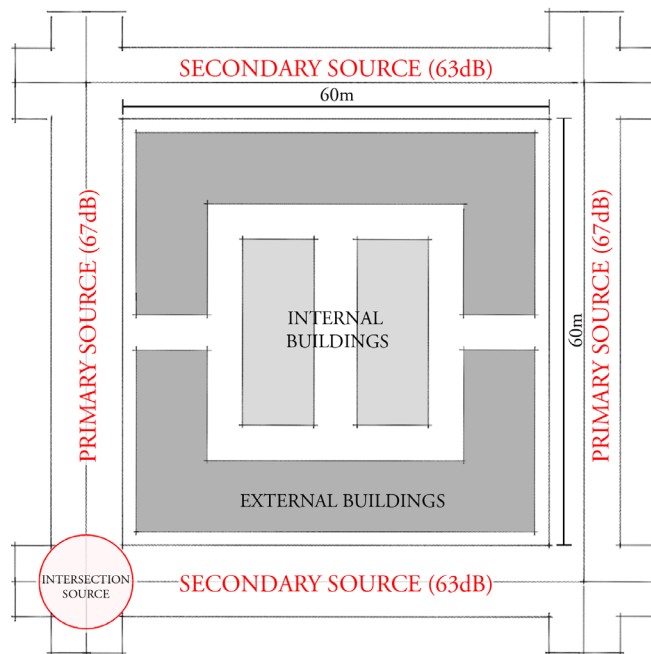
This series of experiments is undertaken within the context of a square block, better emulating typical urban fabric. Test are conducted under three conditions;

- An open block configuration with varied building arrangements,
- A pedestrian corridor configuration centred in the block, and
- An internal square configuration varying shape and entrance placement.

From these experiments, points of acoustic concern within the block configuration can be determined, and ideas for the most efficient rearrangement of built fabric to acoustically utilise internal spaces can be formed.

### 4.6.1 Test Configuration 1 - Building Footprint Variations (Fig. 4.17)

- Type
  - Square Block, 2 Primary Roads (N to S), 2 Secondary Roads (E to W), buildings
- Sounds Sources
  - Primary Roads (67dB),
  - Secondary Roads (63dB),
  - Intersection (+3dB at Centre)
- Variables
  - Building Size and Placement
  - Density and Permeability
- Analysed area
  - Acoustic Environment of Block



**Fig. 4.17** Footprint Variations Test Configuration (note - this diagram is just an example of one of the tested arrangements).

#### 4.6.2 Study Interpretations of Large Footprint Buildings

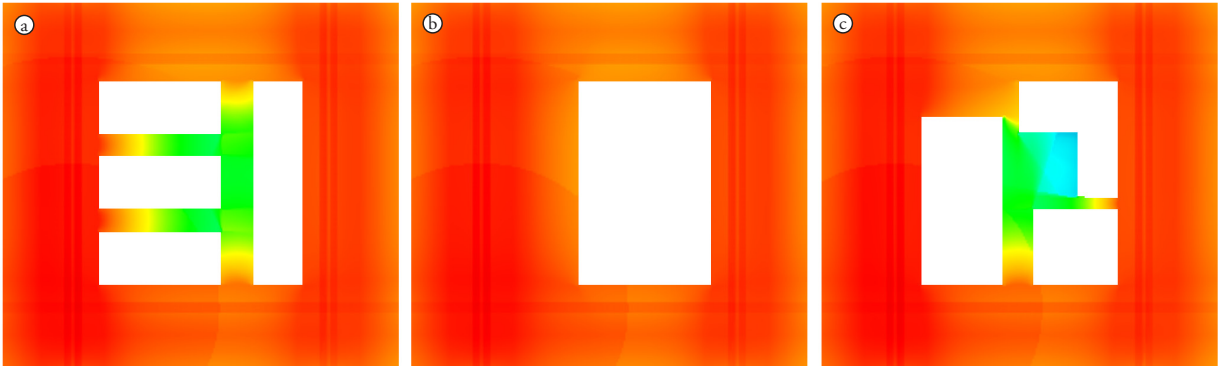
This set of experiments examined the block layout in terms of building density and permeability.

**Built Density** – The first studies conducted involved sparsely placed large floor-plate buildings (office park layout (Fig. 4.18)). These layouts afforded no real acoustic protection to internal building faces or open areas within the block. The large, irregular open spaces, created by such building layouts invariably become desolate parking areas, uncomfortable for public use.

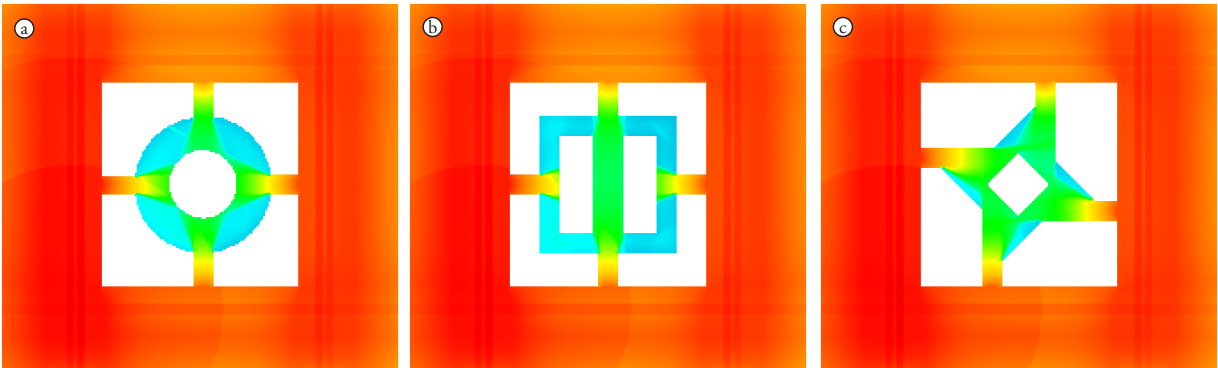
Later studies maintained similar built to open space ratios with smaller floor-plate buildings (Fig. 4.19). Here we begin to see how internal spaces of blocks can gain some acoustic quality. By using outer perimeter buildings as ‘Protective/Sacrificial’ buildings, the acoustic quality of a large portion of built edges and open space within the block can be vastly improved.

This approach could increase pedestrian permeability, add open areas of high acoustic quality, and provide internal building facades with ‘quiet sides’. The diversity of building types could also be appropriate for residential development. However, when considered this approach in conjunction with good urban design principles, such a layout could have negative impacts;

- Reducing visual permeability,
- Drive costs up by increasing the number of structures, and
- Increasing the requirement for vehicular circulation within the block.

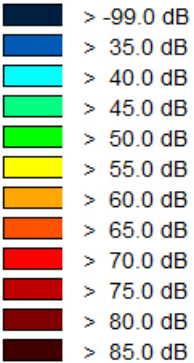


**Fig. 4.18** Large Footprints Analysis -  
(a) 3x horizontal, 1x vertical layout, evenly spaced,  
(b) single building with western open parks space,  
(c) 3x differently shaped buildings with central open space.



**Fig. 4.19** Perimeter Block Analysis  
(with internal buildings) -

- (a) perimeter block with circular core and 1 internal building,
- (b) square core, 2 internal buildings,
- (c) diamond core, 1 internal building.



Configuration 2 examines the conditions of a pedestrian corridor running through a block, parallel to the primary street network. The simplicity of this set of experiments afforded me the ability to compare results of varied reflection order. The quality of a pedestrian corridor is measured by a number of criteria; ease of access, amenity, mixed-use, visual permeability, acoustic quality. These corridor studies are conducted from an acoustic standpoint to determine how best to aid the acoustic performance of the pedestrian corridor without disturbing other urban conditions.

### 4.6.3 Test Configuration 2 - Pedestrian Corridor (Fig. 4.20)

- Type
  - Square Block, 2 Primary Roads (N to S), 2 Secondary Roads (E to W), internal buildings
- Sounds Sources
  - Primary Roads (67dB),
  - Secondary Roads (63dB),
  - Intersection (+3dB at Centre)
- Variables
  - Internal Corridor Shape
  - Acoustic Obstacles
  - Reflection Order
- Analysed area
  - Acoustic Environment of the Corridor

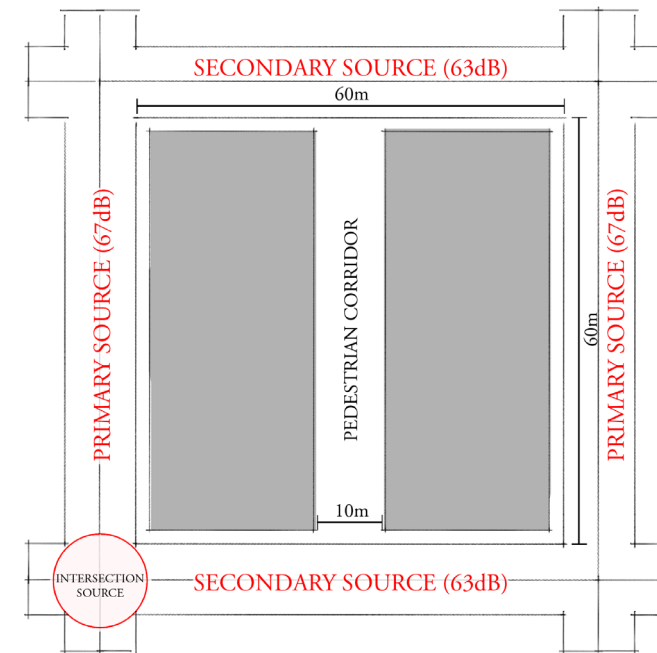


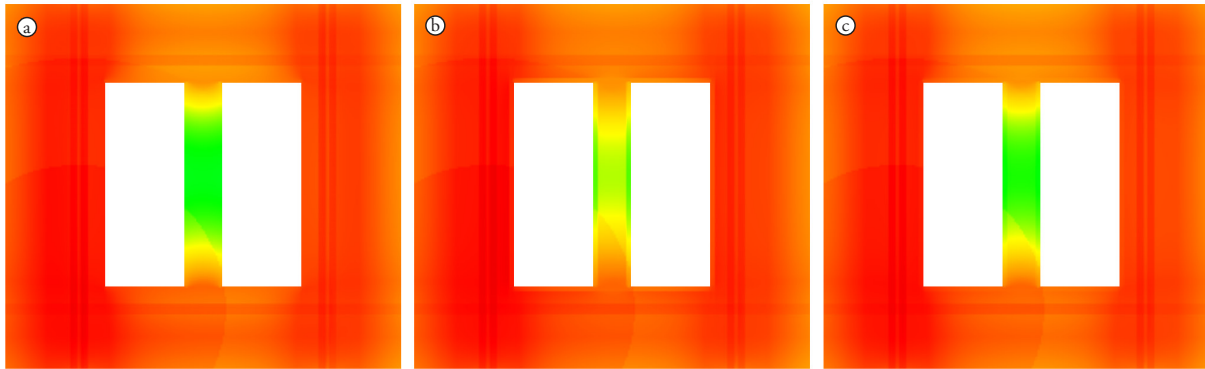
Fig. 4.20 Pedestrian Corridor Test Configuration.

#### 4.6.4 Study Interpretations

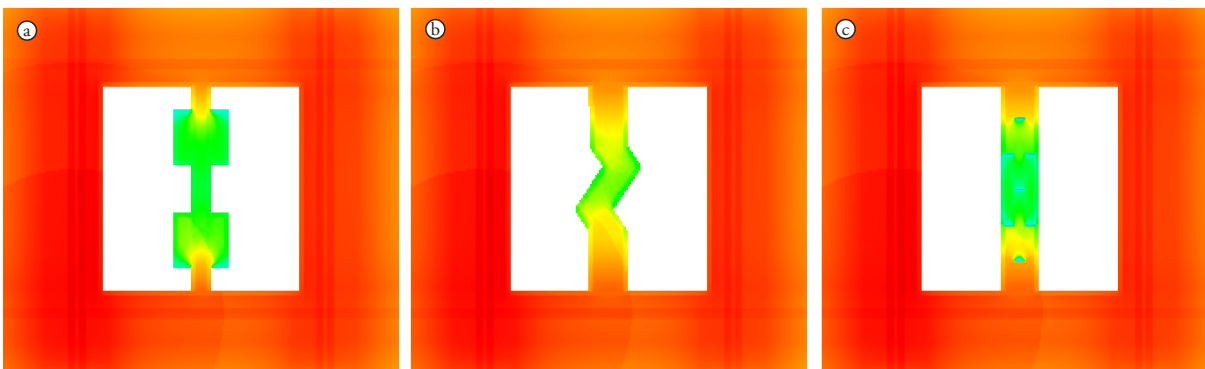
Using a base width of 10m, a number of corridor types were tested. Noise levels within the corridor were greatly effected by changing reflection order, as shown by the comparison of simple straight corridors illustrated in Figure 4.21

**Corridor Shape** - Having a zigzagging corridor provided some shelter by generating alcoves within the corridor, but with regards to the original test, the change in acoustic performance was negligible (Fig. 4.22 (b)). The chambered corridor was of more interest as it seems the chambers limited a large portion of reflected sound from penetrating deeper into the corridor, improving the acoustic performance and providing additional areas in acoustic shadow (Fig. 4.22 (a)). For these strategies to be most successful, they would best be implemented at the entry points of a pedestrian corridor.

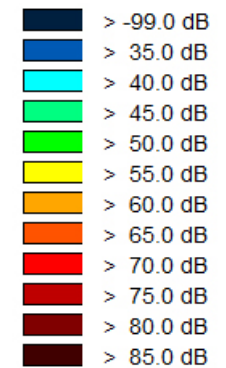
**Barrier Corridors** - The first barrier corridor iteration employed a series of offset barriers throughout the corridor (Fig. 4.22 (c)). This was ineffective, as any mitigated sound was offset by reflected sound around the barriers. Additionally, the corridor was made far less pedestrian friendly. A far more effective measure may employed a series of edge partition barriers (see Appendix 4). While not providing any direct protection, the partitions essentially stop any reflected sound reaching the central corridor area (much like the chambered corridor iteration). This strategy could be an element introduced into the design of building facades rather than freestanding barriers (i.e. diffusive facades).



**Fig. 4.21** Pedestrian Corridor Analysis. Simple 10m wide corridor -  
 (a) Reflection Correction of 1.5dB,  
 (b) Reflection order of 2,  
 (c) Reflection order of 2 with Sound Absorbing Facade.



**Fig. 4.22** Pedestrian Corridor Shape Analysis.  
 (a) Chambered corridor,  
 (b) Zigzagging corridor,  
 (c) Barriered corridor.





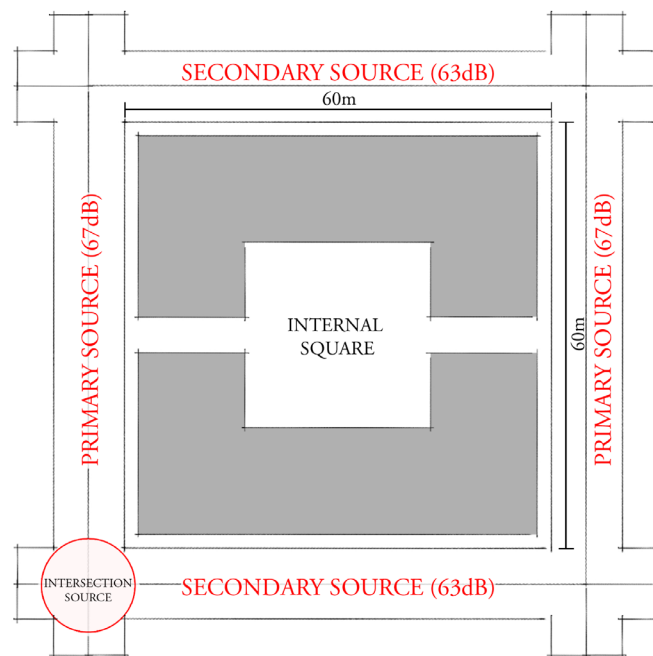


Fig. 4.23 Internal Squares Test Configuration.

The Internal Squares configuration compares a range of internal square shapes and access points. Both the acoustic quality of outdoor space and urban practicality are analysed. Like the pedestrian corridor, a square should include elements like good amenity, legibility, ease of access. In Carmona's 'Public Places - Urban Spaces', he notes that a distinction should be made between squares designed for civic prestige and those design as people places, as they do not necessarily perform the same task (for example, a 'civic square' is designed to show off a particular building, or for certain civic functions, and may be judged unsuccessful as a people place)(2010, p. 182-183).

#### 4.6.5 Test Configuration 3 - Internal Squares (Fig. 4.23)

- Type
  - Square Block, 2 Primary Roads (N to S), 2 Secondary Roads (E to W), internal buildings
- Sounds Sources
  - Primary Roads (67dB),
  - Secondary Roads (63dB),
  - Intersection (+3dB at Centre)
- Variables
  - Internal Square Size
  - Internal Square Shape
  - Entrance Placement
- Analysed area
  - Acoustic Environment of Square

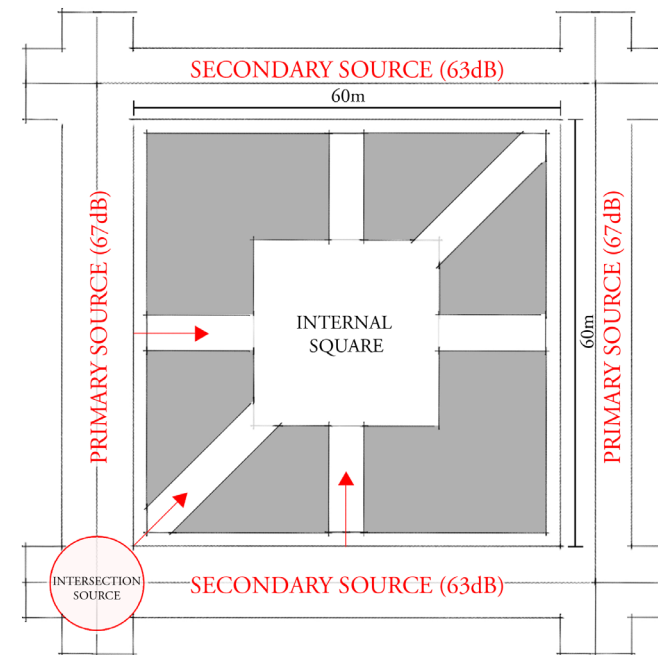
#### 4.6.6 Study Interpretations

The square layouts tested are better described as perimeter blocks with internal square. By nature, the perimeter block is perhaps more semi-private than public, but that does not discount its inclusion in the experimentation process.

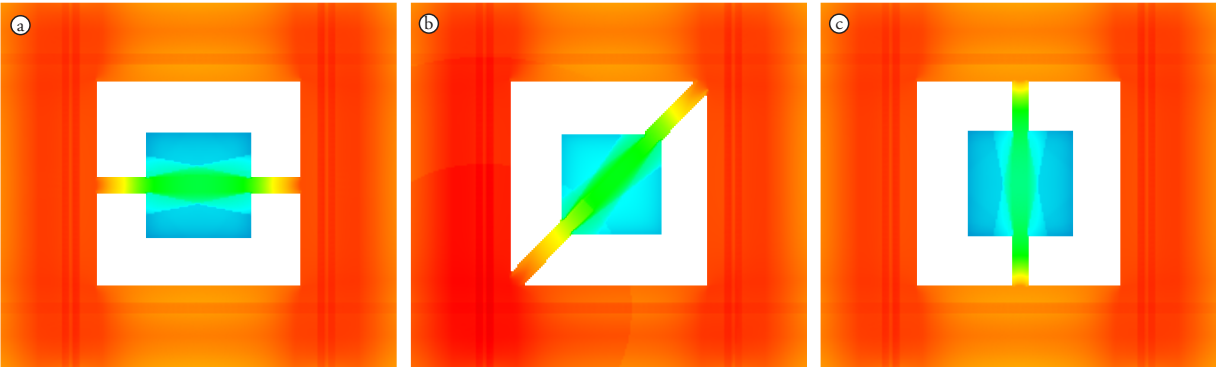
**Entrance placement (Fig. 4.24)** - Entrance Placements have a substantial effect on the acoustic environment of the square. The first experiments observed the acoustic environment of a conventional square with varying axial intersections (Fig. 4.25). Horizontal, diagonal and vertical intersections were all tested to determine the best result. Best results came when entering from a secondary street; conversely the worst results came when entering from a busy intersection (up to 5dB difference at centre of the square). This design parameter may, however, be defined by factors of greater importance than acoustics, such as existing pedestrian thoroughfares or buildings.

**Square ratios** - The truncated rectangular square stretching perpendicular to pedestrian axis (Fig. 4.26(a)) performed better than the elongated rectangular square (Fig. 4.26(b)) providing a greater area sheltered from noise. This is due to the acoustic shadow effect. However, this shape doesn't reflect good urban design, as the square has poor legibility and may be an uncomfortable space to inhabit.

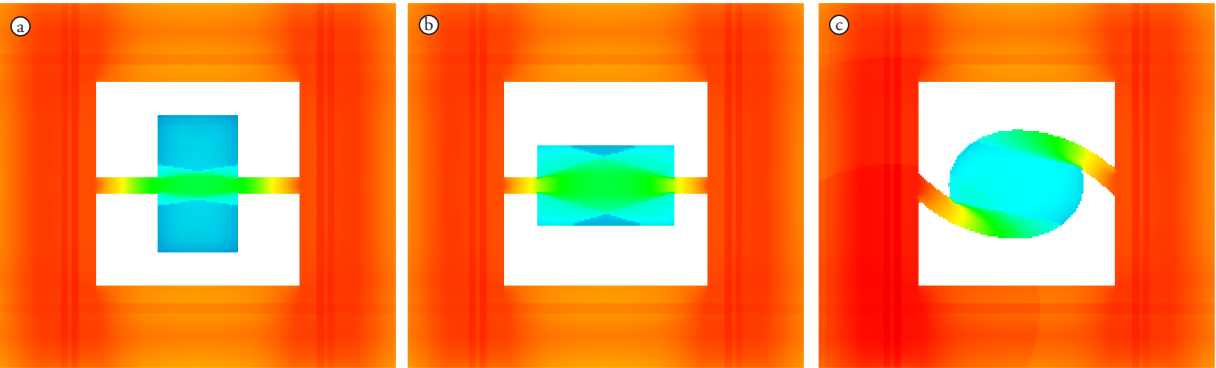
An intriguing square design was the oval shaped square (Fig. 4.26(c)). The entrances off the roads are curved, stopping any direct sound from road sources penetrating into the square. This does make the square design less legible visually, but with a vast expanse of the square in acoustic shadow. This is a potentially good design for a nuclear square with a central focus.



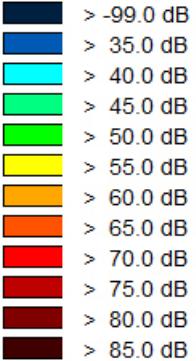
**Fig. 4.24** The effects of entrance placement on Internal Square acoustics; loudest at the intersection entry, quietest when entering from a secondary road.



**Fig. 4.25** Internal Square Analysis; Entrance Placement -  
(a) Entrance off primary road (horizontal),  
(b) Entrance off intersections (diagonal),  
(c) Entrance off secondary road (vertical).



**Fig. 4.26** Internal Square shape Analysis -  
(a) Deep rectangular square,  
(b) Shallow rectangular square,  
(c) Oval shaped square.



#### 4.6.7 Urban Design Implications of Block Experiments 1-3

The block experiments provided some interesting results concerning acoustic performance. The urban context of a block firstly determines whether internal spaces are even feasible. With a strict urban criteria placed on the design of city blocks, an acoustic agenda may be undermined. A city block has to adhere to an overall urban structure, including zoned usages, existing pedestrian/vehicular movements, etc.

**Block Splitting** - Breaking large footprints into multiple smaller footprints could both increase the variety of leasable spaces and uses, and produce quality acoustic spaces within internal block areas. The introduction of an internal outlook has the potential to add commercial value to what is perhaps the least valuable space of an urban block (the centre).

It should be noted that such measures have to contend with a spatial hierarchy already inherent in the urban fabric, and while opening internal spaces in a block may introduce new potential uses, the block perimeter will likely remain the most valuable space. Additionally, the level of reduction in building mass within a city-scape prompts additional questions about the financial feasibility of such a ploy.

Unless newly defined internal spaces are establishing a new primary route, they are likely to be enclosed or semi-private. In cases involving new public thoroughfares, path directions (and shapes) will likely be predetermined. Without compromising visual permeability and general legibility, noise can be addressed in a number of ways;

- Using diffuse/irregular building facades can minimise noise amplification due to sound reflections,

- Limiting direct sight lines from traffic sources at entry and exit points can limit sound propagation.

