THE LIVING BARRIER

Residential architecture acting as a noise barrier near railway corridors

JONATHAN LIM

A thesis submitted in partial fulfilment of the requirements for the degree of
Master of Architecture (Professional)

Victoria University of Wellington, Wellington, New Zealand, 2018

ABSTRACT

As urban regions increase in population and density, the need for quietness and spaces of relative calm becomes important to inhabitants' physiological and psychological health and wellbeing. Noises, and the sounds that create them, are treated as a by-product of urban densification and the advancement of technology. This led to uncontrolled and incidental acoustic environments around notable points of urban densification. Each sound adds together in the acoustic environment to create a composition that is labelled collectively as noise. Those in the professions of planning and designing these urban environments have a responsibility to become the composers of the grand aural experience that is the worldly soundscape.

In response to this design problem, this portfolio explored how architecture can be designed to enable this sustainable densification of noisy urban environments. It proposed the incorporation of psychoacoustics and R. Murray Schafer's soundscape philosophy (and ongoing related research) into acoustic design. By understanding the complex creation of the aural experience, this portfolio investigated whether the key to living healthily and sustainably in an inevitably sound-filled urban environment laid in the design of soundscape as a perceptual construct.

The investigation translated relevant literature into broad explorations of soundscape design elements at a variety of architectural scales. Using soundscape principles in a design process produced a strong architectural proposition that could solve both densification and acoustic problems. This had widespread and profound implications on architectural design practices. The portfolio therefore prompts further explorations into soundscape design for other architectural problems and applications.

CONTENTS

CHAPTER 1
INTRODUCTION

1.1 The Architectural Design Problem

Spaces of relative calm and quietness are becoming increasingly scarce as cities and suburbs increase in population and density. The availability and effects of these types of places play a large role in inhabitants' health and wellbeing. Cardiovascular diseases, elevated blood pressure and psychological stress levels are but a few of many documented effects of excessive and/or extended exposure to undesirable sound, i.e. noise (Figure 2.3). In a survey of over 200 cities/regions spanning six continents, 63 cities/regions imposed quantitative acoustic-based legislature on places and buildings (Schafer, 1993, pp.191-194). This number was expected to have risen since the publication in 1993. The uptake of quantitative legislature, especially in Europe and North America is spurred by availability of technology, acoustic measurement experts offering services, and the usefulness and objectivity of establishing allegations of noise (Schafer, 1993, p.196).

The 1993 survey indicates New Zealand had quantitative legislation against noise planned. Today, these are implemented in some city/regional legislature. Quantitative legislature prescribe limits on noise level exposure (measured in decibels) with limits changing during different times of the day (e.g. E25 of the Auckland Unitary Plan (Auckland Council, 2018)). The current New Zealand building code is a mix of qualitative and quantitative criteria. Where the subjective and experiential quality of life is maintained and valued there are some quantitative measures prescribed as "acceptable solutions" to help enable a qualitative criteria to be achieved, e.g. minimum noise reduction, sound transmission classes and transmission loss of the building envelope (e.g. in Clause G6 Airborne and Impact Sound from the New Zealand Building Code (Ministry of Business, Innovation and Employment (NZ), 1995)).

The disadvantage of a purely quantitative approach to noise is its measurable and objective elements, it removes the goals of subjective and qualitative experience. As revealed in Chapter 2, humans do not perceive sound in acoustic measurements. Even with quantitative legislature in place, research indicated that people living near urban noise sources may still experience heightened levels of stress, annoyance, and illnesses (Spencer-Hwang, et al., 2014), even if the source is a beneficial force in urban development (Mindell, Watkins, & Cohen, 2011), regardless of the acoustic conditions. Therefore quantitative legislature cannot necessarily fulfil a qualitative criteria.

While the correlation between sound exposure level and annoyance is well established, since the 1960s psychoacoustics and 'soundscape' design give further insight as to how and why noise annoyance occur. Despite some ongoing research since its introduction as an alternative approach to environmental design, relatively little knowledge has developed in understanding how 'soundscape' design is used "in the improvement of urban acoustical environments beyond (conventional) environmental noise assessment measures" (HEAD acoustics GmbH, 2015, p.2). A significant proportion of relevant literature referenced in this portfolio project have been published in the 21st Century (see List of References). Some new (tentatively established) discoveries were published the year before this portfolio project began in 2016. These recent studies translating soundscape philosophy and psychoacoustics into implications on architectural design were spurred by late 20th Century psychoacoustic studies (subsequent to Schafer's 1977 publication) strongly indicating that noise annoyance is influenced more by an individual's sight, psychology, social background, and wider personal context than the acoustic environment itself (Guski, 1998; Berglund, 1998; Job, 1988; Lercher, 1998). In response to these new areas of research, the direction of this portfolio actively moved away from conventional environmental noise assessment measures into exploring through design the wider factors that influence how individuals perceive sound in the environment.

As the world urban population increases, densification often occur in suburban areas around transportation hubs. Through urban planning, areas within walking distance such places are encouraged to develop as a mix of retail and medium density residential units (Carmona, Tiesdell, Heath, & Oc, 2010). As populations and living condition densification increase, so too will our average sound exposure. While there are many advances in acoustic attenuation of noise at the individual architectural project scale, the planning and design of regional sounds remain relatively unresolved and uncontrolled. 'Soundscape' design and philosophy proposes a way to manage this urban environmental noise issue. The term 'soundscape' was coined in the late 1960s by R. Murray Schafer; head of the World Soundscape Project (WSP), Canadian musician, composer, and former Professor of Communication Studies at Simon Fraser University. His conception and research of soundscape culminated in his seminal work, The Soundscape: Our Sonic Environment and the Tuning of the World, first published in 1977 and republished in 1994. Significant subsequent books like Soundscape and the Built Environment (Kang & Schulte-Fortkamp, 2016), Urban Sound Environment (Kang, 2006) and Spaces speak, are you listening? (Blesser & Salter, 2007) all have references back to Schafer's work. To Schafer, 'acoustic design' is the use of design principles which improve the aural aesthetic qualities of our acoustic environment. These principles include the elimination or attenuation of certain sounds while preserving and enhancing others. Other authors add to this by exploring the relationship between visual and aural preferences (Joynt, 2005; Viollon, Two examples of audio-visual interactions in an urban context, 2003; Viollon, Lavandier, & Drake, Influence of visual setting on sound ratings in an urban environment., 2002), how one can have an effect on the other (Aylor & Marks, 1976; Magrab, 1975), and the semantics of noise shaped by the built environment (Blesser & Salter, 2007). In conclusion, 'soundscape' philosophy gives us a new and interesting perspective to dealing with environmental noise within densifying populations by contextualising and designing it with regards to a wider soundscape composition.

1.2 Research Question, Aims & Objectives

This portfolio investigated how architecture in noisy urban environments can be designed using benevolent soundscape design, thereby enabling healthy (physiologically and psychologically) and sustainable densification.

The aim was to explore how soundscape philosophy and associated fields of study can be used in architectural design to protect people from the harmful effects of undesirable sounds. The soundscape approach/theory uses a more full-bodied experience of the environment as means to mitigating detrimental effects. Soundscape approach offers a potential to greatly supersede the quality of improvements achieved by conventional acoustic measures, while also making it easier for non-experts in acoustics to contribute to improvements. On that level it is more closely aligned to architectural design practices, and could become an important vehicle to support greater uptake of acoustic principles in architectural design. Therefore, this portfolio focused on the experiences and sensory perception of environmental sound instead of measured acoustical methods. An important supporting aim of this work was to use a literature review to identify a range of environmental interventions/elements/factors which can support the achievement of good soundscape design. These were then tested by applying them to in a project. Therefore the portfolio's aims involved physical design and intangible, theoretical, and experiential evidence to propose an alternative design framework for sustainable densification.

To address these aims the following objectives were proposed:

- Design comfortable medium density housing (mdh) for increased urban density within a noisy environment.
- Give treatment to environmental noise both acoustically and aurally to restore/heal inhabitants of residential dwellings.
- Preserve and enhance identified developing aural architectures within the wider soundscape whilst maintaining a reasonable urban design framework.
- Revitalise the wider context by selectively mitigating and enhancing environmental effects, experimenting with visual-aural relationships and other affectual aural factors.

The preliminary and developed design was the result of design strategies and principles established through research of relevant literature and an iterative design process. The selected site posed both acoustic and aural challenges. These challenges work against the sustainable and healthy densification of the wider context, inhabitation of noisy spaces, and integration of the space into the wider community. By understanding and employing soundscape design and associated psychological and experiential implications into design, this thesis speculates and explores design solutions which depart from traditional measured, acoustic solutions to environmental noise.

1.3 Design Methodology & Process (Figure 1.1)

The portfolio's design methodology and process was constructed to address to the research question, aims, and objectives.

Although research into soundscape is still developing, some of the current understanding and exploration gives the architectural designer an additional new lens with which to consider different elements of a design process. It changes how the individual approaches the world of sounds by reframing it as a perceptual construct. Therefore, for this project a thorough understanding of relevant soundscape literature was important before any other steps were taken. Consideration of the soundscape informed the many steps and aspects of the selected methodology process, and the scope of design exploration.

There were no specific architectural precedents which directly reference a dealing with environmental noise through an understanding of soundscape philosophy and design. Therefore, the work was developing a new methodology to address this gap. This new methodology was based on existing considerations of how soundscape is influenced by a multitude of fields (e.g. building material, visual aesthetics, visual-aural psychology, sociology, acoustics, etc.). It is possible to see where architectural precedents inadvertently and loosely engage with soundscape design while pursuing other design agendas. The case studies ranged from the micro individual dwelling to the macro district masterplan (Chapter 3). Thus based on prior established literature, case studies helped to identify useful design elements which embody soundscape design principles. Despite the portfolio's interest in the experiential factors of soundscape, it was still important to review the acoustical science used in the case studies' designs. A successful design has to balance subjective soundscape with objective acoustics since (as established in Chapter 2) they are still interdependent fields. This informed the portfolio's exploration into different parallel paths of design, each exploring a different design element to enable sustainable densification of noisy environments through different methods.

Many aspects of the overall design process had to be developed in a way which strengthened the ability of the project to engage with the soundscape design and philosophy. Soundscape philosophy was a driver in the site analysis, adding a need to understand not only how the offending noise pervades through the site but also how the architectural programmes lend themselves toward different attitudes towards the noise. The project site selection process and programme was therefore developed through a close consideration of the project's needs. It allowed a broader exploration of noisy sites and analysis of urban noise as a soundscape composition. Potential project sites were favoured for their bad aural qualities and its potential for improvement through an architectural design intervention, thereby resolving one of the design problems that bar sustainable and healthy urban densification.

Departing from a relatively linear methodology, preliminary design diverged with a broad experimentation of various design lines which arose from prior literature and site analysis. These were undertaken simultaneously or in close succession, with each iterative design process serving to solve different design issues, some in different acceptable ways. The objective was to explore design solutions as widely as possible, and so each iterative design line was kept relatively brief. Beyond the final developed design, this portfolio took the position of valuing the replicability of preliminary design experiments to inspire designs for other locations with similar densification enablement problems due to noise.

The developed design evolved from amalgamating preliminary design experiments which were the most successful, applicable and adaptable to the selected site and programme within the core design concept. Overall, the portfolio forgoes any design decisions based on the author's aesthetic preference in favour of adhering unwaveringly to the scientific knowledge given by the literature. The agenda of soundscape and acoustic design took precedence over other design principles because noise was the main project site design issue.

1.4 Design Research Scope & Structure

Although the research question implies an acoustic design problem, the literature research compelled this portfolio to explore the developing field of soundscape design and the perceptual experience of architecture through sound. Due to limitations in technology available to the author (the school did not have access or funding to the software necessary for detailed acoustic modelling) measured acoustic evaluation of the design was minimal. As a result, attempts at acoustic design in this project were informed by rule-of-thumb acoustic design principles and literature.

This portfolio book primarily serves as a written and illustrated explanation of the design process which lead to the developed design addressing enabling sustainable densification in noisy environments. Without the relevant literature, insights and discussion, visual means of design through the main portfolio alone (Figures & Appendix) are inadequate in critically exploring and resolving this design issue. The structuring of this book roughly follows the design methodology and process illustrated in Figure 1.1. Although linearised as a written book, it should be noted at times the design process diverges into simultaneous (or closely successive) exploratory events to converge later in the developed design.

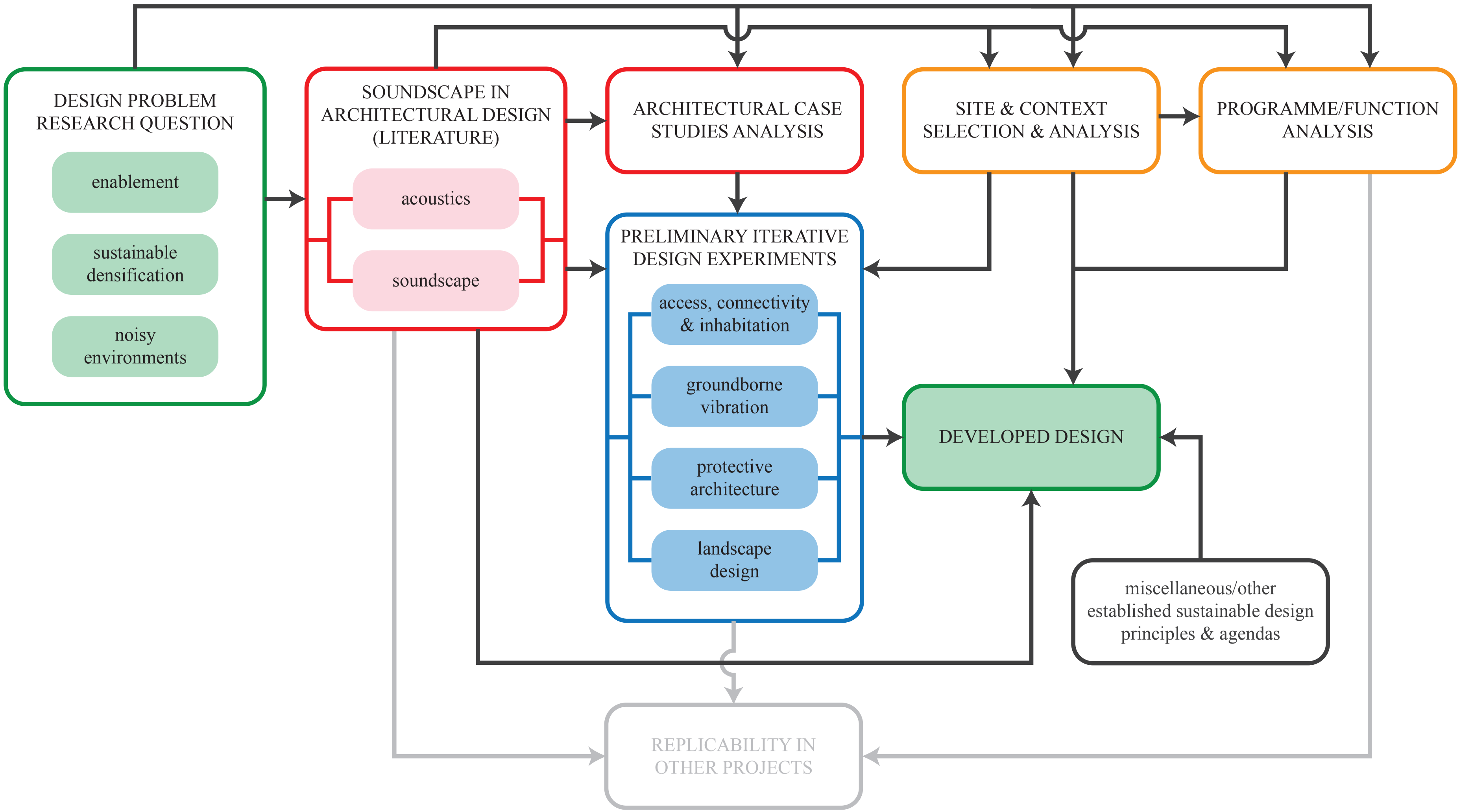


Figure 1.1 Research methodology diagram & process. The design problem components and the relevant literature review dictates the direction and nature of the iterative design experimentation and analyses that informed the portfolio's developed design.

CHAPTER 2
SOUNDSCAPE IN ARCHITECTURAL DESIGN

The two most significant bodies of literature influencing this portfolio discuss acoustic design and soundscape considerations of space. The key question when reviewing these fields are what can be learnt and applied to create holistic, successful design solutions when designing for a noisy environment. Literature on acoustic design principles are common, and the mechanics of sound energy transfer is well understood. This portfolio instead focused on exploring architectural design using soundscape philosophy and design principles. These soundscape design experiments differ from acoustic design by focusing on the subjective experience and preferences of individuals and groups of people.

At its core, soundscape philosophy is relatively straightforward. Its founder, Schafer, asks us to consider a simple question:

> "Is the soundscape of the world an indeterminate composition over which we have no control, or are we its composers and performers, responsible for giving it form and beauty?"
>
> (Schafer, 1993, p.5)

By designing and manipulating the surrounding environments, the architectural profession in particular has played a large and enduring role as the composers of this 'soundscape of the world'. Traditionally, soundscapes of older townships were composed of 'soundmarks', the auditory equivalent of physical landmarks (Truax, Acoustic Communication, 2001). Soundmarks are sounds which hold a high semantic value to a community, including social, historical, symbolic and practical (Blesser & Salter, 2007). Churches and government buildings with bells are the architectural manifestations of powerful soundmarks. Furthermore, architects and city planners organised the town around these soundmarks. Both landscape and architectural design result in an acoustic arena ensuring the individuals' soundscape includes the soundmarks that promotes social cohesion with the wider community. Chapter 2.5.1 describes the point in history where Schafer sees architectural design has lost its grip on composing soundscapes, and its damaging effects.

By reviewing the literature on soundscape, this portfolio reframes acoustic design problems as wider interdisciplinary and transdisciplinary issues. Acoustic methods incorporating decibel measurements, spectrometer visualisations, noise mapping, etc. are only one way of understanding sounds:

> "The true acoustic designer must thoroughly understand the environment he is tackling; he must have training in acoustics, psychology, sociology, music, and a great deal more besides, as the occasion demands."
>
> (Schafer, 1993, p.206)

Therefore, the reviewed literature influencing this portfolio pays particular attention to the other elements and factors which affect the design of our perceived soundscape beyond the physical acoustic environment.

2.1 Definition & Framework

The definition of soundscape varies between professions. City planners, architects, acoustic designers, laypersons, etc are "those likely to think of soundscape as the collection of all sounds in a place" (Brown, Gjestland, & Dubois, 2016, p.7). Therefore 'acoustic environment' and 'soundscape' are thought to be synonymous and used interchangeably. This was not satisfactory for the purposes of this portfolio's research process because it neglects Schafer's definition of a holistic, true acoustic designer informed by many academic fields.

2.1.1 A Perceptual Construct

Schafer defines 'soundscape' as an (acoustic) environment of "events *heard* not objects *seen*" (1993, p.8). This definition may seem obvious, but is actually highly insightful and challenging in what 'sounds' and 'events heard' ultimately are. It acknowledges that although a group of people may be in the same acoustic environment, the individual's interpretation of sound signals are unique and one's own. Many authors have therefore concluded that the 'soundscape' is a 'perceptual construct' (Brown, Gjestland, & Dubois, 2016; Porteous & Mastin, 1985; Truax, Handbook for Acoustic Ecology, 1999; Finegold & Hiramatsu, 2003; Gage, Ummadi, Shortridge, Qi, & Jella, 2004; Brown & Muhar, 2004; Yang & Kang, 2005; Dubois, Guastavino, & Raimbault, 2006; Kang, 2006). This leaves the 'acoustic environment' redefined as the medium where particles are moved, detectable by instruments and the human ear, but not yet perceived as sounds within the mind. This portfolio uses these now separated terms to distinguish between different factors and considerations in design.

Figure 2.1 illustrates the process which creates each person's soundscape. Context is an important element. It is both creates the acoustic environment as well as influences how we perceive and respond to it. People's response to their soundscapes can change the context and the cycle continues. By following this framework, we can attribute any expressions of noise annoyance to a negative interpretation of 'auditory sensation' and the 'context'. Feelings of pleasure, acoustic comfort, excitement, or even fear are examples of 'responses' (Kang, 2006; Brown, Gjestland, & Dubois, 2016, p.6). Detrimental health effects, place attachment, or aural restoration (discussed in Chapter 2.4) are examples of 'outcomes'.

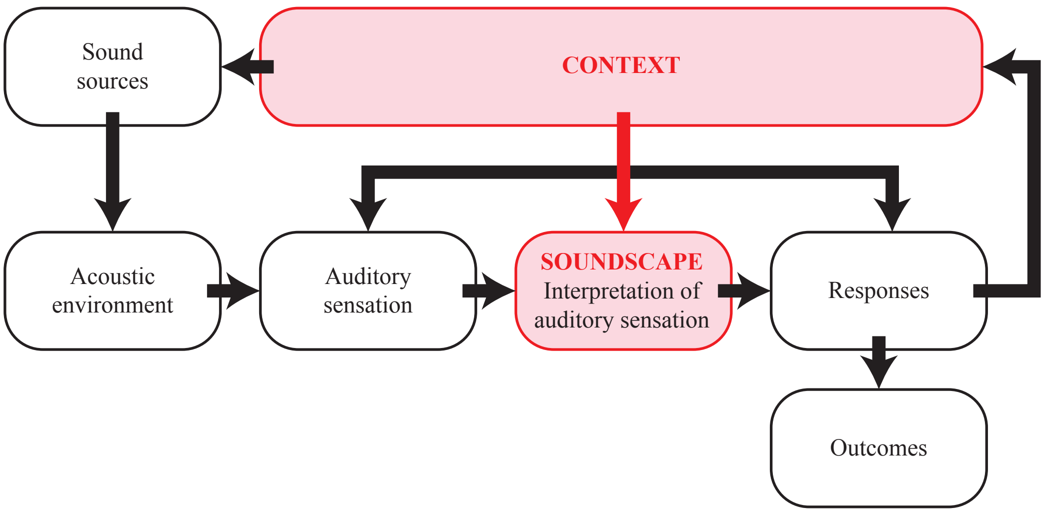


Figure 2.1 A conceptual flowchart within which an individual's perceptual construct of a soundscape occurs. The 'context' includes the physical environment and the prior knowledge and experiences of the individual.

After separating the acoustic environment from soundscape it becomes suggestible that, given the right context, people are capable of living in denser, louder living environments. Guski (1998), Berglund (1998), Job (1988) and Lercher (1998) have all demonstrated "that correlations between noise annoyance and acoustic/physical factors are often not high" (Kang, 2006, p.23). Across the authors, less than 20% to only as high as 33% of factors causing noise annoyance are because of the acoustic environment. It indicates even if densification leads to a louder context, the context is also the instrument to temper any negative soundscapes. Figure 2.2 expands upon 'context' given in Figure 2.1. There are four categories in 'context': (1) person, (2) place, (3) person-place interaction, and (4) activity. Architectural design can control these categories to varying degrees depending on the project scope; even the 'person' somewhat. If an acoustic environment is unavoidably loud and noisy, architectural design must ensure the context is benevolent to the soundscape, counteracting the anticipated poor 'auditory sensation'. There will also be design instances where the acoustic environment benefits at the detriment to the soundscape, and vice-versa. Therefore, maintaining at least an acceptable soundscape is the most important objective when designing for a noisy environment.

2.2 Designing for Health & Aural Restoration

The adverse effects of noise on personal health and how it occurs have been well-documented. Figure 2.3 is a conceptual framework prepared by the Health Council of the Netherlands on

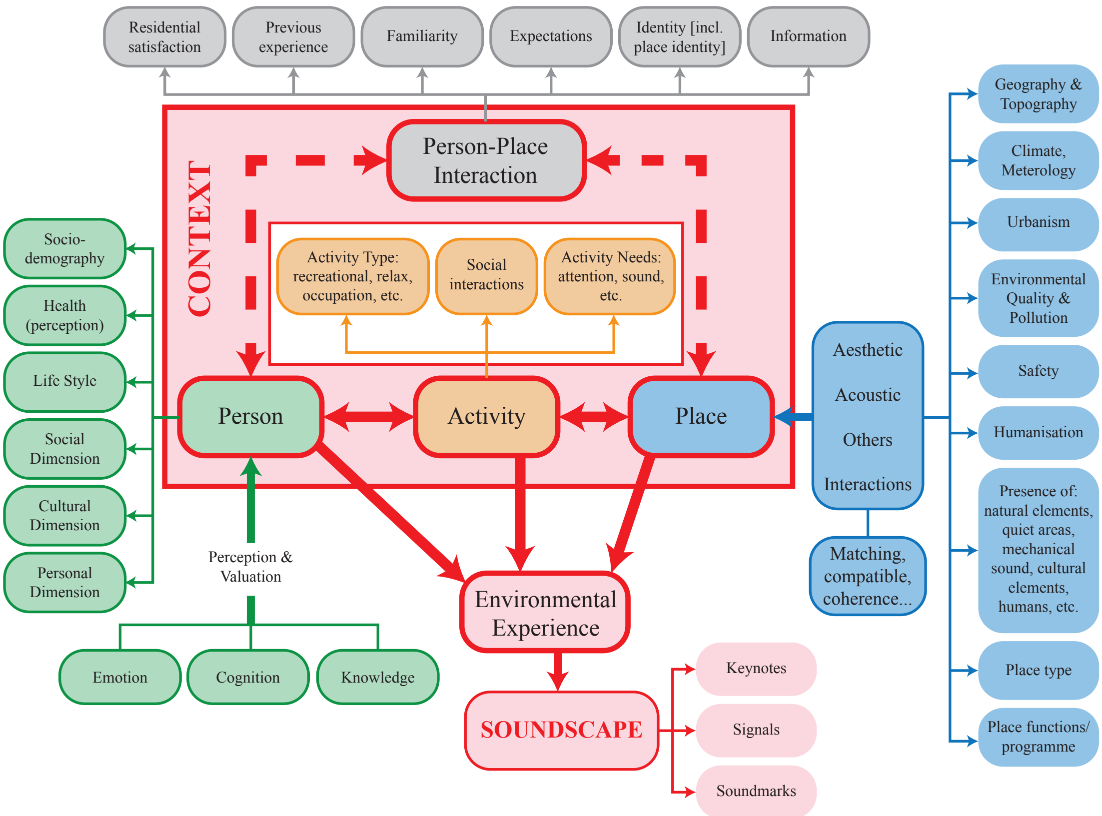


Figure 2.2 Conceptual model categorising elements that inform a person's context and its influence on soundscape.

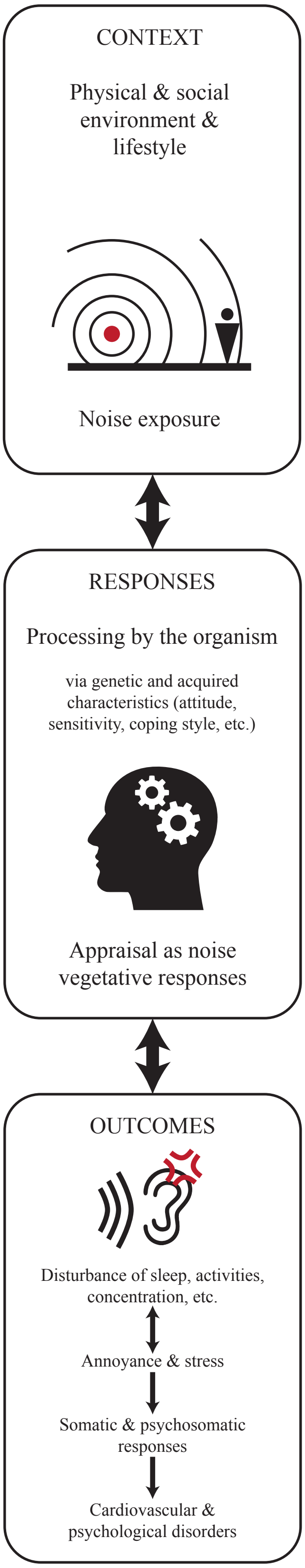


Figure 2.3

Framework for the effects of high levels of sound on health.

the appraisal and processing of noise, adapted with terminology from Figure 2.1. Although this visual resource was for evaluating the impact of airport noise on public health, it illustrates the prevailing approach to noise and health "built on a cognitive emotion stimulus-response model" (van Kamp, Klaeboe, Brown, & Lercher, 2016, p.46). Additionally an individual's need for quietness is illustrated in Figure 2.4. These frameworks specify the elements of context that not only affect one's perception, but also physiological and psychological health.