Finally, these studies have provided examples of what might be considered private internal squares, but the acoustic principles derived from their analysis are still valid when discussing public squares. The primary concern in the acoustic design of squares is attenuating as much negative noise as possible before it enters the square. It is important that equilibrium is reached between acoustic and urban principles in square design.

The success of a square could be attributed to how it is perceived externally; its potential for activity, and the vibrancy created by its existing inhabitants. Creating squares that have no direct line of sight to a sound sources may be a good acoustic solution, but they come at the cost of legibility to the pedestrian, who can no longer perceive the square as part of a greater succession of spaces.

As a compromise, simple additions like acoustically diffusive facades along entry points could have a small but positive effect on the SPL within a square without compromising legibility. Soundscape Design elements may perhaps be a more appropriate aid to the acoustic design of a space so heavily defined by the existing urban condition.

## 4.7 Street Canyon Experiments

This series of studies analyses the acoustic environment of the street canyon on the vertical plane. The base experiments contain a 10m wide high volume 2 way road and 3m wide pedestrian pathways either side (with variations). The roadway produces 67dB at its 2 sources. The purpose of these experiments is to examine different attenuation methods on the vertical plane from two perspectives;

- Self-protecting building techniques and,
- Terrain Manipulation

These results become significant when considering upper level building usage (namely residential), and when planning parks adjacent to streets.

### 4.7.1 Street Canyon Test Configuration (Fig. 4.27)

- Type
  - Vertical Section, 2 lane road of 10m width, 3m wide footpaths
- Sounds Sources
  - Primary Road (67dB) from 2 car sources
- Variables
  - Building Facade
  - Building Ascent
  - Landscaping
- Analysed area
  - Acoustic Environment within street canyon and into adjacent open space

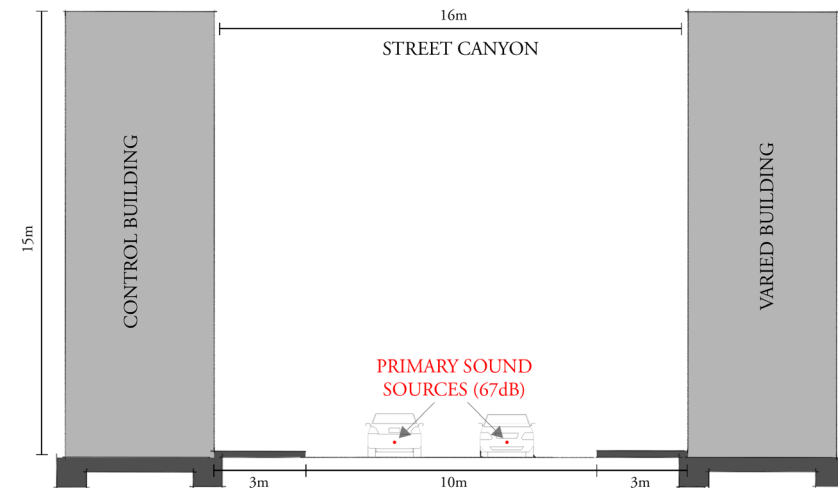


Fig. 4.27 Street Canyon Test Configuration.

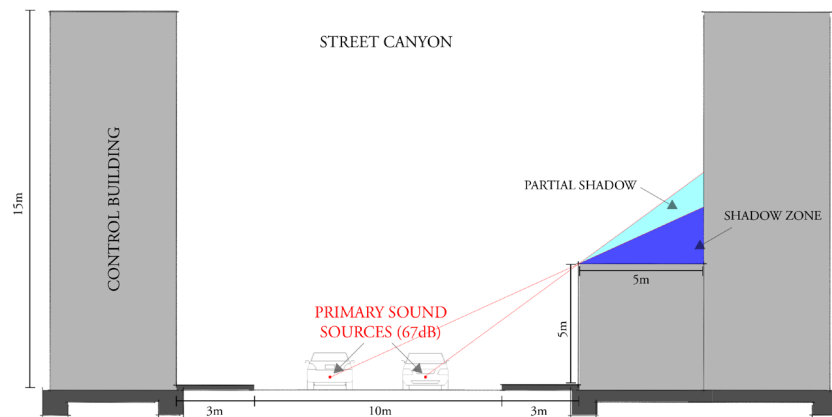


Fig. 4.28 Acoustic shadow created by Podium Building; as a result of the angle created between the source and podium edge, a portion of the facade is acoustically shaded.

\*Note - Balconies can also reflect sound from their underside into facades. (CadnaA did not have a balcony tool so experiments used reflective horizontal noise barriers instead)

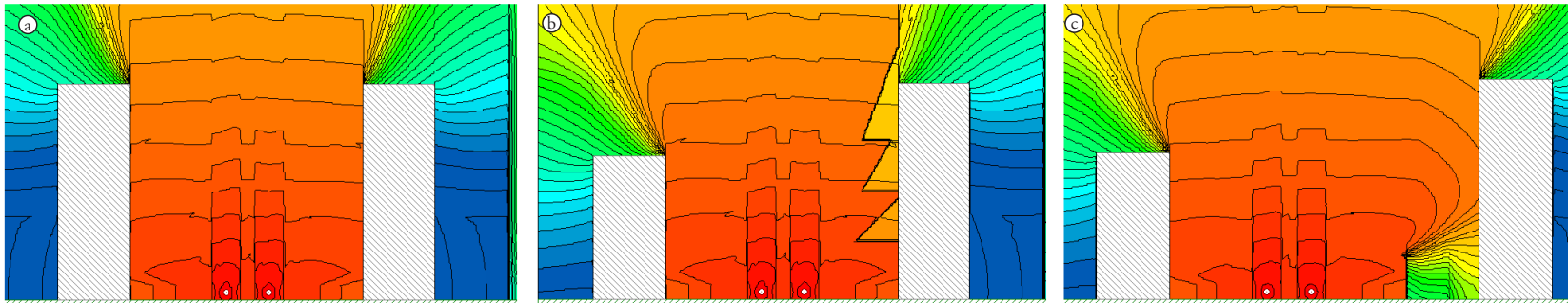
### Study Interpretations – Self-Protective Buildings

Without any attenuation, sound travels vertically in street canyons virtually unhindered. ‘Self-Protective Building’ is an expression taken from Kang’s ‘Urban Sound Environment’ (2007, p. 175). It refers to a design approach that implements noise attenuation techniques in the design of buildings with the potential for upper level residential development.

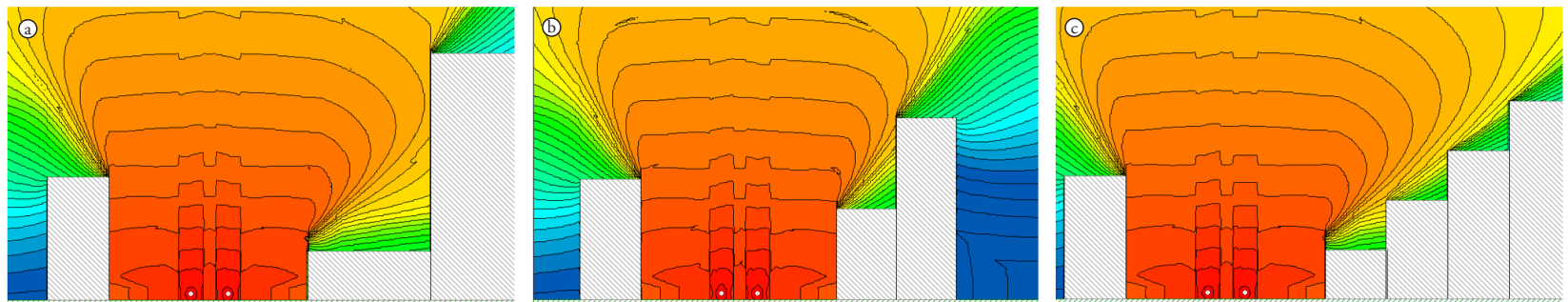
From the basic test (Fig. 4.30 (a)), it appears that there is very little SPL reduction over the 15m high building façade (63dB at top). Like earlier experiments, the best means of reducing sound is to introduce an obstacle between source and receiver (Fig. 4.28). ‘**Balconies**’ can provide some attenuation to the facades of a building\*. Figure 4.30 (b) showed improvements of up to 5dB.

Shielding upper levels from noise can be achieved by using lower levels as sacrificial protectors. ‘**Podium building and Setbacks**’ both showed good results for reducing noise levels on upper floors. As can be seen from Figure 4.29, any podium will shield a portion of the upper floors relative to the angle created from the source to the edge of the obstructing obstacle. An even more effective profile is seen in Figure 4.29 (c), the terraced building. This is, however, a particularly difficult architectural feature, and lacks spatial definition, important to urban areas (perhaps better utilised in a semi-urban area)

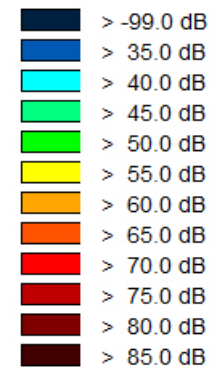
Attenuation can also be supplemented by a cantilevered handrail that create sharper angles, reducing diffracted sound. Elements like walled courtyards also contribute to sound attenuation, but may be more suited to private buildings or sheltered parks.



**Fig. 4.29** Street Canyon Analysis -  
 (a) Control experiment; general noise propagation up canyon,  
 (b) Balcony analysis over 3 levels,  
 (c) 3m high walled private courtyard analysis.



**Fig. 4.30** Street Canyon Analysis; Podium/Setbacks -  
 (a) 10m deep Level 1 podium with noise barrier handrail,  
 (b) 5m deep Level 2 podium without noise barrier,  
 (c) 5m Level setbacks with Level 1 noise barrier handrail.

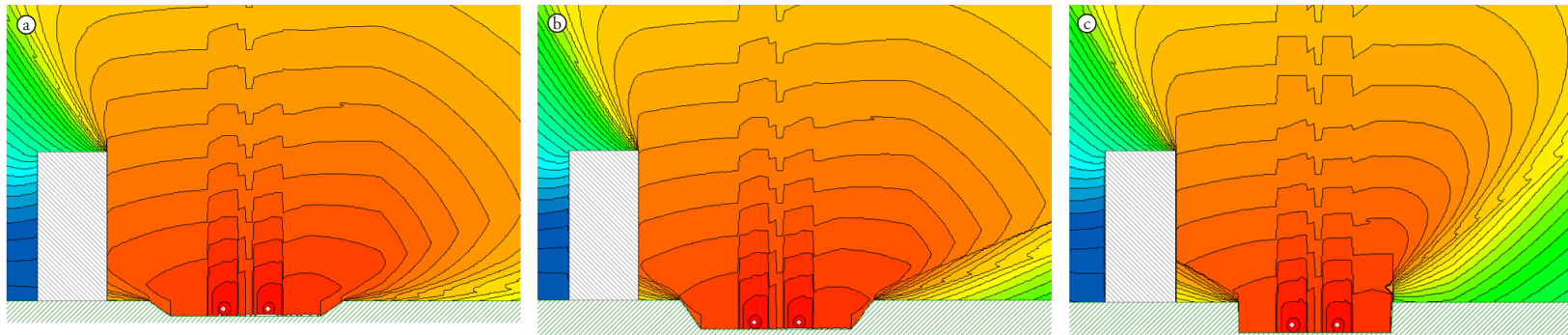




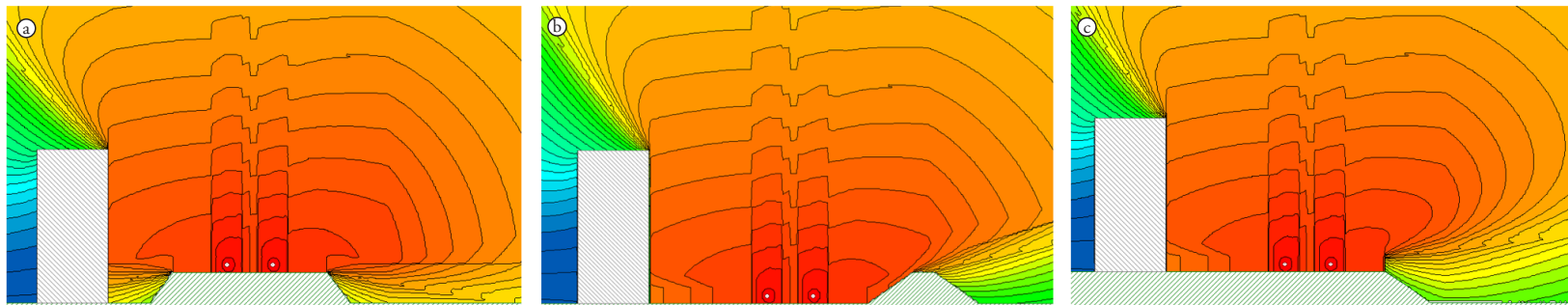
### Study Interpretations - Terrain Manipulation

Noise from vehicles comes primarily from two sources, the engine, and the tyre contact with the road. With the source sitting so low to the ground, small interventions could have significant results. Early tests analysed '**Lowering roads**' (Fig. 4.31). Some sound reduction occurs, but to have any significant effect at a distance of less than 10m one would have to lower the road 2 metres or more. Small additions like acoustic barriers improved screening, and reduce sound diffraction. '**Raising roads**' had a slightly different effect (Fig. 4.32 (a)). By raising the road 1 metre, the sound source is raised to a level approximately parallel with a pedestrian ear height (poor performance). There is a shadow zone created at the base of the rise, but for this to be substantial, the road would have to be raised more than 2m, a feat both aesthetically unattractive, excessively expensive, and impractical.

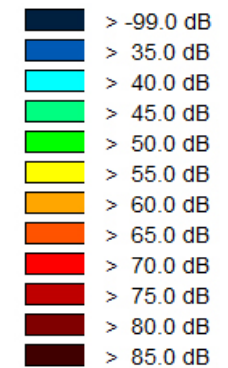
'**Embankments**' are a popular attenuation device in larger park areas (For example, Frank Kitts/Waitangi Park, Wellington). They provide a natural sound barrier and more ground absorption by utilising softer natural ground covers (Fig. 4.32 (b)). Lowering adjacent parks (like the raised roads) may not perform as well acoustically as dropping roads, but can satisfy the urban design principles of enclosure and visual permeability in a square/park situation. With the addition of a low level handrail noise barrier, it can also be strengthened acoustically. Ideally, the majority of attenuation should occur at an average conversational height (1.8 to 2.0m). The disruptive effects these attenuation methods have on the continuity of urban space far outweighs their acoustic efficiency, which is perhaps why their use is limited to only the most extreme of situations (e.g. Entrenching a 4 lane major highway adjacent to residential development).



**Fig. 4.31** Terrain Manipulation -  
 (a) 1m lowering of street,  
 (b) 2m lowering of street,  
 (c) 2m vertical dropping of street with noise-barrier handrail on park side.



**Fig. 4.32** Terrain Manipulation -  
 (a) 2m raising of street,  
 (b) 2m embankment on park side,  
 (c) 2m lowered park with noise-barrier handrail.



#### 4.7.2 Urban Design Implications of Sectional Experiments

The purpose of these experiments was to analyse different vertical attenuation methods available from built and landscape elements. These results become significant when considering upper level building usage (i.e. residential), and when planning parks adjacent to busy streets. The principals of vertical attenuation are much like those of the horizontal plane; minimise sound wave's angle of incidence to create shadow zones, and physically distance receivers from sources. The three main methods of self-protective building design are;

- Setbacks; utilising lower level buildings and sacrificial objects to screen upper levels
- Barrier Attenuation; adding balconies and handrails to building edges further cuts down the angle of incidence increasing acoustically shaded zones.
- Façade Treatment; by treating building façade as diffusive layers with irregular surfaces, reflections within street canyons can be reduced. (not tested)

These architectural design techniques should again be paired with good urban design principles. For example, it would be impractical to add a terraced housing block to an inner city urban street, surrounded by vertical high rises. It may, however, be appropriate to set back a building on the second level to adhere to existing historic surrounding, thus opening the door for potential residential development above such a setback (in the acoustic shadow zone and above).

Strategically designing the elevation of roads and landscape elements may also reduce traffic noise for surrounding buildings and public spaces. Techniques like raising/lowering roads and parks, adding embankments or sound barriers to the design of streets could have a positive effect on the surrounding acoustic environment.

However, it is unlikely that the inherent pitfalls of such design decisions will warrant their inclusion in the urban landscape. This is perhaps why such techniques are not seen in urban areas to date. The negative consequences of such techniques could include; excessive costs, disruption of urban continuity (visual and physical), loss of street character, and even the potential for monumental drainage difficulties.

The most appropriate and financially feasible use of these techniques is likely an amalgamation of multiple solutions, which adhere appropriately to the existing urban context.

#### 4.8 Conclusions on the Experimental Process

Overall, I can conclude that the experimental process using CadnaA was a relative success. Acoustic Principles derived from experimental results - though perhaps exaggerated by the simplicity of the test configurations coupled with the unimpeded nature of the simulated environment - were both surprising and informative.

A particularly enlightening conclusion came early on in the experimental process, when analysing single street configurations. In defining the fundamental components that make up an acoustic shadow, it was very interesting to note the importance of the role neighbouring buildings play in the creation of acoustic shadows. Embodying the idea of contextual significance, an ever present theme in the field of Urban Design.

Many of the simulated situations exposed fundamental conflicts between acoustic and urban design principles (for example, when considering the manipulation of road height). Interestingly, it could be argued that such situations less conducive to grander urban acoustic design intervention provide a stage on which the more perceptual elements of soundscape design can be implemented and assessed.





Fig. 5.1 Contextual Site Plan; Wellington City (site highlighted in red).



Fig. 5.2 Close Site Plan; Harbour Quays Precinct (Centreport).

## 5. URBAN DESIGN PROPOSAL

### 5.1 Introduction

The first section of this chapter is comprised of a comprehensive urban and acoustic analysis of the selected site. The acoustic analysis includes a series of 'Site-Specific Acoustic Studies' that determine an optimum street/building layout. Then, using the knowledge gained from these studies and earlier research, a series of macro-design objectives is established.

Site selection was based on a specific challenge; establishing a diverse, liveable urban environment within an acoustically challenging area (for example, adjacent to a major highway, airport or in this case, operational port land).

### 5.2 Site Selection

The selected site, known as the 'Harbour Quays Precinct', is located at the Northern Gateway to Wellington City on Centreport Land. Currently the site is bordered by Operational Port Land, and is dotted with large Office Park buildings, industrial warehouses and parking areas. Adjacent to the site is Aotea/Waterloo Quay, the primary Roadway into the City's CBD. Additionally, the City's rail-yard is located just west of the site. Two rail corridors that carry freight to the Operational Port frame the site physically and acoustically. These trains only travel at low speeds in this area.





**Fig. 5.3** Contextual Site Photos; (a) Statistics Building, (b) BNZ building, (c) Site overview from Stadium Concourse, (d) Shed 35 heritage building.



### 5.2.1 SWOT analysis

**Strengths** - It can be assumed that older buildings will be demolished essentially providing a clean slate (apart from heritage and new buildings). The site's proximity to the CBD and major transport hub will also aid in reducing traffic levels.

**Weaknesses** - The location of the site is severely exposed to the elements. This will have to be addressed in the new urban layout. Furthermore, the existing allowance for car parking is excessive. The existing pedestrian connection to the city will also have to be addressed as it lacks comfort, legibility and sufficient shelter. The difficulties of adjacent port noise will be discussed later.

**Opportunities** - As an office park area, the site has not yet developed a specific character. Drawing on Soundscape Principles and the site's port heritage, a new identity for the site can be created. This can also be integrated into a greater diversity of site use. Additionally, there are a few good chances for creating positive pedestrian links to the transport hub and the waterfront boulevard to the south.

**Threats** - The site itself must act as a transition space between the current city grid and the distinct layout and orientation of the wharves. This may create some difficult spaces along that transition line. The sites proximity to existing commercial noise also make 'reverse sensitivity'\* a real issue. To introduce noise sensitive activities into the area, one must be wary of the impact it will have on current Operational Port activity.

\* Reverse sensitivity describes the effect that development of one kind may have on activities already occurring in an area. Usually, it is a result of people involved in an activity that is newly established, complaining about the effects of existing activities in an area.

### **5.2.2 Port Reduction Plan**

While Wellington's Operational Port is still very much in constant use, the natural growth of the city is pushing north into Centreport land. The port sits on reclaimed land that could be considered prime real-estate for Wellington. Practically speaking, the port is poorly located and too small for larger vessels to dock. As a premise for this urban design intervention, it is speculated that there will be an eventual relocation of a large quantity of the port's trade and a reduction in its size. This reduction will take place in a series of steps;

1. Triangular Harbour Quays site will be cleared of Operational Port Use.
2. Finger Wharfs will be given over to city development.
3. Operational port will move to northern part of reclaimed land.

Eventually, the 'Operational Port' will be relocated further north towards the Interislander Terminal. The context in which my Urban Design Proposal takes place is between stages 1 and 2 of the port reduction (Fig. 5.4). As the finger wharves are being given over to city development, rail and truck freight traffic to the southern corner of the Port reduce and eventually cease, thus extinguishing the substantial acoustic aggravation created by such sound sources. It is therefore important that the proposed site plan/street layout work well in urban design terms, as the acoustic environment will improve with diminishing port operation, rendering remedial measures unnecessary.

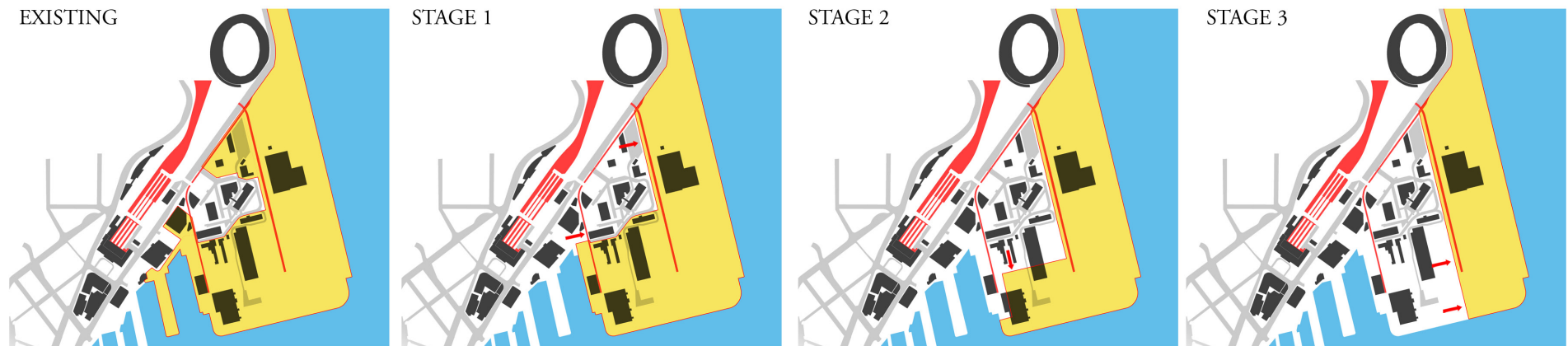


Fig. 5.4 Proposed Port Reduction Plan.

### 5.2.3 Analysing the Existing Acoustic Situation

The acoustic environment of modern cities has essentially been reduced to a universal monotone of traffic, construction and industrial noise. Wellington city is fairly well protected from major noise sources such as high volume highways and rail areas. State Highway One is positioned well above and behind the CBD (bordered by tall office buildings) and the city railway ends at the CBD borders. This does not mean, however, that all areas of Wellington are free from invasive noise.

The 'Harbour Quays Precinct' is one of the most sonically difficult areas of Wellington. Wedged between the city's Operational Port and Primary Gateway Road 'Waterloo Quay' (as well as the adjacent rail yard which is not considered in this research), it provides a unique opportunity to study the implications of introducing mixed-use urban development in an acoustically challenging area.

#### Current Government Rules and Regulations

There has been much debate in recent years over how to address issues of reverse-sensitivity in any future urban development within port-noise control line. Currently, proposed solutions are to;

- Better manage and regulate noise emission levels from port related activities (Fig. 5.7),
- Impose a mandatory level of acoustic insulation on building envelopes within port-noise effected areas, and
- Avoid the introduction of noise sensitive activities (residential development) altogether.



Fig. 5.5 Map of Port Noise Control Line within Wellington CBD.

	Base cost (no additional acoustic insulation)	% increase in cost from base case	
		30dB acoustic insulation	35dB acoustic insulation
Model 1 - Bedroom <i>Mid floor apartment</i>	\$84,000	1.8	4.8
Model 2 - Bedroom <i>Penthouse apartment</i>	\$144,900	5.6	16.1
Model 3 - Villa retrofit 1 bedroom with ensuite extension	\$63,300	12.2	26.5

Fig. 5.6 Cost feasibility of acoustic insulation in residential apartments within noise control lines.

Time Period	Sound level
Any 5 consecutive 24 hour period	65dBA $L_{dn}$
Any 24 hour period	68dBA $L_{dn}$
10pm to 7am (all days)	60dBA $L_{eq}(9 \text{ hour})$ 65dBA $L_{eq}(15 \text{ minute})$ 85dBA $L_{max}$

Fig. 5.7 Wellington City Council limitations for sound levels within the noise control lines.

This approach may, however, render future development financially unfeasible (Fig. 5.6). The focus of my redevelopment is therefore to introduce a diversity of activity and mixed-use into the precinct, including residential areas, urban parks and commercial spaces, through the use of urban layout and soundscape design, without a reliance on high-cost acoustic insulation throughout the site.

To mitigate the adverse effects of noise pollution, specific rules and regulations have been set out in Wellington's District Plan. These conditions apply to any new building development.

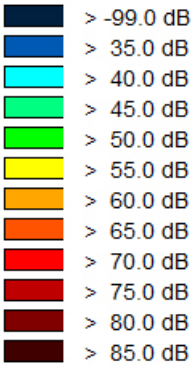
#### 5.2.4 Mapping the Existing Soundscape

The site sits on reclaimed land adjacent to a series of wharfs that follow the waterfront around the City. Due to the site's proximity to the Operational Port, issues of reverse-sensitivity regarding the introduction of acoustically sensitive activities (namely residential) into the site are prominent. The area has consequently been developing into an office park, exploiting large footprint office buildings and disproportionate parking areas.

As Figure 5.8 illustrates, the existing site performs poorly acoustically. The primary noise sources are Waterloo Quay and the port itself. From a series of measurements taken on site, the ambient noise level from the operational port seldom drops below 60dB. Waterloo Quay is more variable, averaging between 70 and 80dB depending on traffic flows.

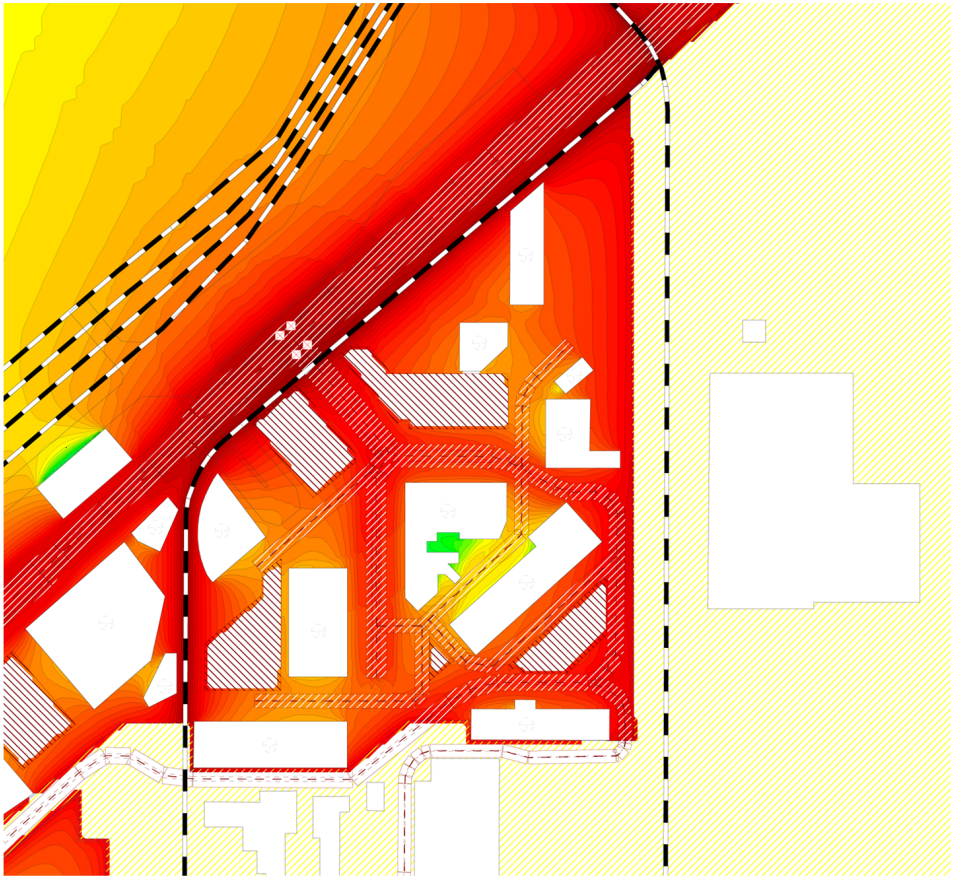
Another major annoyance is the flow of heavy trucks into the port via the central intersection. This flow is largely determined by incoming and outgoing vessels, but at peak times could be in excess of 5 trucks every 10 minutes, some producing sound levels in excess of 80dB. The route trucks must take to enter the port requires them to wind their way through the site, exposing much of the site to their noise.

The vast expanses of open space allow these sound sources to propagate unimpeded, consuming the site with noise.



# Existing Soundscape

DAYTIME



Traffic Light Intersection Built Fabric Car Parking Operational Port

Fig. 5.8 Daytime noise-map of the current Harbour Quays Configuration.



### 5.3 Acoustic Experimentation of Abstracted Site

This series of Acoustic Studies acts as an intermediary step between the previous chapter's 'Urban Form' studies and the later Urban Design Proposal of the Harbour quays Precinct. The studies are undertaken using a simplified version of the Harbour Quays site. To draw useful conclusions, the following parameters are used;

- Type
  - Triangular Site, Approximate Size of Harbour Quays Precinct
- Sounds Sources
  - Primary - 16m wide heavy traffic road (67-68dB) i.e. Waterloo Quay
  - Secondary - 8m wide light traffic road (57-58dB)
  - Area Source - Operational Port (69-70dB at Source edge)
  - Intersection Source - (+3dB from Centre)
- Variables
  - Primary and Secondary Road Network
  - Building Footprints (Simplified Block Patterns)
- Constants
  - Waterloo Quay and Central Intersection
  - Multiple Connections to future site (East and Southern Edges)
  - BNZ Building at South-west corner
  - Park in Centre of Site
- Scope of Analysis (horizontal calculation area)
  - Daytime sound (all sources accounted for)
  - Nighttime sound (internal roads disregarded, only port and Waterloo Quay considered )

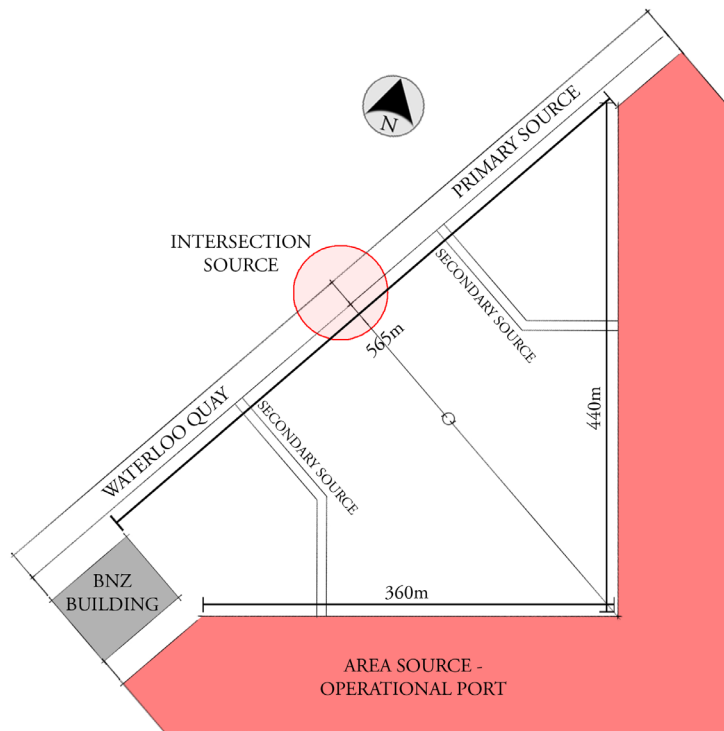
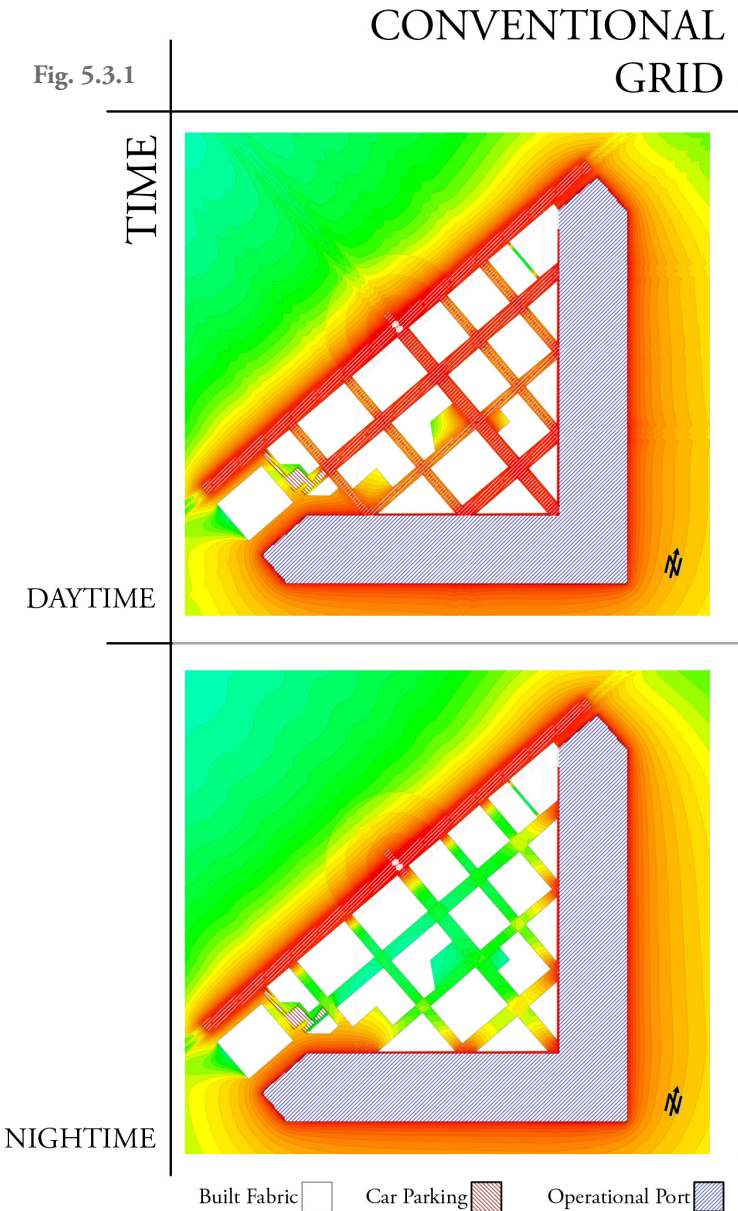
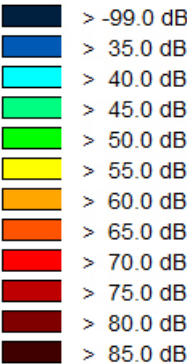


Fig. 5.9 Abstracted Site Test Configuration.

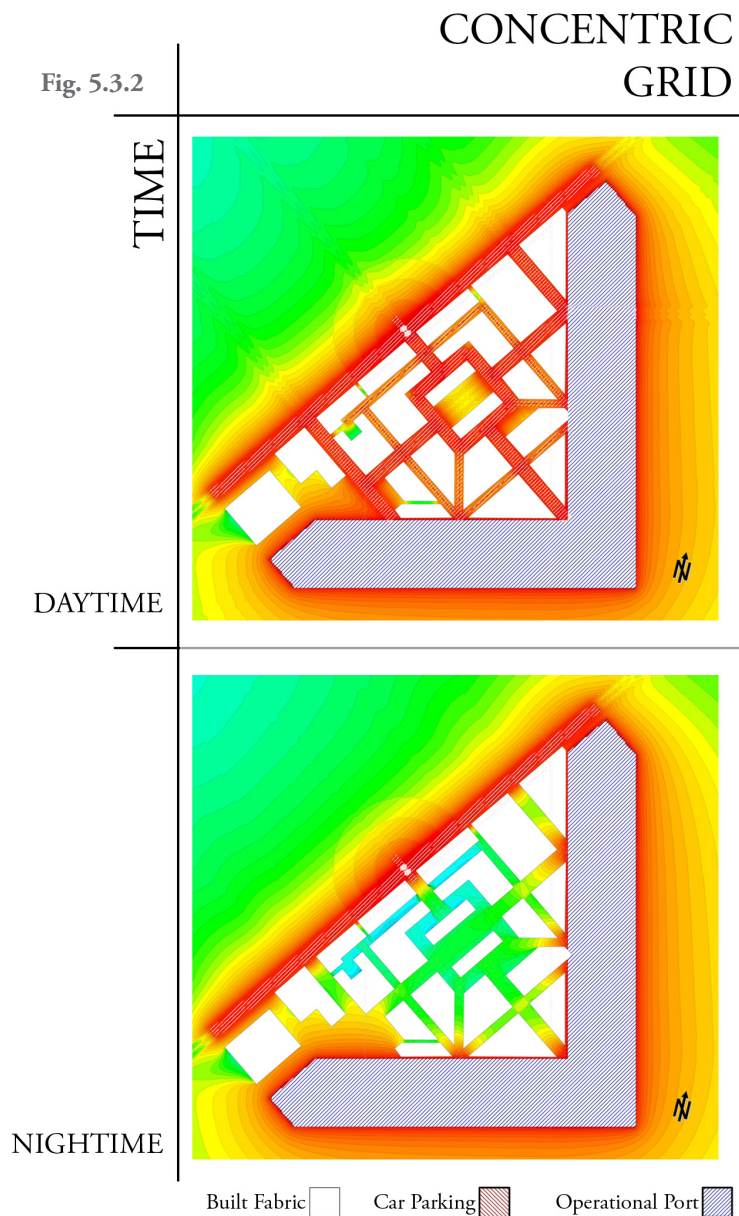
5.3.1 Conventional Grid

Urban - This grid privileges the existing street axis with major roads running parallel and perpendicular to Waterloo Quay. While this grid has good connectivity and visual permeability, human scale is dwarfed by large block sizes, and pedestrian comfort is reduced by the need to cross too many major roads. Additionally, the site edges prove problematic, producing a number of triangular buildings, and disregarding future connections. The park network is treated as an extension of the Waterfront Boulevard, adjacent to the BNZ building, and in this case is fairly well connected.

Acoustic - A lack of street hierarchy, and the subsequently large block sizes both contribute to a degree of noise permeation through the grid. Parks and building facades are exposed to high levels traffic noise during the day, and to noise permeating from Waterloo Quay and the Operational Port at night (due to linear connections from source to the centre of the grid). This would limit the location of any residential development to the centre of the site (an area likely reserved for commercial use).





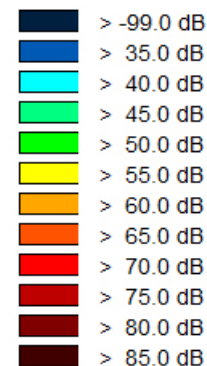


### 5.3.2 Concentric Grid

Urban - Like the previous example, this grid remains on the existing axis, but includes a central park. Concentric ring roads spreading outwards, combining orthogonal streets adhering to the existing grid and diagonal streets adhering to the future grid. Again, connections to a future grid will be problematic.

The street network becomes overly complicated and there is no park network to speak of. The central square is isolated, surrounded by primary roads. A greater variety in block sizes could be more conducive to mixed-use but a lack of a solid street edge makes the grid confusing.

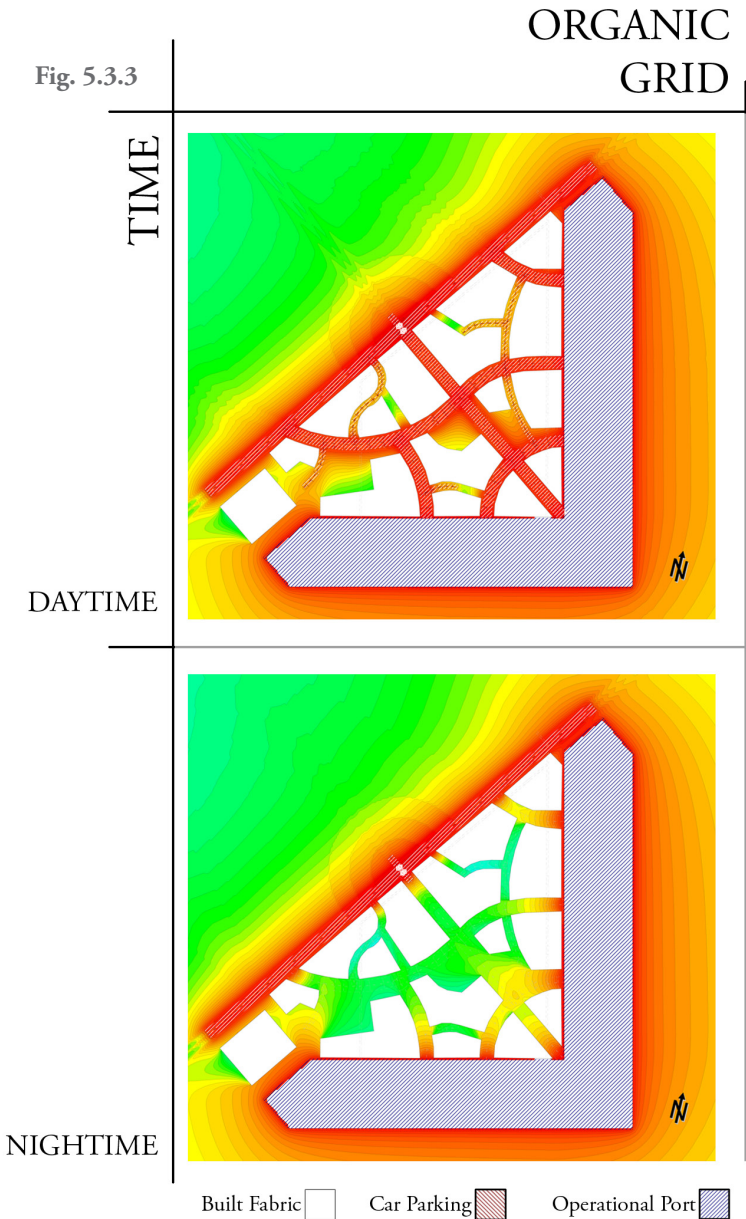
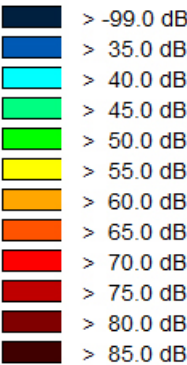
Acoustic - Again, the site is generally loud, though an increase in secondary roads is provided some facades with less noise exposure. The central park is particularly poor acoustically. Some relief can be found in the secondary roads adjacent to Waterloo Quay, sheltering enough to consider residential development. The rest of the grid, however, is similar to the previous example



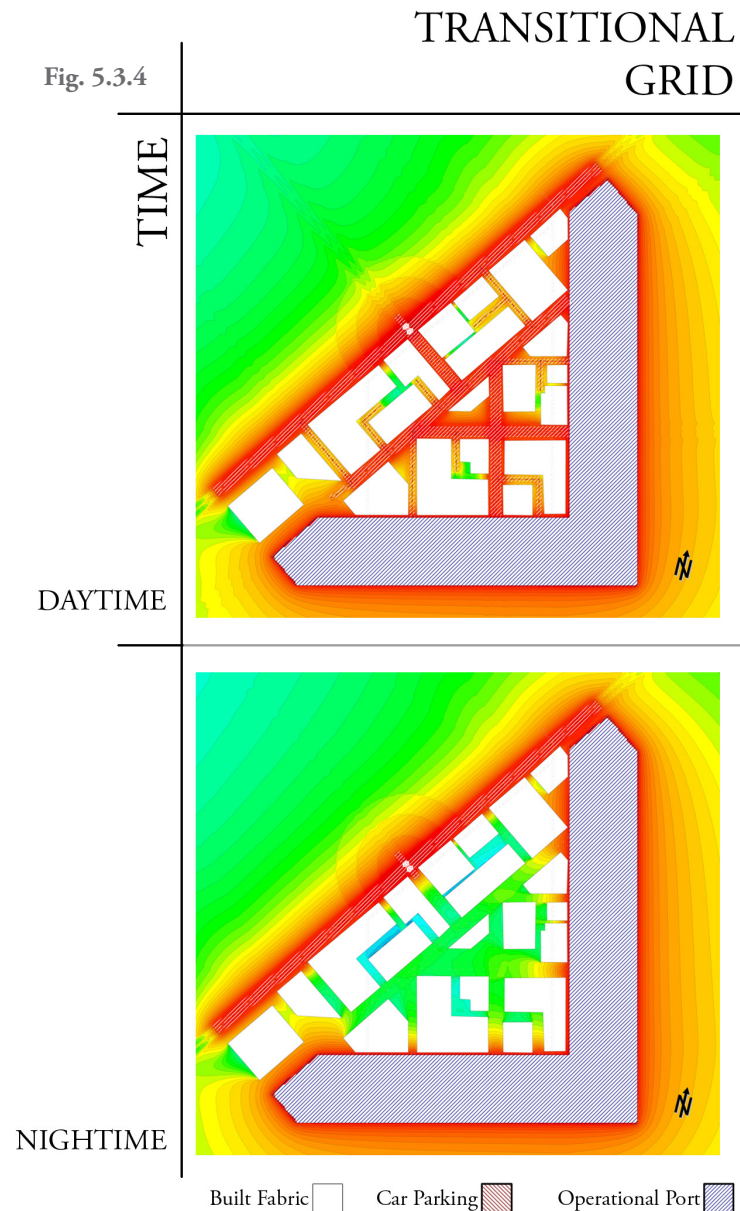
5.3.3 Organic/Curvilinear Grid

Urban - The organic grid has one straight primary road running perpendicular to Waterloo Quay. Otherwise, all the roads are curved. The organic shape of streets enables primary roads to link up to a future grid more sensitively than previous examples. There is some pedestrian connectivity from the BNZ to the central park (which sits on the corner of a major intersection). The block shapes created are also organic, perhaps contradicting the existing linear city grid. Secondary roads do provide some sheltered building edges, but these are largely negligible.

Acoustic - The positive urban properties of placing the central park at the intersection of two primary routes (good thoroughfare and visual presence) are perhaps offset by the inherent acoustic difficulties it presents (evident in the daytime noise map). Areas of note are pedestrian lanes that connect primary and secondary roads. With respect to night time noise, this street grid is too open to render any areas adequately quiet.

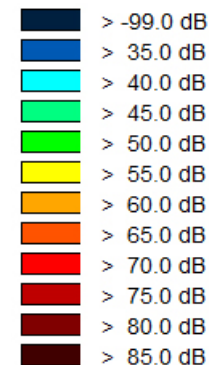


### 5.3.4 Transitional Grid



**Urban** - This grid is the first that incorporates elements of the previous. The block width between Waterloo Quay and the primary road permits a secondary road network between buildings (seen in the concentric grid example), allowing for smaller footprints which assist residential development. Difficulties arose at the attempted transition of grid axis. The central park is isolated by 3 primary roads, and the angles created by those roads create extremely awkward intersections. The grid change needs to be more sensitive to both axes. The only pedestrian path to the centre crosses multiple major intersections.

**Acoustic** - The secondary road network generates some interest between the blocks bordering Waterloo Quay, with internal alleys providing facades with good acoustic shelter. The central park is poor, however, as it is located at the major 3 way junction where the street grid changes direction. This is really the first appearance of a sound level below 40dB at night. The same areas specified in the day acoustic environments are well sheltered and appear ideal for residential development.