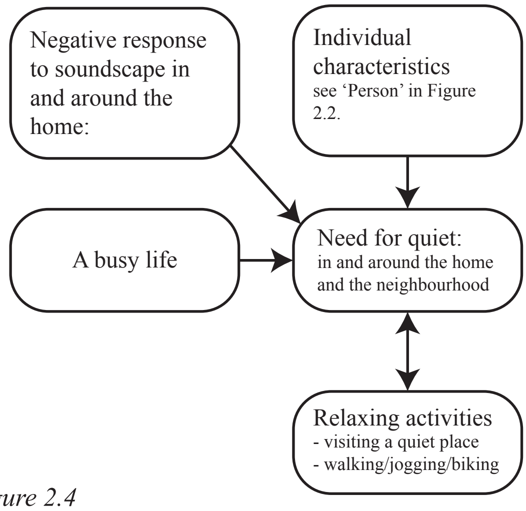


Figure 2.4

A model to determine the need for quietness, remedying the negative outcomes caused by context through relaxing activities and/or removal of the noise.

2.3 Noise Barrier Design

One of the most common and straightforward ways to deal with noise, is to erect barriers to block, reflect and/or attenuate. Noise barriers are often made with minimal gaps in its construction to prevent sound from transmitting through. They are also of appropriate height to cast an effective acoustic shadow upon the protected area. However, the design of a noise barrier using effective barrier materials is not as straightforward as one may think when considered within the realm of soundscape design. For the purposes of broadening the design exploration this portfolio takes the broader definition of a ‘noise barrier’ by including building masses strategically placed in the acoustic environment.

2.3.1 Visual Permeability & Aesthetic Appeal

There have been strong indications that our sense of sight plays a significant role in the perceived performance of a noise barrier. A study by Aylor and Marks (1976) explored the hypothesis posed by Magrab (1975) that “the visual shielding of the noise source by a noise barrier has a considerable psychological effect” (Kang, 2006, p.197). Figure 2.5 summarises their conclusion that the relationship between visual permeability and perceived performance is, surprisingly, inversely proportional. In that experiment, sound was played to subjects from barriers of varying designs. A barrier that partially obscures the sound source, thereby compromising its acoustic performance with holes was perceived as more effective than a barrier which was visually impenetrable for best acoustic performance. What was most surprising was that the control test with no barrier produced better perceptual results than the solid barrier.

Aylor and Mark’s experiment, although simplified, is an example of the independence

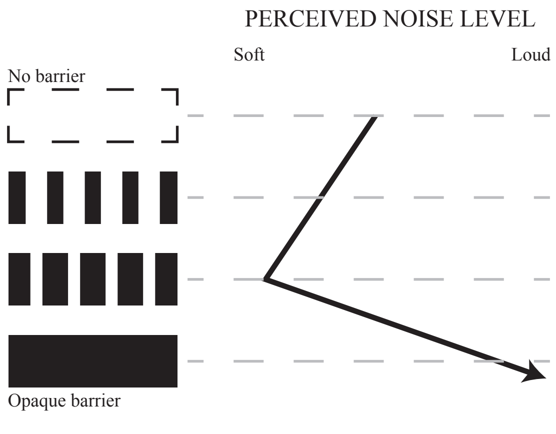


Figure 2.5
Graph of noise experienced/perceived when visual connectivity to the noise source is varied. The noise level produced by speakers behind the barrier is kept constant.

of the acoustic environment and soundscape. A similar trend has been noted by Watts, Chinn, & Godfrey, where despite the same noise exposure level on the subject’s side, “average ratings of noisiness were higher where the degree of visual screening was higher” (1999, p.55). The noise exposure of a scene with no barrier had to be increased by 7 dB(A) in order to achieve the same perceived sound level behind a willow barrier. This is a significant increase, considering an increase of 6 dB and 10 dB are roughly 1.5x and 2x perceptually louder respectively. The study concluded vegetation should not substitute actual noise barriers, under the sole belief it will improve the soundscape experience. When the willow barrier was compared to a metal barrier, the former was rated as more visually attractive, but it bore no significant effects on improving noise sensitivity.

Conversely, there are significant bodies of literature which still insist the visual pleasantness of a noise barrier is tied to its perceptual performance. Viollon et al.’s (2002; Viollon, 2003) conclusions were summed up as “the more pleasant the noise barrier was, the less stressful was the road traffic noise” (Kang, 2006, pp.196-197). Residents surveyed in another study by Perfater (1979) were adamant an original row of vegetation was more effective at blocking noise than the replacing noise barriers. This was despite the measured decrease in decibel levels behind the built noise barrier. It is also worth noting that around 30 metres of thick vegetation was required to reduce noise by 6 dB(A) (Huddart, 1990).

The literature discussed shows the complexity of human perception, and that vegetative barriers should only be used as visual pleasantness enhancers in design. If excessive noise is unavoidably prevalent in a noise-sensitive site, opportunities to see the noise source should be provided. The counterintuitive removal of the noise source from view producing higher perceived noise levels is explained by erroneous expectations concerning the effectiveness of noise barriers.

2.3.2 Building Materials

To continue exploring the impacts of visual pleasantness brings the portfolio research into looking at building materials. Joynt (2005) carried out an experiment to ascertain the effectiveness of different materials purely based on subjects' preconceptions. Figure 2.6 shows the results of their survey. Concrete was perceived as the best noise barrier material. Interestingly, natural vegetation and transparent materials had the worst preconceptions. This may seem opposite to the results of Viollon and Perfater discussed prior, but it shows that the preconceptions of vegetation as a material outside of a site context may be different to experiencing a vegetative barrier in reality. Considering the prior discussion of visual connectivity to the noise source, the preconception of materials is a contradiction in research. Where visual connection to the noise source was stated to be beneficial to perceptual noise, the materials which enable this have preconceived acoustic weaknesses. This is supported by acoustics itself, with transparent surfaces like glazing and clear acrylic having lesser acoustic performance to more solid building materials.

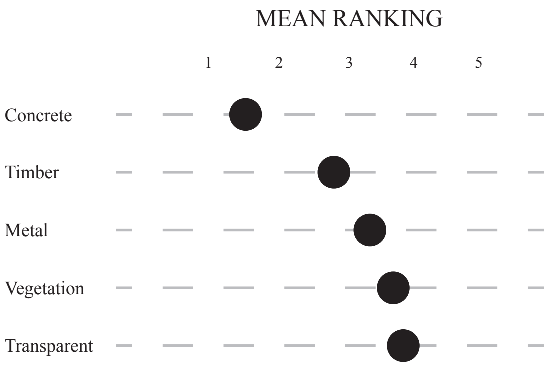


Figure 2.6

Various types of noise barriers are ranked from 1 to 5 (most to least effective) in a survey based on participants' preconceptions on the constructional material used.

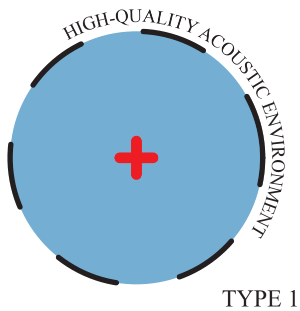
The conflicting evidence given between visual permeability and material aesthetics had Jian Kang ultimately concluding that more experiments and research needs to be carried out. It also shows the complexities of the psychological effect of noise barriers on the perceptual construct that is our soundscape. Since research is fairly recent and clearly ongoing, the resulting portfolio had to find some compromise between the two conflicting principles. Based on the above it was established that where there is excessive noise which cannot be adequately acoustically blocked, a better soundscape treatment was to acoustically compromise a noise barrier wall in strategic places. This is speculated to provide what could be described as 'visual comfort' while maintaining preconceived barrier material performances.

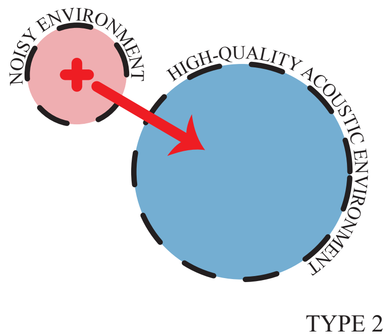
2.4 Aural Restoration

By understanding how we process noise and the factors which create our need for quietness, how we aurally restore health through the use of soundscapes can be discussed. Research has deduced two methods by which human health may be aurally restored, both of which have implications on architectural design (van Kamp, Klaeboe, Brown, & Lercher, 2016). The methods were simply named "Type 1" and "Type 2" aural restoration (Figure 2.7).

Figure 2.7

The two methods of 'aural restoration' as identified by van Kamp et al. (2016), with the individual represented by the red cross. Note the parallels between Type 2 and Figure 2.4.





Type 1 is aural restoration through direct exposure to a higher quality acoustic environment. Immersion in spaces with natural elements, e.g. vegetation and wildlife, has been proven to be beneficial to health.

Type 2 is aural restoration through a subjects' knowledge of a nearby, higher quality acoustic environment than their current location. This nearby acoustic environment can be as close by as the building having a distinct 'quiet side', or a local park/recreation area within walking distance.

In densifying living environments, filled with an increasing variety of sounds, spaces for Type 2 restoration are becoming scarcer, yet more important. Studies have indicated that residents near noise sources like main roads report less annoyance, a better quality of life, and less sleep disturbance when a quiet side of their dwelling is present (Forssen, 2009; Ohrstrom, Skanberg, Svensson, & Gidlof-Gunnarsson, 2006; De Kluizenaar, et al., 2011; De Kluizenaar, et al., 2013; Van Renterghem & Botteldooren, 2012). Looking at the architectural planning of these studies, the quiet side should ideally contain the sleeping areas. In Chapter 6.3.1 a programme hierarchy based on sensitivity to noise and context is proposed in response to this 'quiet side' and Type 2 aural restoration research.

2.5 Sound Fidelity Definition

Schafer introduces designers to many new dimensions of considering sounds. A problem currently faced in noisy urban and suburban spaces is the lack of high-fidelity (hi-fi) acoustic environments, with low-fidelity (lo-fi) environments often prevailing. Figure 2.8 gives a simplified visual representation of this concept.

A lo-fi environment is an increasingly common occurrence in dense urban areas and near individual noise sources. A perfect example is a noisy restaurant with many hard, reflective surfaces. Despite its visually intimate lighting

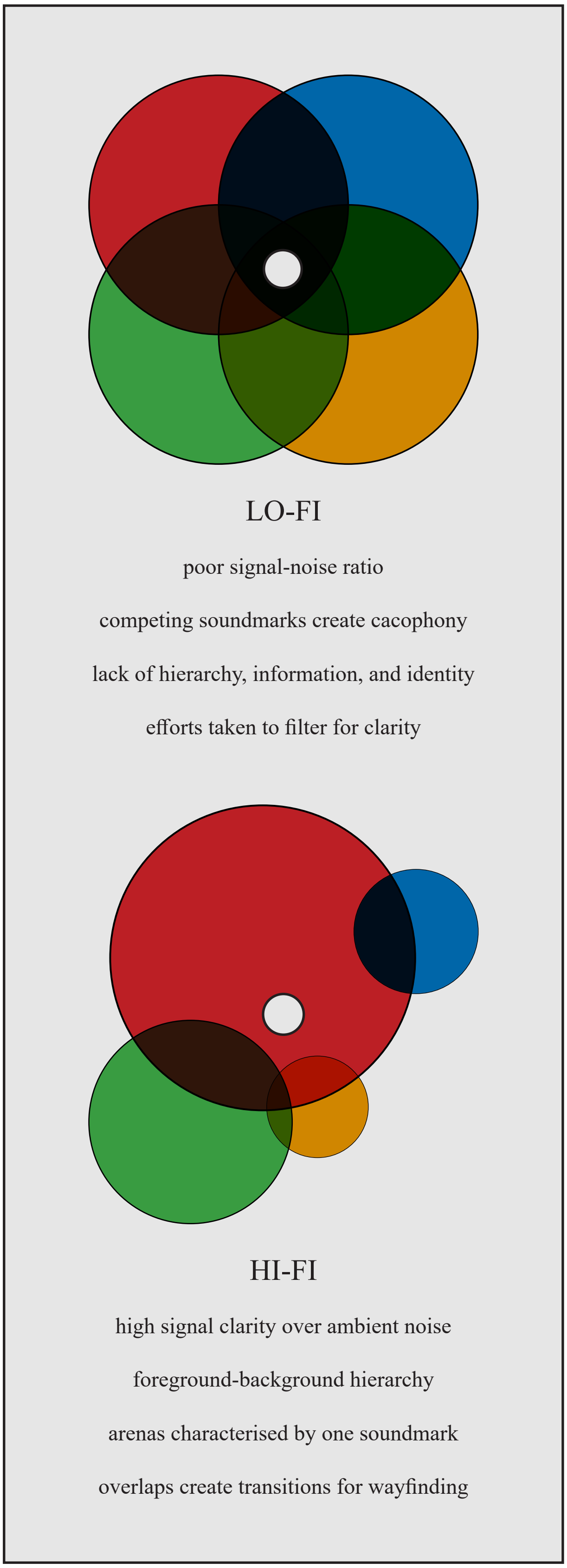


Figure 2.8

Simplified visualisation of lo-fi and hi-fi acoustic environments with each colour representing different compositional sounds within an acoustic arena.

and design setting, one struggles to hold a pleasant, coherent conversation without difficulties in hearing and speaking. The acoustic design of the space enables sounds from other patrons to carry across from one side of the acoustic arena to the other, thereby obscuring any soundmarks. This problem is also present to a lesser extent in residential environments next to highways and railway lines. Without effective measures, sound can permeate and invade the residential soundscape. This can mask sounds which characterise and identify residential spaces, and disrupt communication in poorly-insulated dwellings. A hi-fi environment is simply the opposite where there sounds are of high signal quality and information is clearly conveyed. There is a clear hierarchy of sounds between foreground and background. These sounds are often found in rural areas where birds, trees and the snap of branches underfoot are clearly differentiated.

2.5.1 Sound Fidelity in Soundscape Design

Through studying the different soundscapes of history, Schafer delineates the Industrial Revolution as the point where a lo-fi acoustic environment begins to become prominent in human society. This is where "overpopulation of sounds" arguably originated from (Schafer, 1993, p.71). Mechanical noise, especially ones which persist, are especially damaging to what was originally a hi-fi soundscape. Research has shown that lo-fi vehicular highway environments have an effect on wildlife, with birds avoiding the surrounding area because they cannot communicate effectively (Brumm, 2004; Halfwerk, Holleman, Lessells, & Slabbekoorn, 2011). However, surprisingly and possibly due to the intermittent nature of railway services, birds are capable of close cohabitation with railways (Wiacek, Polak, Filipiuk, Kucharczyk, & Bohatkiewicz, 2015). The maintenance of local wildlife in the soundscape may have its uses in helping people cope with technologically noisy environments, especially with regards to masking (further discussed in Chapter 3.4).

The definition of hi-fi and lo-fi has profound implications on how we consider the composition of our soundscape. Sound levels may be within permissible ranges, however sound designers should compose the soundscape like a musical conductor directs how loud sections of an orchestra are to play. Ambient sounds are ever-present as keynotes, but should not interfere with sonic events important to the architectural programme, soundmarks. The hi-fi and lo-fi concept also opens discussion for the design technique of sound masking. Some sounds which are undesirable like mechanical noise, even if attenuated to within reasonable decibel levels, may still be psychoacoustically loud whereas natural noises can be excessively loud without people reporting any annoyance.

2.6 Chapter Conclusion

Comparison of literature between acoustics and soundscape show that studies into the psychological and perception-based soundscape has been, to date, insufficiently explored in built environmental studies. With insufficient resources and facilities provided to pursue a comprehensive exploration of acoustic design solutions to noisy environments, this portfolio instead focuses on soundscape design. Additionally, the redefinition of the 'acoustic environment' separate to an individual's 'soundscape', and the importance of 'context', reframes the importance of acoustic design in achieving sustainable urban densification in a noisy environment. Soundscape's position as the perceptual construct created mostly by context and only partially by the acoustic environment show that its manipulation and design is the ultimate determinant for whether people can live in a noisy environment.

This page intentionally left blank

CHAPTER 3
ARCHITECTURAL CASE STUDIES

This chapter explored several key architectural projects where the design engaged with sustainable densification of a site in a noisy environment. It could not be determined whether the architects consciously engaged with experiential soundscape design. However, many of their design decisions are nevertheless capable of altering inhabitants' soundscapes simply through the manipulation of the architectural context for acoustic environmental reasons.

3.1 House-K | K2YT | Tokyo, Japan

House-K is a detached residence designed by Japanese studio K2YT for two households. The project is located on a heavily constricted corner plot in a densely-built suburban area in Tokyo. Two elevations immediately look onto the street and a busy raised railway line abuts the rear exterior wall. With the project scope restricted to a small plot, House-K had to focus on internal planning and materiality to resolve issues of acoustics, soundscape, and privacy.

K2YT used concrete as the predominant building material, tempered with timber finishes. These materials were established in Chapter 2.3.2 as the two most perceptually strong materials for attenuating noise. The programme was ordered according to privacy requirements and noise/vibration sensitivity, using the structural bays to delineate rooms.

Five gardens are interspersed through House-K. Living spaces and bedrooms have prominent views of these gardens, creating visual and aural opportunities for Type 1 restoration. K2YT co-principal Takuichiro Yamamoto stated, "the noise from the railway is mitigated to the level that it is still audible but much less annoying" (Frearson, 2014). The final words of Yamamoto's statement supports the suggested semi-independence of the acoustic environment and soundscape. House-K shows in a loud acoustic environment, one's soundscape can be made to accept it, especially despite the expectations of bedroom and living spaces.

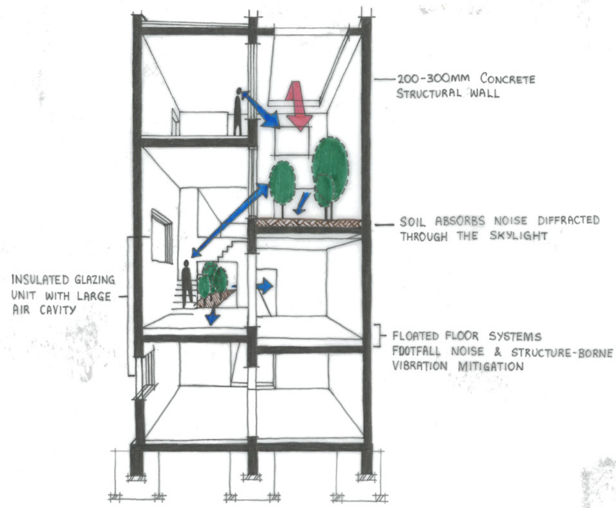
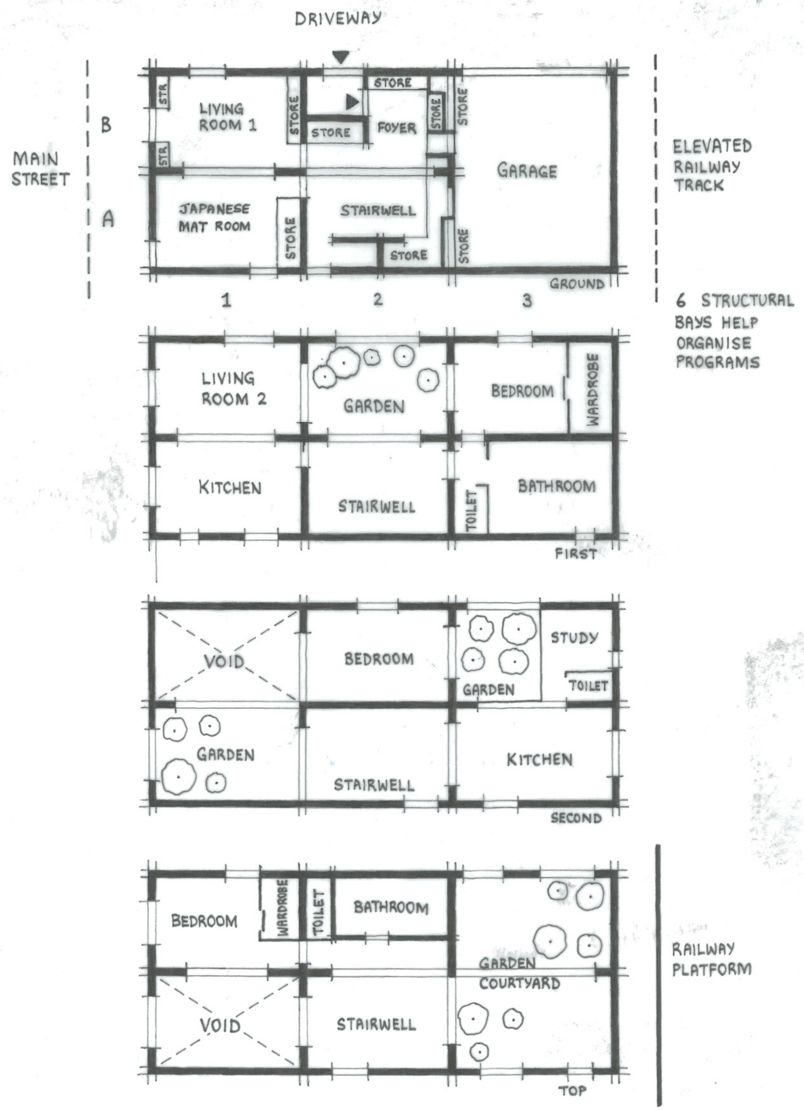


Figure 3.1 Acoustic and soundscape analysis of House-K by K2YT.



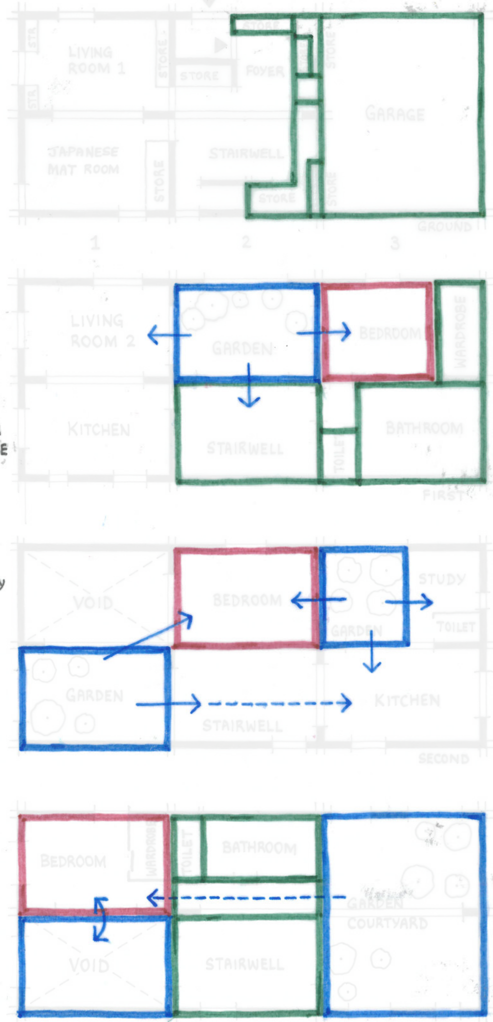
K2YT USES SMALL GREEN SPACES TO CREATE A "MICRO-UNIVERSE" OF GREENERY TO SHIELD THE INTERIOR FROM RAILWAY NOISE BOTH PHYSICALLY & PSYCHOLOGICALLY.

THE DEPTH OF GARDENS SHIELDS OF DIRECT VIEWS INTO THE HOUSE WITHOUT THE NEED FOR CURTAINS.

PROGRAMS LESS SENSITIVE TO NOISE ACOUSTICALLY ISOLATE BEDROOMS.

GREENERY CREATES A SENSE OF SERENITY & VIEWS WHICH WOULD OTHERWISE BE IMPOSSIBLE TO ESTABLISH IN A DENSE TOKYO SUBURB.

THE RAILWAY NOISE IS MITIGATED TO THE EXTENT IT IS AUDIBLE BUT MUCH LESS ANNOYING.



- ACOUSTIC BUFFER SPACES
- GARDEN
- BEDROOM (SENSITIVE TO NOISE)

3.2 Rail House | Clare Cousins Architects | Melbourne, Australia

Rail House is a private residence designed by Clare Cousins Architects. Similarly to House-K (Chapter 3.1), it immediately abuts a railway line and level pedestrian crossing. Due to its proximity to excessively loud noise, the site "languished on the market for three years" (Crafti, 2016). Rail House not only mitigates noise within itself, but also acts as a noise barrier to the wider site. This increases sound signal fidelity, allowing soundmarks and keynotes to be better appreciated, and signals to be heard.

Noise is mitigated with a five-metre-high core-filled concrete block wall, stretching for almost 40 metres along the railway line. Although this acoustically reduces noise, Cousins' nevertheless demonstrates the importance of visual aesthetics on the perceptual soundscape. The concrete blocks are "expressed internally reinforcing the "protective wall" from the trains" (Clare Cousins Architects, 2015). The combination of the wall height and depth of the house creates a large acoustic shadow over the garden. This provides opportunities for both Type 1 and Type 2 aural restoration. Large doors seamlessly flow the kitchen, dining, and living spaces into the main garden. The garden context is too small and protected to produce any significant natural sounds of its own. From a soundscape design perspective, it positively affects through the visual sense. The sounds of domesticity from the house and activities on the garden then enhances the natural soundscape by masking with train noise diffracted over the house. This concept can be scaled, where a taller, longer building protects the wider suburban soundscape, thereby restoring the fidelity of sounds that identify with suburban residential life.

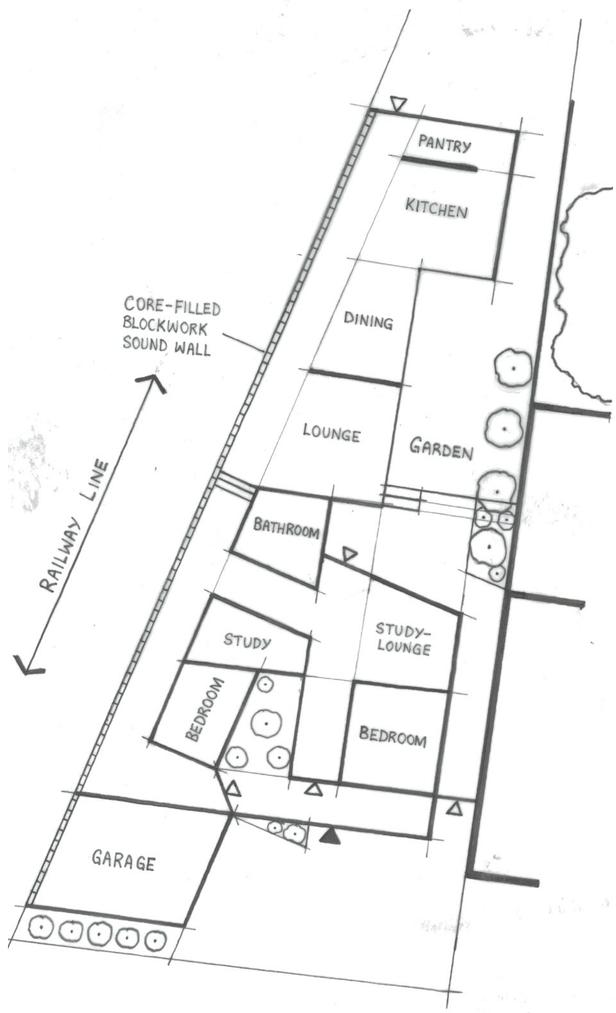


Figure 3.2 Acoustic and soundscape analysis of Rail House by Clare Cousins Architects.