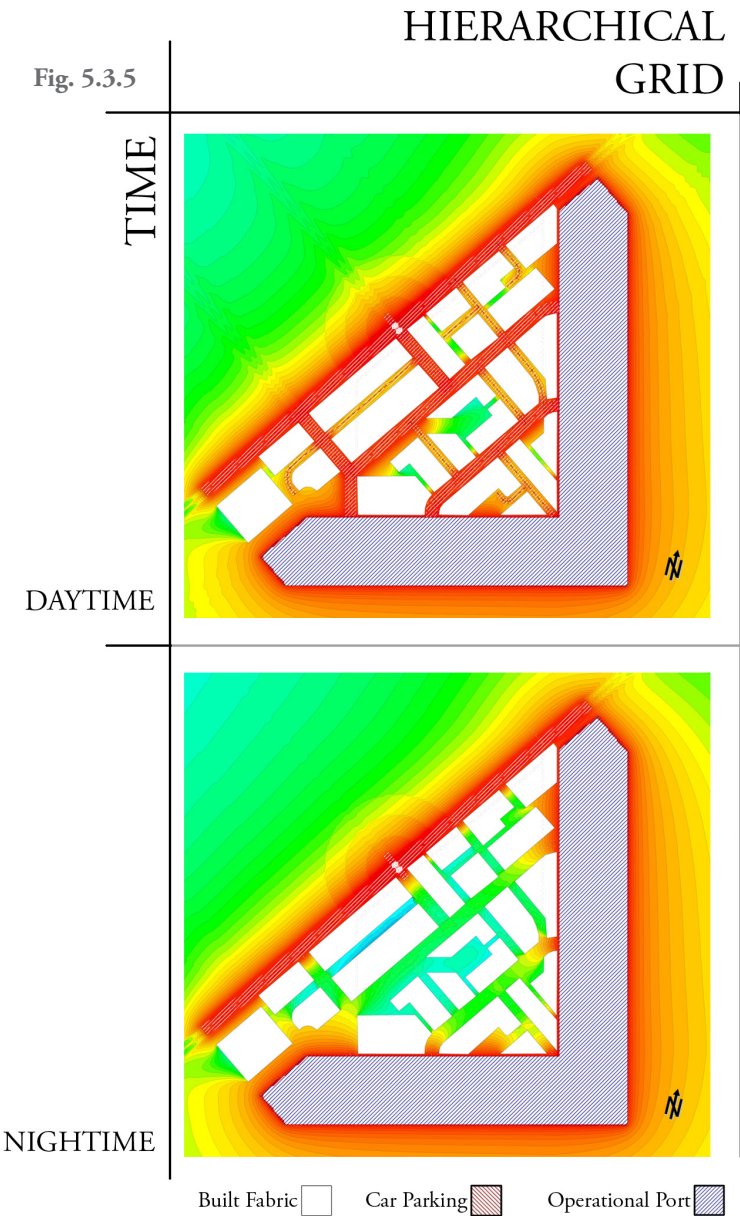
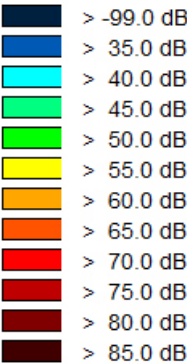


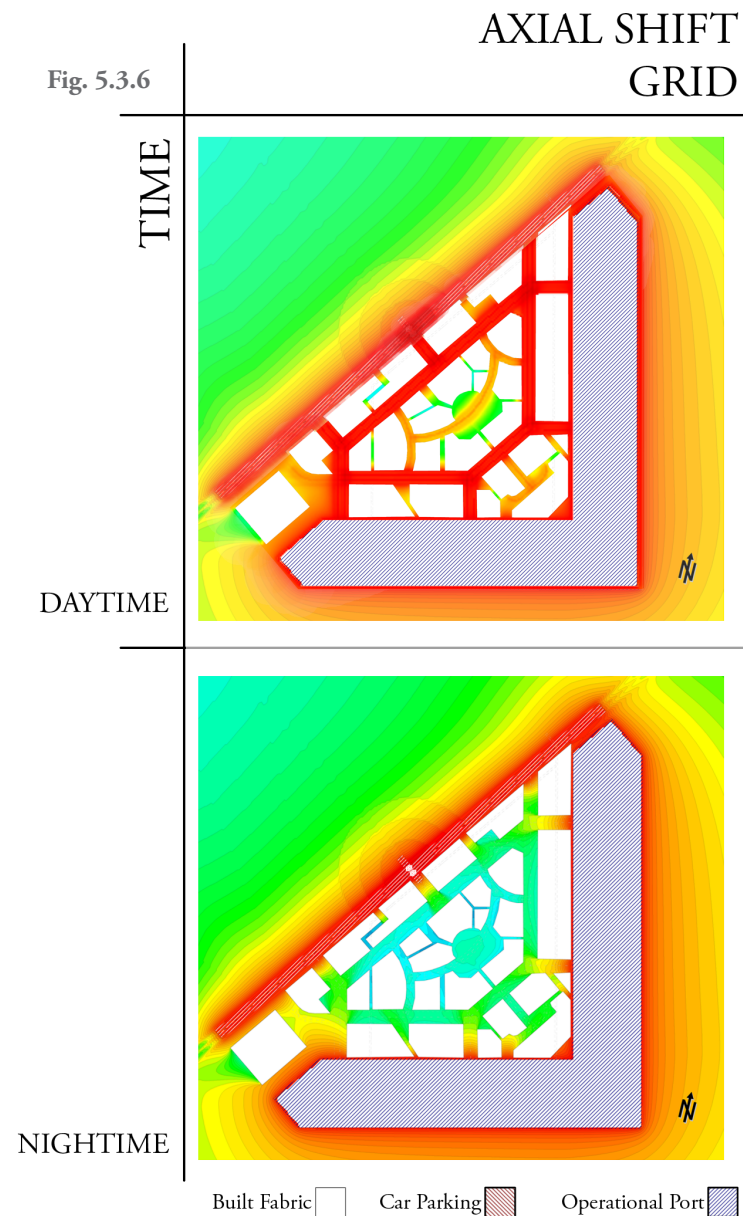


5.3.5 Hierarchical Grid

Urban - The street grid again has deep enough blocks for secondary roads and smaller building footprints. Like the conventional grid, the street layout stays on the existing axis, but only has primary roads in a single direction (parallel to Waterloo Quay). The grid change is more sensitive than the previous tests, and will largely occur in future at the edge of the site. Pedestrian connectivity is also better with good connection from BNZ to the park.

Acoustic - The introduction of a directional hierarchy provides an opportunity for residential development along secondary roads in the opposite direction. The park displays good acoustic traits (due to the level of enclosure provided by its surrounding buildings), but is also one of the least accessible Like previous examples, the most positive areas if this night time noise analysis are those that lie in lanes between primary roads. The directional change on the edges also mitigates a lot of the port sound at night.

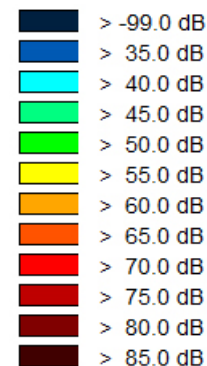




### 5.3.6 Axial Shift Grid

Urban - This street grid test is a further improves on the Hierarchical Grid. The north-east edge follows a conventional pattern with a more gradual transition into the future axis. Primary roads run adjacent to the port edges with a large internal block only divided by secondary roads. There is a good range of block sizes for varying building footprints. There is a pedestrian connection from the BNZ to the central park but it is somewhat disjointed. Strong built edges and building variety contribute to good legibility and human scale also.

Acoustic - This iteration proved most promise in terms of daytime areas of high acoustic quality. The perimeter roads are primary and connect to the new grid sensitively, leaving an internal block solely for secondary roads and good park space. The internal block performs particularly well at night. Any sound allowed in from the port is then attenuated by offset built layers in the next block.



5.3.7 Resultant Grid

Figure 5.3.7 represents the result of the grid experiment process, bringing together the best elements of earlier test to provide a coherent street grid/building configuration.

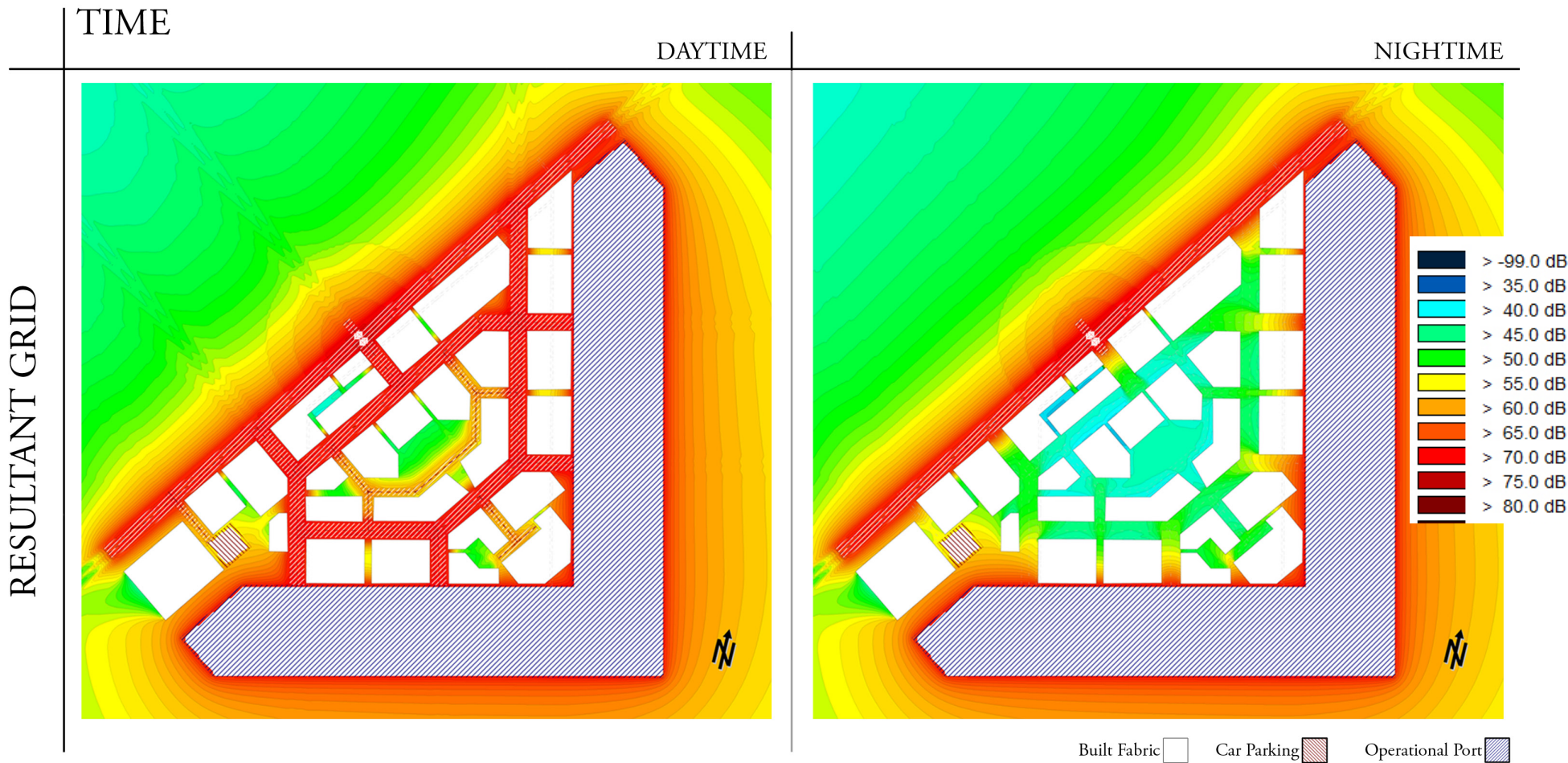


Fig. 5.3.7 Resultant Grid noise-map results.



### 5.3.8 Urban and Acoustic Design Implications

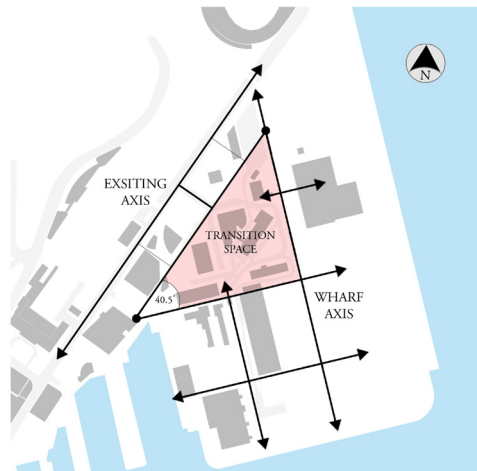


Fig. 5.10 The area in which the required grid transition should occur.

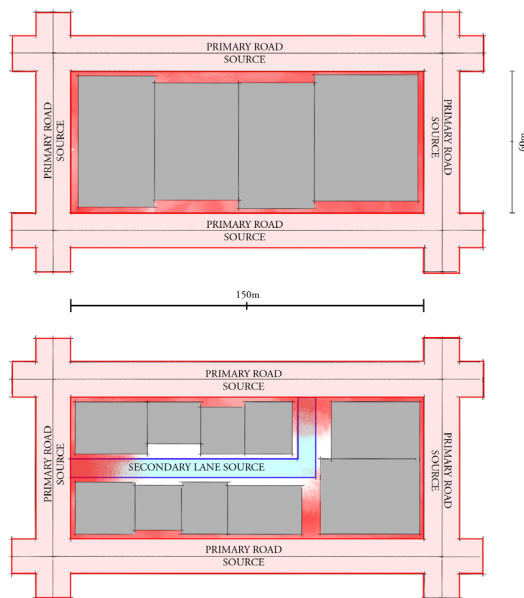


Fig. 5.11 Block splitting with secondary roads.

**Transition between Grids** - The first major issue considered is the required ‘Transition between Grids’ (Fig. 5.10). For future connections to be made, the street grid has to rotate approximately 40 degrees to meet a grid that parallels the reclaimed port land. Earlier Grid tests (5.3.1 and 5.3.2) avoided the problem by disregarding the grid transition. The subsequent tests show more sensitivity to the issue. The difficulties that arise from rotating the grid include;

- Awkward triangular spaces created along the axis change
- Loss of visual clarity and legibility
- Further complication to the street grid making vehicular navigation more difficult.

It became apparent that for the axis change to be sensibly managed, it had to be gradual so as to reduce the requirement for excessively sharp angles, and should not occur along a major pedestrian route (i.e. 5.3.4).

**Block Splitting** - Having a diversity of activity is crucial for any future Harbour Quays development. It was therefore important that the Street Grids displayed a variety of block and lot sizes to accommodate different building uses. Early grid tests (5.3.1-3) produced large blocks, promoting large freestanding office buildings, dwarfing human scale. For mixed-use to occur, the street grid needed a hierarchy of primary and secondary roads and variety in building sizes. Later grid tests begin to better utilise this idea, breaking up larger blocks with secondary roads and creating a greater variety of built fabric as well as areas of diminished noise.

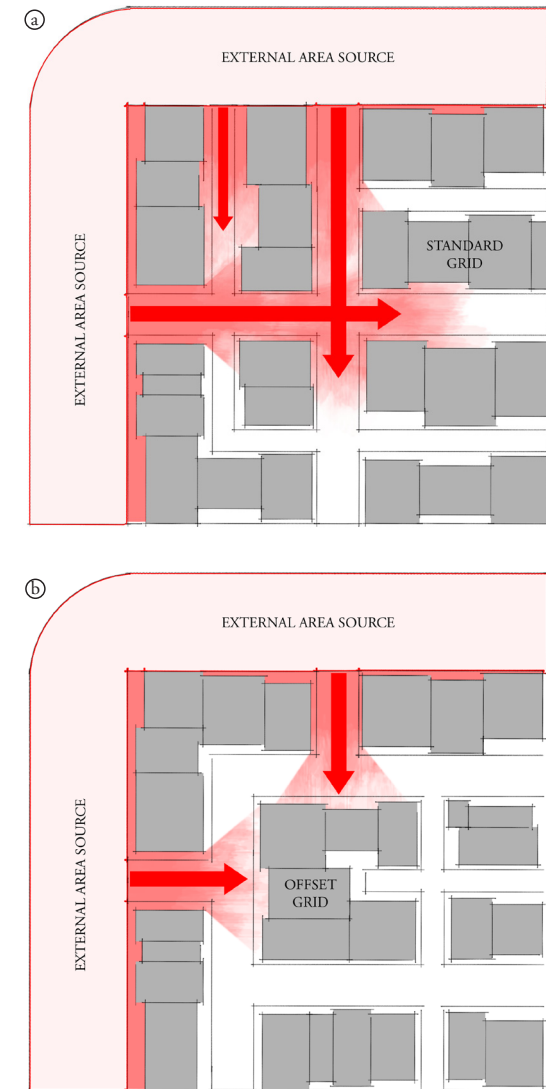
Grids 4-6 begin to show areas of good daytime acoustic performance. Firstly, along secondary streets that split major blocks, and secondly, in park areas not directly exposed to primary road noise. These tests identified the importance of a Secondary Street Network with lower traffic volumes and speeds. Spaces created by such a network could sustain a daytime noise level feasible for residential development (creating a quiet side for dual aspect apartments).

**Offsetting Built Layers** - The acoustic issue of greatest importance is the potential of residential development so close to a 24 hour sound source like an operational port. It is also the cause of the current attitude of reverse sensitivity towards mixed-use development within the Harbour Quays Precinct. The night time noise analyses take two sources into account, the port noise and Waterloo Quay, surrounding the site with continuous noise. What became apparent from the earlier tests was that any straight links from edges to the centre of the site substantially reduced the nocturnal acoustic performance (Fig. 5.12 (a)).

By layering the buildings and offsetting connecting roads, a large portion of that nocturnal noise is mitigated nearer the site edges, leaving central areas relatively quiet and ideal for residential development (Fig. 5.12 (b)). This suggests that a pure offset of the 'Concentric Grid' may work best for external noise threats. The obvious urban design pitfalls with this approach are the loss of visual permeability and legibility, but for a site with the acoustic constraints of a neighbouring port, these measures gain some validity.

**Fig. 5.12** Difference in noise penetration when comparing Direct and Offset street grids -

(a) Direct grid with straight links to the centre of the site,  
(b) Offset grid with right angle turns at grid entries.





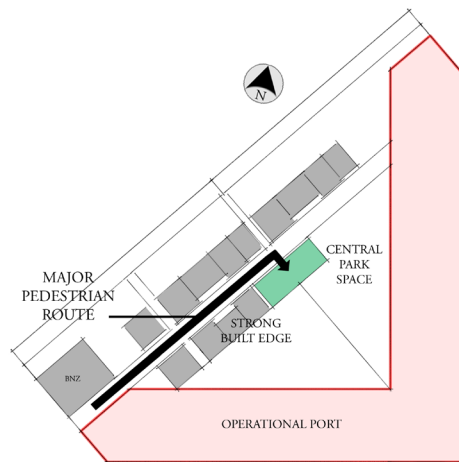


Fig. 5.14 Pedestrian Connection Diagram

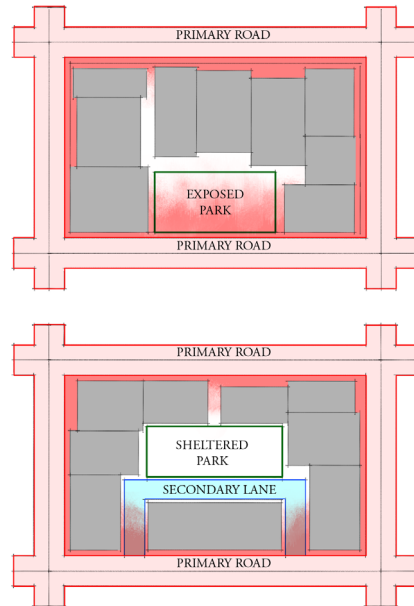


Fig. 5.13 Park Placement Diagram

**Pedestrian Connection** - In terms of a park network, the size and shape of the site may not justify a network of public spaces, but a strong pedestrian connection is necessary between the southern corner of the site (Waterfront Promenade/BNZ) and a centrally located park. Difficulty arises when this path crosses multiple high volume traffic routes and large expanses of undefined space (tests 3 and 4). The strongest grid tests were 5 and 6, in which the pedestrian flow only crosses one major road and the street is well defined by bordering buildings. This connection should ideally be straight with a well-defined built edge.

**Sheltering Public Spaces** - Finally, the acoustic performance of the central park was studied. Tests 1-3 exhibited poor acoustic performance in their respective parks. It wasn't until the park was removed from a primary road that any improvement was seen (tests 5.3.5 and 5.3.6). The studies showed that primary road noise was detrimental to all adjacent open space, and while having an active edge is an important principle for the success of a public space, removing such a space from a primary road showed a vast improvement in its acoustic performance (as seen in grid 6 (5.3.6), where a large portion of the park is within the green zone (45-50dB)). Importance should therefore be placed on creating such an active edge away from primary vehicular roads.

## 5.4 Macro-Design

Upon completion of the Abstract Site Experimentation, a final Master plan of the site is conceived (Fig. 5.15). This Master plan closely resembles the final iteration of the Abstract Experimentation process (Fig. 5.3.7) with a few key differences;

- Existing buildings such as Maritime House, Shed 35 and the Statistics Building have influenced the street grid, thus eliminating the potential for a major road connection at the southwest corner of the site,
- The existing port HQ is kept for ongoing operational port activity,
- The secondary road network of the central block has been moved to run along the norther edge, thus opening up north facing facades for public activity,
- Residential development off Waterloo Quay has been restricted to the northern most block, due to existing infrastructure, and
- The freight rail network is addressed to allowed for continued use (until such time as it is no longer needed).

The Urban Acoustic Design Principles that follow form the framework for the macro-design of my site from an 'Urban Acoustic' standpoint, and represent a consolidation of my research thus far.

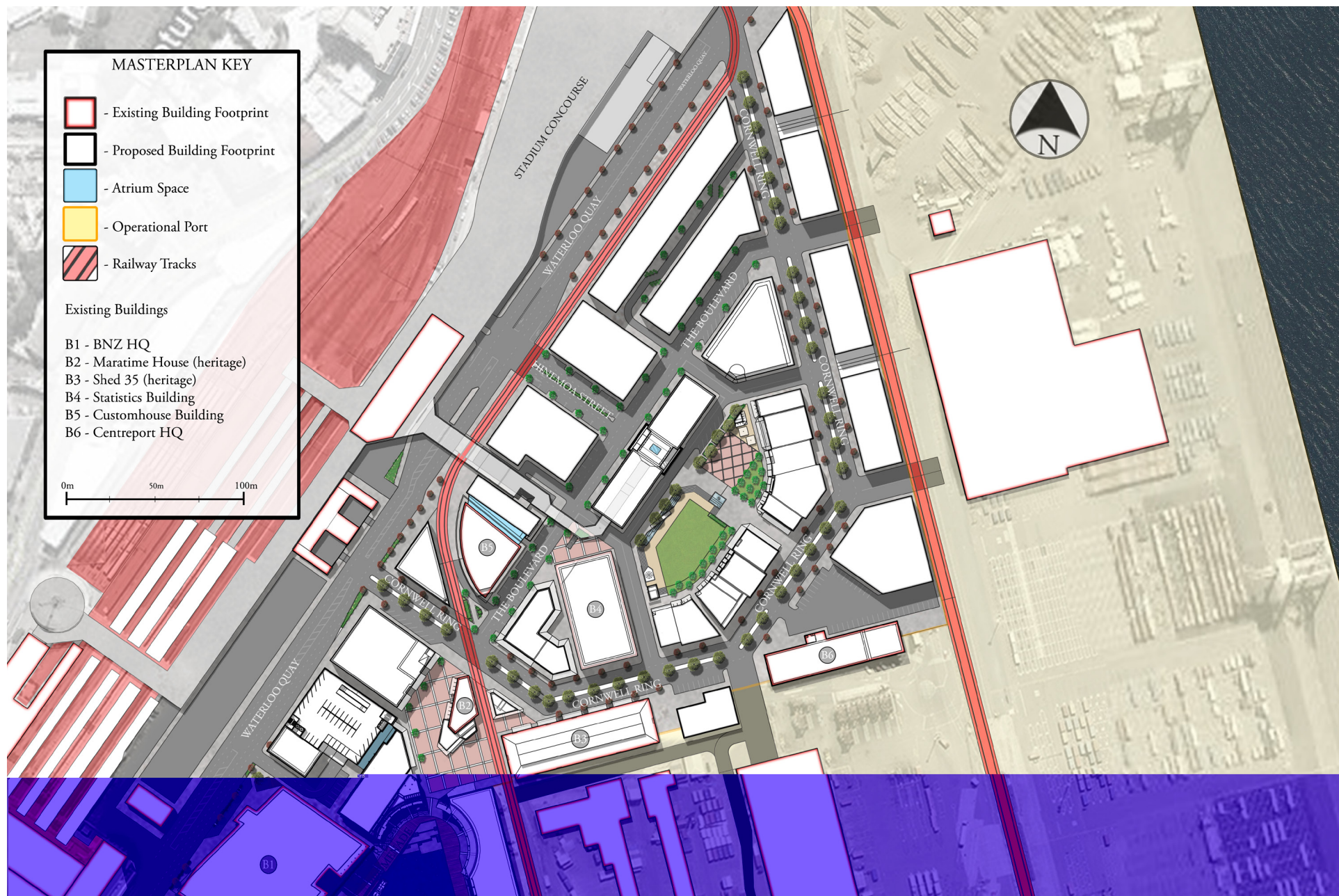


Fig. 5.15 Harbour Quays Master Plan



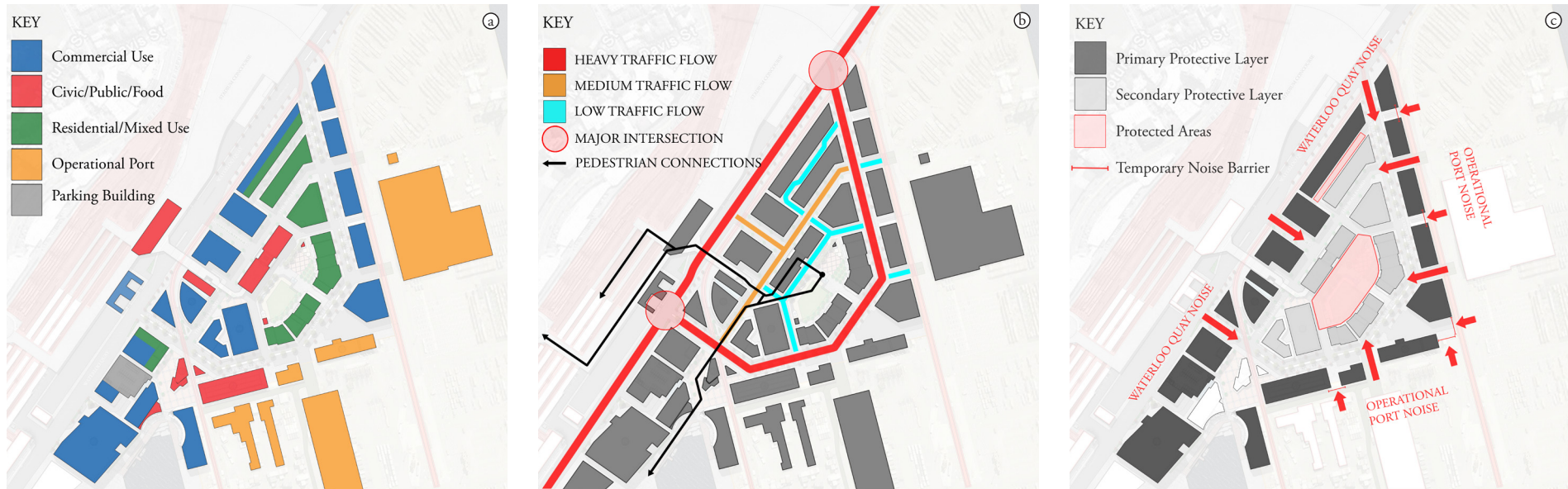


Fig. 5.16 Master plan analysis; (a) Building Use, (b) Movement throughout site, (c) External noise protection.