NOISY SIDE
CORE-FILLED BLOCKWORK SOUND WALL
RAILWAY LINE
PANTRY
KITCHEN
DINING
QUIET SIDE
LOUNGE
GARDEN
BATHROOM
CORRIDOR - ACOUSTIC AIR BUFFER
STUDY
STUDY-LOUNGE
BEDROOM
CORRIDOR BUFFER
BEDROOM
GARAGE
LIVING SPACE
SLEEPING SPACE
DIFFRACTED NOISE
BEDROOMS & STUDY (SENSITIVE TO NOISE)
ACOUSTIC BUFFER SPACE
GREEN SPACES
A HIGHER SOUND BARRIER WITH DEPTH IS EFFECTIVE AT PROTECTING & SHELTERING SPACES FURTHER FROM THE NOISE SOURCE

3.3 Elizabeth II | Bates Masi Architects | Amagansett, USA

Elizabeth II is a private residence designed by Bates Masi Architects. It's located near the town centre on Main Street in the bustling resort town of Amagansett. According to the architects:

> "Too often, architecture fixates on the visual sense, with little regard for the other faculties of perception… research in architectural acoustics drove the form, materials, and detail of the house, not only shielding the property from the sound of the village, but also manipulating interior details to create unique acoustic character for the house"
> (ArchDaily, 2016)

Bates Masi Architects clearly support the importance of acoustic and soundscape perception in the full experience of architecture. Like Schafer encourages, the Elizabeth II was designed as a soundscape composition working with visual aesthetics to enhance it. The physical mitigation of noise from the acoustic environment was achieved through a layering of parallel walls. This resulted in a house that was both long and narrow, parallel to Main Street. Similarly to Rail House, the house functioned as a noise barrier, "casting an acoustic shadow over the property to create a quiet outdoor gathering area" (ArchDaily, 2016). The living spaces are also able to be fully opened onto the garden, extending its soundscape when appropriate.

The Elizabeth II also introduces a new element, that of perceived environmental control. Adjustable sound baffles in the combined kitchen-dining-living room allow the room to be "acoustically tuned for intimate gatherings or boisterous parties" (ArchDaily, 2016). Even if the difference in environmental acoustics is not substantial, the ability to alter the context could have similar psychologically beneficial effects to environmental control in offices (Zhou, Ouyang, Zhu, Feng, & Zhang, 2014). Although the actual performance of the sound baffles have not been published, the intention on altering the soundscape fidelity is strongly felt and would be appreciated.

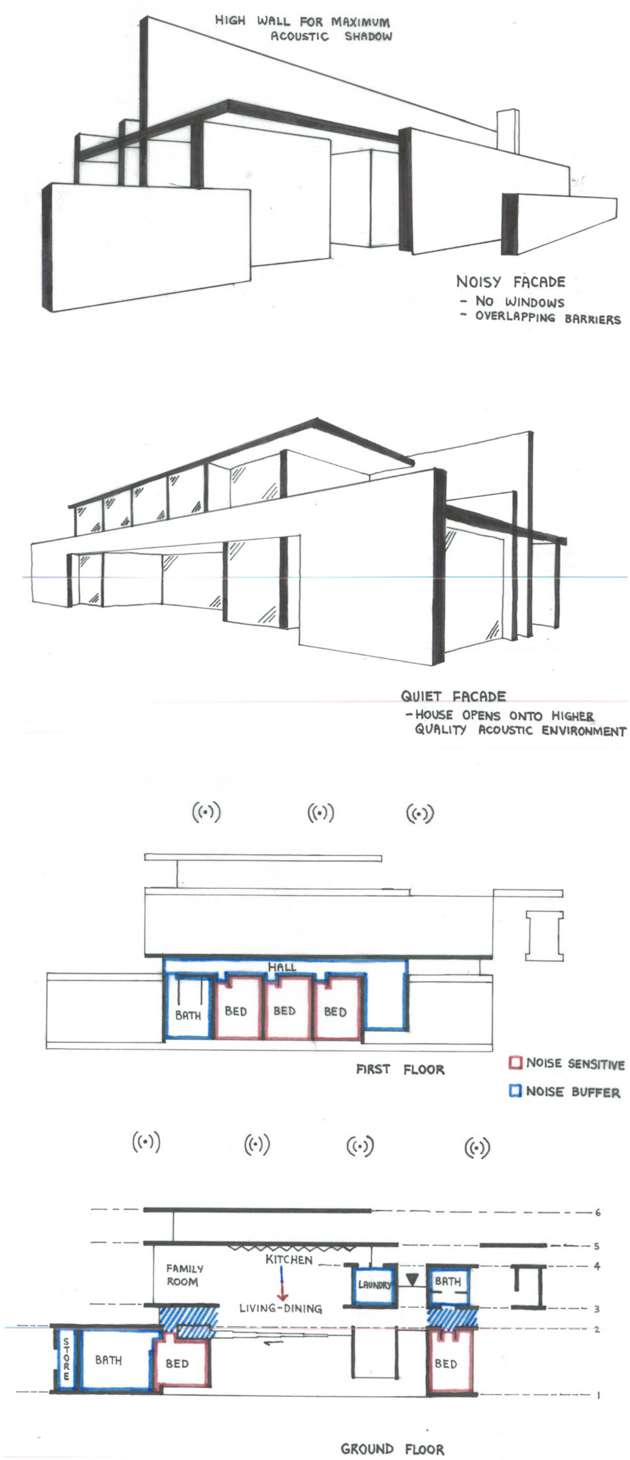
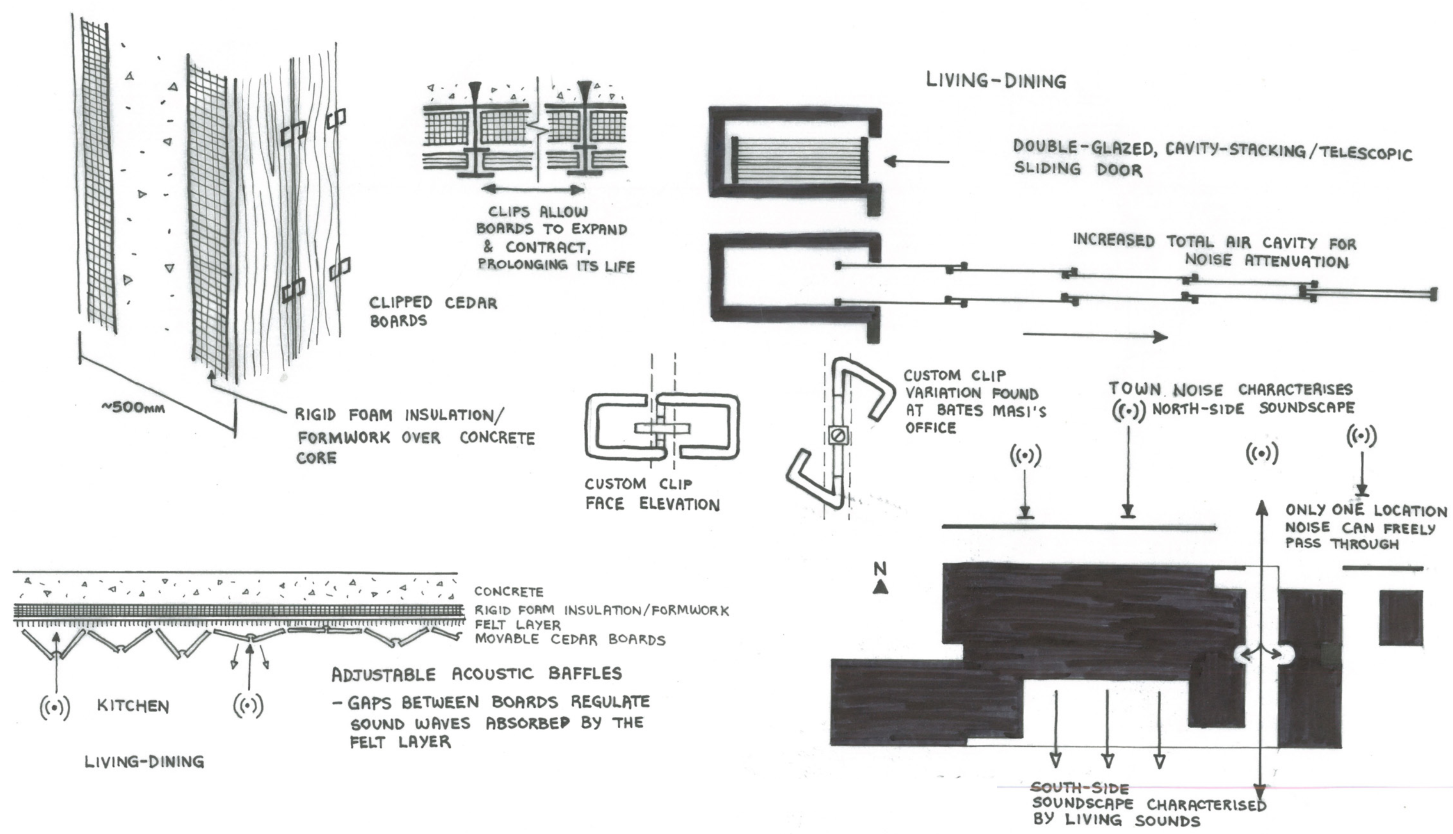


Figure 3.3 Acoustic and soundscape analysis of Elizabeth II by Bates Masi Architects.


~500MM
RIGID FOAM INSULATION/ FORMWORK OVER CONCRETE CORE
CLIPPED CEDAR BOARDS
CLIPS ALLOW BOARDS TO EXPAND & CONTRACT, PROLONGING ITS LIFE
CUSTOM CLIP FACE ELEVATION
CUSTOM CLIP VARIATION FOUND AT BATES MASI'S OFFICE
LIVING-DINING
DOUBLE-GLAZED, CAVITY-STACKING/TELESCOPIC SLIDING DOOR
INCREASED TOTAL AIR CAVITY FOR NOISE ATTENUATION
TOWN NOISE CHARACTERISES NORTH-SIDE SOUNDSCAPE
ONLY ONE LOCATION NOISE CAN FREELY PASS THROUGH
N
SOUTH-SIDE SOUNDSCAPE CHARACTERISED BY LIVING SOUNDS
CONCRETE
RIGID FOAM INSULATION/FORMWORK
FELT LAYER
MOVABLE CEDAR BOARDS
ADJUSTABLE ACOUSTIC BAFFLES
- GAPS BETWEEN BOARDS REGULATE SOUND WAVES ABSORBED BY THE FELT LAYER
KITCHEN
LIVING-DINING

3.4 Noise Barrier Houses| Crepain Binst Architecture | Goirle, Netherlands

Located adjacent to a busy highway, Noise Barrier Houses is an assortment of three different low-rise apartment and terraced house types arrayed behind an extensive concrete wall. Designed by Crepain Binst Architecture, the slanted concrete noise barrier forms the back wall of the residential units while the houses faces onto a forest. As with the Rail House and Elizabeth II residences, two soundscapes become distinguished, the bustling highway and the forested residential.

The protection of this forest has a sustainability element which contributes positively to the local soundscape. It is well established that due to the masking effects of continuous traffic noise over breeding calls and their own safety, birds would generally avoid living near highways (Wiacek, Polak, Filipiuk, Kucharczyk, & Bohatkiewicz, 2015). The Noise Barrier Houses are of sufficient height to cast an effective acoustic shadow over the forest, enabling local wildlife to live within. This not only improves the biodiversity of the area, but also improves the potential for type 1 aural restoration, because natural sounds aid in the creation of a higher quality acoustic environment.

Some traces of highway noise may diffract over the noise barrier, but is more easily masked by natural sounds of trees in the wind and birds. Studies across various locations into the effects of different types of sound masking suggests natural or sociologically preferable sounds can overwhelm technological sounds like traffic noise up to 70dB without negative psychological or physiological health effects (Kang, 2006). Interestingly birds are not adversely affected by railway corridors. This is most likely due to the relative infrequency of passing train services compared to the constant sound of road traffic on a highway and the more diverse habitats near tracks created by the "edge effect" (Wiacek, Polak, Filipiuk, Kucharczyk, & Bohatkiewicz, 2015; Varughese, 2011). Aesthetically, the Noise Barrier Houses creates an imposing concrete wall to the noise source. With a stormwater ditch and carparking adjacent to the highway, it is quite explicit that this area is unlikely to be actively inhabited. This portfolio explored further integration and mixing of uses within these leftover spaces.

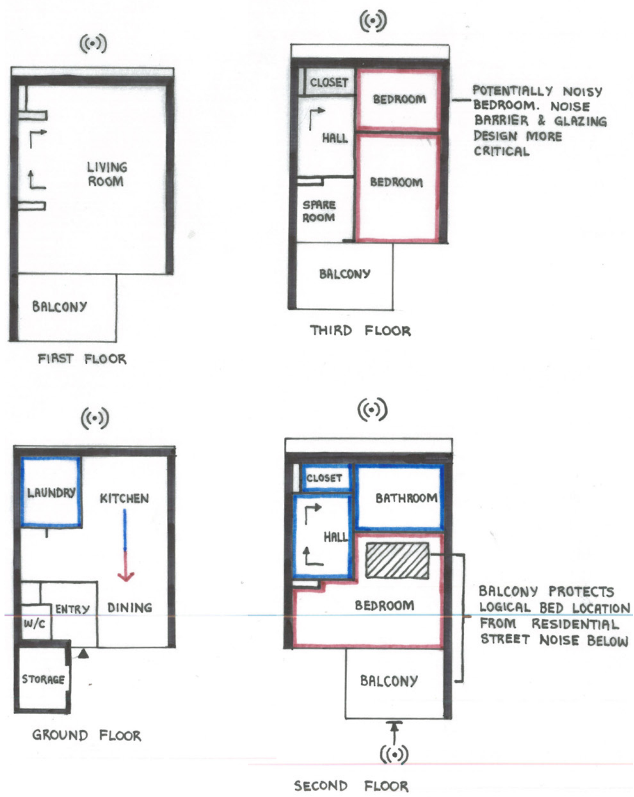
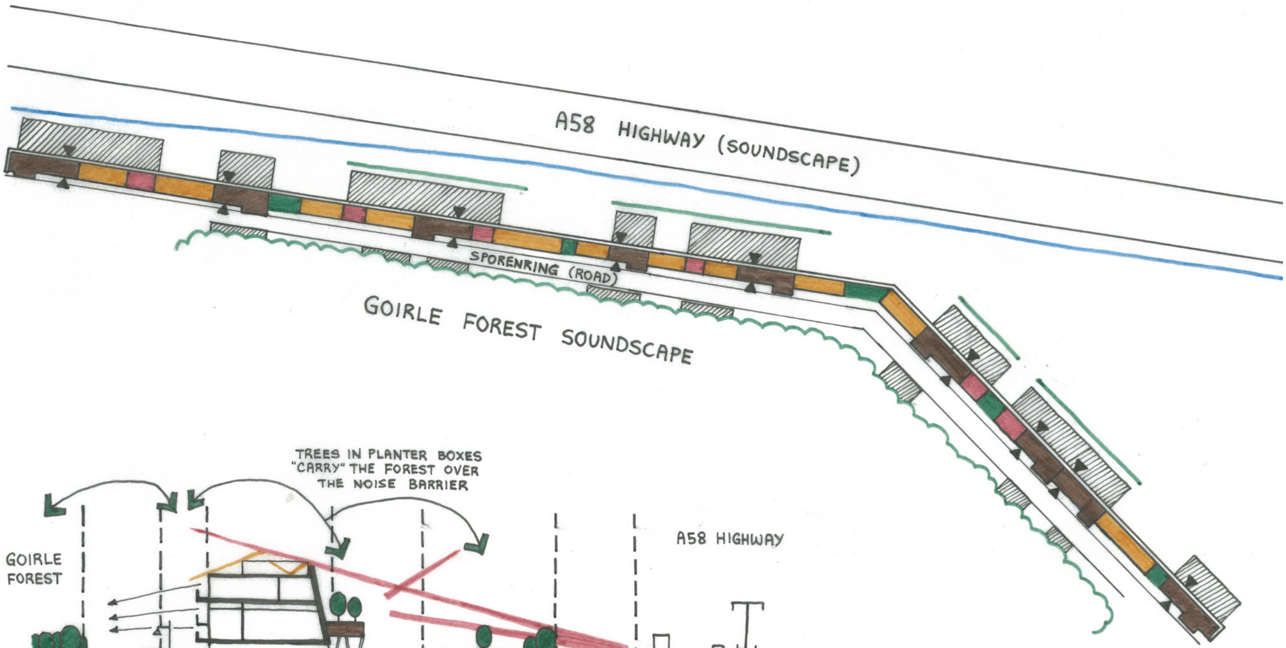
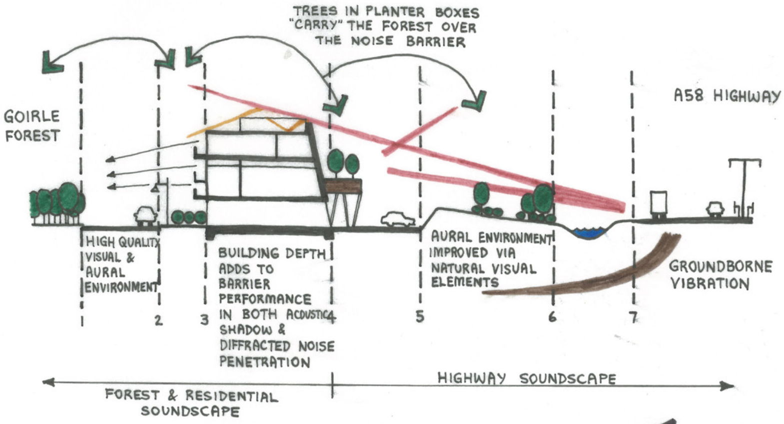
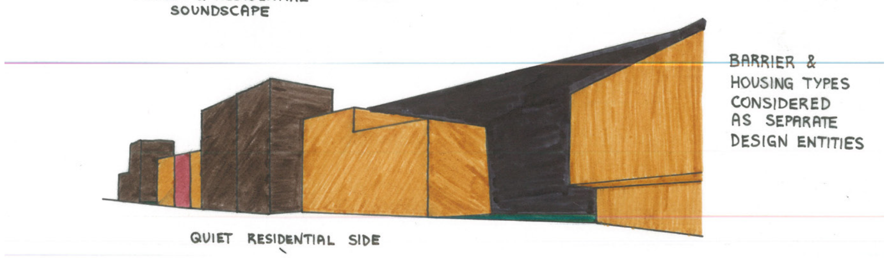
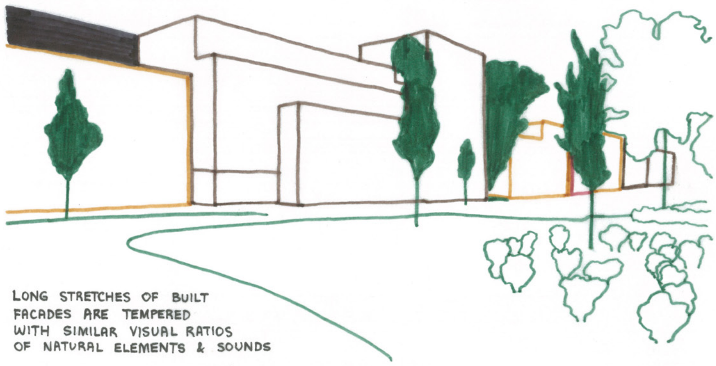


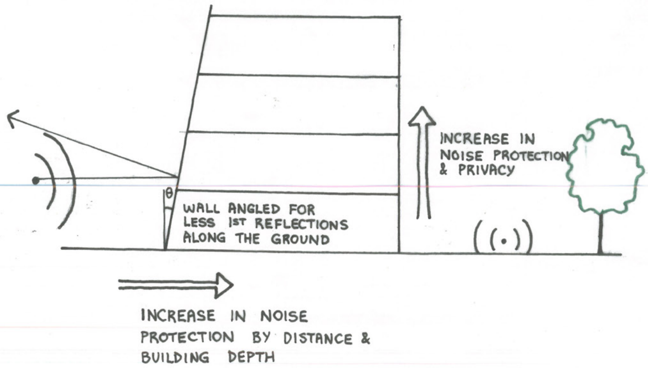
Figure 3.4 Acoustic and soundscape analysis of Noise Barrier Houses by Crepain Binst Architecture.


A58 HIGHWAY (SOUNDSCAPE)
SPORENRING (ROAD)
GOIRLE FOREST SOUNDSCAPE


TREES IN PLANTER BOXES "CARRY" THE FOREST OVER THE NOISE BARRIER
GOIRLE FOREST
A58 HIGHWAY
HIGH QUALITY VISUAL & AURAL ENVIRONMENT
BUILDING DEPTH ADDS TO BARRIER PERFORMANCE IN BOTH ACOUSTIC SHADOW & DIFFRACTED NOISE PENETRATION
AURAL ENVIRONMENT IMPROVED VIA NATURAL VISUAL ELEMENTS
GROUNDBORNE VIBRATION
2
3
4
5
6
7
FOREST & RESIDENTIAL SOUNDSCAPE
HIGHWAY SOUNDSCAPE


BARRIER & HOUSING TYPES CONSIDERED AS SEPARATE DESIGN ENTITIES
QUIET RESIDENTIAL SIDE


LONG STRETCHES OF BUILT FACADES ARE TEMPERED WITH SIMILAR VISUAL RATIOS OF NATURAL ELEMENTS & SOUNDS


INCREASE IN NOISE PROTECTION & PRIVACY
θ
WALL ANGLED FOR LESS 1ST REFLECTIONS ALONG THE GROUND
INCREASE IN NOISE PROTECTION BY DISTANCE & BUILDING DEPTH

3.5 Railyard Park | Frederic Schwartz Architects | Santa Fe, New Mexico, USA

Railyard Park is a redevelopment of a 13 acre space straddling the railway line into the Santa Fe railway station. Frederic Schwartz Architects, along with collaborating landscape architects, designed a local cultural precinct to link the nearby neighbourhoods which used to be separated by the former light-industrial site. Through visual design aesthetics and adherence to the site's identity as a former railyard, the architects were able to introduce programmes which would not normally be associated nor suitable to a railway environment.

A sectional analysis of the external acoustic environment showed no attempts were made to mitigate railway noise. With only eight inbound and outbound services each on weekdays, the infrequent arrival and departure of trains from Santa Fe train station through the Railyard Park district was no doubt a notable acoustic event. Coupled with the redevelopment of the old light-industrial rail sheds and disused siding yards, it could be inferred that the architects decided to include the soundscape as part of the site's cultural heritage. Although the frequency of noise was also a factor in its perceived annoyance, the Railyard Park instead draws upon people's expectations as a form of improving the soundscape while leaving the acoustic environment relatively unaltered.

Surveys of other popular public gathering locations and events support this theory of expectation and tolerance of noise. 'Quietness' can be discriminatory where certain sounds are perceived as annoying and unexpected to the site regardless of their sound energy level. If sounds are contextually appropriate, a "deafening atmosphere does not annoy people, as they are in tune with the music and the event" (Maffei, Brambilla, & di Gabriele, 2016, p.236). In the context of Santa Fe's Railyard Park and train station, the acoustic event of a train becomes positive and celebrated. Despite the deafening roar of the diesel locomotive, one's soundscape in the Railyard has been shaped by the context to create a positive perceptual experience.

3.6 Chapter Conclusion

The portfolio's design problem has been addressed in the past. In their attempts to create inhabitable spaces in noisy urban and suburban environments through acoustic measures, architectural practices have also created different soundscapes. The variation of project scales indicated a good potential for soundscape philosophy to be an active consideration in architectural design. Considering the case studies as a whole, a spectrum could be created based on how actively soundscape was manipulated in comparison to acoustic measures. Designs could either expressive of its acoustic properties, with contextual design supplementing the soundscape; or (exemplified by Railyard Park), the design of the site and context heavily influenced the spatial experience with minimal acoustic intervention. This concept was carried ahead into the preliminary design process (Figure 6.1) where design elements were evaluated by whether their particular design are an acoustic measure, a soundscape/perceptual measure, or a combination of the two.

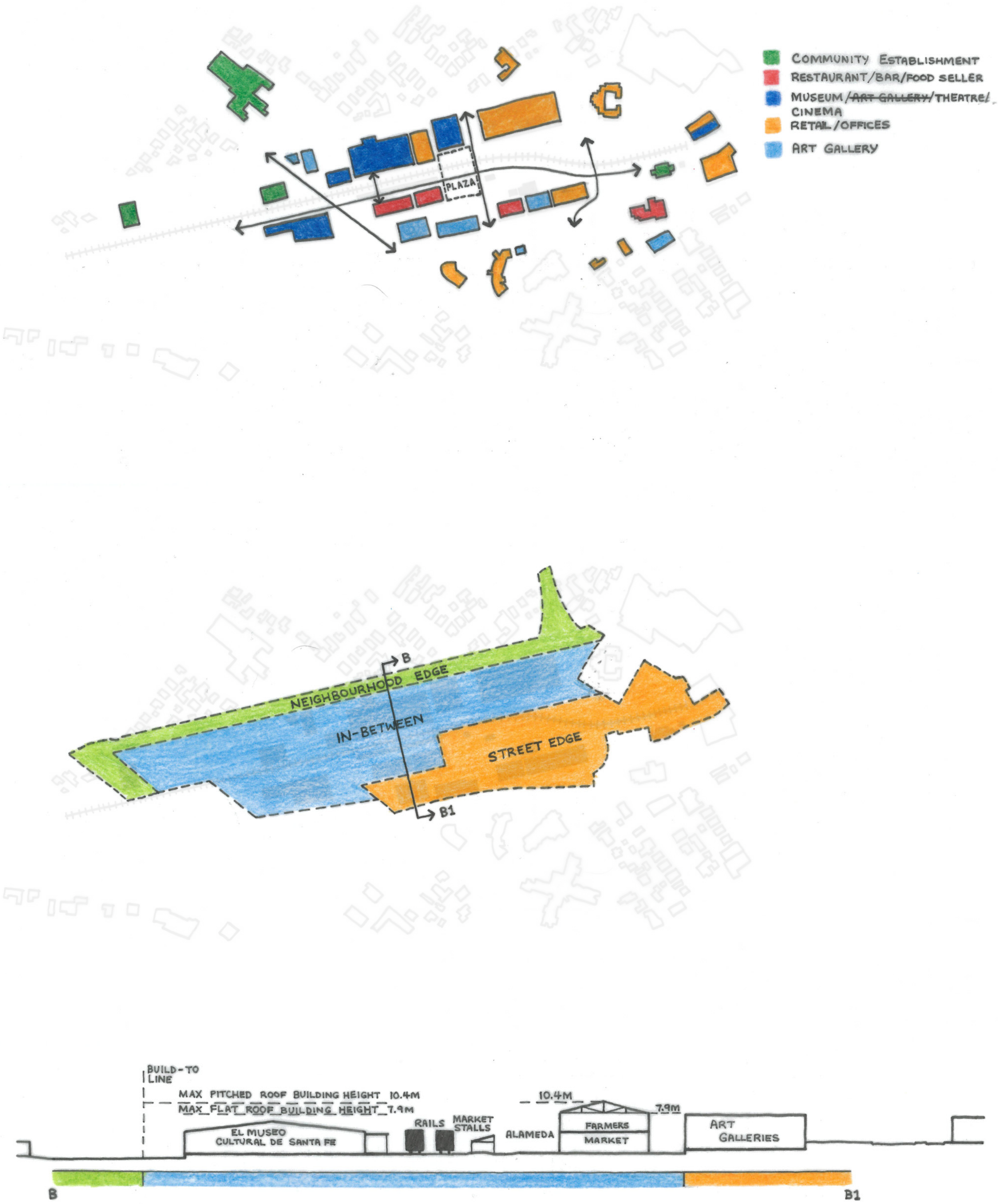


Figure 3.5 Soundscape arena and programme analysis of Railyard Park by Frederic Schwartz Architects.