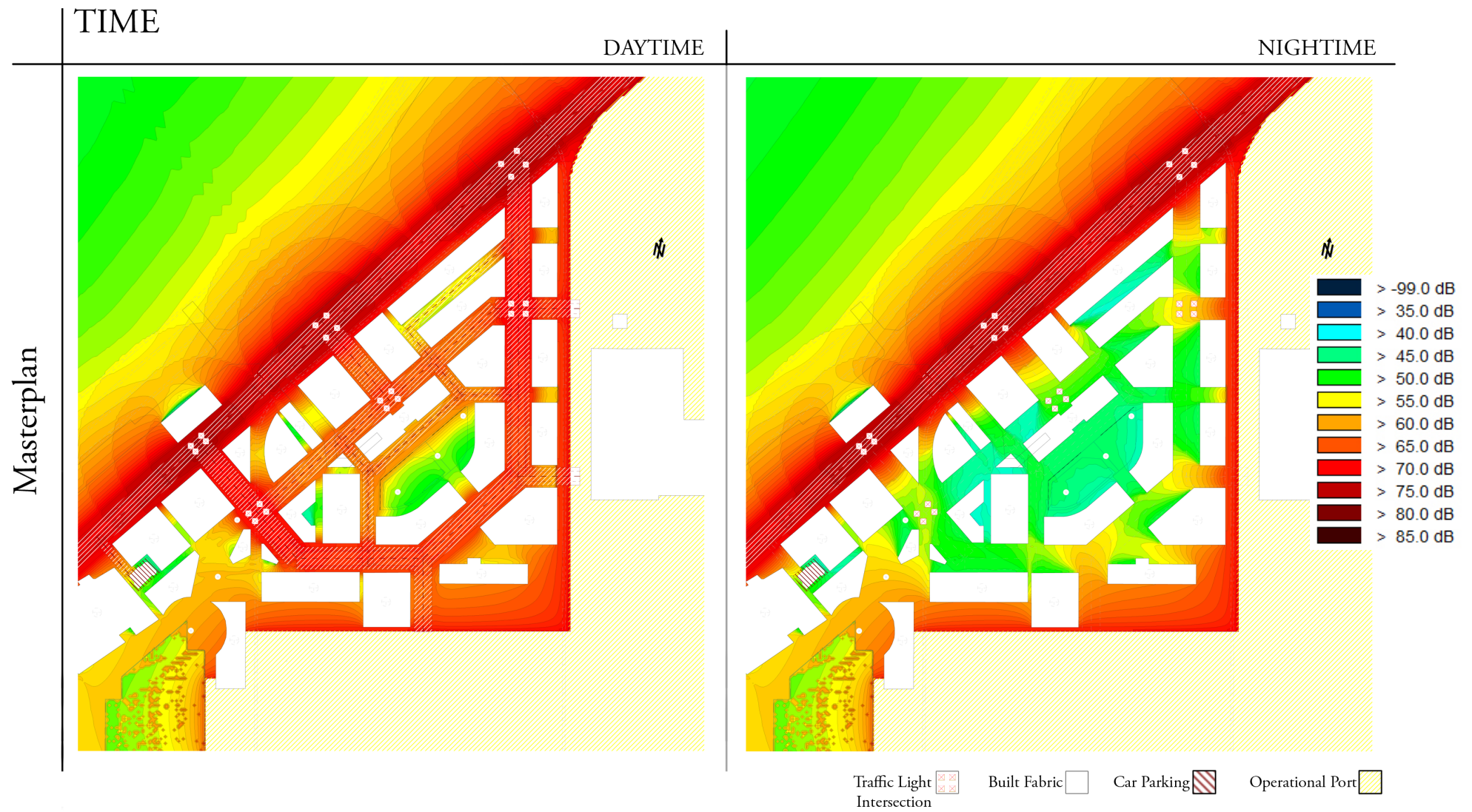


Fig. 5.17 Day and Night time noise-map for the proposed Harbour Quays Master plan.

## 5.5 Urban Acoustic Design Principles

To further clarify, the following principles are derived from the cumulative research of the preceding chapters, and are proposal specific. They are derivatives of Urban Design Principles, but are modified to promote an acoustic agenda in order to enhance the experimental value of this Design Proposal.

(Note - For further information on unaltered Urban Design Principles, please refer to either Chapter 2.4, or Appendix 1.)

### Urban Densification

In this context, densification refers to a rise in the Built/Open-Space Ratio from approximately 22% built to just over 53%. This allows for a greater diversity of street/building types, uses and activity, it also better encloses the site, limiting the inward propagation of external noise (Fig. 5.18).

### Urban Morphology - Protective-Building

Where possible, existing noise sources (Operational port, Waterloo Quay) are attenuated using a solid built-layer. Buildings adjacent to these noise sources act as acoustic protection for internal areas of the site. Any noise leakage through necessary breaks in the external layer of built fabric is mitigated by the second built layer, subsequently protecting the inner most areas of the site (see Fig. 5.16 (c)).



**Fig. 5.18** Built to Open Space Ratio - (a) existing ratio of 22% built footprint, (b) proposed ratio of 53% built footprint

### **Movement Hierarchy**

A street hierarchy is established through road width and tree type. Vehicle circulation is controlled by a ring road (Cornwell Ring) that frames the site, intersecting with Waterloo Quay at both the northern and southern ends. This is intended to take the majority of the site's traffic flow, reducing central area traffic flow and therefore excess noise (Fig 5.16 (b)). Bringing pedestrians into the centre of the area as early as possible is important. To do this, a road that parallels Waterloo quay and acts as an extension of the Waterfront Promenade is proposed. Additionally, the existing pedestrian walkway from the stadium concourse is modified to bring pedestrians to the centre of the site. This in turn connects internal residents with Wellington's transportation hub and vice versa.

### **Limiting Permeability**

The inward visual and physical and permeability of the area is important in providing value and legibility. With an acoustic agenda, however, levels of visual and physical permeability are compromised to ensure an acoustic environment viable for residential development and Soundscape Designed public space. Remedial measure such as glass atriums could be used to provide some additional visual permeability, while maintain a level of acoustic protection (as used in the Civic Building that connects Fryats Park and Hinemoa Street).

### **Precinct Character/Acoustic Identity**

Currently, the site is laid out as an open office park development. The solitary program on site has produced no discernible identity. This affords an opportunity to develop a new 'acoustic' identity for the site. This includes an acoustic connection to the

waterfront and port activities, and a uniquely Soundscape designed public park central to the site.

### **Contextual Street Grid**

The Street Grid is largely informed by existing buildings and infrastructure. The following existing elements are accommodated in the master plan;

- Heritage Buildings Maritime House and Shed 35 are reclaimed as public elements of the Kings Park area.
- New Office Buildings (Statistics Building, Customhouse Building) are kept.
- Future disused Freight Rail lines will be incorporated into future developments.
- Some existing Roads and Stadium Concourse are incorporated.

Mixed-use within the development is integral in creating the vibrancy the site currently lacks. The Master plan provides a mix of opportunities for work, accommodation, retail/commerce, recreational and entertainment space.

### **Robust Planning/Future Connections**

Connections to potential future areas of development are also considered (Fig. 5.19). These connections are articulated in the Master plan, but to limit the spread of excess noise from these openings, temporary noise barriers are implemented (Fig 5.16 (c)). It is important that this Urban Design Proposal has a degree of robustness to it to ensure its future



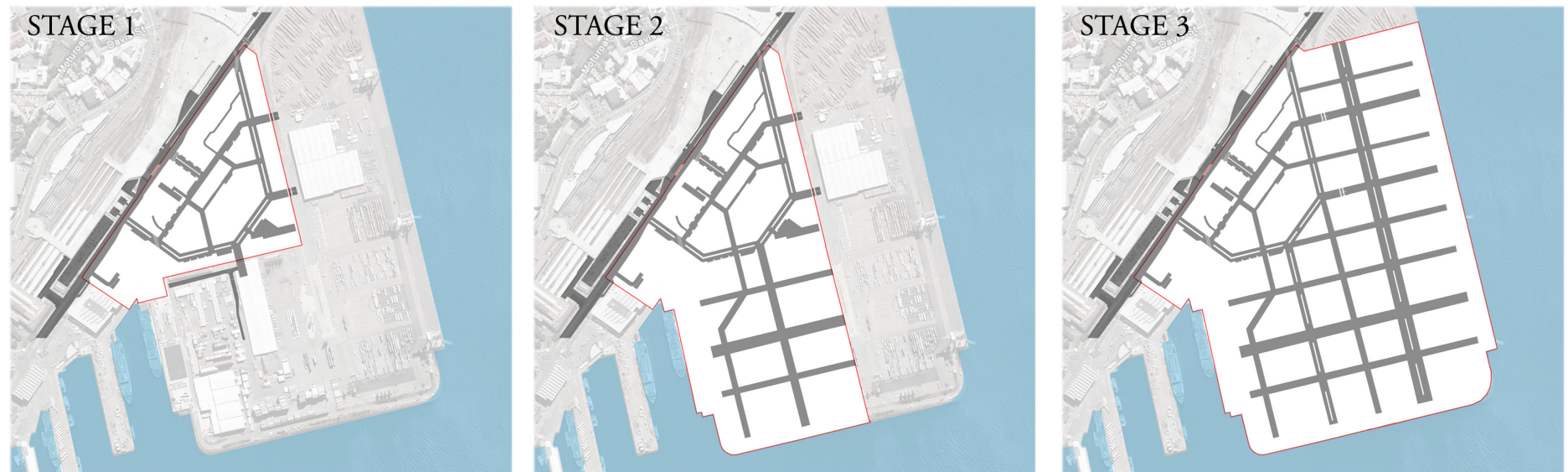


Fig. 5.19 Proposed street grid evolution

## 5.6 Micro-Design

Having finalised the master plan for the site, more detailed elements of Soundscape Design are introduced. These design techniques have a more significant influence on the acoustic environment of open spaces, creating diversity in the site's Soundscape. It should be noted that without a qualitative survey of prospective site inhabitants, the conceived Soundscapes are based on intuitive design decisions.

### 5.6.1 Acoustic Identity in Public Spaces and Residential Development

#### Public Space Network

The public spaces within the precinct reflect the principles by which the overall design is conceived (Fig. 5.20). Both Kings Park and Fryats Park incorporate different Soundscape Design Principles to produce two unique acoustic spaces. Within the Master plan, the public space network incorporates the following;

- A clear and permeable hierarchy of internal streets.
- A high quality connection between Kings Park and Fryats Park, not dominated by vehicles.
- A variety of contrasting spaces to provide a diversity of experience. Spaces should also be destinations in their own right.
- A connection to the sites waterfront identity through street furniture and acoustic environments.
- Parks include opportunities for future connections to urban developments.



Fig. 5.20 Open Space Network

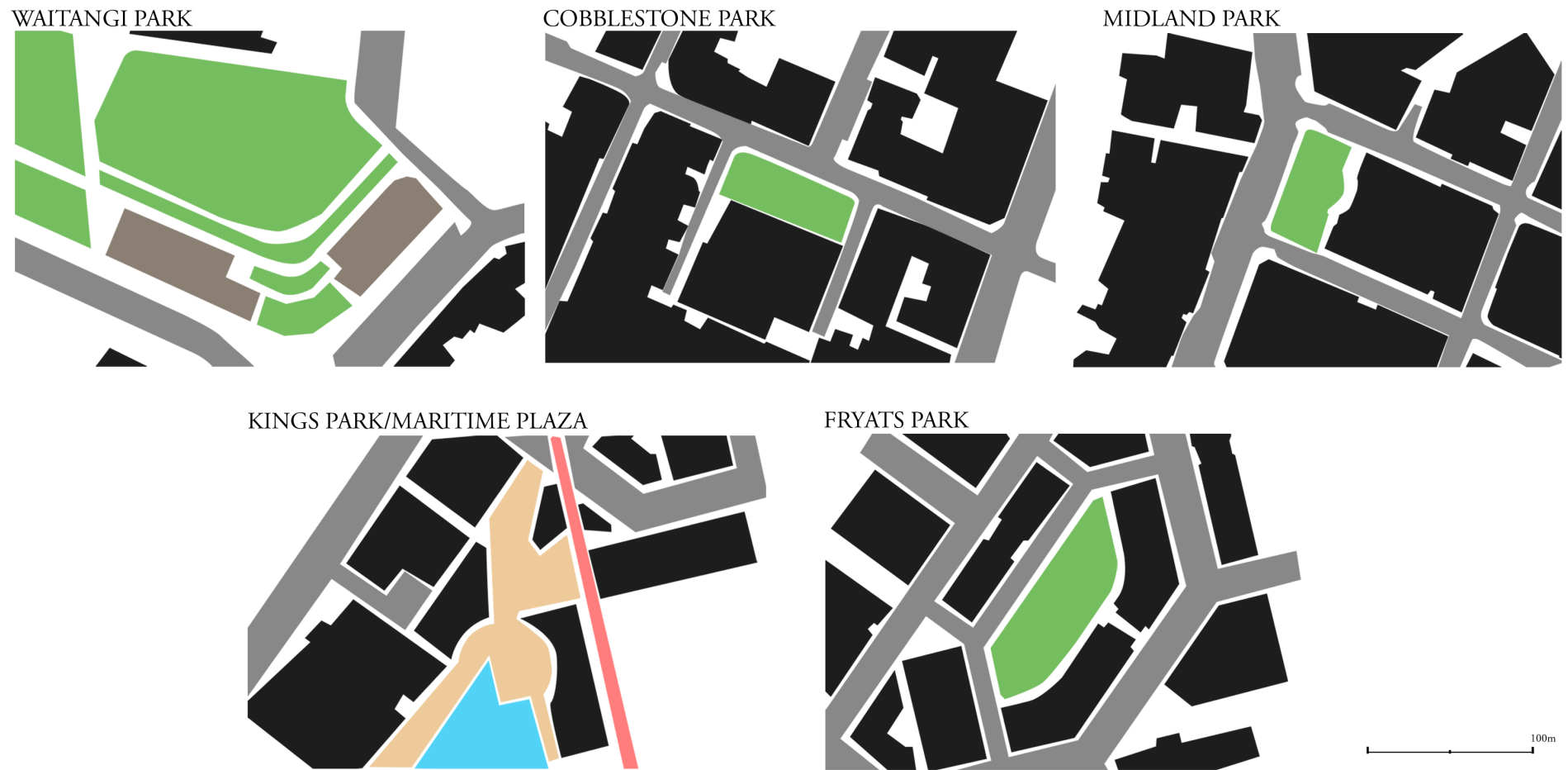


Fig. 5.21 Comparison of park sizes in Wellington City

## Built Environment

With the substantial increase in built density in the Harbour Quays site, a variety of building shapes and sizes are conceived. New buildings are of a contemporary and environmentally sensitive design, and shall incorporate different forms and articulated facades to create a stimulating built environment and landscape. As this thesis has progressed, there has been less emphasis on the architectural detailing of buildings and facades. Design of the built environment, articulated in the following image sequence, implements the following principles;

- A strong active urban edge along primary streets through building massing, active ground floor uses and well-designed, open building facades (Fig. 5.22).
- Building bulk is broken down in scale through varied form, and existing buildings determine the approximate heights of those nearby.
- Buildings including residential use incorporate retail/commercial spaces on ground floors.
- To celebrate the proposed landmark Civic Building, additional building height will be utilised to increase its visibility and prominence across a wider area.
- The primary frontage of each new building will be the principle pedestrian entrance to the building, i.e., key streets within the precinct, principally The Boulevard, Cornwell Ring and the Fryats Park area.

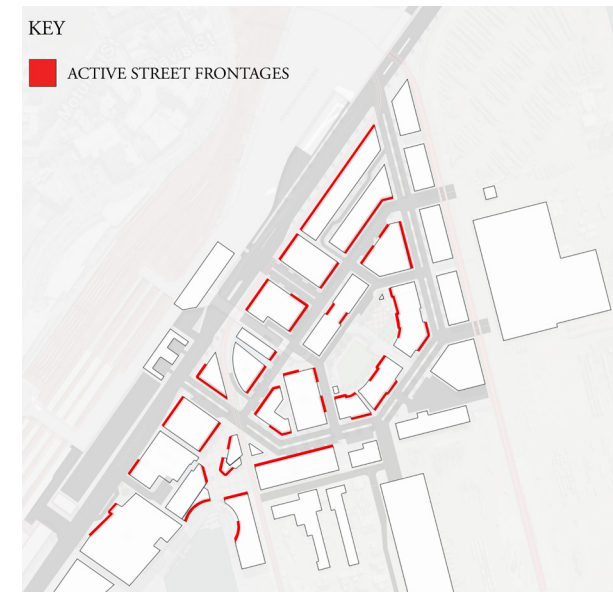


Fig. 5.22 Active Ground Floor Frontages

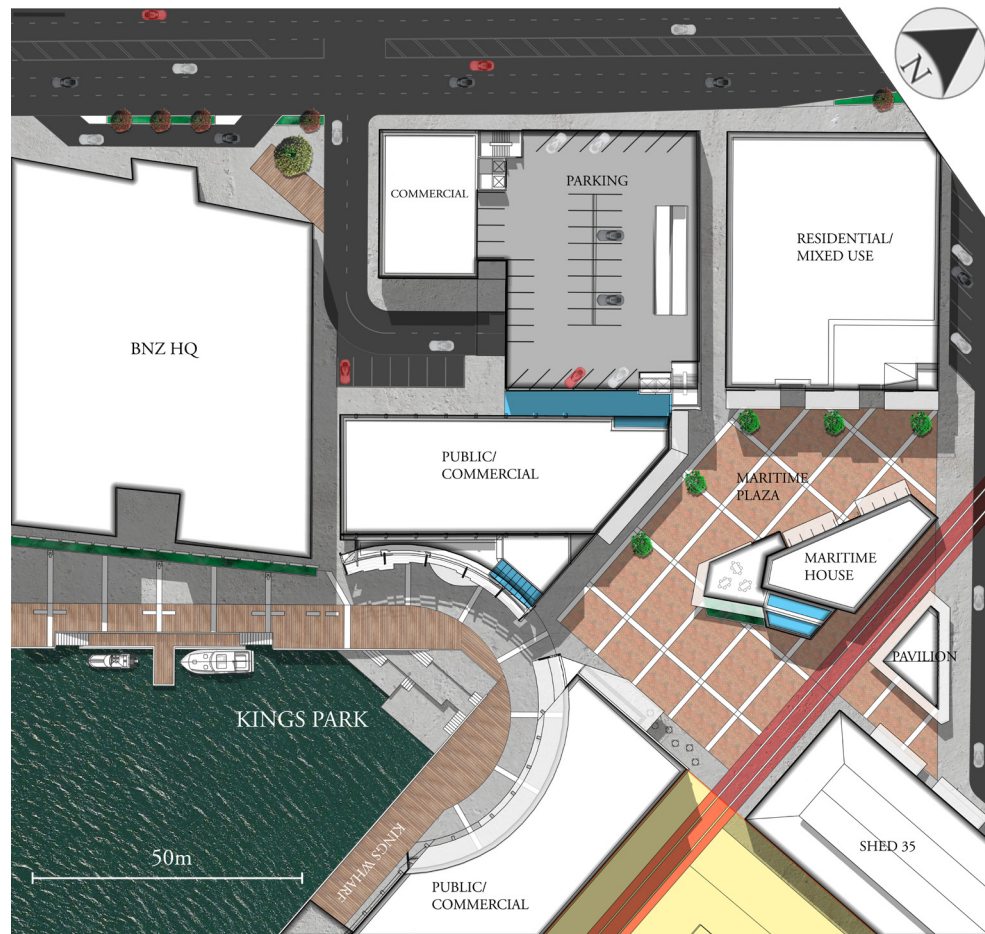


Fig. 5.23 Kings Park Plan View

## 5.7 Kings Park

Kings Park (Fig. 5.23) is the pedestrian gateway from the Waterfront Promenade to the Harbour Quays precinct. It is important that the park's design make a statement about the character of the greater site. Placed at the southern corner of the site on the Kings wharf waterfront, Kings Park is relatively withdrawn from invasive traffic noise. The main feature of the park's design is the double curved facades of the two buildings framing the wharf corner.

### 5.7.1 Urban Design

The park is split into two distinct spaces, the enclosed waterfront semi-circle (Kings Park) and an open plaza (Maritime Plaza). The spaces are designed to be distinctly different, and their threshold to be the entry to the precinct. Surrounding buildings house commercial, residential and public uses, creating a variety of park users (Fig. 5.25 (c)). The space also incorporates Heritage buildings 'Maritime House' and 'Shed 35', both of which will be restored and integrated into the park, giving a sense of the historic character of the site.

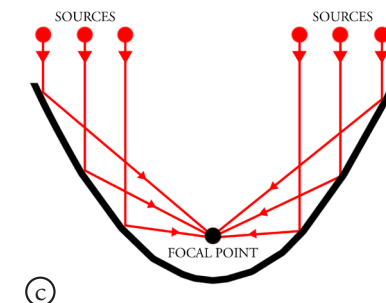
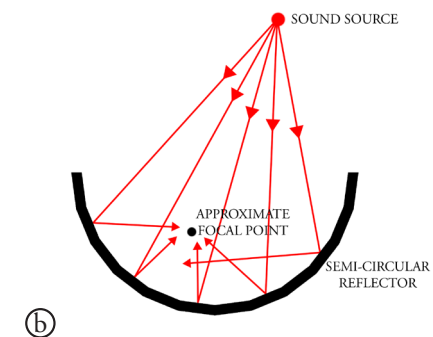
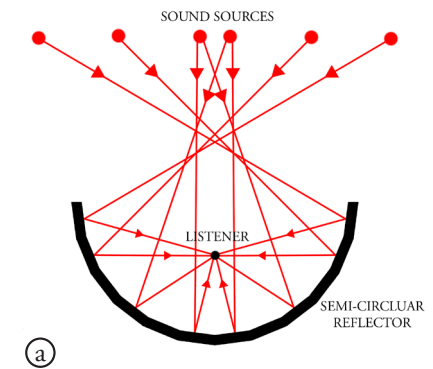


### 5.7.2 Sonic Environment

In terms of Soundscape Design, Kings Park was not conceived of as a quiet space, removed from noise sources, but a celebration of the sites history and connection to the water. Figure 5.25 (a) illustrates the average daytime sound level of the general Kings Park area. Note that it generally sits around 55 to 65 decibels, namely due to the proximity of the port, an element that may initially define the park (acoustic mapping in conceptual analysis is a massively underutilised tool, and should be considered a justifiable addition to a designers toolkit.).