CHAPTER 4
SITE & CONTEXT SELECTION & ANALYSIS

The design problem of enabling sustainable densification of noisy environments makes it fairly straightforward what type of site would be the ideal design vehicle for this portfolio. However, there are many urban acoustic environments, both outdoor and indoor, which may induce one's soundscape to perceive as loud and noisy. Exploring a classification scheme of sound sources Kang modified from Brown et al. (Figure 4.1) shows the number of sounds to be found across any acoustic environment. The Wellington Region, New Zealand, was explored referring to this classification scheme to find the types of sound most prevalent in urban environments. Unsurprisingly anthrophonic sounds dominate the denser urban soundscapes. In the suburbs (included in 'urban areas' and distinct from 'rural' by population density), there are better allowances for some natural biophonic and geophonic sounds to be perceived. Motorised transport sounds was found to be the most prevalent noise source in urban areas. Concentrations of these sounds are found on major roadways, railway spaces, and airports.

To address the agenda of sustainable densification, sites located adjacent to these concentrations of motorised traffic were evaluated based on their potential for sustainable community growth. A sustainable method of using of motorised transport is public transportation. In the Wellington Region, many of the developing northern suburbs are serviced by trains. The Kapiti Line in particular is shared with national freight and long-distance passenger (Overlander) services. It connects Wellington City and port to New Zealand's wider North Island. The Wellington city region's northernmost suburb is Tawa, located roughly 15km north of the CBD. It is nestled within the Tawa Flat, a north-south valley with the Kapiti Line running down the centre. The four train stations (south to north: Takapu Road, Redwood, Tawa, and Linden) provide comprehensive walking-distance coverage for Tawa residents, as shown with the radial coverage in Figure 4.2. The map also includes Wellington City Council's district plan for the Tawa region. Residential parcels within walking distance of railway

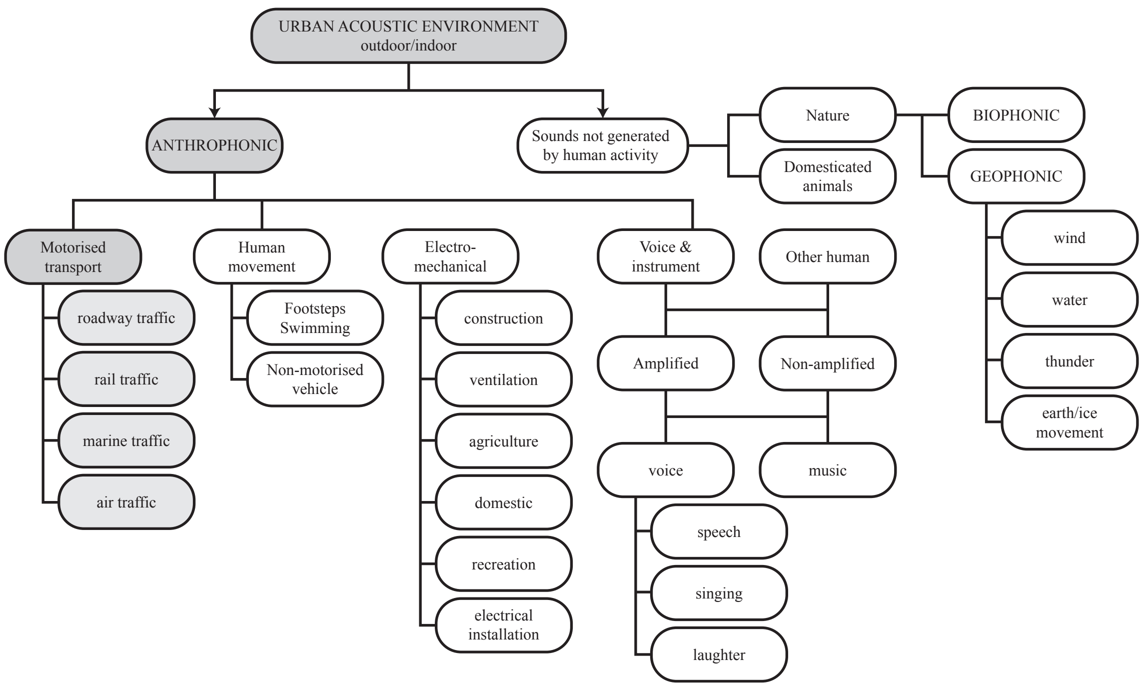


Figure 4.1 Classification scheme of urban sound sources.

stations have been rezoned for medium density housing. The site/context selection process narrows down to places along the Kapiti Line, with specific attention to the train stations.

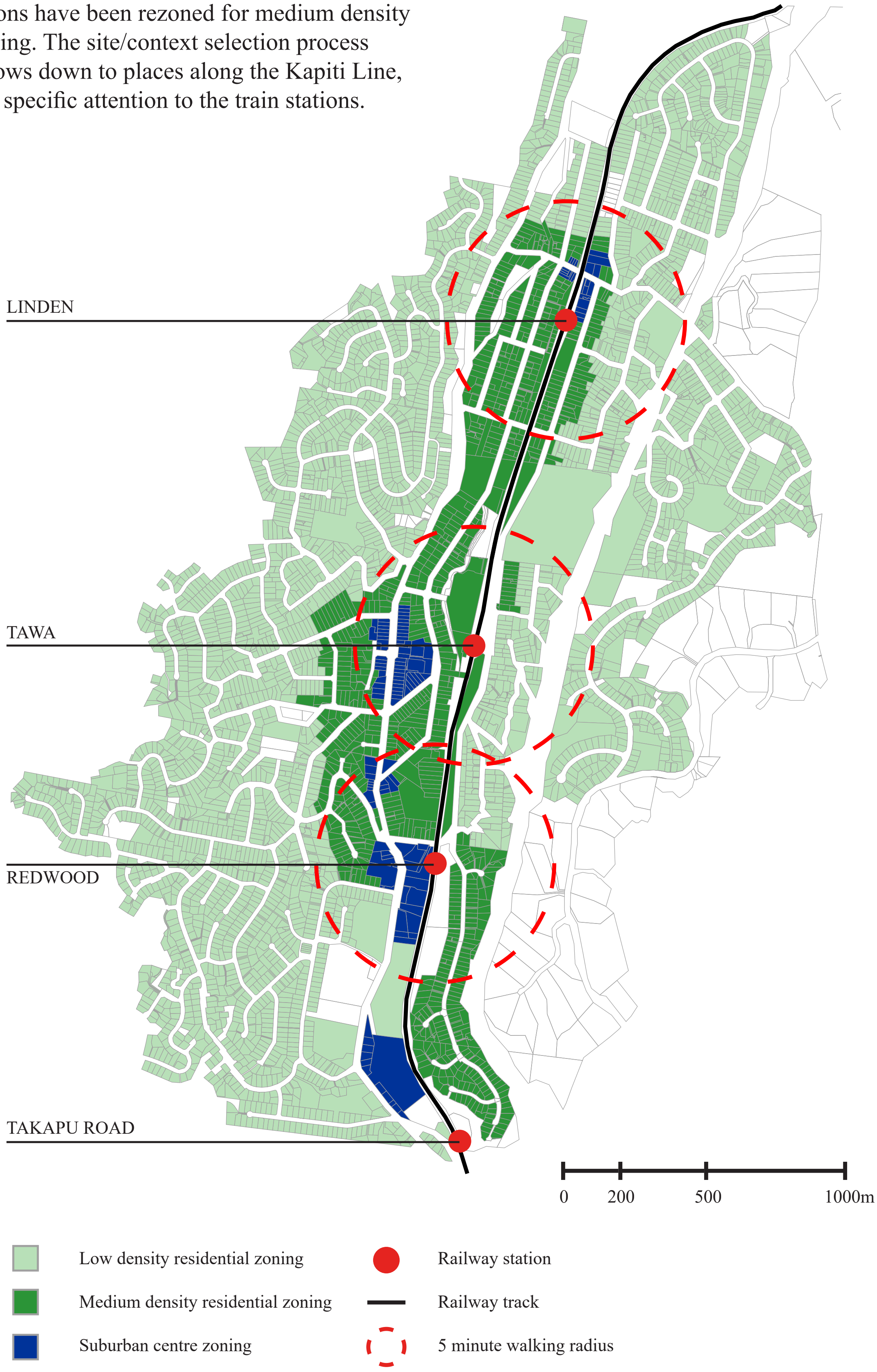


Figure 4.2 Map of Tawa train stations and residential zoning types.

Current sustainable practices encourage increased use of public transportation. As suburbs increase in density, much of their medium density and mixed-use developments are focused around their main transportation hubs and corridors. These parcels create “local centres” (Carmona, Tiesdell, Heath, & Oc, p.221) which distinguish themselves from the lower density residential hinterland further out (Figure 4.3). This complex interweaving of architectural programmes is a key factor in creating lively, well-used public spaces. Liveliness and appeal is maintained through the temporal dimension as the type of sounds created by mixed-use programmes evolve throughout the day and night. Train stations act as focal points for people of all types to converge upon in the local centre. Densification of both residential, retail and light-commercial is encouraged within walking distance.

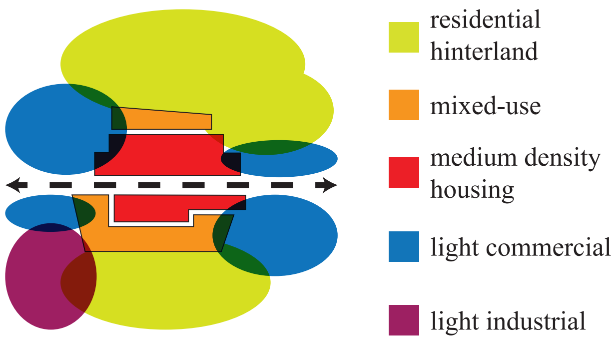


Figure 4.3
Composition of a lively ‘local centre’ along a main road.

Train stations are only single points, while the rest of the local centre spans outwards and along the railway corridor (Figure 4.4). Beyond the train station, ground-based railway corridors can be highly divisive, delineating boundaries of entire districts and suburbs (Edwards, 1997, p.37). Continuous strips of land are left empty on both sides of the tracks. These are created by parcel boundaries distancing themselves from the tracks, and buffer spaces for maintaining visual separation, noise barriers and/or aesthetic planting. Roads can also run parallel to railway corridors, further widening this corridor.

Parcels abutting railway lines are commonly accessed from the road on the opposite side, with fences and walls facing the railway corridor. This leaves the railway corridor relatively untouched and underutilised. Therefore, a lower density site/context within a developing suburban local centre, abutting a loud, well-used railway corridor is ideal for exploring the enablement of sustainable densification in noisy environments.

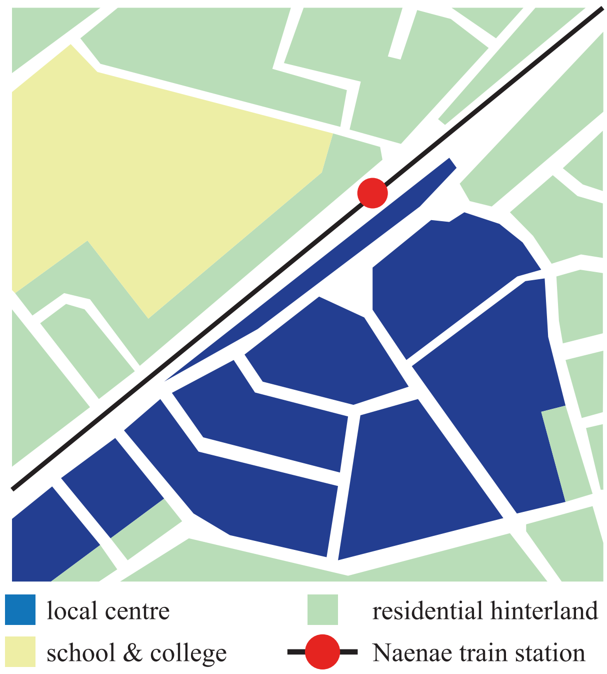


Figure 4.4
Naenae Train Station and local centre composition along the railway corridor.

Analysis of the different compositions, characters, and locations of railway stations in the Tawa Flat and their respective local centres (Figure 4.5) has narrowed the site selection to the Linden Station area. The Linden area of Tawa has a strong history with the development of the Wellington railway system. Unlike Tawa Central’s local centre, Linden’s local centre developed around the railway track and nearby train station (see Appendix B).

The development of Linden and its residential history has a strong connection with the train.

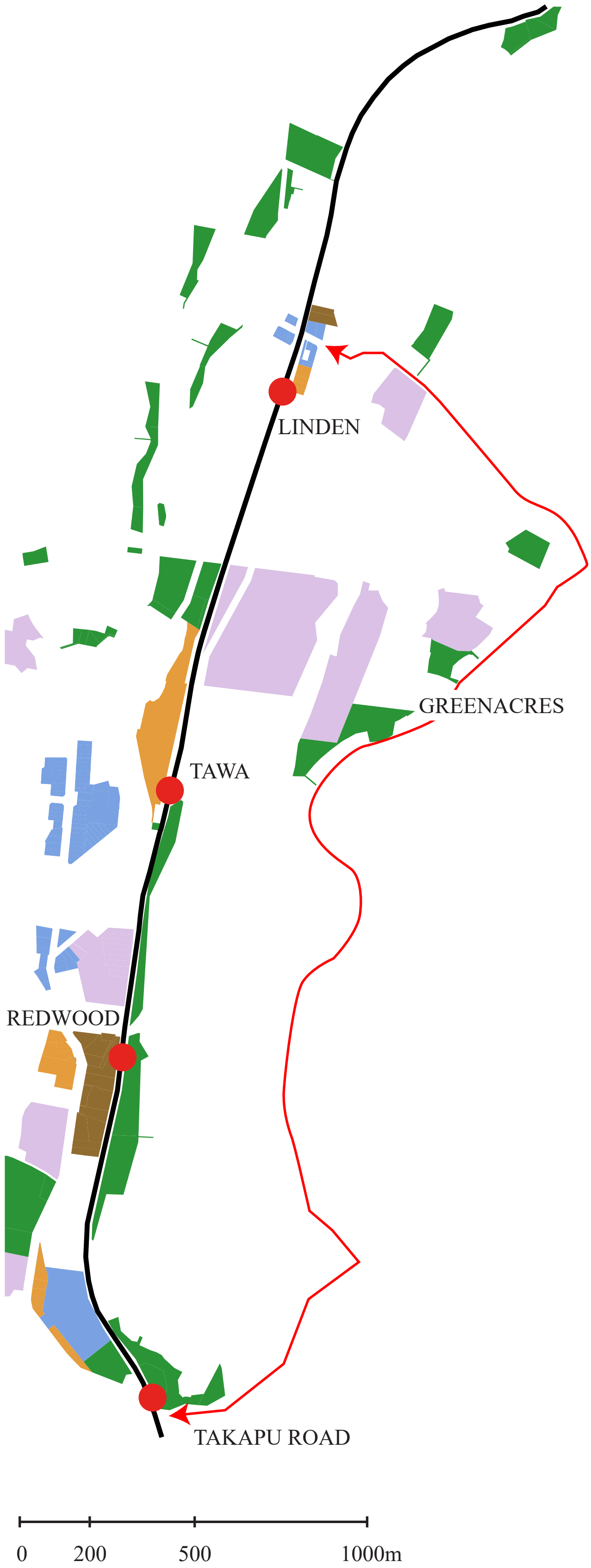
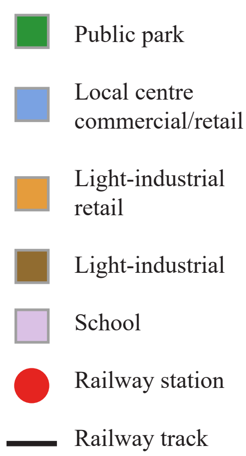


Figure 4.5 Tawa Flat non-residential land-use composition with a route to railway stations from Greenacres delineated.

Linden Station was opened on 28th July 1940; after over thirty years of requests from developers and residents to New Zealand Railways (NZR) who were dissatisfied with the mile-long walk home from Tawa Station. NZR gave in after the locals took to civil disobedience, by pulling the train's emergency brakes, stopping the train in the vicinity of Collins Avenue and the current Linden Station (Murray & Parsons, Rails through the Valley: The story of the construction and use of the railway lines through Tawa, 2008, p.33; Murray, A History of Tawa, 2014, p.154). When works to electrify the Kapiti Line between Wellington and Porirua (to the north) were completed in June 1940, a month later Linden residents were the first commuters to board the first electric-powered passenger service to Wellington.

Currently Linden is the fastest growing Tawa area in population (Figure 4.6). The sudden drop in population in 1991 was caused by the separation of the Greenacres area from Linden in surveys. Since then, the Linden population has steadily rebounded at a rate faster than Central Tawa; while Redwood/South Tawa's population has stagnated. Observation of programme composition and site access to Greenacres indicate the closest developed local centre for shopping and mass transit is Linden. This connects the development of the two suburban areas, further placing emphasise on the Linden mixed-use local centre and residential surroundings.



Trains as a Noise Source

Part of the context the portfolio assumed was the quality of New Zealand's rolling stock through the Wellington region is not expected to change nor improve in the foreseeable near future. The local passenger services on the Kapiti Line are carried out by New Zealand FP/FT "Matangi" class electric multiple units. They run on tracks of 3ft 6in (1,068mm) gauge (the distance between inner faces of rails) (KiwiRail, 2011?). Listening to these electric multiple units have found they are characterised by the medium-to-high frequency "whining" and "whirring" of their electric traction motors at lower speeds. Once moving, their noise is mostly composed of lower-frequency rolling noise from rail-wheel contact. The Matangi fleet was put into service in 2011 (KiwiRail, 2011?). They replaced an aged fleet of two electric multiple unit models operating from 1938 to 2012 and 1982 to 2016 (Stewart, 2012; Burgess, 2014; Hunt, 2017). Considering the 34-year-use of the latter (shipped to South Africa for reuse), the 74-year lifespan of the former, and the track gauge used throughout the country (KiwiRail, n.d.), it is highly unlikely the passenger trains nor tracks system will be changed.

A mixed fleet of diesel-electric locomotives use the Kapiti line for freight and Overlander services. They are extremely loud to the soundscape. Multiple personal soundscape evaluations at various stations through Tawa, approximately 10 metres from the tracks, proved to be almost unbearable experiences; not to mention the subsequent, sustained rolling noise of the towed carriages. Their prevalence, capabilities, nation-wide usage, and difficulties in electrifying the North Island Main Trunk Line suggests there are no immediate plans to replace these trans-regional locomotives either (KiwiRail, n.d.; Kirk, 2016). Through circumstantial evidence, the portfolio assumed the current state of railway sounds will remain a prevalent component of the Tawa soundscape (the perceptual sound experience of Tawa) for many years to come.

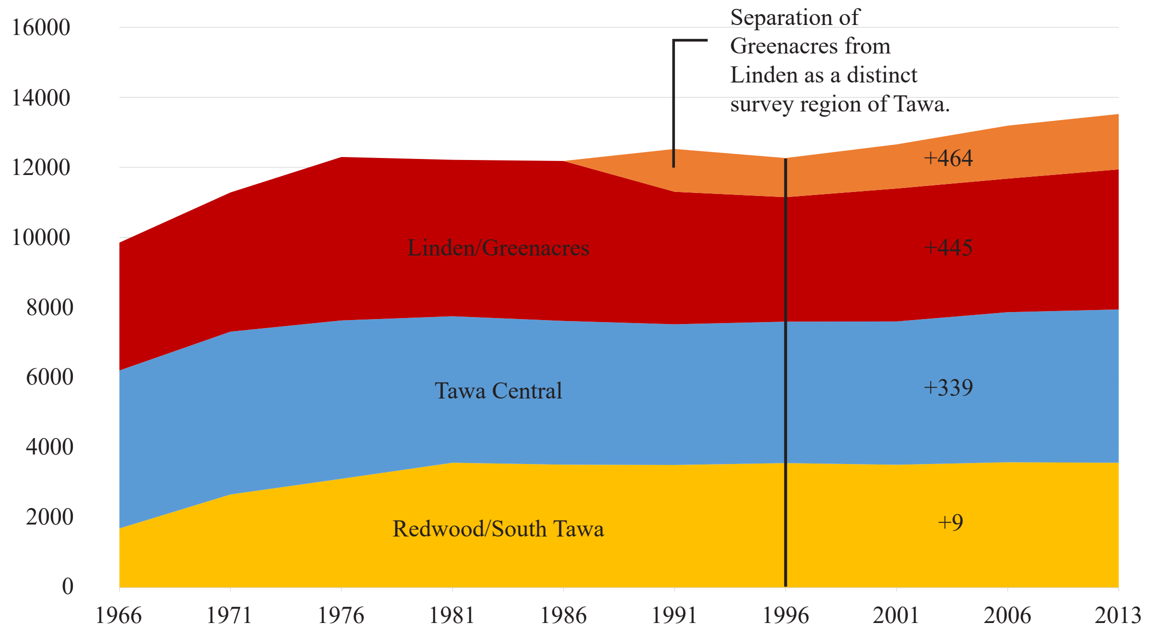


Figure 4.6 Tawa Flat population

Ultimately, a long and narrow site on Beauchamp Street, Linden, Tawa was selected as the design vehicle to explore the enablement of sustainable densification in noisy environments (Figure 4.7). The site is composed predominantly of 50 Beauchamp Street, an infill parcel that runs alongside the Kapiti Line railway corridor. The railway corridor, portions of neighbouring infill parcels and Linden local centre parcels on Collins Avenue are also included in the scope of the portfolio project.

The following is the most common, currently used definition of medium density housing (mdh) in New Zealand:

> Housing at densities of more than 150m²/unit and less than 350m²/unit, or 30–66 dwellings per hectare (dph).
> (Turner, Hewitt, Wagner, Su, & Davies, 2004, p.22).

For the purposes of increasing densification, the latter definition of 30–66dph was used by this portfolio. A map adapted from Statistics New Zealand survey of the Linden area shows the area is of particularly low dph (Figure 4.8). The housing typology is predominantly detached housing, with increased densification achieved through infilling. I. Instances of infill housing and medium density typologies are highlighted in Figure 4.9.

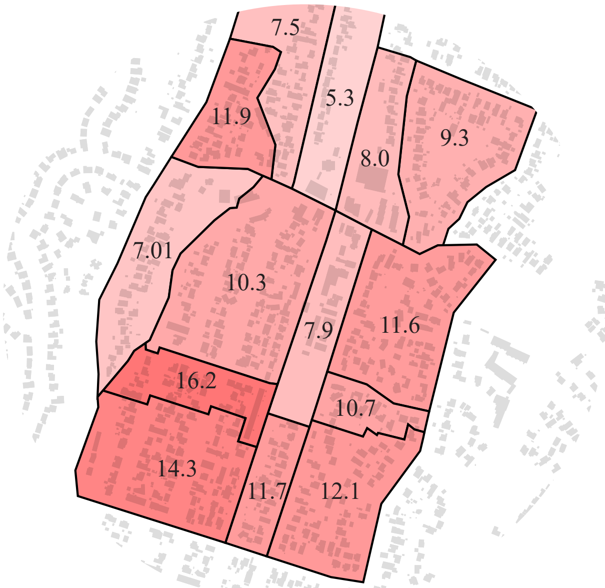


Figure 4.8 Linden area dwellings per hectare.

Figure 4.7 Selected portfolio site in Linden, Tawa, Wellington, New Zealand.

Figure 4.9 Instances of infill housing and medium density typologies.

To better understand this acoustic environment, a noise map was useful in observing visually how train noise pervades into the suburban context (Figure 4.10). The maps are rudimentary because it only shows through colour the propagation of a diesel locomotive's maximum sound exposure at 79km/h, sourced from Figure 4.11 (Kang, 2006, p.7). It does not account for the subsequent sound of carriages. Although by no means a representation of reality, one can observe how the linear layout of the urban grain enables train sounds to pervade deep into the residential hinterland. The colours do not show the content of the sound, however other sources can inform us. At speeds below 50km/h traction noise (composed of motor and auxiliary sounds) dominate. Between 50-300km/h, rolling noise from wheel-track contact and axle movement becomes more prominent (Kang, 2006, p.8; Van Beek, et al., 2002).

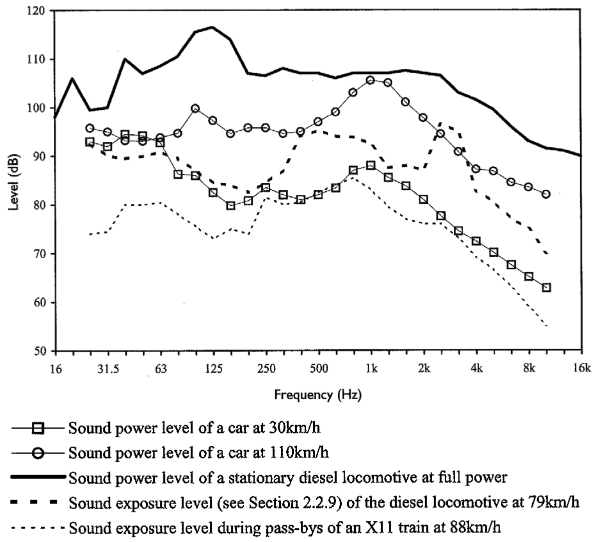


Figure 4.11 Typical frequency spectrums of car and train noise.

4.1 Chapter Conclusion

As established in Chapter 2.1.1 the selected site gives a context, which through design creates an acoustic environment and a soundscape. Although context can be designed to treat the acoustic environment, it is ultimately the inhabitants' soundscape (informed by both context and the acoustic environment) which determines how well or badly the space is perceived. Site analysis of the Linden station took this extra soundscape dimension into account. Like a musical composer, sounds were evaluated on their subjective and experiential qualities.

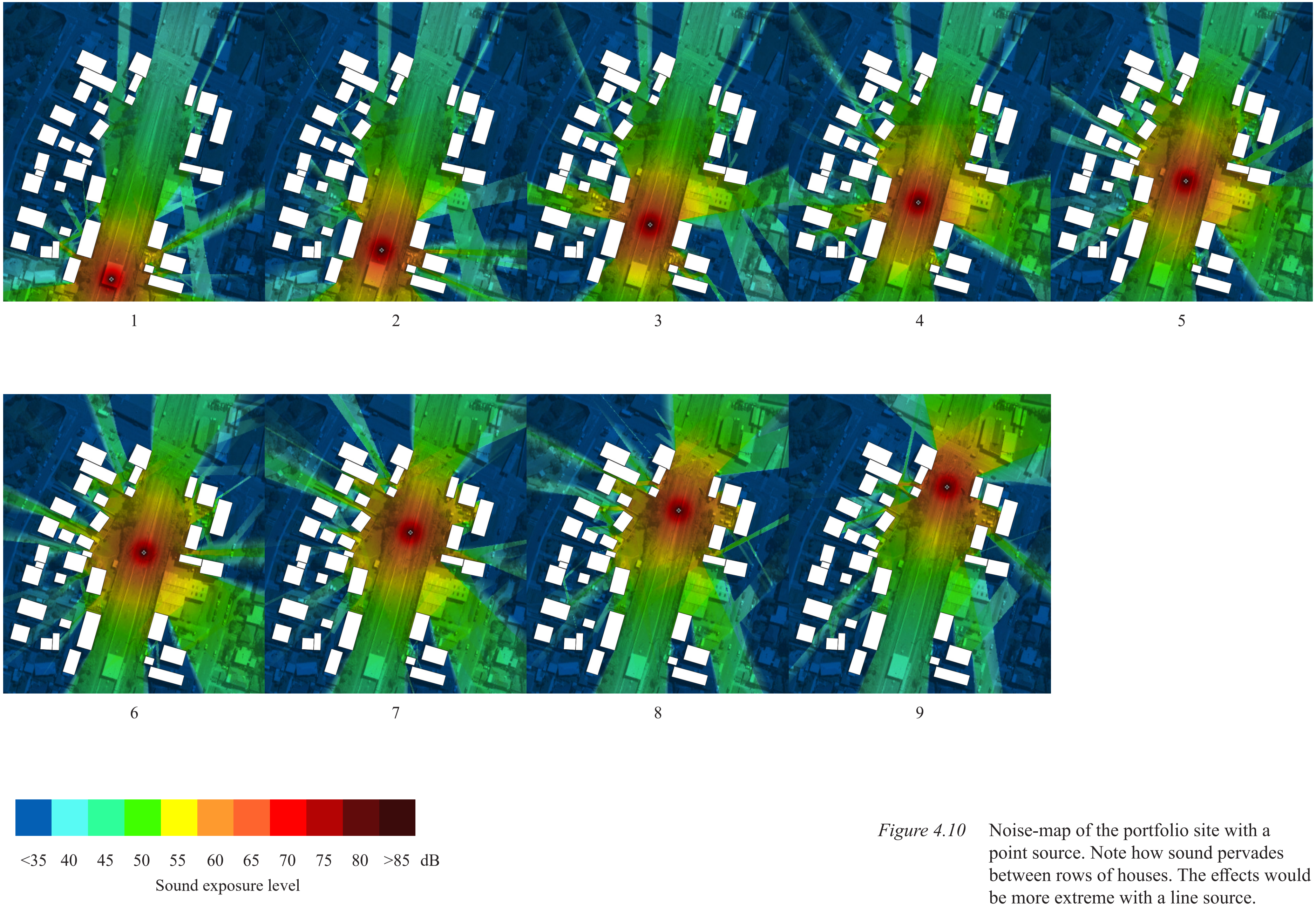


Figure 4.10 Noise-map of the portfolio site with a point source. Note how sound pervades between rows of houses. The effects would be more extreme with a line source.

CHAPTER 5
PROGRAMME ANALYSIS

The programme analysis was closely considered and developed in response to the site and context. Referring back to Figure 2.2, one of the sub-elements of 'place' was the 'place type' and 'place function' (i.e. the programme or building-use). These are particularly important with the elements of 'person-place interaction'. In predominant 'place type' was established as residential, with future designs for a denser mixed-use local centre. Two key criteria became clear in the programme selection and analysis process:

1. The relationships between various programmes (including users) and sound.
2. The needs of the site and local context as it increases in living density and activity while simultaneously considering the first criteria.

A train and nearby programmes' can influence one another to various extents. Figure 5.1 classified possible local centre programmes into three categories:

1. Programmes that are noise-sensitive or focused on signal clarity have the most disjointed relationship. Neither sound components support the other.
2. Programmes which generate their own sounds could either mask the train, or mix with it to create a unique soundscape composition.
3. Lastly, programmes could be in alignment with the sound of a train to the point the presence or absence of train sounds have no major implications upon the spatial experience.

These categories informed the project on which programmes, other than the residential scope, could have had the most interesting interactions and effects on the soundscape.

There will be some 'expectations' in 'person-place interaction' (Figure 2.2) for supporting amenities and services to be provided as residential programmes increase in dwelling density. These include many of the social activity programmes that were defined as sound generative in Figure 5.1 (e.g. cafes, restaurants, dance studio, gym, etc.) Initially, this introduction of local centre programmes seemed at odds with residential programmes in close proximity; which valued the need for quietness in and around the home (Figure 2.4). However, plausibly explaining the success of the bustling Railyard Park (Chapter 3.5), Maffei et al. (2016) posited that quietness can be discriminatory to the programme. This soundscape design parameter allowed inhabitants of programmes considered as noise-sensitive (e.g. offices, museums, art galleries, theatres, etc.) to become tolerant with uncharacteristic levels of noise and content. Therefore a residential programme could still be aurally successful, provided residents are aware of the differing programmes of nearby spaces.

It was decided that a medium density residential programme would hold the largest portion of design focus and area in the project (Chapter 7). Increasing residential density was a project objective but it was also a programme which had a disjointed relationship to other sounds. Therefore, due care and diligence were given to dwellings in acoustic design inspired by acoustic principles explored in Chapter 6. General open spaces were created in the developed design for a variety of local centre programmes. While programmes were suggested (Figure 7.19), the exact design of these spaces remained the domain of the tenants and their type of service.

5.1 Chapter Conclusion

Determination of the project programme was kept relatively brief given the predominance of residential usage of the site and suburban context. Analysis and discussion took the form of considering how a unique railway context would affect the generation of a soundscape within other possible local centre programmes. In order to create a full-bodied lively and diverse experience of public spaces and local centres, the environment should engage physical, visual and aural perceptual constructs. This was later achieved through the project suggesting in the developed design (Chapter 7) programmes which would not only activate and increase habitation of the noisy environment, but also potentially create interesting indoor and outdoor compositions of sound to accompany introduced visual and physical activities.

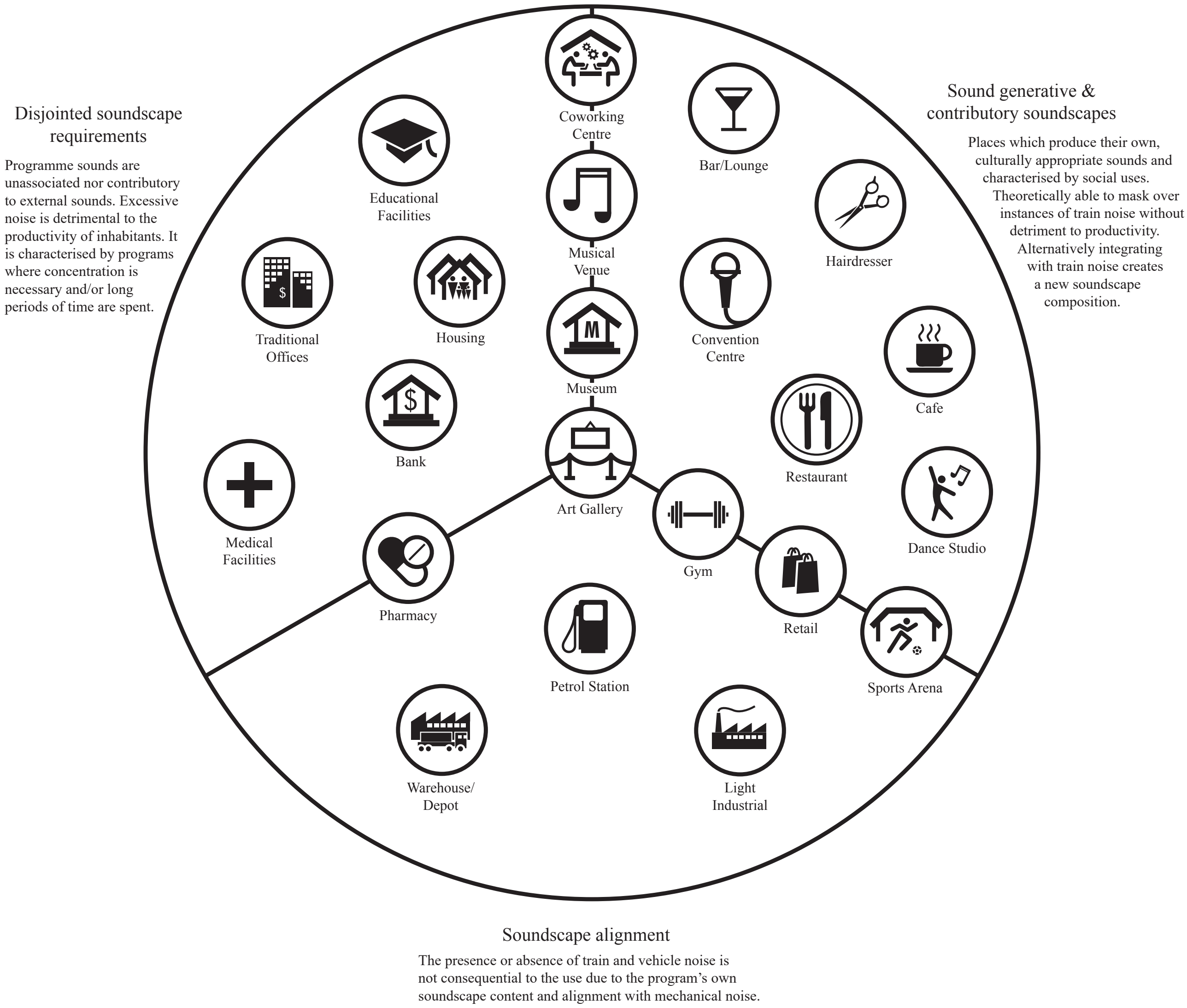


Figure 5.1 Classification of possible local centre programmes into categories on they interact with train noise. Some programmes are debatably between categories due to certain internal programmes.

CHAPTER 6
PRELIMINARY DESIGN & EXPLORATIONS

The preliminary design process consisted of many design experiments running in parallel or in close succession. Each design experiment looked at a different element of architectural design. The objective was to explore how the residential suburban context can be manipulated to enable sustainable densification in a noisy environment. This was based on the material and knowledge gained from prior chapters, with content varying from designs affecting soundscape perception and/or acoustic design. The broadness of exploration and the design principles gained from these experiments were valued for their replicability and incorporation into different sites.

In order to sustainably densify and activate less-desirable land, the portfolio design had to not only improve the site conditions, but also the aural experience of its context. This meant the design elements explored within preliminary design simultaneously considered how it affects the soundscapes of (1) the architectural intervention, (2) the railway corridor, and (3) neighbouring land parcels. It was counterproductive to improve the spatial experience of one space at the detriment of another. Therefore preliminary design fluidly moved between locations and scales.

When evaluating the functions of residential spaces against the categories of sound in the urban acoustic environment, it became clear that motorised transport should not be a soundmark, i.e. characterises the residential environment. It should be a keynote; ambient sound that is ultimately filtered out cognitively, serving as a baseline and reference for more residential-characteristic soundmarks. These include sounds such as people interacting, children playing, wildlife, trees, running water, domestic, leisure, and recreational activities, etc. Train noise was evaluated as annoying because of its sound level, coupled with its irregularity. Although Tawa's Main Road was audible from the site its ambient drone and the fact it did not disrupt sound signal quality qualifies it as a keynote. When a train service passed through Linden, it momentarily masked other anthrophonic, biophonic and geophonic sounds which would typify residential suburban life. This was particularly strong with the passing of a freight or Overlander service, especially at night.

This interplay between soundmarks and keynotes naturally became more complex when a location was used for different functions; i.e. mixed-use. Shops and businesses may have assigned positive semantic meanings to the passing of a train and the hubbub of people in the local centre. More dedicated residential areas may have perceived the same sounds as a nuisance and invasion of privacy. Therefore some delineations in acoustic arenas and soundscape were made dependent on the function of spaces. The practice of selectively filtering and enhancing different sounds to restore a high-fidelity environment was important in this endeavour.

Before design occurred, it was useful to understand where each design element fits in the process of how an individual's soundscape occurs. Sound is created from the source, passes through the medium(s) and shapes that compose the acoustic environment, and reaches the individual as an auditory sensation. Figure 6.1 shows an arrangement of design elements on a spectrum between source and architecture, and acoustic to soundscape. It indicated in what manner the developed design affected the aural spatial experience and its location.

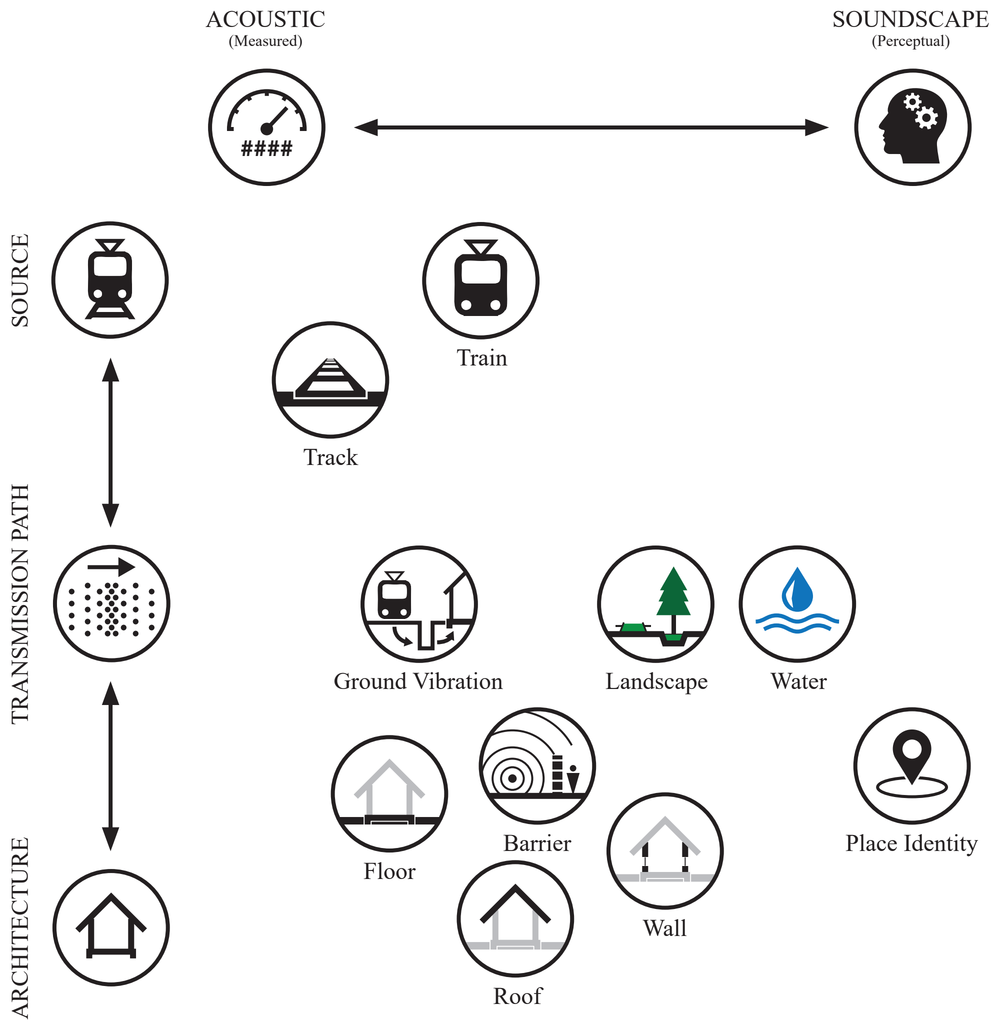


Figure 6.1 Arrangement of design elements on a spectrum between source and architecture, and acoustic to soundscape. Some design elements have higher potential to affect the acoustic environment whilst others have a stronger affective effect through an individual's soundscape.

6.1 Railway Corridor

Regardless of a noisy environment, opportunities had to be created to access and use the land to enable any kind of densification. The primary inhabitants of the Kapiti Line railway corridor are the trains, and those who use them. Houses accessed from the streets put their backs to the trains (Figure 6.2), while local centre shops opened onto Collins Avenue. There was no good reason for buildings to face and open toward the tracks. This was a barrier to the effective use and sustainable densification of the area. Despite being a noisy space during commuter peak hours (and the intermittent freight and Overlander services), there was a lack of activity in the railway corridor during the periods of relative quietness.

Railway commuters were unable to interact with the community once segregated on Linden Station's island platform, sandwiched between railway tracks. Figure 6.3 is a diagrammatic layout of a typical island platform, where railway, commuter, and general community spaces are highlighted. An island platform has its listed advantages and disadvantages (Vuchic, 2007; Ministry of Railways: Government of India, 2009). Of particular note was in order for the tracks to diverge around an island platform, extra width was required. When tracks are surface-based, it emphasised the view that railway tracks are one of the major 'edges' found in urban areas (Lynch, 1960, pp.62-66). It also

Metro systems stations with central platforms, compared with lateral platforms, have the following characteristics:

+ Narrower total platform width: the central platform is usually required to handle the peak in one direction plus the contraflow peak volume in the other, while each lateral platform must be designed for its peak-hour volume. This applies more to outlying than to centre city stations.
+ A single set of facilities can be utilised. The savings in investment and operating costs of escalators, elevators, lighting, information boards, and so on, can be substantial.
+ Easier supervision by a single person or a single set of TV cameras.
+ Passengers can reverse the direction of travel in case of errors without paying another fare.
- Higher construction costs, since both tracks must have "double S" curves in the alignment, which require widening of the tunnel at station approaches. The curves slightly affect riding comfort, but not train speeds.
- Possibly more passenger confusion about train directions.
- It is impossible to separate directional flows of passengers where this is desirable for operation or fare-collection purposes.

(Vuchic, 2007, p.395)

Figure 6.2
Road access to properties in Linden. Parcel lines along the street are removed for clarity of access. Facades of buildings are similarly oriented to either face the road or the path leading into the infill property.

Figure 6.3 Diagrammatic layout of a typical island platform train station with overbridge.

development edge
commuter space
local centre
train-only space

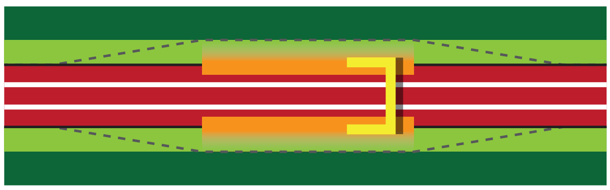
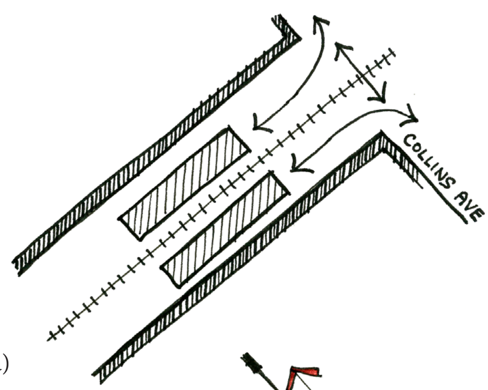


Figure 6.4 Diagrammatic layout of a typical lateral platform train station with overbridge.

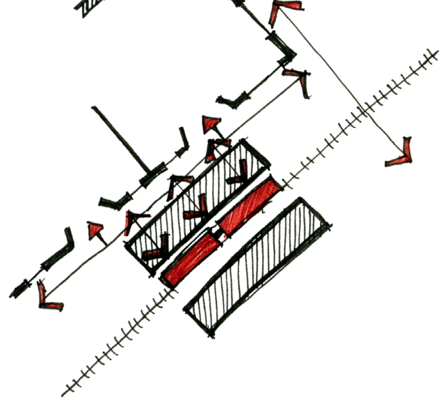
set any station structure apart from the urban fabric (Edwards, 1997), for better or for worse. The composition of Linden Station had to be changed in order to initiate reintegration of commuters into the community, and reduce the space dedicated solely to trains and tracks.

A train station with 'lateral platforms' was better able to increase the variety of people in an inhabited railway corridor. For comparison with Figure 6.3, Figure 6.4 provides an example of a lateral platform configuration. The combined minimum widths of two lateral platforms may be wider than the minimum width of a single island platform (Neufert, 2012, p.416), but the delineation of functions could be weakened between the railway station and local centre. There were no longer a brutally divisive railway tracks and station platform in-between. The separation of the community on either side of the tracks still remained. However, with the retention of narrow double-tracks, the nearby level-crossing on Collins Avenue, and possibly an overbridge, the Linden community was better capable of bridging the gap. Integrating and spanning the tracks opened the railway corridor to "thinking about the secondary functions of a suburban station (thereby allowing) the designer to add complexity and richness to a form (and space) that otherwise can be rather singular in nature" (1997, p.37). Encouraging and enabling this inhabitation and mixed-use of the railway corridor was an objective in the densification of the noisy acoustic environment.

Changing to lateral platforms draws commuters alongside parcels abutting the railway corridor. The space still served as a transit and waiting area (Figure 6.5a). Reorienting local centre residential and mixed-use buildings to face the train platforms will draw residents, shopping visitors and workers into the railway corridor as well. People arriving on the train are immediately engaged with the local centre (Figure 6.5b). This action should change the soundscape of the railway corridor by introducing the preferable sounds of human interactions. The current lack of activity in the railway corridor leaves a stark contrast between the keynotes of fauna, flora and road traffic, to passing trains. As mentioned in Chapter 2.1, the majority of noise annoyance is caused by non-acoustical factors. Intermittency is one such factor. Intermittency of train sound events occurred during peak hours where more train services (including louder, faster and more sudden express services) are added, breaking from the more regular off-peak timetable passing through Linden (Figure 6.6). The sounds of mixed-use activities can potentially introduce ambient keynotes to the soundscape which temporally ebbs and flows between the two extremes of sound intensity; swelling as train peak-hours approach, and receding with people dispersing and train service frequency reducing. In theory, and albeit counterintuitively, inserting local centre sounds into the railway corridor should help people inhabiting nearby buildings and the corridor for long durations to cope psychoacoustically.



(a)



(b)

Figure 6.5 Using lateral platforms to bring people into the railway corridor edges, creating opportunities to activate the unused space.

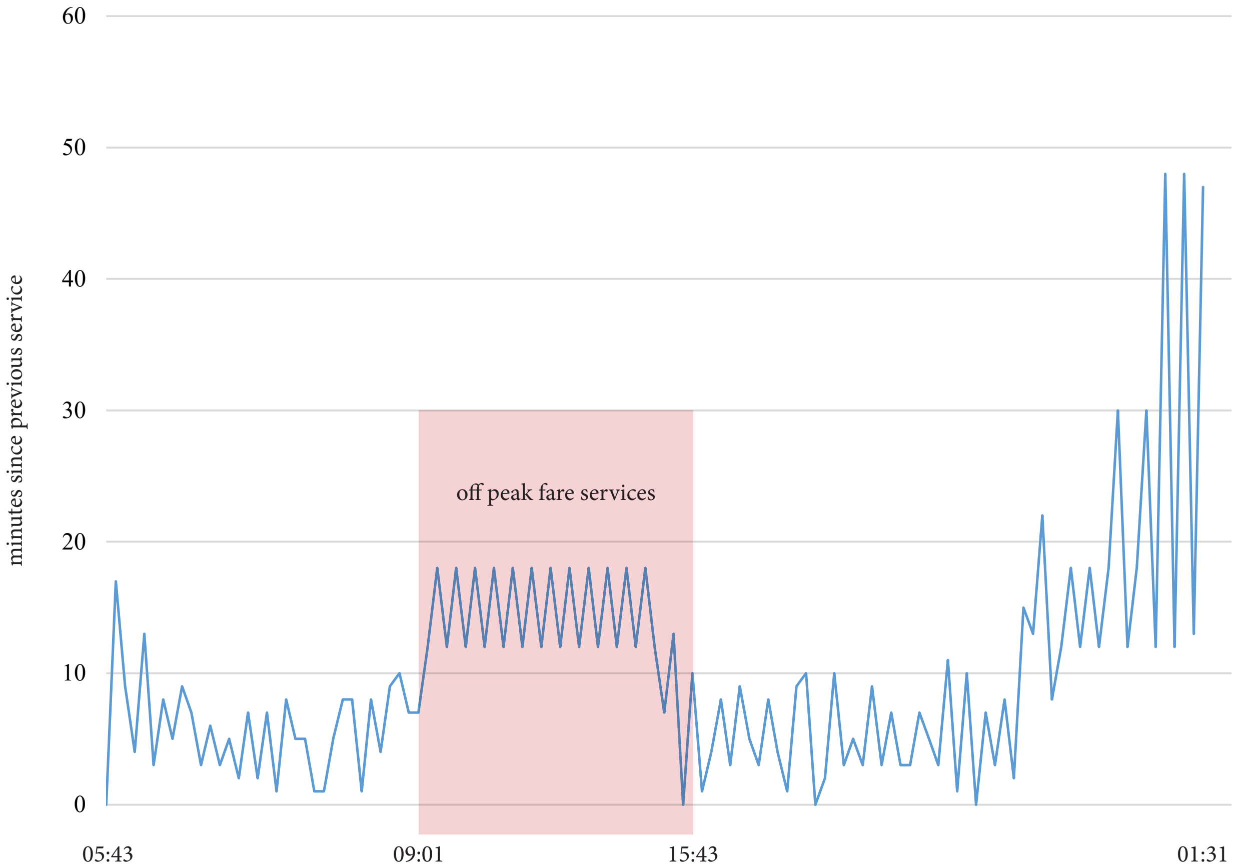


Figure 6.6 Kapiti Line passenger services through Linden in both directions, including express services through. Off peak fare services, passing through Linden between 09:01 and 15:43, are where the most consistent intervals of time between services/sound events are found. The more sporadic the time intervals, the more likely noise annoyance due to intermittency may be found.

6.2 Ground-Borne Noise & Ground Vibration

Railway operations induce vibrations within the ground, resulting in felt vibrations and ground-borne noise. Since sounds are created by oscillating particles in a medium (as the acoustic environment has been defined in Chapter 2.1.1), when a surface in contact with vibrating ground itself vibrates at a high enough frequency it creates an audible sensation which is turned into soundscape. Lower frequency movements are imperceptible to our ears but can still be physically felt. Ground vibration is often associated with heavy freight trains, but it is nevertheless also part of the environmental impact of passenger services. Although railway noise is considered less annoying than road traffic noise (Miedema & Vos, 1998; Moehler, 1988; Moehler, Liepert, Schuemer, & Griefahn, 2000; Guski, 1998), it is demonstrated that when vibration is perceived alongside noise, total annoyance is considerably higher than noise alone (Lee & Griffin, 2013). Schomer et al. (2012) suggests with vibration, railway noise can become more annoying than road traffic noise. Even considering the overwhelming evidence that road noise and vibration is more annoying than railway, Yano et al (1996) have suggested this opinion may not be applicable in Japan; demonstrating part of the context creating soundscape are the preferences and background of individuals and communities involved.

A method of attenuating ground vibration was to remove the medium of energy transfer altogether. This involves physically creating a gap between source and receiver. Architecturally this was done by base-isolating the building from the ground. Perfect base-isolation is the complete removal of all contact between the building and the ground (Figure 6.7). Achieving this was naturally impossible. Base-isolation materials like rubber-lead bearings are flexible enough to attenuate major seismic movements, but they remain rigid enough to support the building above. If the material is too flexible, the building becomes suggestible to movement while the ground remained stationery. The properties of rubber does have some merit in attenuating vibration, particularly in shear. Looking at the construction of base isolation, it seems highly impractical and costly to base-isolate all architecture near railway lines. As shown by Figure 6.8 a building with a concrete ground floor requires two slabs to be poured, with the isolation bearings placed between.