There are no masking sounds or major buffering elements beyond human activity sounds and buildings (Fig. 5.25 (b)). The purpose of the enclosed semi-circular space is to create both an architectural and an acoustic gesture. Using the sound mirror concept, the double curved facades act as magnifiers of external sounds, enhancing the listener's experience of sounds occurring out on the harbour (Fig. 5.25 (a), Fig. 5.27).

As can be seen from the diagrams in Figure 5.24, a parabolic shape may act more efficiently than a semi-circle, but is more difficult to appreciate aesthetically from a visual perspective. The acoustic contrast between the enclosed area and plaza will also provide pedestrians with a unique acoustic experience.



**Fig. 5.24** Mechanics of curved mirror reflection;

- (a) Range of sources that will focus to a listener from a semicircular reflector,
- (b) Approximate focal point of a particular source in a semicircular reflector,
- (c) Defined focal point of a parabolic reflector.

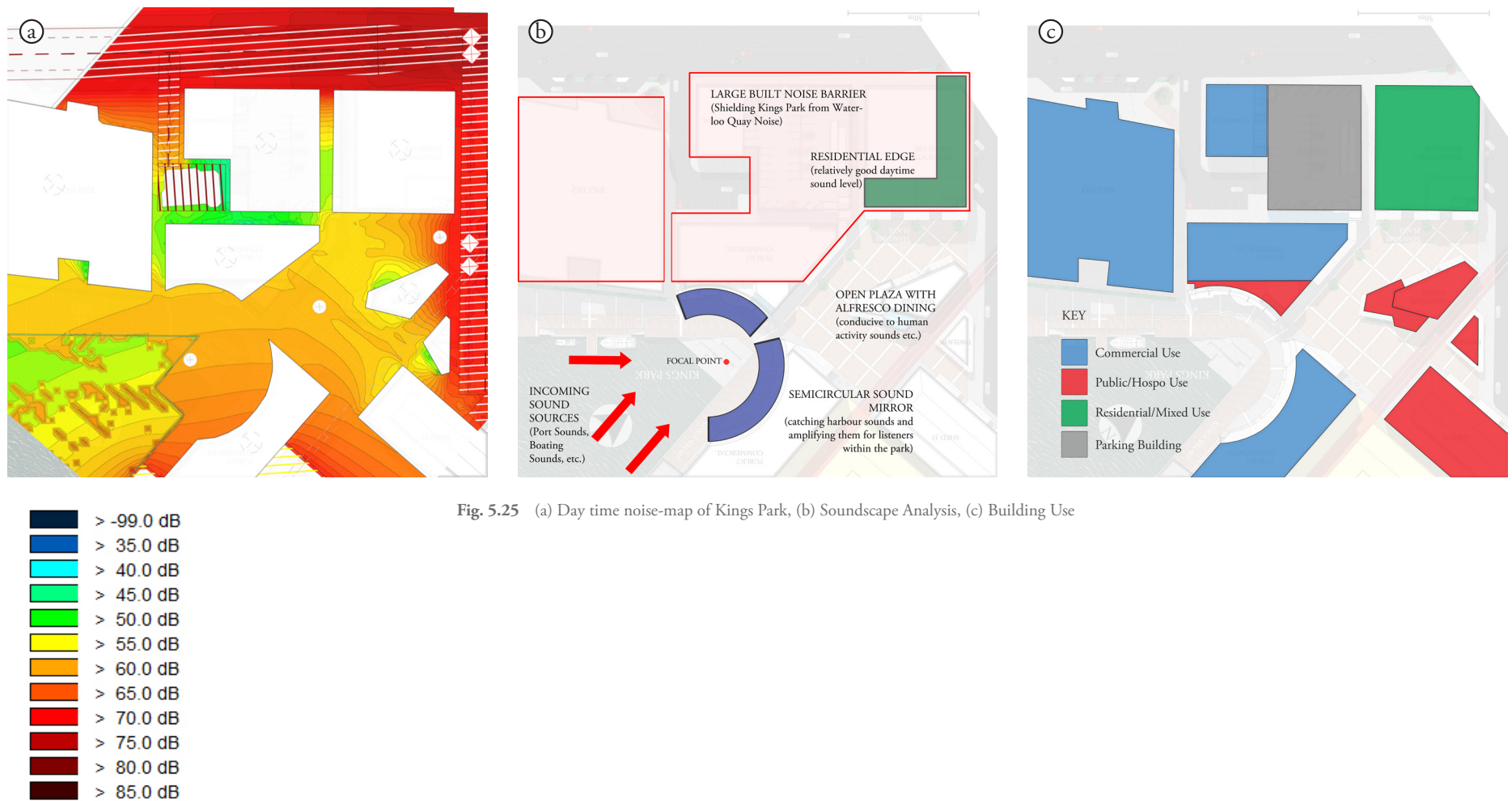
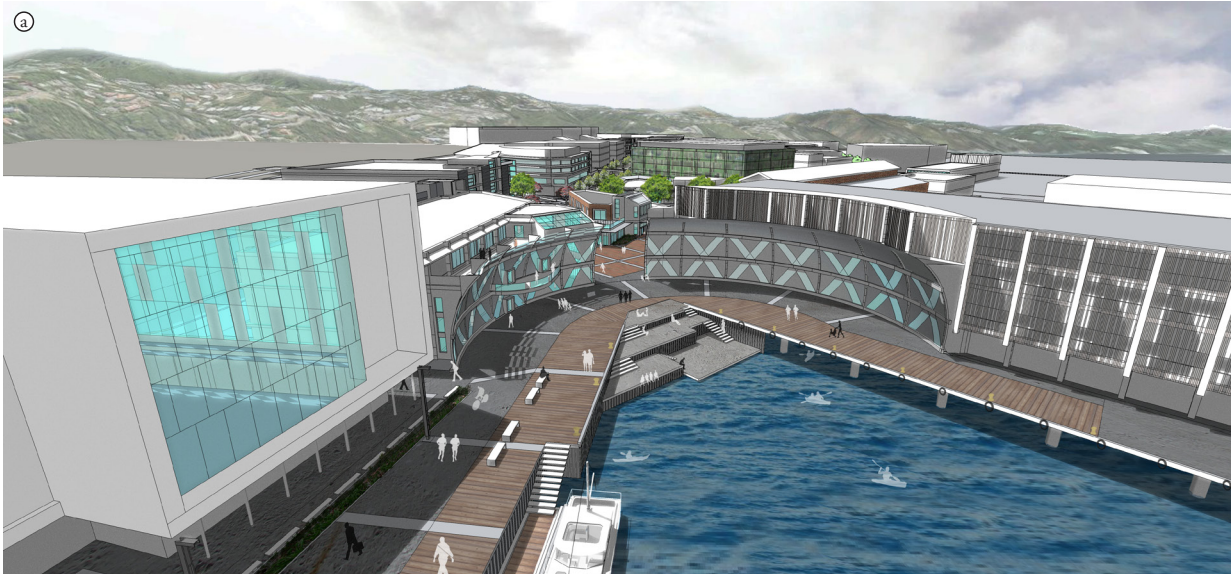


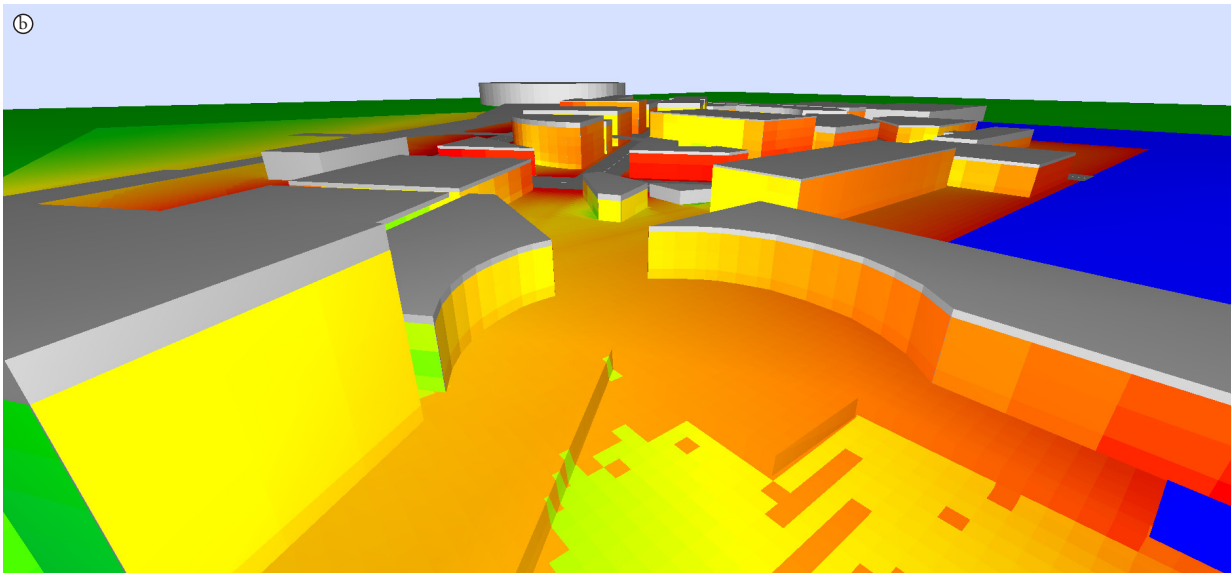
Fig. 5.25 (a) Day time noise-map of Kings Park, (b) Soundscape Analysis, (c) Building Use



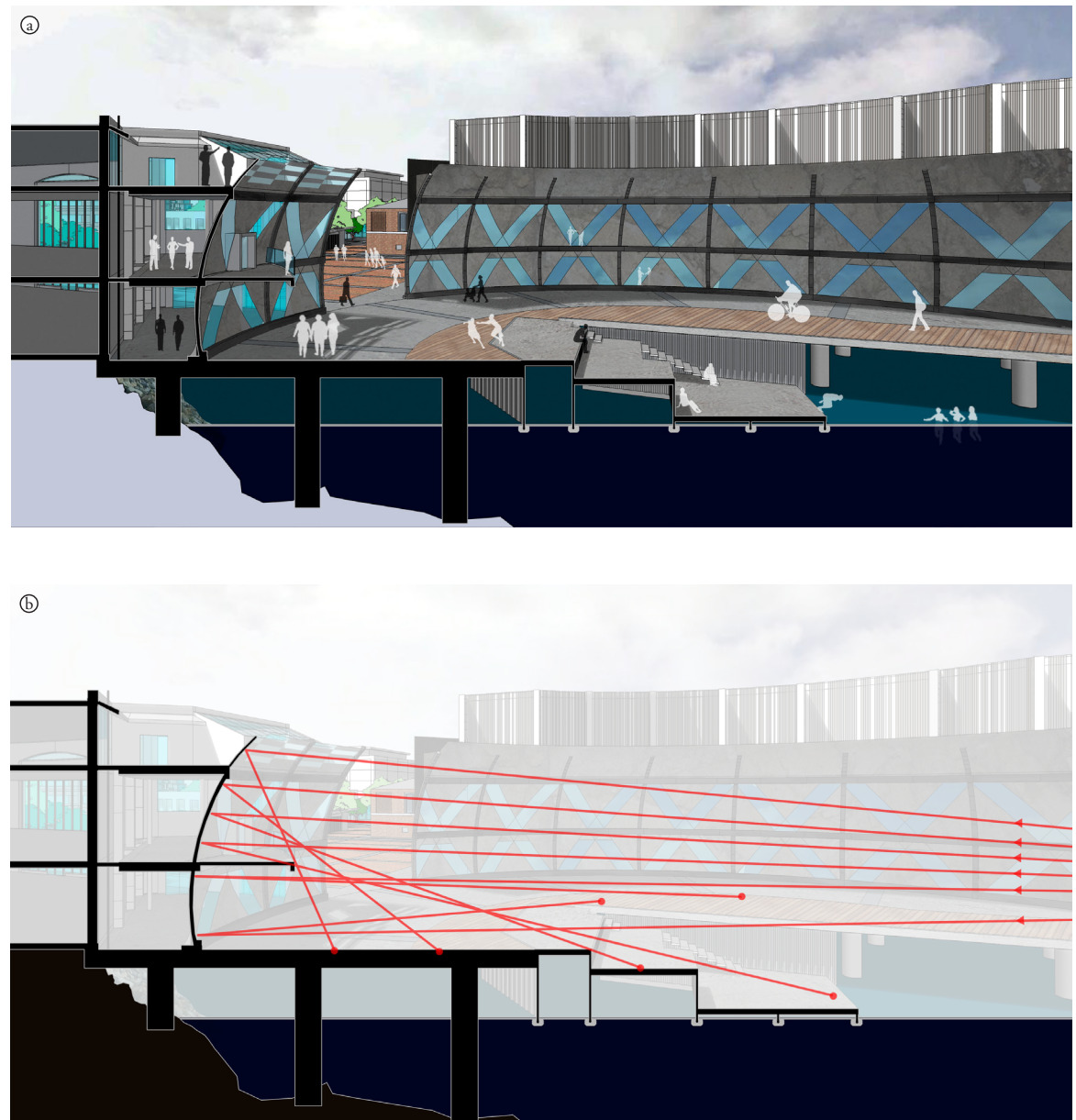


**Fig. 5.26** Overview of Kings Park -

(a) Perspective from Southwest Corner,  
(b) 3D daytime noise-map of Kings  
Park



**Fig. 5.27** Sectional perspective of Kings Park -  
(a) Sectional Perspective,  
(b) Acoustic reflections from sound source out on the harbour amplified by the curved facades.



## 5.8 Fryats Park

Fryats Park (Fig 5.28) is distinctly different from Kings Park. As the focal point of the precinct, the park serves multiple purposes;

- Establishing an acoustic identity while connecting to the rest of the site.
- Creating a vibrant, diverse destination with good amenity,
- Providing surrounding residents with a positive outlook.

### 5.8.1 Urban Design

Placed central to the Harbour Quays site, Fryats Park is the space most protected from external noise (Fig. 5.29 (b)). With two layers of buildings buffering the park from port noise, any further buffering or masking techniques have only to mitigate sound from adjacent internal streets. Its placement is, however, contrary to typical urban design practice, as it is removed from major streets. A lack of visual legibility (difficult to find) makes it imperative that the space become an attractive destination with a diversity of activity. Such square placements are not unheard of; London residential squares are often located away from major streets and are considered successful spaces (they are well known by the local population of course).

Remedial measures like the connection to the stadium concourse, and the glass atrium of the Civic Building will aid external users. Sound is also used as a way finder, with

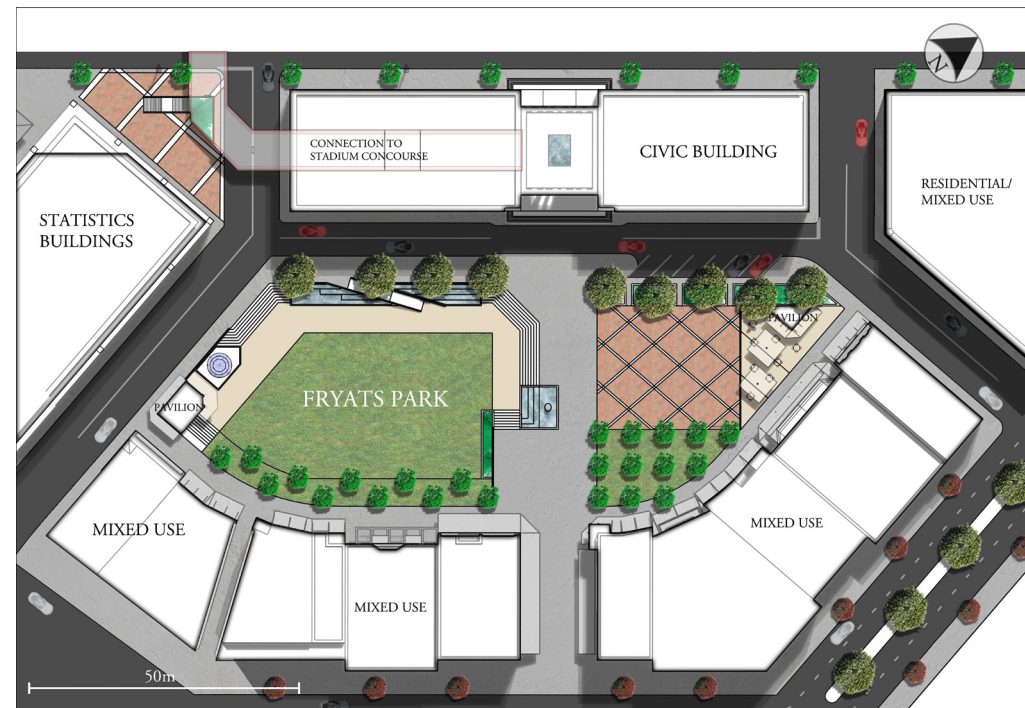


Fig. 5.28 Fryats Park Plan View



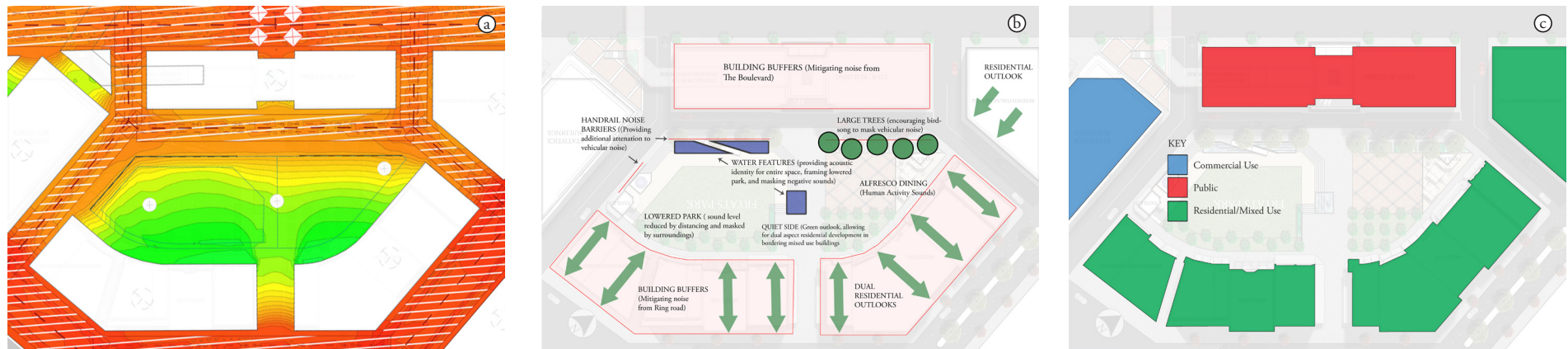
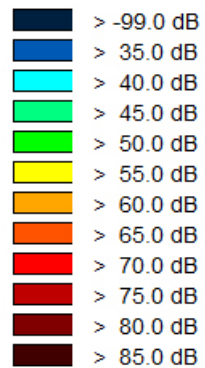


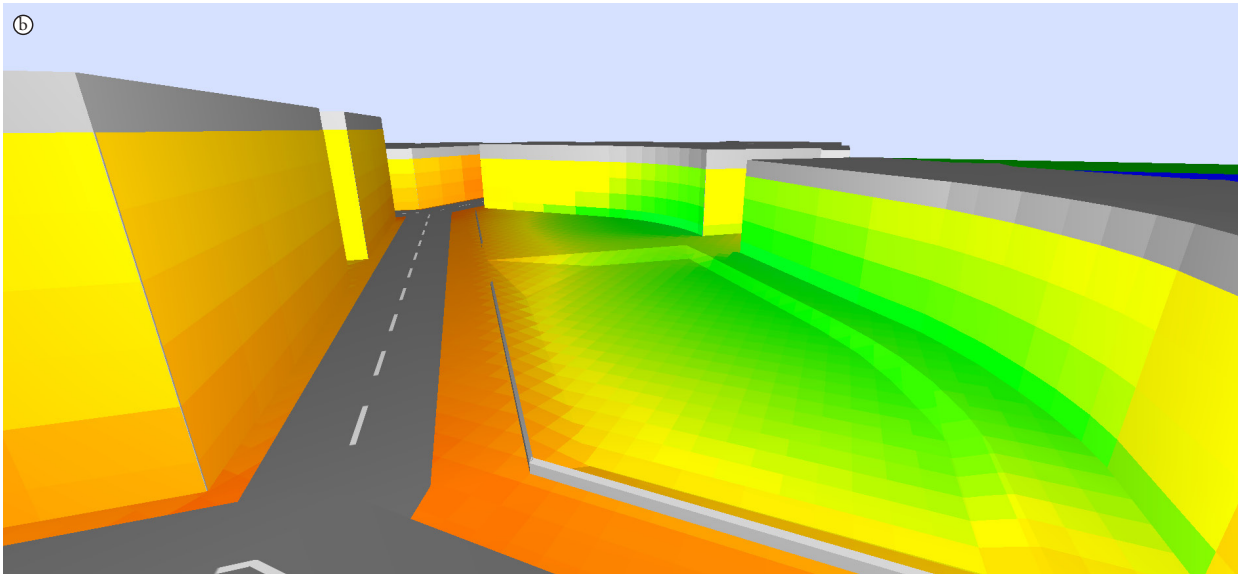
Fig. 5.29 (a) Day time noise-map of Fryats Park, (b) Soundscape Analysis, (c) Building Use Plan





**Fig. 5.30** Overview of Fryats Park -

(a) Perspective from Statistics Building,  
(b) 3D daytime noise-map of Fryats  
Park



water features legible from beyond the park borders. Again, the park is split into two spaces, the northern upper level and southern lower level. The soft lower level consists of a large grassed area for recreational activity, an embankment (planted with trees) and small play area. The upper level of the park is hard surfaced, with alfresco dining at the northern end and bordering tree lines on either side. The existing axis which bisects the park has the potential to act as a pedestrian thoroughfare in future developments. Surrounding buildings entail a diversity of uses (Fig. 5.29 (c)), ground floors are reserved for commercial activity (retail, dining, etc.), encouraging external visitors and adding vibrancy. Residential apartments also overlook the park, aiding in passive surveillance.

### 5.8.2 Sonic Environment

Fryats Park actively employs Soundscape Design techniques to create a diverse and unique acoustic environment. The space's only major noise threat are the bordering secondary roads, making it a relatively quiet space at all times (Fig. 5.29 (b), 5.31 (b)). The acoustic identity of Fryats Park is created by a central water fountain (connecting the visually isolated park to the waterfront acoustically). The positioning of the fountain allows it to be heard throughout the park (depending on flow, even before seeing such features). Trees framing the park induce bird song around the park edges, masking vehicular noise. On the lower level the same is achieved with a cascading water feature along the street line. The site contours also aid in sound mitigation, with handrail noise barriers off the street protecting the lower level park from traffic noise (Fig. 5.29 (b)).

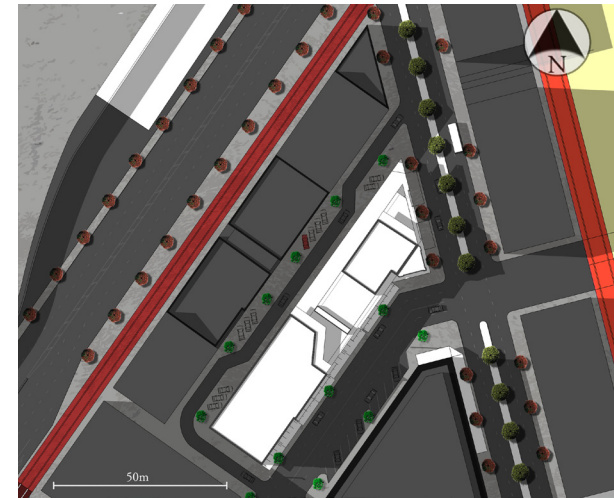
These Soundscape Design elements don't define Fryats Park, but merely enhance it for its users, providing a variety of acoustic environments with a diversity of activities.

## 5.9 Residential Viability

For residential spaces to be introduced into the Harbour Quays precinct, issues of reverse sensitivity have to be addressed. My Urban Design Proposal implements the following acoustic design techniques to render residential inhabitation feasible;

- Residential buildings will be located on the internal built layer, partially shielded and physically distanced from night time Operational Port and Waterloo Quay noise.
- Where possible, residential buildings will incorporate a high quality 'Quiet Side', allowing for dual aspect apartments with positive outlooks, aiding in psychological wellbeing.
- Buildings with residential tenancy will be mixed-use, incorporating commercial ground floor activity on major street fronts and ground floor parking off secondary lanes.