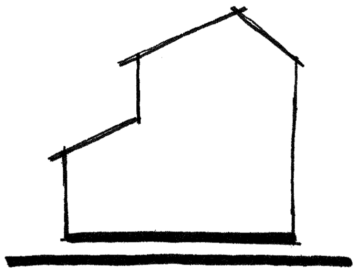


Figure 6.7 Representation of perfect base-isolation from a vibrating ground plane.

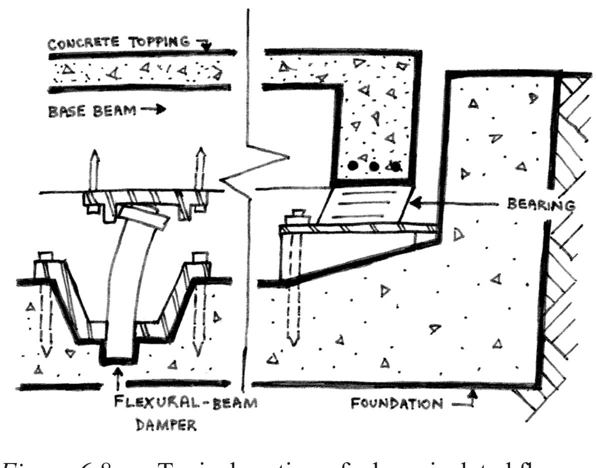


Figure 6.8 Typical section of a base-isolated floor slab. Note the two layers of concrete.

A ground vibration 'barrier' was an alternative measure against ground vibration. The basic principle was an open trench between the source and receiver. Since it removes the medium of energy transfer, the width of this trench was proven to be of little significance to its performance, as was its proximity between the source and receiver (Figure 6.9b-c)(Jiang, et al., 2013). The depth of this trench needed to be substantial enough for vibrations to be attenuated through distance and direction. A trench's performance was best when it penetrated completely through looser top-soil into stiffer underlying soil (Figure 6.9a).

A drawback to an open trench was the difficulty in maintaining the open gap as well as its substantial depth (Figure 6.9e). Grading the edge back would stabilise the trench, but with its depth it had a substantial impact upon the landscape (Figure 6.9f & h). Filling the trench was an option but severely compromised its performance, with the compactness and rigidity of the infill being determining factors. Although the width was mostly inconsequential with an airgap, "increasing the width of a filled trench reduces the stiffness of the in-fill material, improving the performance of the trench" (Jiang, et al., 2013, p.561) (Figures 6.9g, i, & j). Jiang et al.'s experiments were carried out under lab conditions and computer-generated tests. Field tests were recommended to confirm the conclusions and are yet to be carried out. Nevertheless, the lab results indicated open and/or filled trenches are a promising landscape design element to mitigate ground vibration emanating from a railway corridor. By mitigating vibration between the source and architecture, the architecture became freer to pursue other design agendas and the cost of the foundation design could be substantially reduced.

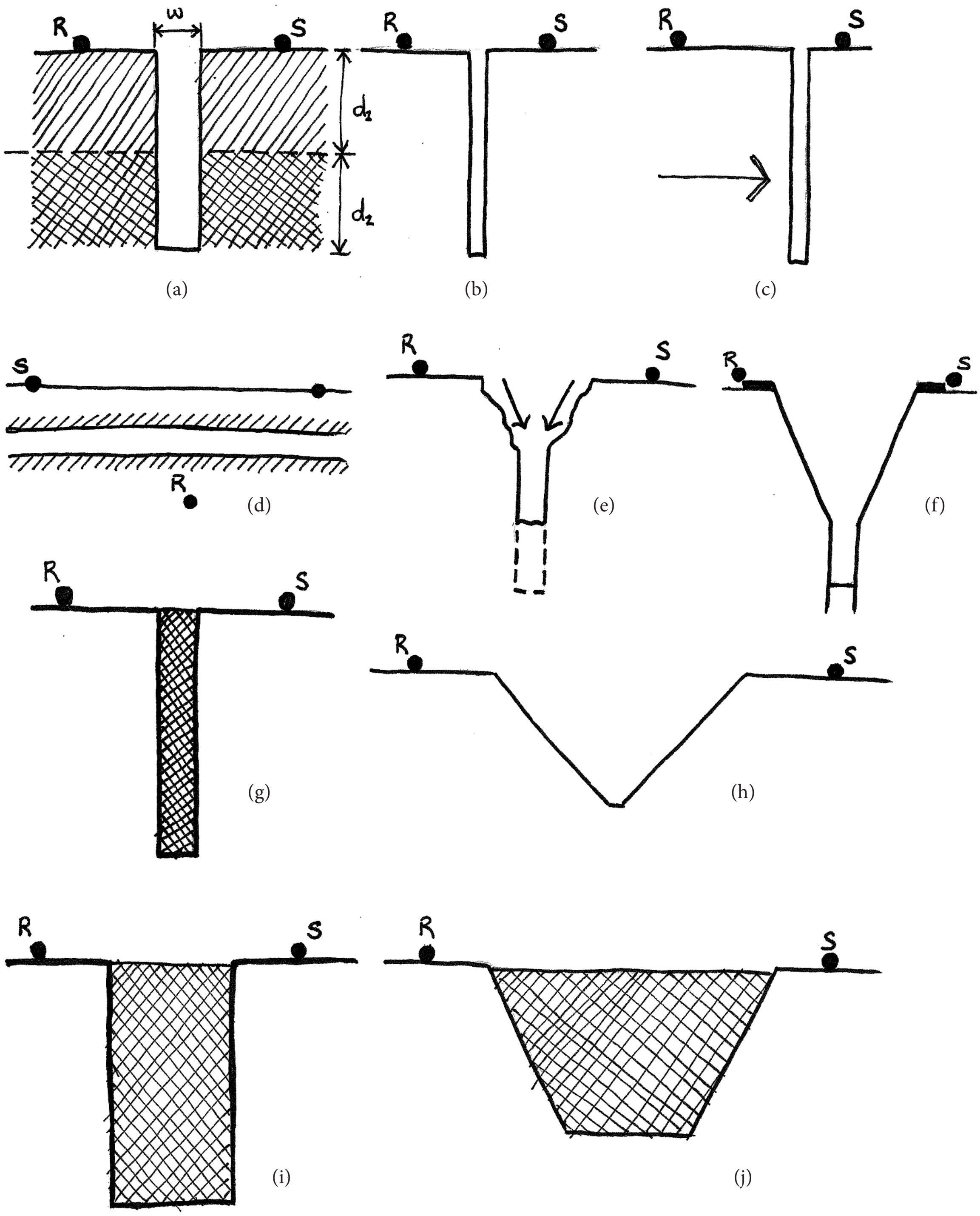


Figure 6.9 Design exploration of a ground vibration ‘barrier’ between a receiver (R) and source (S).

6.3 Protective Architecture

6.3.1 Planning Hierarchy

Similarly to evaluating the context of building and place functions, the room-by-room internal planning of buildings also had implications on an individual's soundscape. In Figure 6.10, typical residential programmes are ordered based on how affected they are by externally produced sounds unrelated to the activity taking place. It became apparent that activities of elevated concentration or prolonged rest required quieter spaces. Conversely non-affected spaces were of relatively brief habitation, produced masking sounds of their own, and/or the activity was indifferent to external sounds. By simplifying this scale to low, medium and high noise sensitivity, preliminary massing arrangements were explored (Figure 6.11). These were carried out with the assumption one side was exposed to a line source. This served as a guide for the arrangement of specific programmes in the developed design on site.

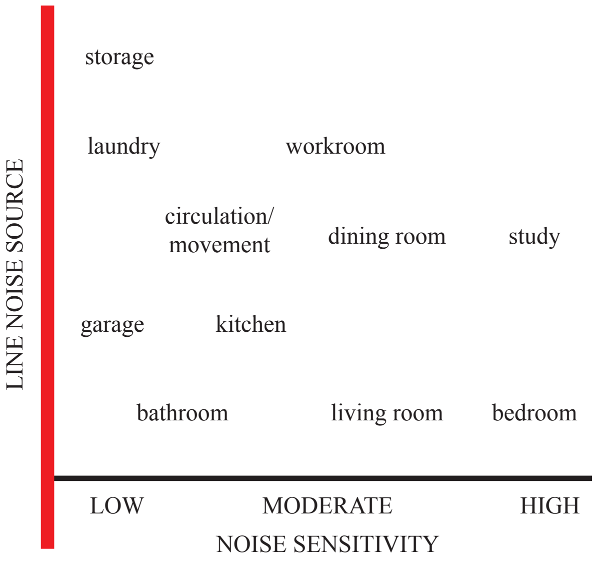


Figure 6.10 Residential programmes arranged based on noise-sensitivity to its function.

With soundscape and acoustic design taking priority in the iterative design process of the programme layout, there were some conflicts with other internal planning agendas. Most prominently in the portfolio, according to the Building Research Association of New Zealand (BRANZ) department Level, "passive design is the key to sustainable building" (Level, 2018). However, with regards to internal programme planning, some of these good design practices came into direct conflict with the portfolio's objective of providing an acceptable soundscape in a noisy environment. The question which arose from this problem was what action to take when factors like good daylighting and passive heating were only achievable by compromising the acoustic environment and soundscape. While sight and touch are important senses with which to experience our physical and thermal environment, hearing and listening are important for communication and gaining a fuller appreciation of our body in space. Walter Ong writes, "The centring action of sound affects man's sense of cosmos… the cosmos is an ongoing event with man at its centre. Man is the umbilicus mundi, the navel of the world" (Ong W. J., 1991). Pallasmaa reinforces this by stating "sight isolates, whereas sound incorporates; vision is directional, whereas sound is omni-directional" (Pallasmaa, 2005, p.49). Compromises and adaptations were made to passive design principles in the developed portfolio design after acoustic and soundscape designed principles were applied.

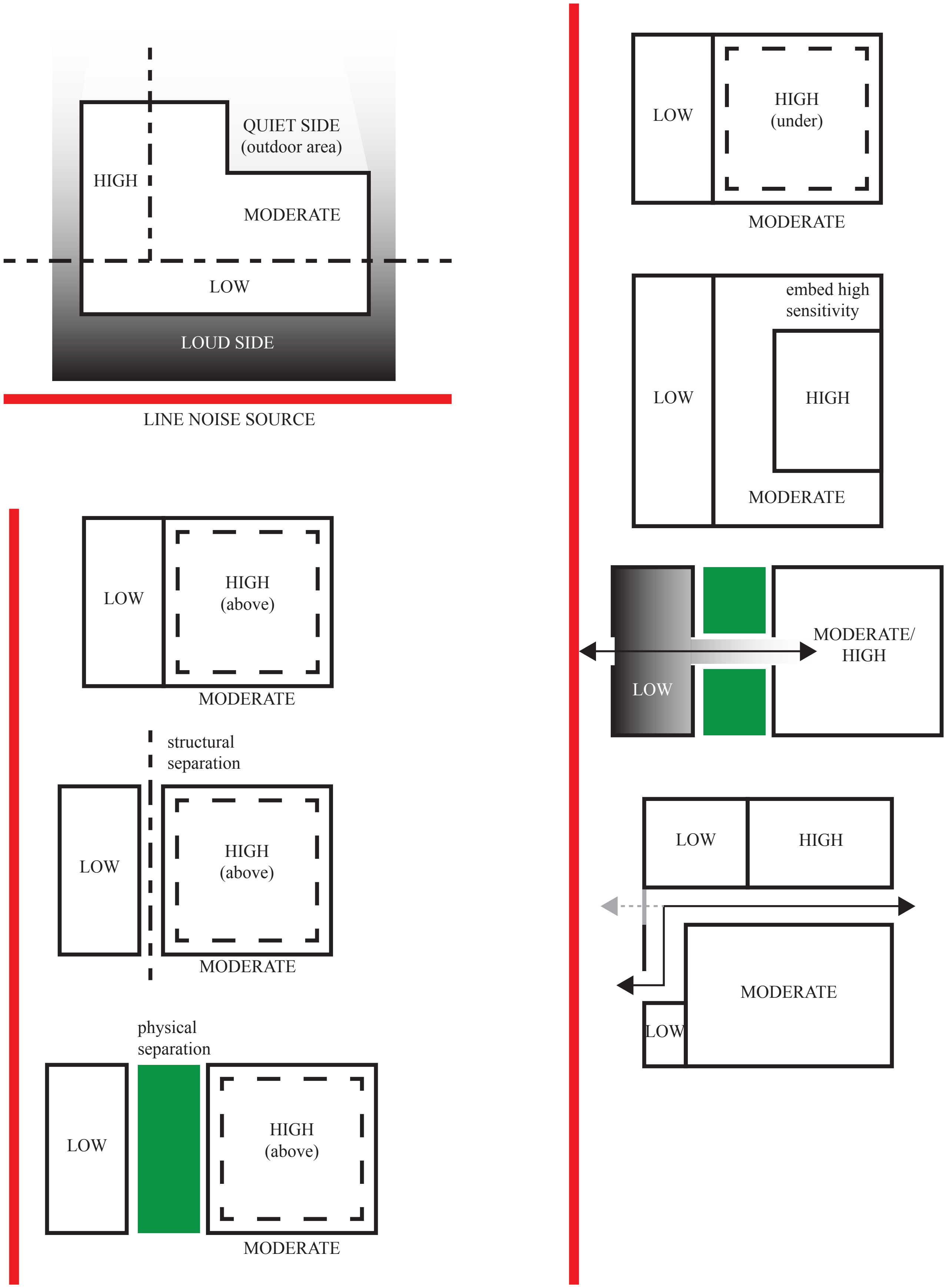


Figure 6.11 Massing arrangements of different noise sensitivity programmes in plan. See Figure 6.16 for further examples from the portfolio.

6.3.2 Built Form

To certain extents, a building's form can be designed to protect its internal programmes from external noise. Figure 6.12 illustrates in sectional view the basic principles of self-protective building forms. Typically one part of the building is used to create an acoustic shadow, screening off setback sections from direct sound exposure, leaving only much quieter diffracted noise. Once within an acoustic shadow, protection from a noise source on the ground typically improves as the distance between source and receiver increases. Balconies need to be of solid build to cast an acoustic shadow over windows and doors. The effectiveness also varies between storeys and proximity to the noise source (Figure 6.12c). In Figure 6.12d a solid courtyard wall acts as a noise barrier. However as demonstrated by Clare Cousins Architects' Rail House (Chapter 3.2) the opposite can be done (Figure 6.12e), using one built form to protect a space or form behind. The internal planning of this 'sacrificial building' must be carefully considered, especially if it hosts an entire dwelling.

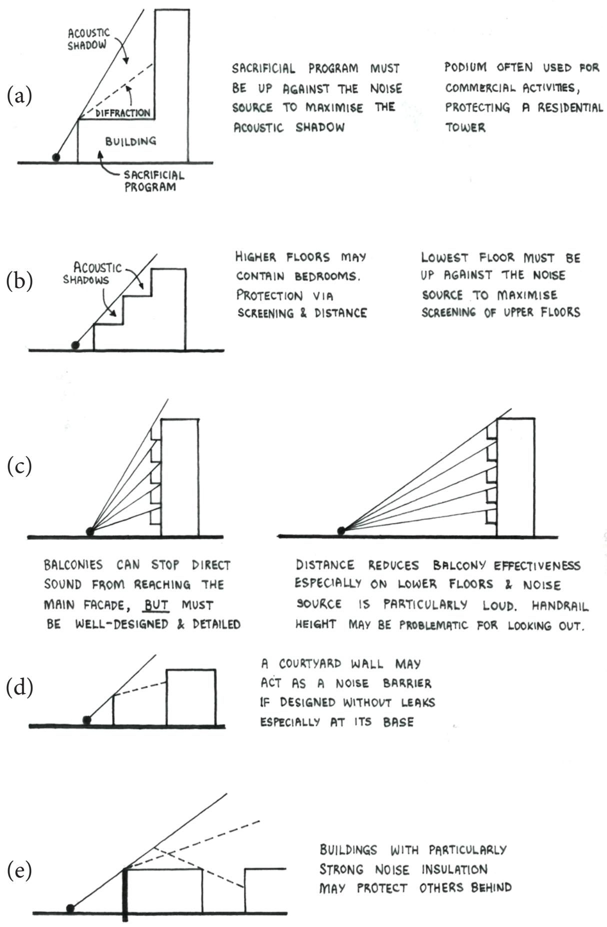


Figure 6.12 Residential programmes arranged based on noise-sensitivity to its function.

Arrangement of building block forms in relationship to a line noise source was explored. Although buildings can be used to protect the acoustics and alter soundscapes of spaces behind, the length, depth, and arrangement in plan were important factors to consider. Of additional consideration to the arrangement and size of blocks was the building typology of residential dwellings and mixed-use buildings. Acoustic groundwork for these massing iterations were laid by Andrew Rieper (2013) since acoustic measurements was not within the scope of this portfolio. Through observation of sound propagation patterns experimented upon by Rieper, Figure 6.13 explores some of the different methods by which building typology massing and gaps in the 'noise barrier' buildings could theoretically be achieved.

Exploration of dwelling typologies concluded that terraced houses were the most suitable for acting as a 'noise barrier' due to their elongated nature and dual elevations. Additionally they would achieve the dwelling density of mdh, as defined in Chapter 4. To continue using detached or semi-detached dwellings, as per the current context, would not achieve the dwellings per hectare of mdh. It also leaves many consistent gaps for train noise to pervade into the residential spaces distanced and visually disconnected from the railway. Long and narrow site dimensions complicate low-rise apartment blocks. Single-aspect apartments on multiple floors subject dwellings to varying amounts of train noise and vibration, while windows opening onto protective gallery-corridor entrances on the railway side can intrude on privacy.

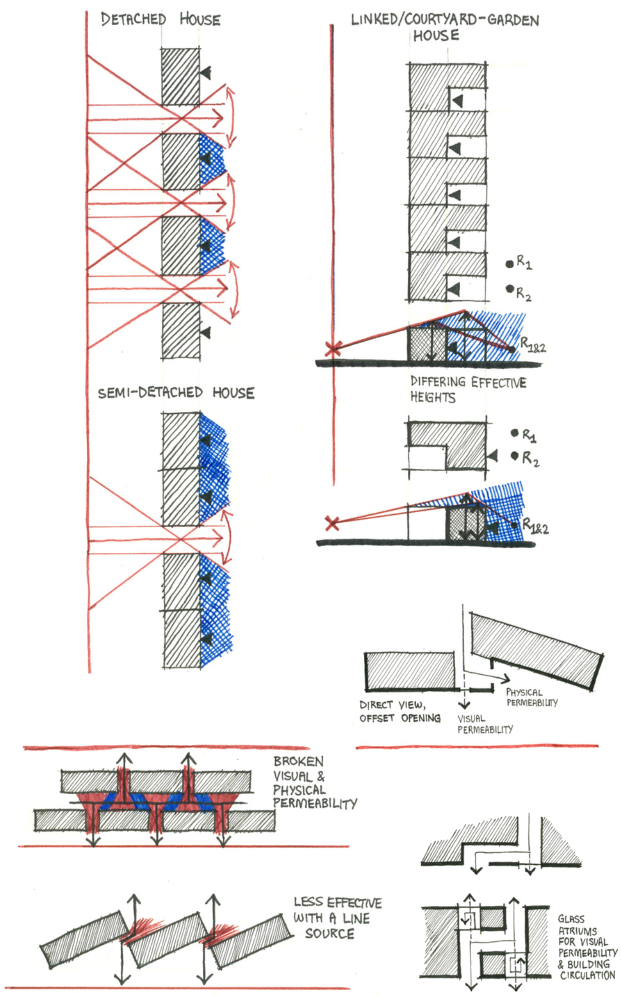


Figure 6.13 Evaluation of different housing typologies to a line noise source & the noise isolation properties of physical and visual permeability.

Visual and physical permeability of the urban fabric is an important aspect of maintaining a comfortable built environment (Carmona, Tiesdell, Heath, & Oc). It became clear that these two types of permeability had to be differentiated in understanding the design and site. Where there was physical permeability, there was an opportunity for unwanted sounds in the railway corridor to pervade into the residential acoustic environment and soundscape, compromising the noise barrier's objective of enabling sustainable densification. In general, where paths through urban fabric approached the barrier to pass through, visual permeability was maintained, but physical permeability was offset and/or angled. The creation of offset and/or angling openings is a variation of "acoustic lock", where the basic principle is an intermediate space between a noise source and an acoustically protected space. This variation is proven to be "an effective solution" (Kang, 2006, p.180) where public passages must remain open.

The design technique of sound isolation through discontinuity of straight lines and offset openings can be applied at all scales of design; down to the offset placement of electrical ports on opposite sides of a partition wall. Regardless of the barrier material, the following passage sums up the approach to sound isolation and prevent sound 'flanking':

> We'll begin our discussion of sound isolation not with the barrier, but with the hole in it. Keeping sound out is like keeping water out. Performance at the weakest point, not the average performance, governs the overall effectiveness of an assembly; therefore, a small leak can render an entire barrier feeble.
>
> (Ermann, 2014, p.133)

When a door or window is left open, outdoor sound is free to pervade into a house not unlike how it pervades through urban space. Openings like doors, windows, ventilation openings, recesses, and even plumbing and electrical ports are the acoustic weak points which determine the performance of both internal and external walls. The same can be said for any other architectural surface: floors, ceilings, and roofs.

What Ermann says is true about the 'hole in the wall'. However, it demonstrates that when facing a noise source, acoustic solutions do not align with soundscape solutions. Sound isolation facts had to be coupled with the knowledge that in soundscape (one's perceptual construct of feeling and experience of the acoustic environment), visual connectivity to noise sources is still related to annoyance. Therefore the logical compromise (other than replacing all windows with limited-purpose and expensive high-definition television screens broadcasting a camera's view of the other side) is to acoustically compromise the barrier wall with glazing, but make the glazing as acoustically robust as possible.

Beyond the building form, as explained in Chapter 2.3.2, the finishing materials and overall aesthetic design of the barrier can play a defining role on an individual's soundscape. If a built form acts as a noise barrier, similar design considerations must be made from both exterior and interior perspectives. The two houses, 'Rail House' and 'Elizabeth II' (Chapters 3.2 & 3.3), were examples of this through expression of their structural and architectural narrative as inhabitable barrier dwellings. The 'Noise Barrier Houses' in Goirle (Chapter 3.4) portrayed a similar narrative by revealing the strong noise barrier wall between the terraced housing and apartment blocks.

When coupled with a suitable internal planning layout (informed by all prior research and discussion to this point), preliminary design massing of programmes started looking at how the structural materials could express, similarly to case studies, a noise barrier narrative. Figure 6.16 shows the iterative evolution of a dwelling layout which concluded in two distinct parts: (1) timber, protected living and sleeping spaces, and (2) concrete, protective secondary and tertiary programmes (Figure 6.14. A distinct 'quiet side' is created opposite to the line source of the proposed mixed-use railway corridor. This creates spaces which enable Types 1 aural restoration (as defined in Chapter 2.4). Residents more exposed to train noise when in the concrete barrier portion of the house are aware of the quieter and more pleasant living, sleeping, and garden spaces on the opposite side of the house, thereby experiencing Type 2 aural restoration.

The thickness of a barrier structure increases its effective height and acoustic shadow coverage. In acoustical design, the top edge of a building's elevation directly exposed to a noise source should be treated as a barrier of the same height. If the building has substantial thickness away from the noise source its effective height is modelled in acoustical design as higher than the actual physical height (NZ Transport Agency, 2010), as shown diagrammatically in Figure 6.15. This is advantageous for the community benefiting from buildings acting as noise barriers. Buildings behind the barrier can be built to greater heights, with the barrier structure's lower height being a tiered-down movement and reduction in visual density before the wide, open expanse of the railway corridor.

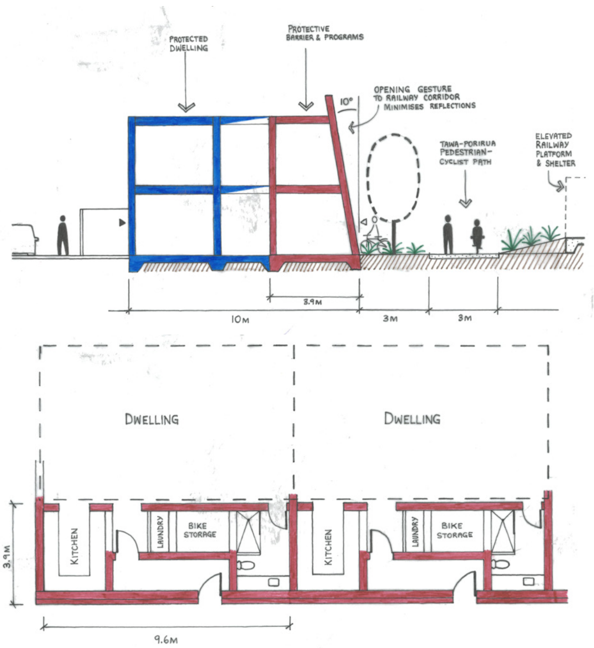


Figure 6.14 Terraced house developed in two parts, delineating railway corridor and residential soundscapes and acoustic arenas.

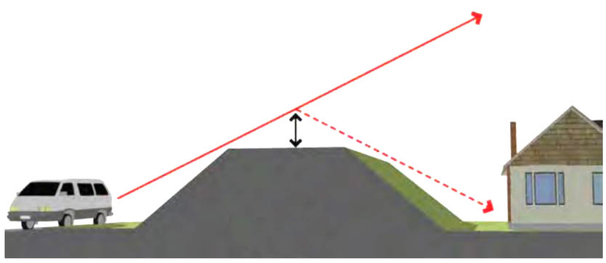


Figure 6.15 Effective barrier heights when a barrier is thickened.

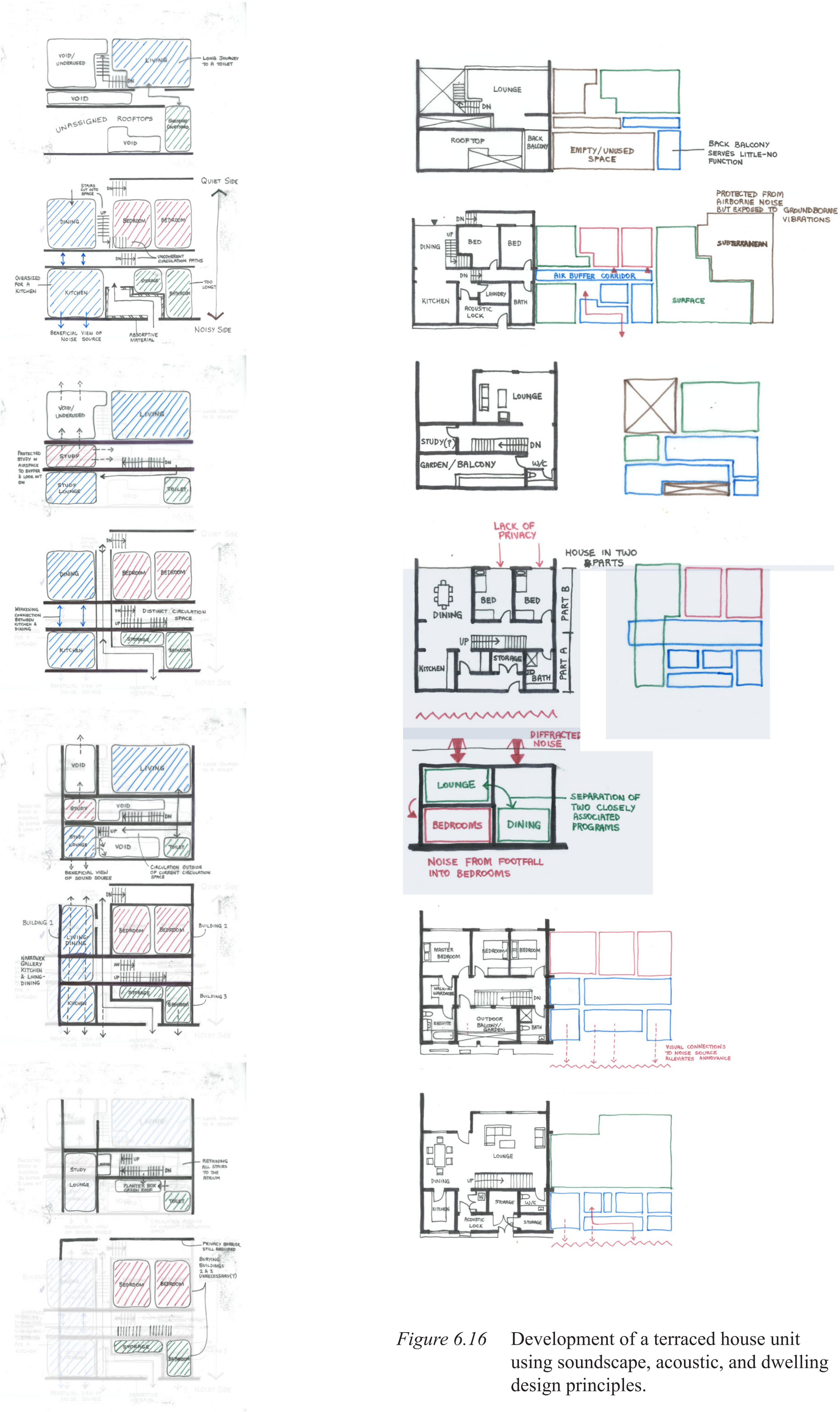


Figure 6.16 Development of a terraced house unit using soundscape, acoustic, and dwelling design principles.

Relatively small angles of tilt can counteract degradation of hi-fi acoustic environments by reducing multiple reflections. Figure 6.17 examines through section sound propagation paths (rays) between a source a reflecting surface, representing a building form. By tilting the surface away, areas at head-height encountering first and second reflections are reduced. Although it reduces reflected sound close to the ground, where there are high-rise buildings near the sound source, angled surfaces may not be appropriate (Kang, 2006). When a vertical surface is above horizontal level with the sound source, incidental sound is reflected upwards. Interestingly, to minimise second reflections (i.e. source-ground-barrier-receiver; or source-barrier-ground-receiver) the reflective surface must be angled with its base perpendicular to the source. This makes the barrier tilt angle dependent on the source's location.

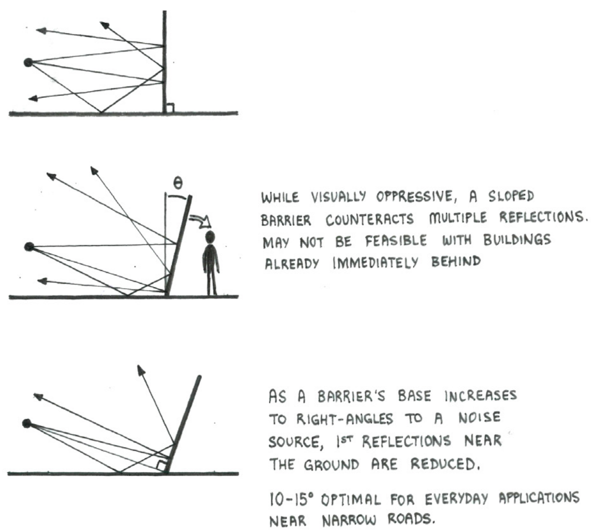


Figure 6.17 Ray-trace of sound paths upon different shaped surfaces proposed for building facades facing the railway corridor

6.4 Strategic Landscape Designs

The design of the landscape in a railway corridor will have implications on the acoustics and soundscape not only itself, but the wider context. Physically, the train tracks and platform can be either elevated or lowered by landscape works (Figure 6.18) and noise barriers erected. This would create acoustic shadows of varying amounts. Due to the limitations of available equipment and the scope of the portfolio focusing on soundscape design, decibel reductions were not measured. Through experimentation with the angles of acoustic shadows casted, it was determined that raising and lowering the station has its different uses. To raise the station would be to create an acoustic shadow closer to the station which reduces as distance away increases. The opposite is found when the station is lowered. Although an interesting and effective proposition, manipulating the landscape and railway elevation was decided as unfeasible. To change the track's elevation would require extensive infrastructural rework, disrupting the train and introduce undesirable construction noise into the site for a long period. In order to get any significant effective height from landscaped berms, significant space is required between the noise source and built architecture; space which can be more actively used. To bracket the railway line between raised landscapes also cuts visual permeability, emphasising the division caused by the railway tracks.

As was mentioned briefly in Chapter 2.3.1, although the sight of visually permeable vegetation is positive for overall spatial experience, they are not space-efficient in attenuating noise. They may even increase perceived noise annoyance if planted too thickly, with only minute reductions in measured decibels (Figure 6.19). Therefore vegetation is not explored through design in any acoustic capacity. Alternatively it was worth recalling from Chapter 2.5.1, that birds are shown to be not adversely affected by train noise. If suitable vegetation were

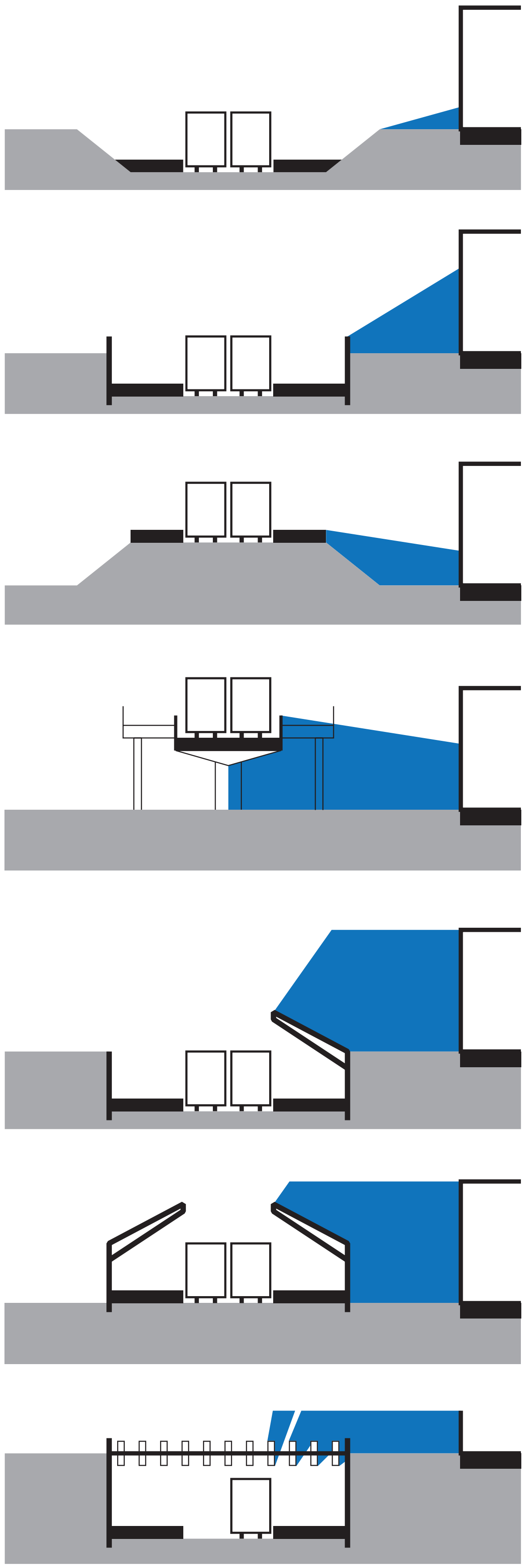
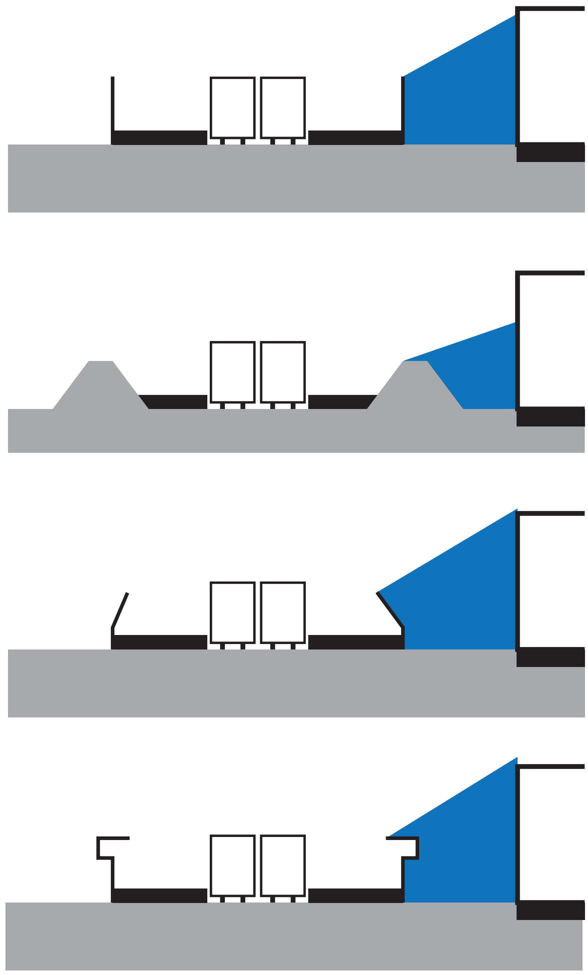



Figure 6.18 Manipulation of the train tracks and platform acoustic shadows through landscape and barriers.

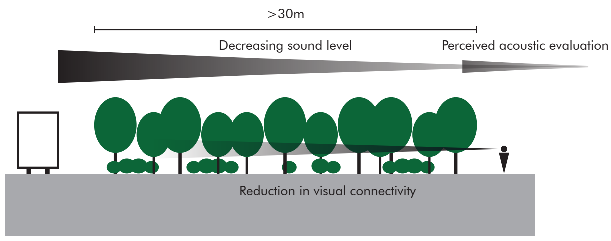


Figure 6.19 Thickness of vegetation required for acoustic mitigation compared to visual-aural perception on sound levels.

introduced into the noisy environment, the sounds of local birds can partially mask the quieter electric multiple units used for passenger services. This also has the potential to change the temporal character of the railway soundscape. Depending on their movement and sleep patterns, twittering of birds can create a much more preferable alternative to the usual morning soundscape of intermittent passenger services, some stopping at Linden Station and some blasting through on an express runs. Unfortunately, this sort of design element can be speculated and facilitated through appropriate planting, but by no means guarantee that birds will inhabit the railway corridor in sufficient numbers.

Although not explicitly designed through iterations, there was a design principle to retain as much 'soft ground' in the railway corridor as possible. 'Soft ground' can be summed up simply as natural unfinished ground; the opposite of ground covered by asphalt or other hard walking materials. Retaining areas of soft ground and vegetation reduces the amount of surfaces available for sound to reflect off, thereby slightly reducing the overall sound intensity emitted by all sources in the acoustic environment.

6.5 Chapter Conclusion

The preliminary design phase was composed of many design experiments running in parallel. Although each line of iteration were brief, the exploration was broad and across a range of design scales. The design elements explored focused on solving soundscape and acoustic problems that obstruct sustainable densification of a noisy railway environment. Understanding each problem under the lens of soundscape design and sustainable densification ensured the iterations specifically addressed the portfolio's aims and objectives. Each design element's underlying soundscape research and concept was specified to ensure clarity in what ways affects the perception of the acoustic environment. This delineation of underlying soundscape concepts aids in the amalgamation of different elements on site to create a Developed Design (Chapter 7) and deeply enhances the depth of even the simplest of design solutions.

CHAPTER 7
DEVELOPED DESIGN

The developed design was the convergence of the many experiments explored in the preliminary design process (Chapter 6). Although soundscape design should be considered as a compositional whole in conclusion, it was nevertheless useful to break down the design into its main soundscape components and design elements. The broader masterplan and context design set the main design intent, movements, and structure of the overall soundscape, the musical composition of the world. The individual architectural elements of the developed design were the soundscape 'instruments' which created the context of 'place' (referring back to Figure 2.2) to play upon the perceptual experience of Linden inhabitants. The depth of design that was able to be discussed and explored was substantial. To keep the project focused on the overarching key qualities of the portfolio, many smaller design details were considered but ultimately excluded from the scope of the portfolio.

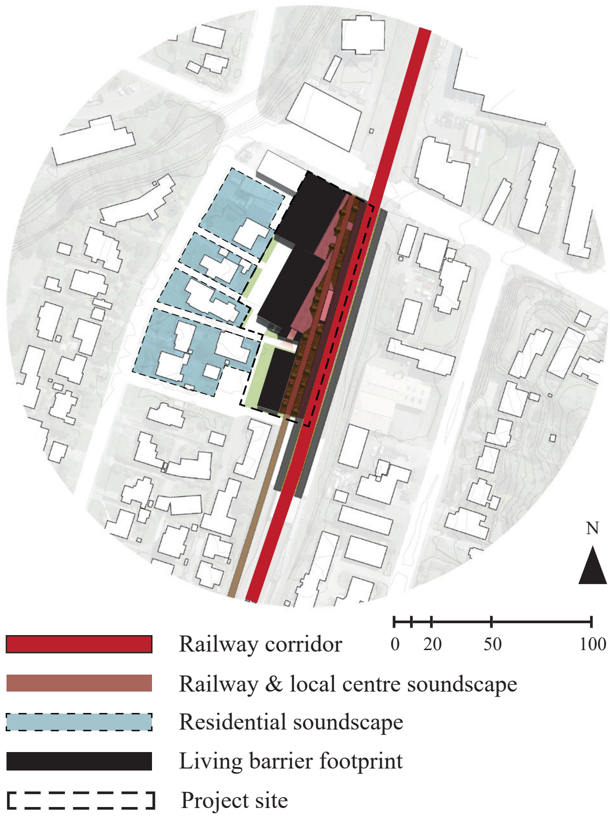


Figure 7.1 Delineation between residential and railway/local centre soundscapes using a 'living barrier' structure.

7.1 Masterplan & Context Design

The macro-scale objective of the project looked to restore sound signal fidelity to the Linden residential soundscape. This resulted in an architectural intervention to acoustically block noise and restore the potential of aural restoration in and around the home. The design experiments covered throughout Chapter 6 informed the development of building forms along the railway corridor (Appendix D) to create a 'living barrier' to delineate between the local centre/railway corridor and residential soundscapes (Figure 7.1). Figure 7.2 shows the performance of this intervention through urban noise mapping. This only shows the propagation of sound based on a lone diesel locomotive at 79km/h (mentioned in

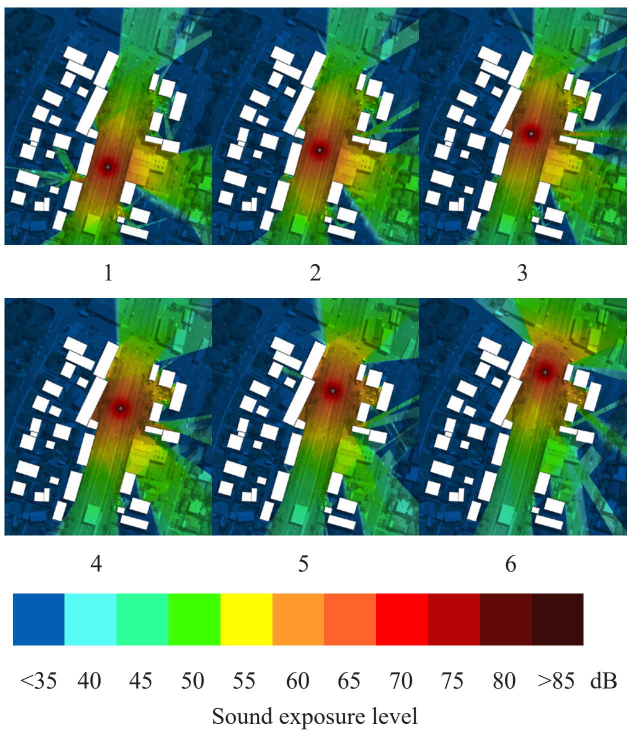


Figure 7.2 Noise-map of the proposed 'living barrier' with a moving point source

Chapter 4 and Figure 4.11), and is therefore only indicative with regards to the sound levels.

Based on the site analysis and programme analysis it was decided for the living barrier to focus upon residential functions. Figure 7.3 shows the progression of barrier programmes from residential to retail/commercial as one travels further into the local centre from the south. This retained focus on the original local centre at the intersection of the Kapiti Line and Collins Avenue. The rotation of the built masses to create small public spaces alongside the cyclist/pedestrian pathway better reflected the angle of the suburban fabric behind the barrier and creates a frontage facing towards northbound train services on the left track.

Navigation through this barrier (Figure 7.4) was based upon design discussions in Chapter 6.3.2 and Figure 6.13. Separation of visual and physical urban grain permeability was very important. Visual permeability through the barrier via glazed portals were beneficial for wayfinding between Beauchamp St and the railway corridor/train station. It achieved this while avoiding the problem of noise travelling in straight lines down corridors created by aligned building masses (Figure 4.10). It is also worth remembering where any noise does pervade through the offset or angled openings, these glazed portals improve residents' soundscapes by giving visual access to the noise source.

Figure 7.3 Programme layout of the 'living barrier' architectural soundscape intervention.

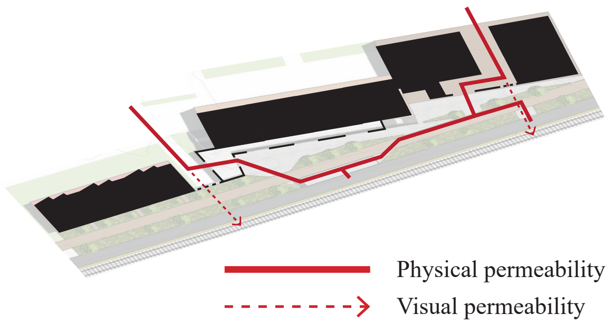
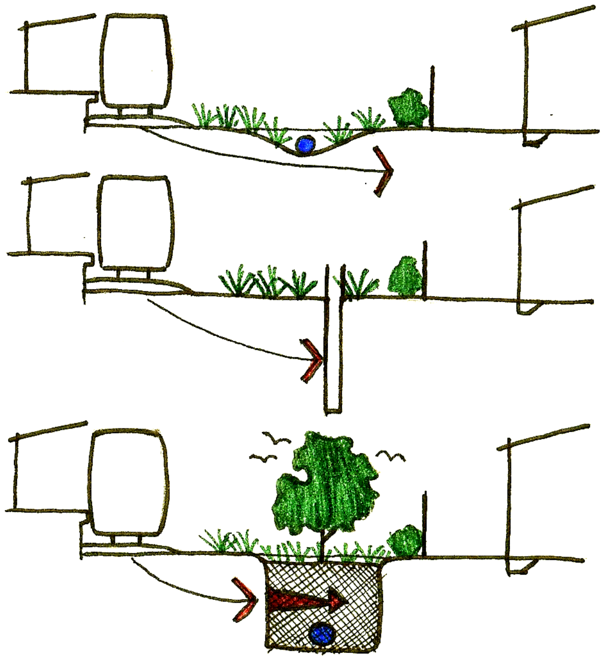


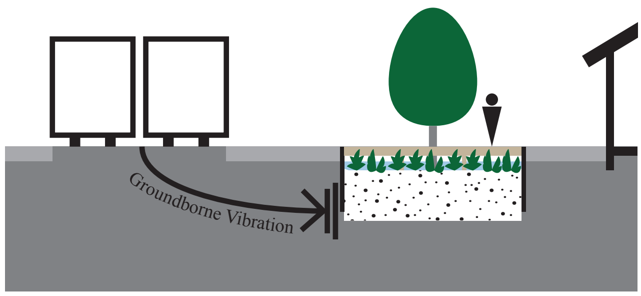
Figure 7.4 Navigation through the 'living barrier' was carefully articulated to ensure where physical permeability does not induce acoustic vulnerability. Visual permeability compensates the soundscape.

7.2 Swale Vibration Barrier

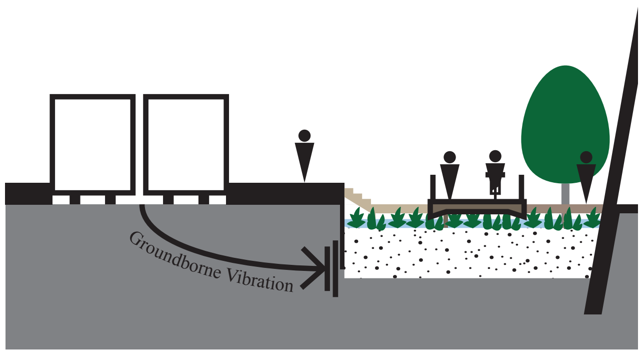
The design and use of a swale is an amalgamation of design experiments and principles. Its primary function is a filled ground vibration 'barrier', as explored and discussed in Chapter 6.2. Stormwater ditches and drainage to Porirua Stream were already present on the sides of the railway corridor (Appendix B). These were developed further, increasing their depth and width (Figure 7.5). Although not as effective as an open air ground vibration barrier, Jiang et al.'s lab results (2013) indicate increasing the width of a filled barrier improves its performance. Details on the material composition of this swale are given in Figure 7.6, an adaptation from a rain garden design recommended by the Christchurch City Council (2016). This filled ground vibration barrier was designed to be carried throughout the design intervention, running parallel to the train lines (Figure 7.7).

Interestingly a swale's acoustic, soundscape and vibration barrier properties will subtly vary depending on the weather. Although not formally investigated in this portfolio, a water-filled swale from prior rainfall will attenuate vibrations differently to drier conditions. The visual and aural presence of water on human restoration has been hotly debated between different researchers. On one side, water indicates an environment's high restorative potential (Ulrich, 1993), while others did not find any connection between water and



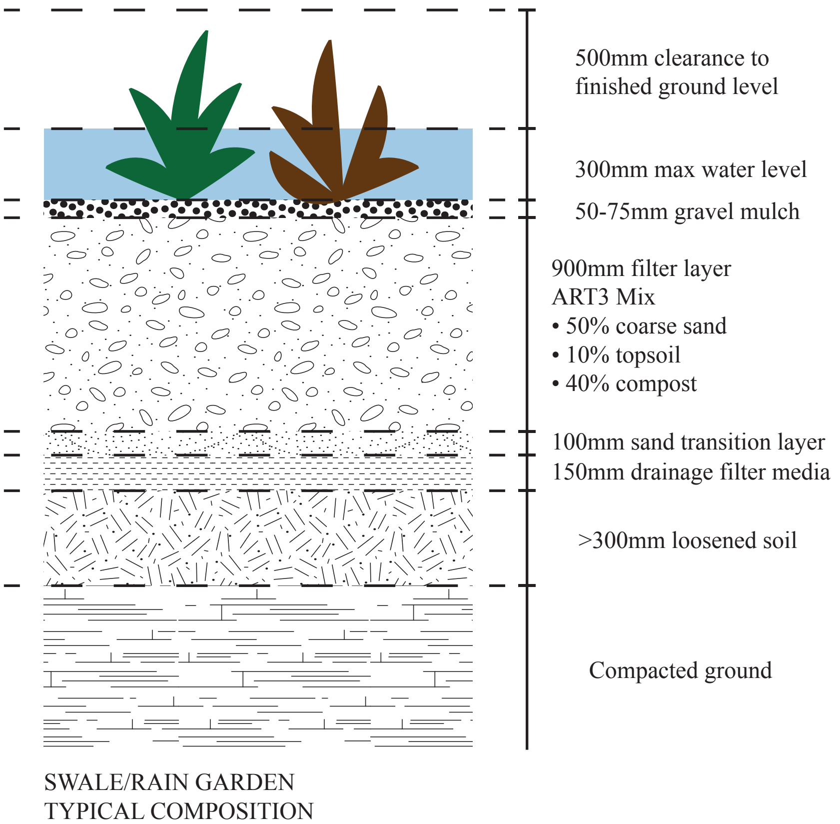


A stormwater swale/rain garden will be less effective than an empty trench. However, it improves the visual quality of the noisy soundscape, responding to human preference for natural vegetation and water.



Boardwalk over a swale maintains the original stormwater ditch while introducing tentative human inhabitation into the space. Continuous foundation work of neighbouring buildings can form one of the swale's edge supports.

Figure 7.5 Development of the ground vibration 'barrier' into a filled 'barrier' and swale.



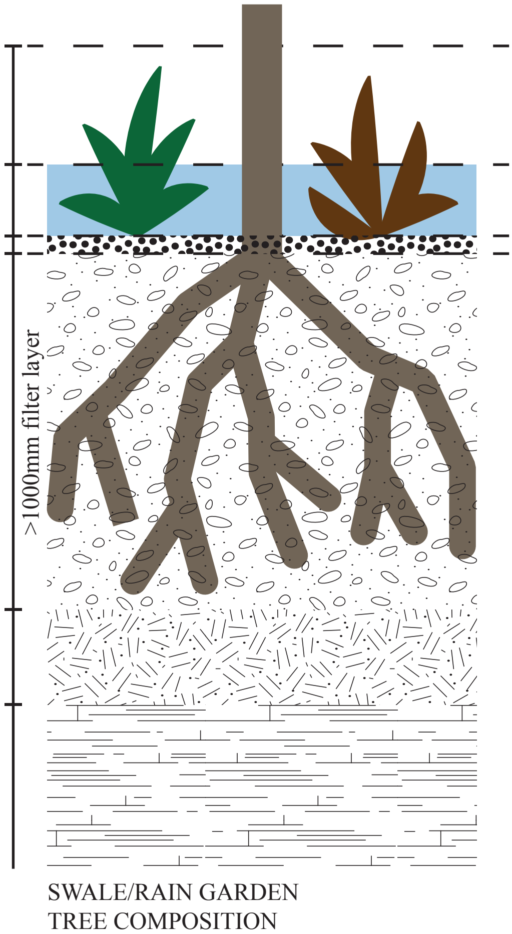


Figure 7.6 Swale/Vibration barrier composition

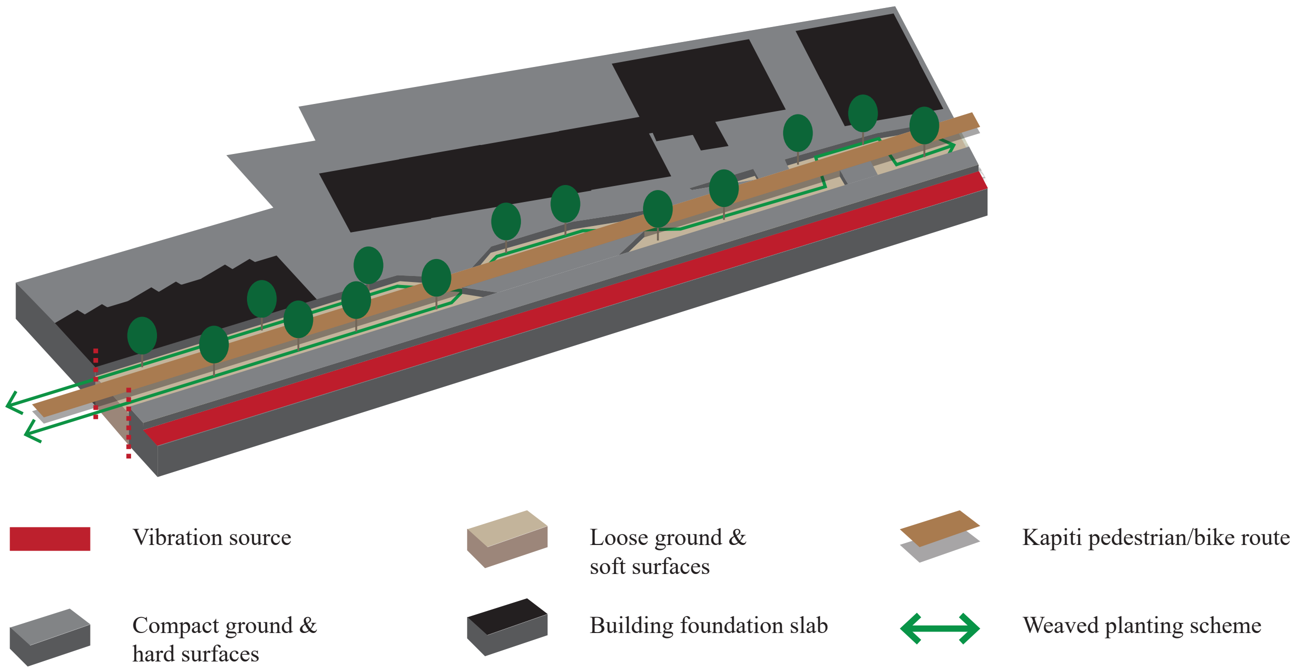


Figure 7.7 Swale/Vibration barrier inserted continuously between the train tracks vibration source and planned architectural intervention.

affective restoration (Van den Berg, Koole, & van der Wulp, 2003). Until future research clarifies this, in-between it is generally accepted that the human preference for natural environments containing greenery and water has evolutionary origins (Kaplan & Kaplan, 1989). Therefore, the swale's presence in this portfolio design as an affectual design element for visual aesthetic and soundscape restoration is speculative; but nevertheless preferable to the alternative of not being present at all in the urban environment.