**Fig. 5.31** Contextual Plan of Residential Mixed-use building at the northern end of the Harbour Quays Precinct.



**Fig. 5.32** Examples of different dual aspect apartments.

(adapted from North shore Good-Solutions Guide for Apartments)

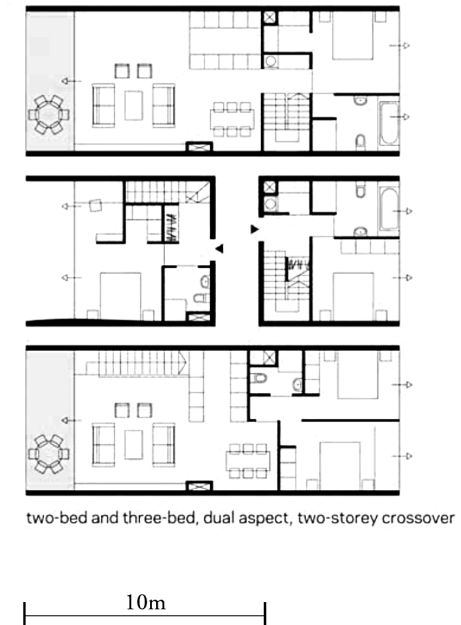
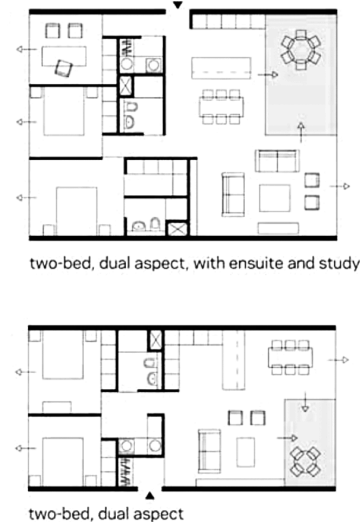


Figure 5.31 shows an example of an on site mixed-use residential building. Its width is sufficient enough to accommodate both single and dual aspect apartments (see Fig. 5.32-33), it has a commercial frontage on The Boulevard, and a private rear lane allowing for ground floor parking and services. As can be seen in Figure 5.34 (b) and (c), the daytime noise level along the northern facade of the building is relatively high as it sits on a major traffic route. Higher noise levels are inevitable during daytime, but can be mitigated by better acoustic insulation, or, as in this case, the placement of vertical circulation (i.e. Lobbies, elevator shafts and stairwells).

It is unrealistic to think that an urban building could be designed to be quiet on all sides (without highly expensive measures), but providing facades of relative quiet is a





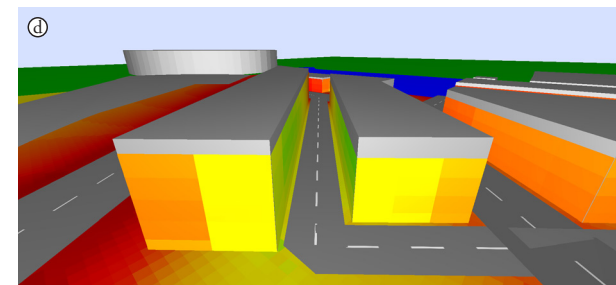
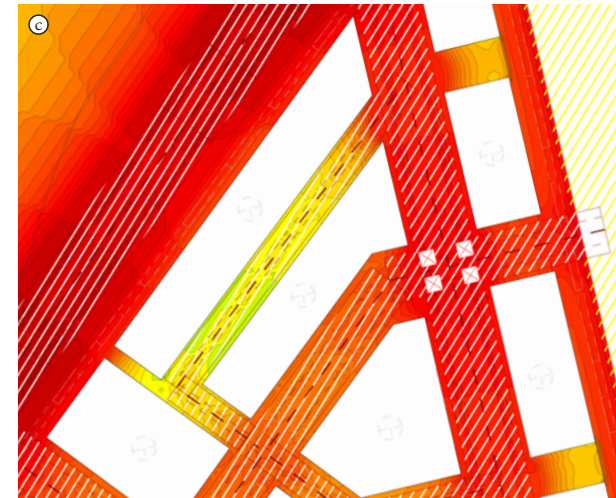
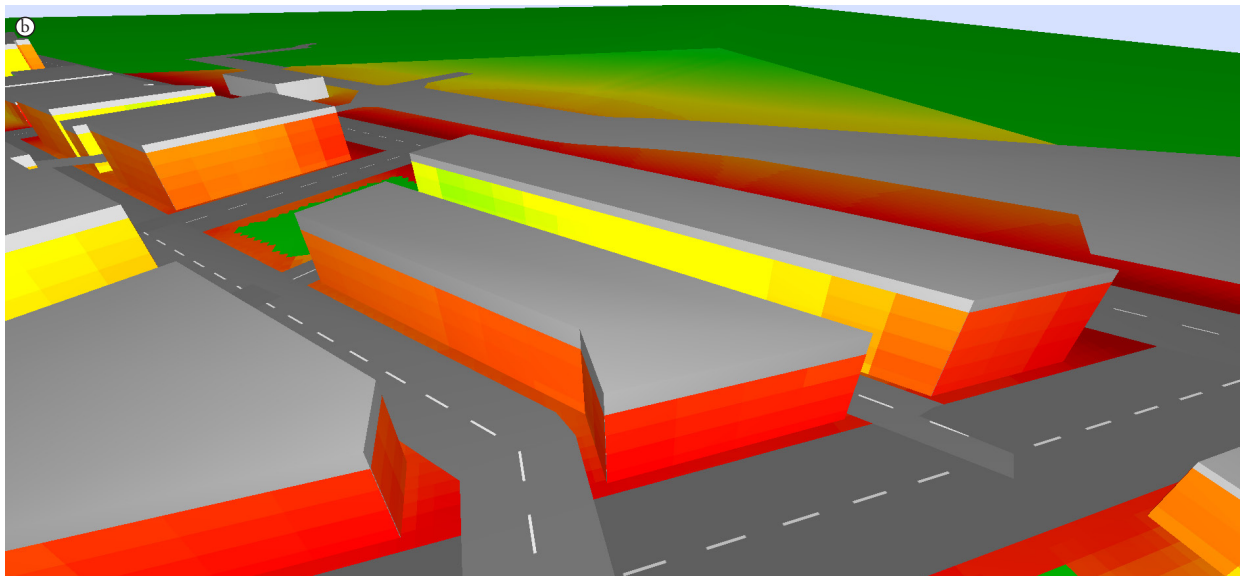
more than achievable goal. Figure 5.34 (c) and (d) present the daytime noise level of the rear lane (modelled conservatively). As illustrated, the noise level averages between 48 to 55 decibels, level which is not only acceptable for outdoor living spaces, but possibly an advocate for the 'Quiet side' concept; whereby, the negative psychological effects of a continuously noisy facade are offset by the restorative psychological effects a high quality, quiet outlook provides.

Throughout the design proposal, I have endeavoured to shield residential mixed-use buildings from night time noise through building placement, and where possible, include a quiet side (i.e. Fryats Park upper level residential tenants) that will provide relief from heavily trafficked facades. These are the principles by which residential tenancy in the Harbour Quays precinct could be achieved.

For future development of the Harbour Quays precinct to be successful, noise sensitive activities like residential development have to be introduced.

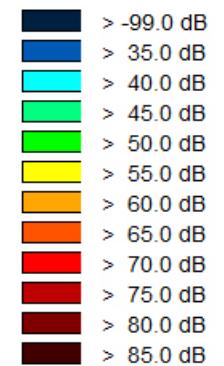
**Fig. 5.33** (a) Examples of different single and corner aspect apartment sizes and layouts, (b) Example of the vertical layout of a mixed use apartment building.

(adapted from North shore Good-Solutions Guide for Apartments)

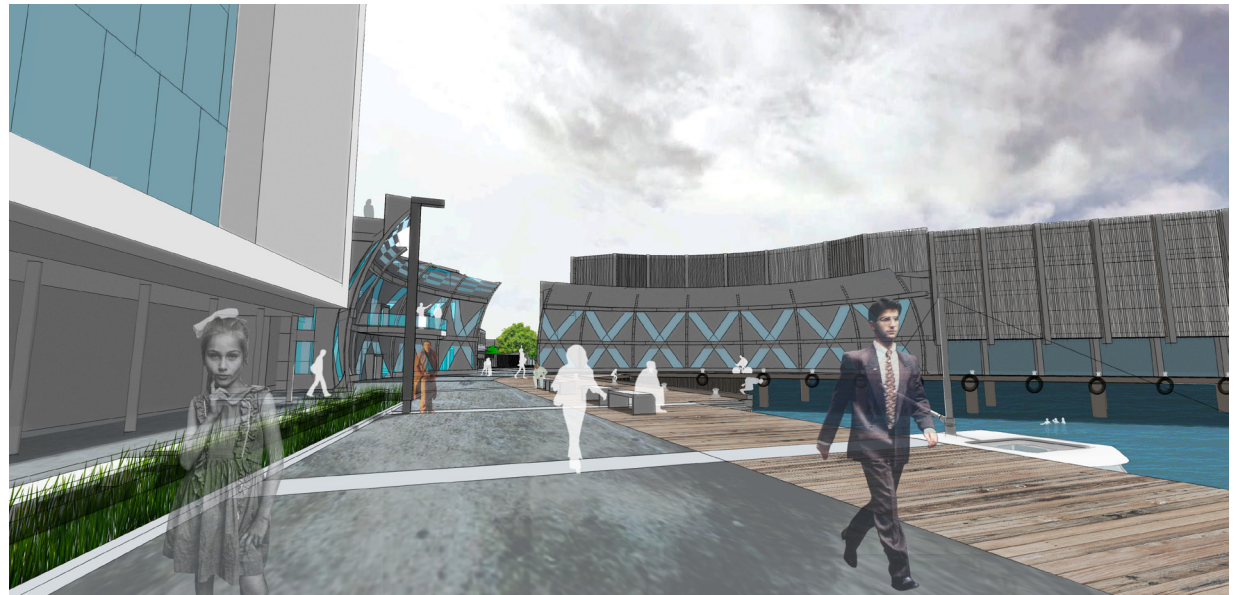


**Fig. 5.34** Overview of Residential Mixed Use Building -

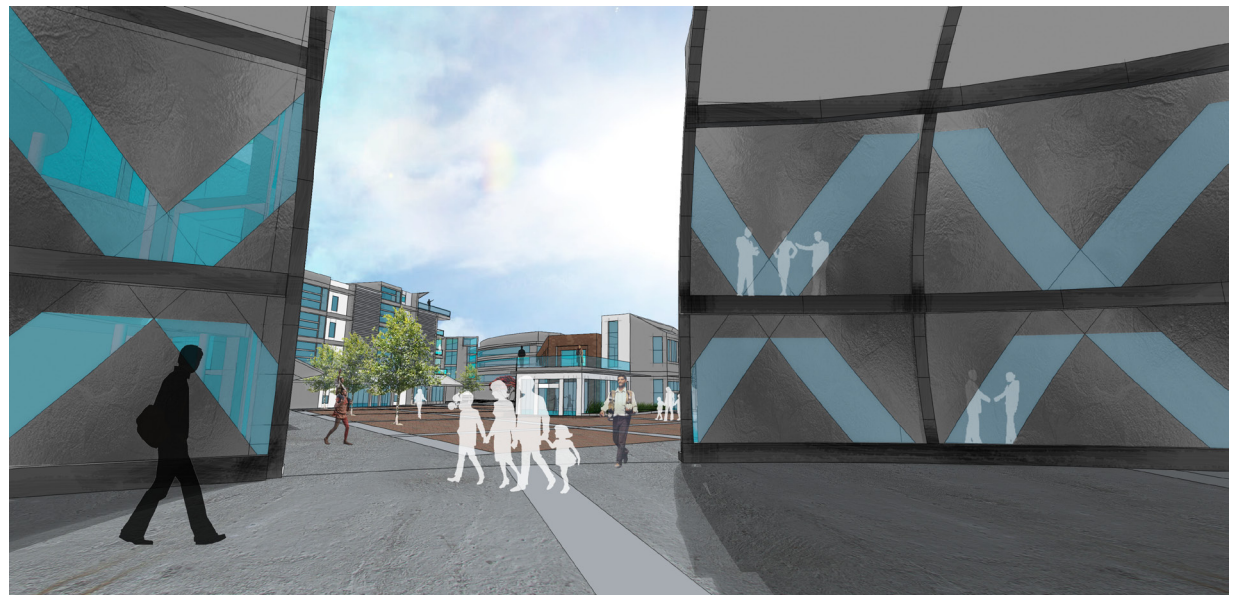
- (a) Perspective from eastern corner,  
(b) 3D daytime noise-map of Residential Building,  
(c) Daytime noise-map plan view,  
(d) 3D daytime noise-map view of Residential Building from western end.



## 5.10 Site Walkthrough



**Fig. 5.35** Walkthrough 1, view towards Kings Park from the Waterfront Boulevard.



**Fig. 5.36** Walkthrough 2, view into Maritime Plaza from semicircle.





**Fig. 5.37** Walkthrough 3, view from Maritime Plaza, across Cornwell Ring, down The Boulevard.



**Fig. 5.38** Walkthrough 4, view down The Boulevard, Customhouse Building on the left.

**Fig. 5.39** Walkthrough 5, stadium concourse connection, view into Fryats Park.



**Fig. 5.40** Walkthrough 6, view from Fryats Park lower level (grass), to upper level.







**Fig. 5.41** Walkthrough 7, view from alfresco dining at northern end of Fryats Park.

### 5.11 Conclusions

In this chapter, I have put into practice the Urban Acoustic Design Principles derived from my research. By applying these principles to a real situation, I was forced to establish an equilibrium between good Urban Design and Acoustic/Soundscape Design. This process enabled me to gain some perspective on the degree of integration these fields would allow.

A particularly unique facility unearthed during the design-research process came from CadnaA's acoustic environmental imagery. The plan and 3D colour contour images available through CadnaA enable a designer to instantly analyse the acoustic efficiency of designed spaces, and represent this analysis with clear, palatable visual imagery. An urban design technique essentially untapped.

The acoustic agenda adopted in the urban design process clearly had an influence on both the practical and aesthetic design of space. It should be noted that the influence of the acoustic agenda on design decision was amplified by two factors;

- The particular acoustic challenge the Harbour Quays Precinct presented, especially at night, surrounded by a 24 hour noise source, and
- As a hypothetical application of these principles, my bias towards their influence and the extent of their use is evident.

The following chapter discusses the successes and shortcomings of this design-research study, and where it might lead in the future.





## 6. DISCUSSION AND REFLECTIONS

### 6.1 Introduction

This thesis explored the consequences of imposing an Acoustic/Soundscape agenda on the Urban Design process. While some of the principles of Acoustic/Soundscape Design contradict well-established Urban Design Principles, my Urban Design Proposal addressed these conflicts in a way that allowed me to assess their potential amalgamation. In achieving this aim, the scope of my research shifted from the architectural articulation of the sonic environment to the more profound effects larger urban design decisions have on the immediate soundscape.

This chapter presents final discussions on the outcomes of the design-research process. It ties together research from the fields of Urban Design, Outdoor Acoustics, and Soundscape Philosophy. The intersections of these fields forms the context in which I offer a more holistic Urban Design Philosophy.

### 6.2 Major Findings

In accordance with my aims, this thesis followed two lines of inquiry;

- Does the value of acoustic design warrant its inclusion in the urban design process?
- How does this approach effect the aesthetic of the built environment on which it is imposed?

These lines of inquiry were addressed from Macro and Micro-design perspectives.

### **6.2.1 The value of an Acoustic agenda in Macro-Design**

After analysing a number of case studies on the effects of urban morphology on Soundscape, it became evident that the soundscapes of cities are seldom designed, but instead are a product of the social and cultural evolution of a city's urban fabric. Sonic indifference is evident in the level of significance placed on sound in the urban design process to date.

The importance of quiet environments has not been discounted; noise sensitive activities (residential development, schools, etc.) are often protected by noise legislation. However, the greater problem still remains; the acoustic environment is seldom considered at a stage when basic decisions are being made about the composition of urban fabric. Solutions to noise are too often remedial, inefficient and expensive, when they could be inherent in the design of the greater urban structure.

As populations push the boundaries of urban areas, progressively noisier industrial areas will be colonised by noise sensitive occupants. When this occurs, incorporating an acoustic agenda will become vital in preserving harmony between neighbouring activities.

Of course every design project is situational, but Urban Acoustic Design can offer solutions to many acoustically challenging sites (as well as complement urban design of sites without specific acoustic challenge). Additionally, with the sound propagation modelling tools available, designers have the ability to reasonably foresee the acoustic consequences of their design decisions, rendering the process harmless.

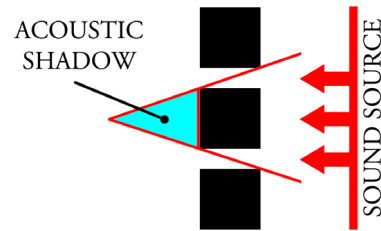


Fig. 6.1 The creation of an 'Acoustic Shadow'

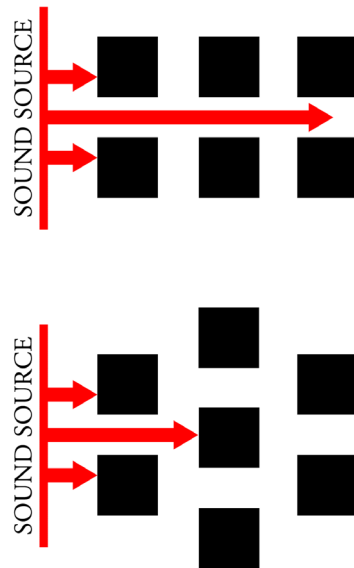


Fig. 6.2 Street grid layering, offsetting connecting streets.

This thesis has provided a unique adaptation of sound propagation software, not only as an analytical tool, but as a conceptual tool for the urban design of built and open space. Tests conducted in Chapter 4 and 5 (using CadnaA) delivered a number of interesting results. The following 'Acoustic Design Principles' were derived from these tests, and were then evaluated through the Harbour Quays Urban Design Proposal.

From the earliest tests, the concept of the '**Acoustic Shadow**' established itself as a core principle of Soundscape Design (Fig. 6.1). It is not a new concept, and is discussed by Kang in 'Urban Sound Environment', but it has yet to be exploited as an effective Urban Acoustic Design tool. In sonically challenging sites, creating areas of acoustic shadow may be the only way to introduce noise sensitive activities. The city environment is noisy by nature, and it is only through the careful design of the street network and built environment that some semblance of quiet can be found. The best acoustic buffering elements available to designers are buildings; by manipulating their size, shape and use, they can provide acoustic relief for surround outdoor spaces (an attribute that is likely overlooked by designers).

When considering external noise sources, the best means of attenuation comes from the design of the street network. By '**Offsetting Connecting Streets**', and reducing visual permeability, external noise sources are unable to propagate beyond a single block (Fig. 6.2). However, this approach fundamentally contradicts principles of good urban design, as it reduces legibility, and hinders the ease with which one can navigate through a space. It is important therefore, to consider this acoustic approach as an extreme measure, and one that may only be feasible for particularly challenging sites.

An approach that could be more easily adopted by urban designers is that of block splitting. Too often, large building footprints dominate city blocks, exposing facades to street noise and providing few if any quiet outdoor spaces. As a means of introducing a more mixed use program into the urban environment, designers should consider **'Splitting large footprint blocks'** into a number of smaller footprints (Fig. 6.3). Internal lanes create areas of quiet, with the potential for soundscape design of parks and corridors, and the subsequent building sizes can prove more conducive to mixed use development. Not to discount the large footprint building, as it also has its place in the city-scape.

This approach could be considered an argument for the separation of vehicular and pedestrian activity. Housing the two movements on separate networks may allow for greater control of the pedestrian acoustic environment, but it is well documented that the success and vibrancy of a street or square lies in its diversity of users. Some of the most successful squares are shared space, catering to all methods of navigation. Instead, this approach may be better suited to semi-private internal block areas (for example, a residential community space).

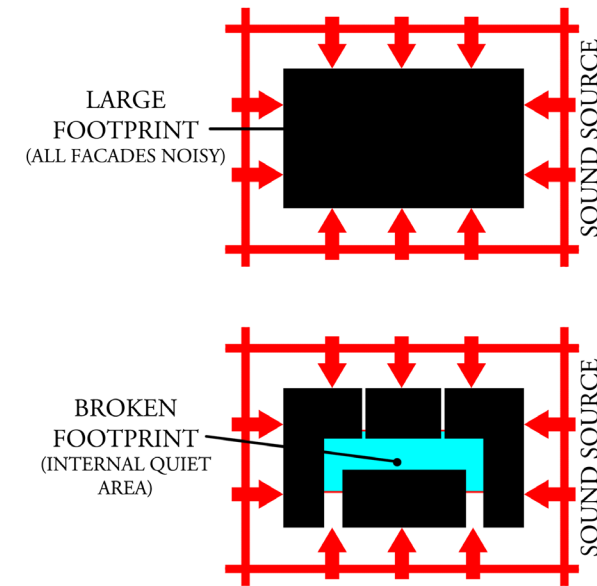


Fig. 6.3 Breaking large footprints to create quiet areas within a block

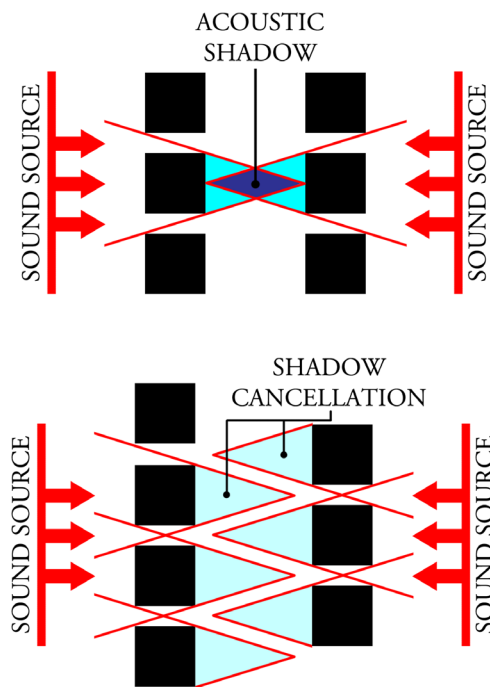


Fig. 6.4 Pattern effects of building placement on an internal pedestrian corridor.

A principle of interest that I was unable to test during the Urban Design Proposal is that of the '**Pattern effect**'. Creating an internal pedestrian corridor between two roads gives particular significance to the buildings bordering that corridor (Fig. 6.4). Of course, the clarity in which these acoustic patterns may be perceived by users comes into question, as there is never a constant flow of sound from street sources. Nevertheless, creating a pedestrian corridor of rhythmic significance may be achievable, and if so, could establish an intriguing acoustic design precedent.

A further line of inquiry that was not pursued was that of building facade treatment. Block experiments with 'Pedestrian Corridors' provided some interesting results regarding noise amplification through reflection (see Fig. 4.21). For a pedestrian corridor to be successful, it should provide - among other things - an unhindered view shaft and movement path. The pitfalls of such a visually and physically linear corridor lie in its acoustic reflectiveness. An interesting direction for future research may be to test the diffusive effectiveness of architectural facades.

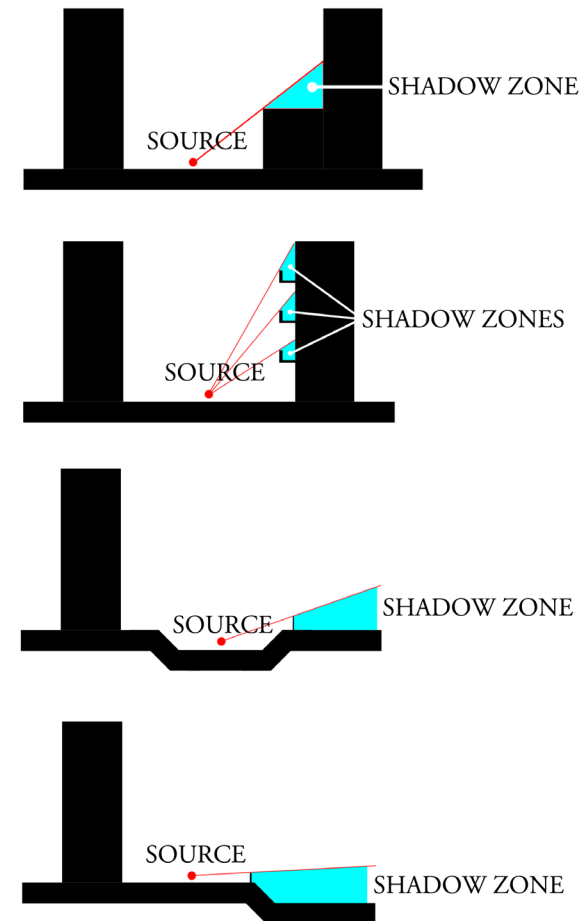
Another untested area of research in my Urban Design Proposal was that of the perimeter block internal square (see Fig. 4.25-26). Experimental tests emphasised the acoustic importance of entrance placement (away from major intersections), entrance size (propagation rate of incoming sound), and shape (limiting sight lines). However, the design parameters of public squares are usually defined by urban elements that outweigh the importance of acoustics; be it civic function, public thoroughfare, street axis, monument focus, etc.. Manipulating the acoustic environment of predefined spaces like public squares may therefore be more suited to micro-level soundscape design techniques.

Finally, sectional tests were conducted to assess the acoustic environments of street canyons. Test configurations were again based on techniques discussed by Kang in ‘Urban Sound Environment’.

It was interesting to note how effective ‘**Podium/Setback**’ building was at shielding upper levels from street noise (Fig. 6.5 (a)). Additional motives for this design tactic include wind protection, street scale, and structural strengthening. The drawbacks are an inflated cost in building setbacks, and a loss of inhabitable space, perhaps limiting this solution to residential dwellings, where roof spaces can be better utilised.

‘**Balconies**’ provide some protection from street noise (provided they are relatively solid), but studies have shown that reflection from the floors of upper balconies can offset any initial attenuation (Fig. 6.5 (b)). As noted earlier, CadnaA was not equipped to properly assess the effectiveness of balconies.

Finally, ‘**Terrain manipulation**’ was assessed as a means of shielding public space adjacent to roadways (Fig. 6.5 (c) & (d)). Lowering roadways/parks and adding small noise barriers provided some positive acoustic results, but in practice, the inherent costs, reduced navigability, and aesthetic unpleasantness of altering road altitudes far outweigh the limited acoustic improvement they provide.



**Fig. 6.5** Vertical Shielding techniques; (a) Podium/Setback Building, (b) Balcony Attenuation, (c) Lowered Road, (d) Lowered Public Space.



### 6.2.2 Aesthetic Implications of Soundscape Micro-Design

As a hypothetical Urban Design Proposal, I was unable to assess the acoustic effectiveness of the more perceptual soundscape design elements. Ideally, the design process would include a participatory design component with current and prospective inhabitants, justifying my design decisions through a contextual understanding.

Instead, I assess the visual aesthetic impact of these soundscape elements on the urban environment, providing some validity to the micro-design process.

Introducing ‘**Human activity**’ could be considered as much a good urban design principle as a soundscape feature (Fig 6.6 (a)). Despite the perceived desirableness of human sounds being contested (see 2.5.3), introducing elements such as open parks for sport, alfresco dining, playgrounds and seated outdoor spaces provide both human activity sounds, passive surveillance, and vibrancy for public spaces.

‘**Water features**’ are perhaps the most widely regarded desirable sounds (Fig. 6.6 (b)). Introducing a water feature can create both a visual and sonic spectacle, as well as masking undesirable noises such as traffic. Water also aligns with Urban Design Principles with regards to a preference of natural elements over built elements.

The previous point is further built on with the introduction of a ‘**Variety of Trees**’ and planting (Fig. 6.6 (c)). Greening public space is widely regarded as a positive urban design principle, as it provides soft areas for physical activity, shelter from weather (sun, wind, rain), and encourages the introduction of animal life (bird song being another masking element of soundscape design).



**Fig. 6.6** Aesthetic Elements of Soundscape Design; (a) Human Activity, (b) Water Features, (c) Trees.

Finally, the '**Preservation and amplification of existing sounds**' is analysed. As the first element of soundscape that specifically draws on architecture to manipulate the acoustic environment, this design technique was of particular significance. A double curved facade is used to reflect sounds from the harbour into a listening area at the centre of the semicircle (Fig. 6.7). As an architectural gesture, this design suggests an aesthetic that is uniquely soundscape. Again, the acoustic effectiveness of this design is not testable, but its striking appearance embodies the ideals of soundscape philosophy.

The difficulty in establishing micro-design principles is that they are essentially perceptual, and there is no standard by which they can be predetermined. It is therefore the prerogative of the designer to take the first step in introducing elements of acoustic quality and intrigue into the design process.

### 6.2.3 Summary of Findings

Generally speaking, both the macro and micro acoustic design principles discussed are beneficial (and at times complementary) to the urban design process. Some of the more contradictory macro-design principles may be limited to especially challenging acoustic cases (like the Harbour Quays site), but overall, it would not be a big leap to see these principles become standard elements of an urban designer's toolkit.

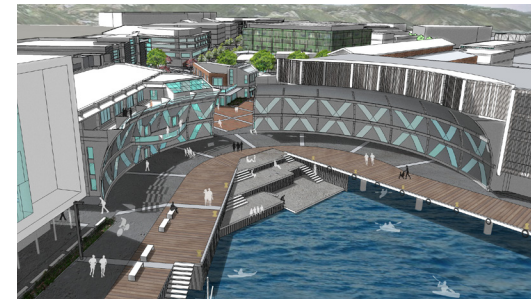


Fig. 6.7 Aesthetic Elements of Soundscape Design; Double-curved facade to amplify existing harbour sounds.

### 6.3 Summary of the Urban Design Proposal

As an assessment tool for the principles derived from earlier research, the Harbour Quays Urban Design Proposal provided me with a unique opportunity. As a site with existing acoustic difficulties and a relatively clean slate, Harbour Quays enabled me to adopt an acoustically biased outlook with regards to macro-design. Additionally, with no specific identity, a soundscape design program could be overlaid to test specific soundscape micro-design techniques.

The success of the proposal was not based on how well it performed acoustically, but how well these Acoustic Principles integrated with Urban Design Principles. With regards to macro-design, an important element of the proposal was the site's connection to future development. The street network enclosed the site as an internal community, which could be considered both a positive trait in establishing community, and a negative trait in isolating the precinct. Additionally, when future developments occur, the acoustic nature of the site will change drastically, thus eliminating the need for measures such as offsetting built layers. In critiquing the macro-design of the site, it perhaps acts better as a self-contained community unit rather than part of a greater development. However, the street network does provide an example of grid transition from existing to new, and the implemented Acoustic Design Principles such as 'block splitting' and 'secondary street public spaces' set a precedent for mixed use development in urban environments.

With regards to micro-design, the evidence of its integration can be seen in the Site Walkthrough image sequence (Fig. 5.35-41). As an additional element to urban design,

I see no reason why it could not be included as a standard, creating intriguing architectural spectacle, enhancing public spaces and generally complementing good urban design practice.

#### **6.4 Research Limitations**

Firstly, while the validity of my macro-design principles are subject to the limitations of the software, it cannot be contested that this thesis has provided a unique acoustic assessment of urban design at a conceptual level. Software packages like CadnaA enable designers to firstly, assess the sonic impact of their design decisions at an early stage, and secondly, communicate those results in an easily comprehensible way to both learned and lay people through colour contour images (seen throughout this thesis). Such a tool could further enhance an ever-expanding approach to holistic urban design.

This research doesn't suggest that one should prefer an acoustic design agenda in urban design. This position would be contrary to the question that prompted this thesis; Why disregard such an important sensory element as hearing when designing urban space? Instead, this thesis finds itself aligned with good urban practice, noting that design should be holistic in nature and contextually sensitive.

As stated throughout my research, Soundscape philosophy places a lot of importance on the contextual identity of a site. Given the nature of my site, I was unable to utilise local knowledge and established preferences of inhabitants as a means of justifying my acoustic design decisions.

Additionally, the size, existing elements, and unusual shape of the site hindered my ability to implement some of the more aesthetically playful principles of acoustic design

like 'Pattern effects'. Perhaps a future line of inquiry would take place on a more open site proposed for renewal rather than one already partially established.

### **6.5 Future Prospects**

The purpose of this thesis was to contribute to the development of the Urban Design field through an understanding of the acoustic environment and the application of Soundscape Design Principles. As this thesis progressed, the sonic effects of architectural detailing fell outside the scope of my research. An investigation into the acoustic implications of architectural form, façade detailing and materiality could provide a closer link between this research and the field of Architecture. This also opens the door for the development of an architectural aesthetic unique to soundscape design, much like that of interior performance acoustic design. Imposing a sensory agenda on the design process also leaves the door open for investigation into other senses; a multi-sensory approach may become a long term goal for a more holistic method of Urban Design.

## **6.6 Final Conclusion**

This research attempted to integrate the well-established principles of Urban Design with the relatively young principles of Soundscape Design. Designers should be aware of the impact their design decisions have on the surrounding acoustic environment.

Evidently, the implementation of Acoustic Design Principles in the field of architecture is uncommon. Its application, as presented in this thesis, is intended to provide an example of its potential use in the field of Urban Design. Acoustically challenging environments will continue to be a problem urban designers have to contend with. It is hoped that this design-research approach casts the preconceptions of Urban Design practice in a new light.







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## 9. APPENDICES

### 9.1 Appendix 1 - Terms and Definitions

<b>Acoustic Ecology</b>	A discipline that analyses how we interpret, and are effected by natural and artificial sounds around us. It suggests an understanding of the acoustic environment as a musical composition and further, that we own responsibility for its composition.
<b>Acoustic/Auditory Refuge</b>	Defined as a place where listeners perceive themselves to be in control of their acoustic environment, a place which offers an alternative and often contrary acoustic environment to that of the surroundings.
<b>Acoustic Shadow</b>	An area through which sound waves fail to propagate due to obstruction.
<b>Angle Scanning</b>	Calculation of the SPL at a receiver point is done by rays starting from the receiver and spaced in equal angle steps. Only objects crossed by the ray are taken into account in the calculation. Point sources in the angle cone are virtually moved to lay on the calculation ray.
<b>Area Source</b>	Area sources are modelled as closed polygons. They are noise sources extending in two dimensions while the third dimension perpendicular to its area is small in relation to the receiver distance. Upon Calculation, CadnaA subdivides the area source into small sub-areas. In the centre of each sub-source a point source with the appropriate partial sound power is placed.
<b>Buffering</b>	The separating of spaces through distance or topography, adding landscaping elements, noise barriers, or buildings to protect public space from negative noise sources.
<b>Calculation Grid</b>	A grid of points on which the SPL is calculated for all defined evaluation parameters.
<b>Contextual Identity</b>	‘Contextual Identity’ or ‘Sense of Place’ is a term used in urban design referring to the maintenance and perpetuation of the unique social and environmental characteristics that make a place.
<b>Decibel (dB)</b>	The unit Decibel is a quantification of sound levels relative to 0dB, a reference which has been defined as the threshold of perception of an average human.
<b>Densification</b>	Densification is a term used in urban design to refer to an increasing of the number of people inhabiting an urbanised area. While contested, it is generally asserted that medium to high density is more sustainable in urban areas..
<b>Frequency (Hz)</b>	The property of sound that determines pitch. It can be defined as the number of occurrences of a repeating sound wave per unit time. The frequencies a human ear can hear are limited to a specific range.

## Appendices

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<b>Geography Information System (GIS)</b>	A geographic information system is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.
<b>Hi-fi Soundscape</b>	A hi-fi soundscape is one possessing a favourable signal-to-noise ratio, one in which discrete sounds can be heard clearly because of the low ambient noise levels. Country is generally more hi-fi than the city, night more than day. In a hi-fi soundscape, sounds overlap less frequently; there is perspective – foreground and background.
<b><math>L_{eq}</math></b>	$L_{eq}$ represents the ‘equivalent continuous sound pressure level’, usually used when measuring areas of varying amplitude.
<b><math>L_{max}</math></b>	$L_{max}$ represents the ‘maximum sound pressure level’ reached.
<b><math>L_n</math></b>	$L_n$ represents the sound pressure level exceeded for n percent of the time, e.g., $L_{50} = 75\text{dB}$ - for 50 percent of the time, the sound pressure level exceeds 75dB.
<b>Line Source</b>	A noise source that emanates from a linear or single dimensional geometry. A method of simplification for modelling and calculation purposes, e.g., roads, rail lines.
<b>Lo-fi Soundscape</b>	A lo-fi soundscape obscures individual acoustic signals in an over-dense population of sound. Sound becomes something that the individual tries to block, rather than to hear. The lo-fi, low information soundscape has nothing to offer. As a result, individuals have tried to shut out the soundscape using methods such as noise abatement, or acoustic perfume – mp3 music, etc.
<b>Masking</b>	The addition of natural or artificial sound into an environment to cover up unwanted sound. Contrastingly to active noise control, sound masking reduces or eliminates awareness of existing sounds
<b>Movement Hierarchy</b>	When referring to the hierarchy of an urban street network, one is generally referring to the preference of one transportation method over another. Good urban design practise fosters pedestrian movement as a positive urban trait.
<b>Noise Control Methodologies</b>	A set of practices in the architectural/environmental acoustic field employed for noise mitigation. E.g. Introducing noise barriers.
<b>Period (T)</b>	The duration of one cycle in a repeating sound wave, period is the reciprocal of frequency.
<b>Permeability</b>	Permeability is an urban design term referring to the degree of movement (connectivity) urban morphology permits (vehicular or pedestrian). More permeable areas are generally considered more positive urban spaces as they foster pedestrian movement.
<b>Point Source</b>	A single identifiable localized sound source. A method of simplification for the modelling and calculation purposes, e.g., loud speaker, water fountain.
<b>Propagation Rate</b>	The rate at which sound dissipates from a source. Propagation rate between and behind buildings is determined by the minimum gap width between adjacent buildings.

<b>Quiet Side</b>	The Quiet Side effect refers to residential dwellings with multiple outlooks. The negative psychological effects of an apartment facade exposed to a high level of traffic can be nullified by the presence of a quiet side.
<b>Ray Tracing</b>	The ray paths between sources and receivers are constructed deterministically. Extended sources are subdivided dynamically using the projection method. The parts covered by a single calculation ray are smaller in small distances and larger in large distances. Screening objects and all gaps between them produce one ray minimum.
<b>Reflection Order</b>	The number of reflection taken into account between receiver and source in an 'angle scanning' or 'ray-tracing' calculation. Increasing reflection order can increase the accuracy of a calculation, but also exponentially increase the calculation time.
<b>Reverse Sensitivity</b>	Reverse sensitivity is a term used in New Zealand's urban planning system. It describes the impacts of newer uses on prior activities occurring in mixed-use areas. Some activities tend to have the effect of limiting the ability of established ones to continue.
<b>Robustness</b>	In Urban Design terms, a robust system of design is one that is resilient in the constantly changing urban environment. Robust design decisions are ones that allow for adaptive reuse and future development
<b>Self-Protective Building</b>	Refers to architectural design techniques used to protect buildings from external noise sources, e.g., podium/set-back/balcony building.
<b>Sound Pressure Level (SPL)</b>	Sound pressure level, or sound level is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. Measured in decibels.
<b>Street Grid Pattern</b>	Street Grid Pattern is an urban design reference to the physical layout of the street network. These network patterns are often products of the age, use, and economical status of a given area. Grids are often influenced by the established movement hierarchy of the given area.
<b>Terrain Manipulation</b>	Refers to landscape design techniques used to shield outdoor areas from street noise, e.g., embankments/road lowering/noise barriers.
<b>Urban Design Principles (UDP)</b>	The term 'Urban Design Principles' encompasses the many integrated facets of the urban design process. These design principles include (but aren't limited to) Accessibility, Aesthetics, Function, Social and Physical Context, Character and Meaning, Density, Morphology, Movement, Mixed-use and Diversity, etc.
<b>Wavelength (<math>\lambda</math>)</b>	Wavelength is a measure of the distance between repetitions of a shape feature such as peaks, valleys, or zero-crossings.

## 9.2 Appendix 2 - Single Street Images

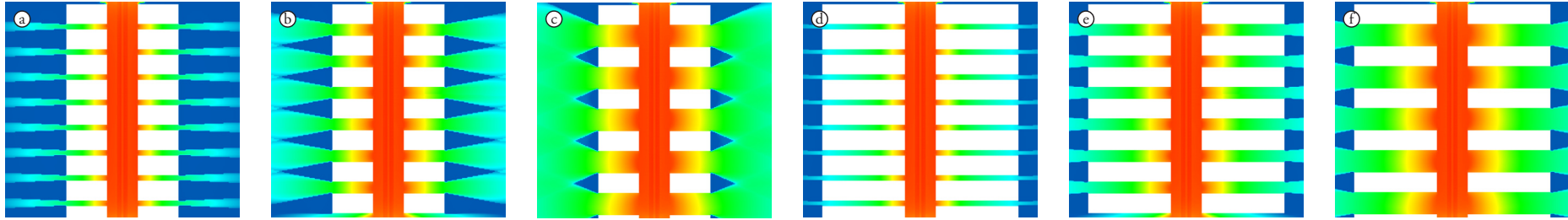


Fig. A.1 10 by 20m; (a)2m gaps, (b) 5m gaps, (c) 10m gaps. 10 by 40m; (d) 2m gaps, (e) 5m gaps, (f) 10m gaps

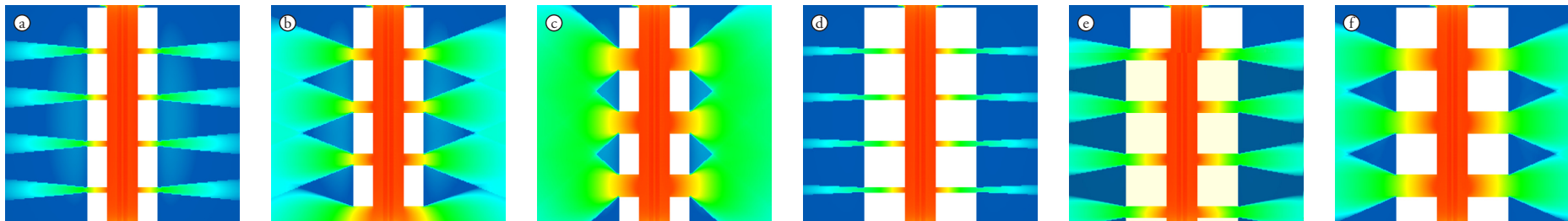


Fig. A.2 20 by 10; (a)2m gaps, (b) 5m gaps, (c) 10m gaps. 20 by 20m; (d) 2m gaps, (e) 5m gaps, (f) 10m gaps

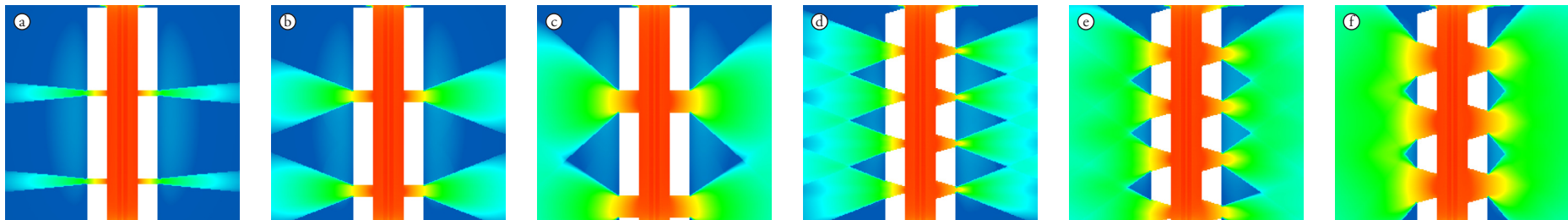


Fig. A.3 40 by 10; (a)2m gaps, (b) 5m gaps, (c) 10m gaps. Trapezoid; (d) 2m gaps, (e) 5m gaps, (f) 10m gaps

### 9.3 Appendix 3 - Dual Street Images

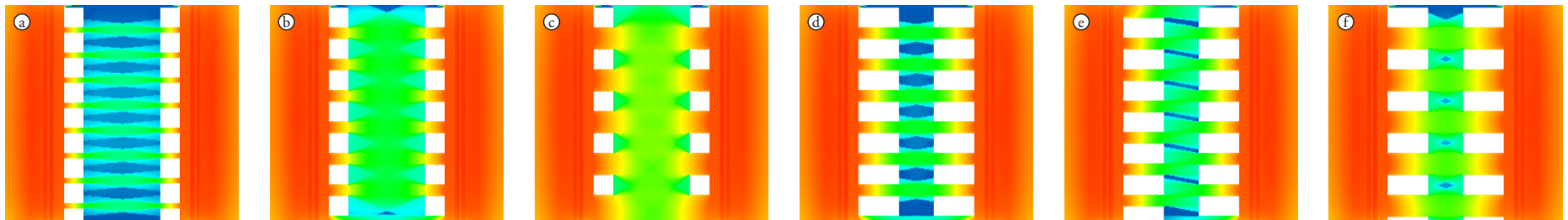


Fig. A.4 10 by 10m; (a)2m gaps, (b) 5m gaps, (c) 10m gaps. 10 by 20m; (d) 2m gaps, (e) 5m gaps offset, (f) 5m gaps

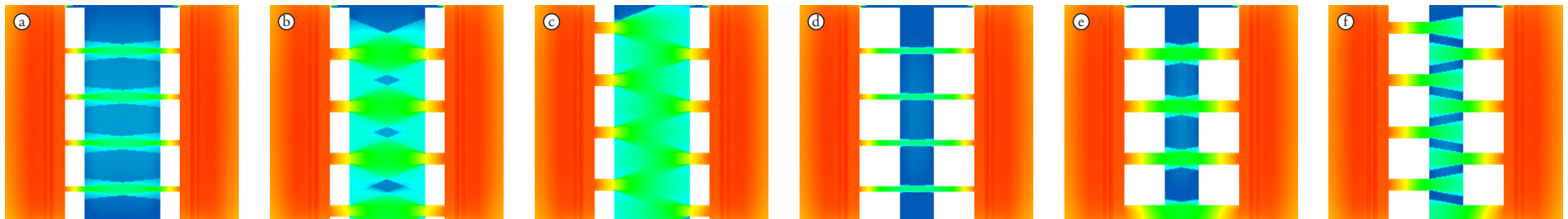
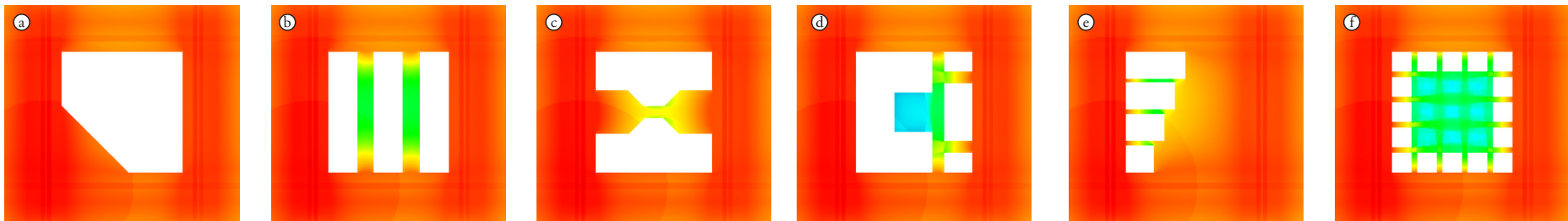


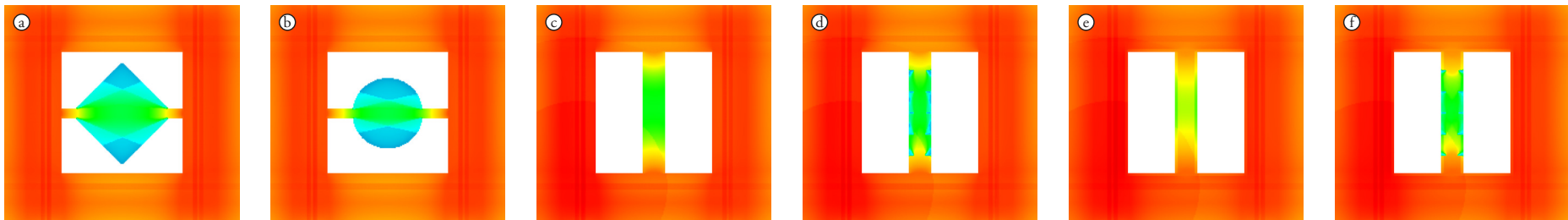
Fig. A.5 20 by 10m; (a)2m gaps, (b) 5m gaps, (c) 5m gaps offset. 20 by 20m; (d) 2m gaps, (e) 5m gaps, (f) 5m gaps offset.



## 9.4 Appendix 4 - Block Images



**Fig. A.6** (a) Corner park, (b) 3x vertical buildings, (c) Dual courtyard with internal corridor, (d) Office block (internal square), (e) Office block (cascading buildings), (f) Freestanding housing perimeter block.



**Fig. A.7** (a) Diamond internal square, (b) Circular internal square, (c) Simple corridor (R=1), (d) Partitioned corridor (R=1), (e) Simple corridor (R=2), (f) Partitioned corridor (R=2).