The introduction of vegetation and water into the railway corridor through the swale will increase the biodiversity of the area. The highly favourable twittering of native birds, flowing water, and chirps of insects (Kang, 2006, p.71; Kariel, 1980; Porteous & Mastin, 1985; Tamura, 1998; Carles, Barrio, & de Lucio, 1999) are brought into the soundscape composition of the Linden railway corridor and surrounding residential areas. The implications of these natural sounds to the sounds of trains were discussed in detail in Chapter 2.5.2 (specifically focused, but not limited to birds).

The swale has more traditional functions in sustainable development by managing and treat stormwater runoff and air quality. By inserting the composition of materials given in Figure 7.6 (or similar) and planting native shrubs and trees suitable for wet conditions, a swale helps to filter sediments, nutrients and contaminants from incoming stormwater (Auckland Council). As Linden increases in density, abundant hard surfaces prevent this process from occurring naturally, with stormwater drains collecting and disposing untreated water into nearby rivers and streams, polluting them. Swales provide areas in urban environments for water to be stored and naturally drained/filtered into the soil; or later collected by underdrain pipes to then be taken to natural waterways. This helps to prevent flooding of surrounding streets and improves the quality of the natural waterways (Figure 7.7) Vegetation also helps to improve the air quality (Neufert, 2012). This is especially important with the use of diesel-electric trains on the Kapiti Line.

A swale is more commonly viewed as an element in sustainable urban design. When the principles of soundscape and acoustics are applied, it adds an extra dimension with which to view it. This alignment with the objectives of environmentally friendly (and perhaps biophilic) design concepts indicate that positive soundscapes are worth considering when evaluating the sustainability of a densifying built environment.

7.3 Pedestrian/Bicycle Boardwalk

Prior analysis of site features showed a shared pedestrian-bicycle trail between Takapu Road Station and Porirua Station. This recreational trail is well integrated with the Kapiti railway corridor but diverges away just before Linden Station. With the portfolio project's intent on introducing human inhabitation into the railway corridor, returning the trail to the railway corridor and into the swale was proposed. This will increase pedestrian and cyclist activity in the reoriented Linden local centre and train station, further reinforcing the space as a complex, vibrant and diverse social hub.

The materials walked on (and probably cycled on) have a noticeable effect upon the soundscape experience of the user. Different path materials are available to traverse the swale proposed in Chapter 7.2. In a noisier acoustic arena like a railway corridor, using a path made of "gravel could achieve a 'masking' effect of unwanted noise sources, thus improving the soundscape perception" (Aletta, Kang, Fuda, & Astolfi, 2016, p.171). However it was found that walking on gravel pathways proved to be the most "tiring" or "arduous to walk on" (p.172). Gravel was ultimately unsuitable due to safety reasons (Figure 7.8). Having an audible path material is important not only to mask nearby noise, but also to aurally transition cyclists and joggers into the railway corridor local centre. “Clearly noticeable walking (and cycling) sounds can also help detecting the presence of other people and this could have positive implications with respect to perceived safety in particular contexts” (p.171). This means grass (the perceptually most favourable material (Aletta, Kang, Astolfi, & Fuda, 2016)) and concrete/stone (the smoothest and easiest material to cycle on) are eliminated. Ultimately a timber boardwalk was found to be the most suitable path material, combining presence through sound, some degree of noise masking, and aural, physical, and visual pleasantness (Figure 7.10).

The design simplicity of a timber boardwalk in the developed design’s soundscape must not be underestimated. It is profoundly affectual to the recreational user’s soundscape experience. The transition from a concrete path to a timber boardwalk will be seen, felt and heard by recreational users travelling through Linden (Figure 7.9). Through sound and touch, cyclists and joggers are induced to slow down as they approach Linden centre. This change in sound character through use of material whilst travelling is an example of a change in space through aural boundary methods (Figure 7.9), without the use of a physical boundary (Blesser & Salter, 2007). It transforms the individual’s way of seeing the same space. Additionally the permanence of the concrete cycling/pedestrian path is swapped for the ‘inserted’ intervention of the boardwalk over the older stormwater ditch (now swale) underneath (discussed in Chapter 7.2).

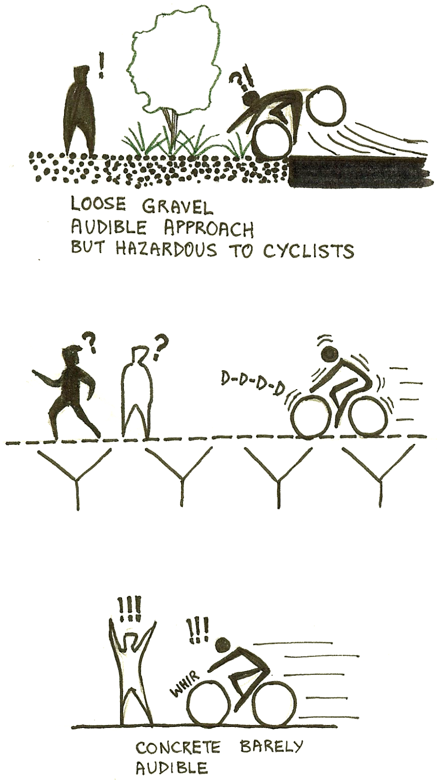


Figure 7.8 Path material selection balancing aural, visual and physical constraints.

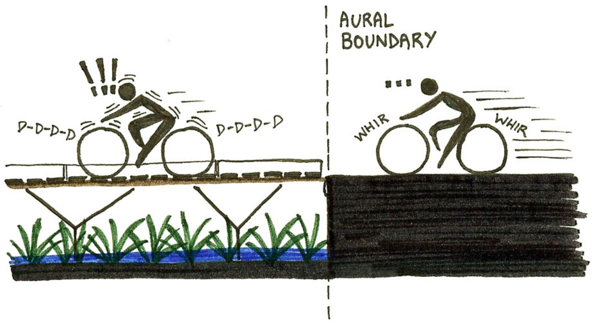
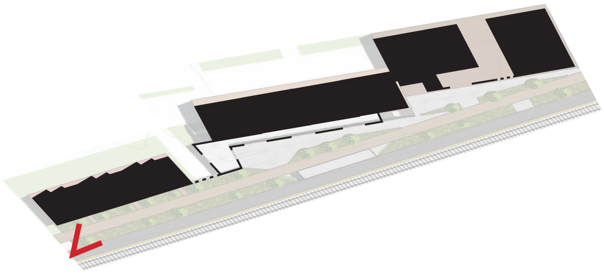


Figure 7.9 Path material selection balancing aural, visual and physical constraints.

Figure 7.10 Timber boardwalk built over the ground vibration 'barrier' swale characterises the soundscape of commuters through the Linden centre through the acoustic environment and aesthetic visual appearance. The design of the terraced houses (foreground) is discussed in Chapter 7.4.



7.4 Terraced Houses

The terraced houses (foreground of Figure 7.10) served as the main focus of design exploration to enable sustainable densification of the noisy railway environment. The elongated nature of the house typology and the duality in main elevations created a balanced combination of noise barrier and residential dwelling. The internal plan layouts (Figure 7.11) were developed based on the hierarchy of residential programmes with regards to noise (established in Chapters 6.3.1-6.3.2 and Figures 6.10, 6.11, 6.15, 6.16). The parallel layering of walls and spaces served to protect, buffer and disrupt the transmission of noise. Programmes less affected by railway noise and vibration (e.g. kitchen, storage, laundry, balconies, bathrooms, and circulation) buffer more noise-sensitive programmes like living-dining and sleeping spaces. Type 1 and 2 aural restorations (discussed in Chapter 2.4) are achieved through the location and relocation of residents within the dwelling.

Glazing provided a visual connection for rooms facing onto the railway corridor, allowing residents to acquaint and familiarise themselves with any audible noise sources, thereby reducing its perceived loudness and annoyance. The glass panes used in the insulated glazing units (IGU) facing the railway line are specially splayed. Internal panes remain vertical whilst the externally exposed pane is angled to the barrier slope. This change in airgap between panes prevents resonance from train noise and vibration from accumulating and transmitting through

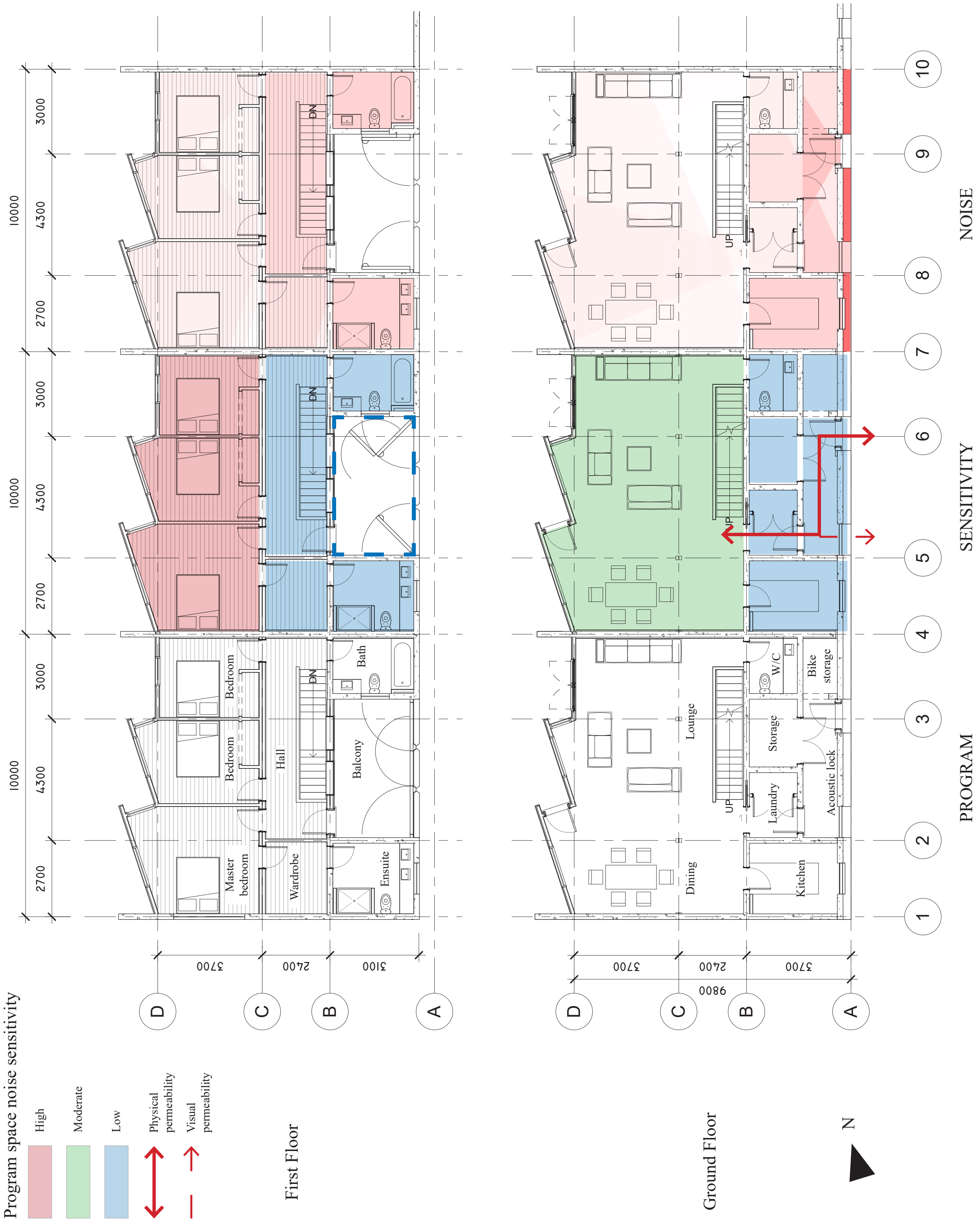


Figure 7.11 Internal plan layout of the terraced houses including overlays of programme noise hierarchy and indicative noise attenuation.

(Ermann, 2014). It improves noise attenuation performance beyond typical IGU's with vertical faces.

As developed from Figure 6.14 the house is constructed in two distinct parts: the concrete 'barrier', and the timber 'home' (Figure 7.12). With concrete established in Figure 2.6 as the most effective noise barrier material by preconception, the programme's function in the residents' soundscape was aligned with the materials used. When viewed from the noisy railway corridor (Figures 7.10 and 7.13) a glimpse is given of the building's true nature as a dwelling.

On the residential soundscape side, the roof and intertenancy walls are exaggerated in construction. Similarly to case studies reviewed in Chapter 3, there was a conscious attempt to express through architectural form and materials the aural and acoustic function of the structure. It creates enclosures which the timber structure and façade of the dwelling is inserted within (Figure 7.14). As established in Figure 6.15, the roof's large eaves maximises the 'effective height' of the building as a noise barrier for those behind. This benefits those in the terraced house's front garden and within residential developments that occur behind (Figure 7.15). Also shown is the acoustic shadow that was sufficient enough for additional residential developments behind to increase in height without having to specifically design to guard against direct noise. This reduction in site design problems can enable greater densification with a focus on residential soundscape design.

Openable shutters are noticeable on the first floor balcony. These were considered with regards to the improvement of perceptual living conditions through a user's sense of control over the environment (Zhou, Ouyang, Zhu, Feng, & Zhang, 2014). However, this design detail, along with many others, were supplementary in the overall moves to improve the soundscape; therefore outside the scope of the main developed design discussion.

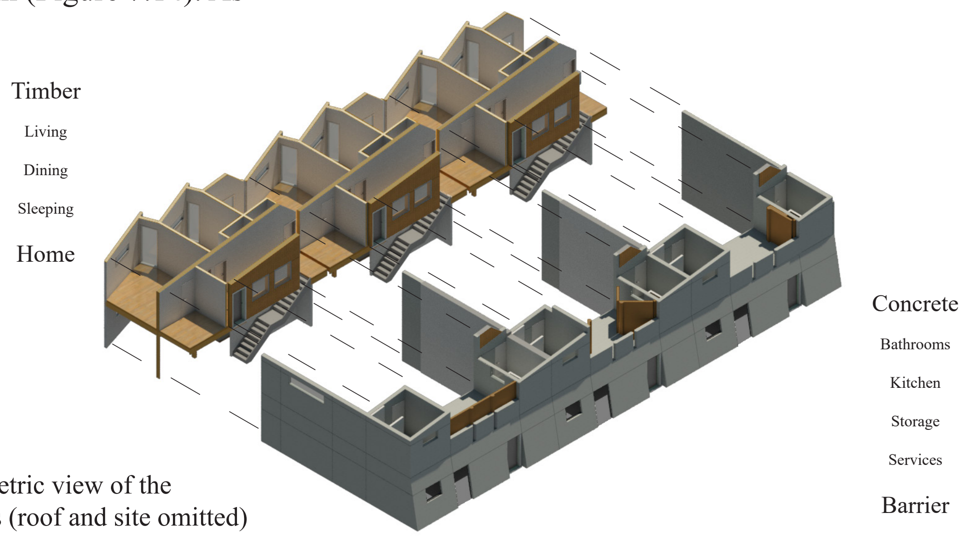
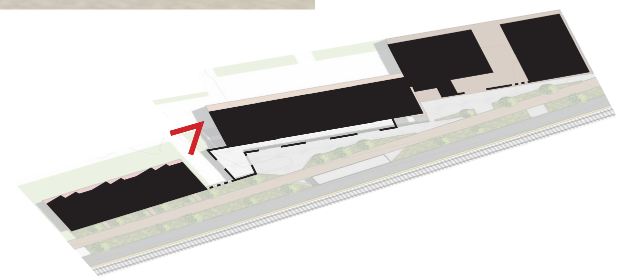


Figure 7.12 Exploded isometric view of the terraced houses (roof and site omitted)

Figure 7.13 Terraced houses: Rendered railway corridor elevation.

Figure 7.14

Terraced houses: Quiet facade for aural restoration and protected residential soundscape. Note the extended eaves and intertenancy walls enveloping the residential programme.



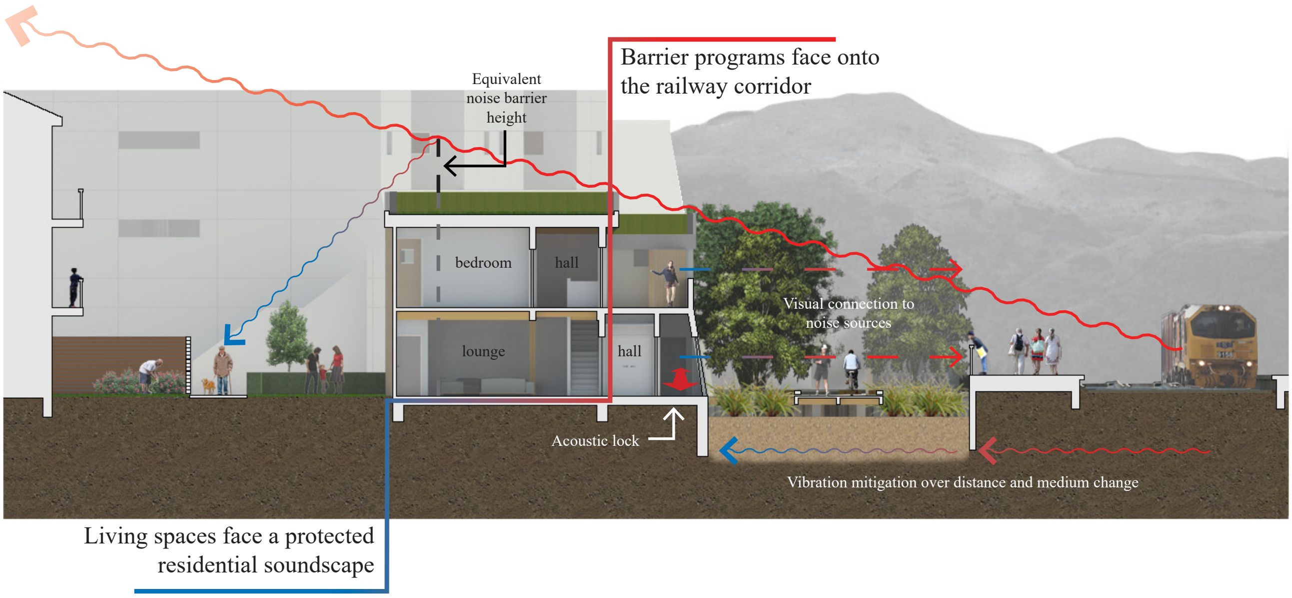


Figure 7.15 Section cut through the terraced house highlighting the transition from between the railway corridor and protected residential soundscapes. The acoustic shadow cast by the terraced house is sufficient to enable soundmarks and keynotes associated with residential life to remain prominent, protected from the soundmark activities of the local centre and trains.

The roof profile and design in elevation was the result of an alignment in sustainable design systems. A green roof system performs a similar function to the swale (Chapter 7.2) by managing and treating stormwater run-off and air quality (Appendix D). Rainwater can be used in some grey-water applications, e.g. stored in cisterns for flushing toilets or stored in tanks for watering the garden (Figure 7.16). The material composition and planting on a green roof also attenuates sound in the overall acoustic environment by acting as elevated soft ground.

A portion of the roof was reserved for photo-voltaic [PV] panels. By almost facing due north, these PV panels will help to heat the house and/or its hot water system. This was conceived to compensate for the lack of north-facing façade. Suitable mounting angles were determined through research by Level (Key features of designing a home with passive design, 2018). The pitch of the roof was the elevation angle for best PV panel performance in the winter sun for the Wellington Region [Figure 7.17]. It is the time of year where electrical heating would be most needed. Any requirement for heating during autumn/spring and summer is achievable by tilting the PV panels on its mount.

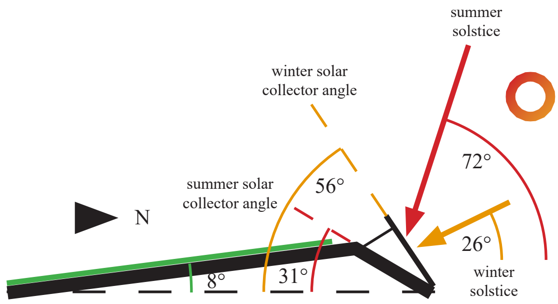


Figure 7.17 Roof angles are informed by solar collectors & planting requirements

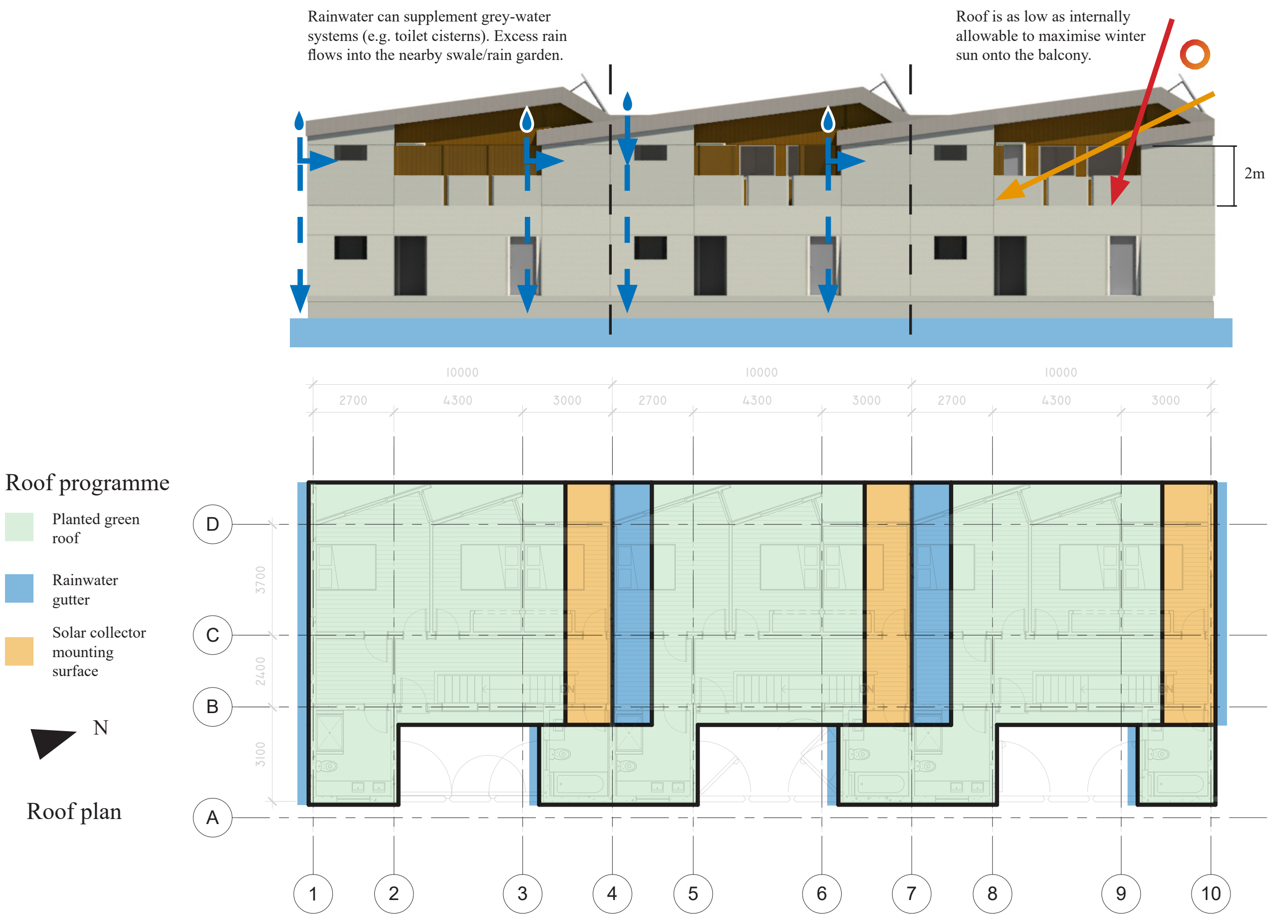
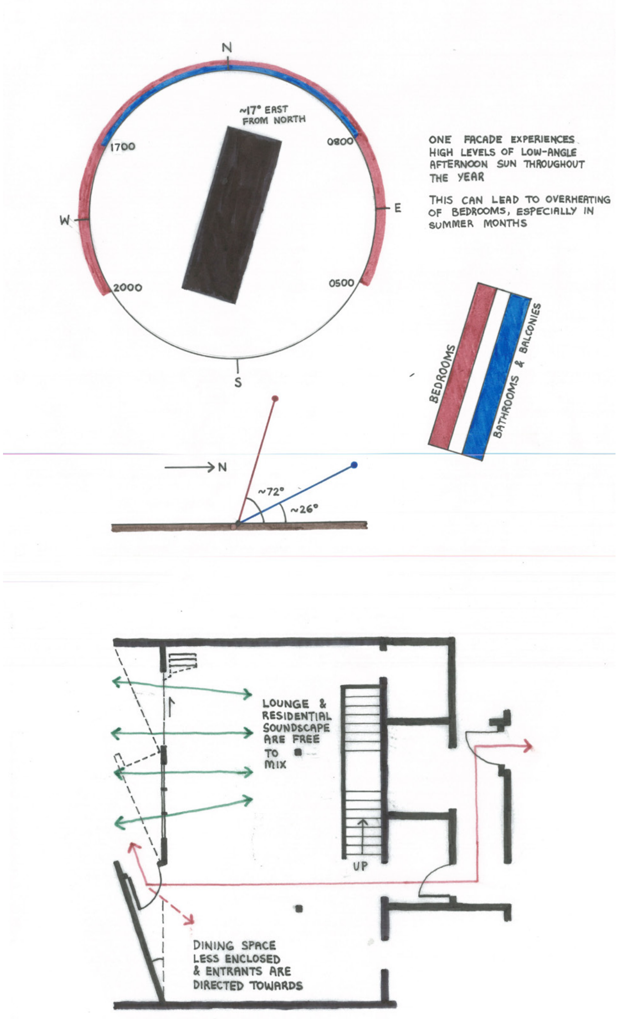


Figure 7.16 Roof plan, programme and rainwater applications

Due to the limitations of the site and location of the noise source, some passive design principles for a more sustainable design were unable to be fully aligned with a soundscape design agenda. Bedrooms are preferable on the north-east façade to capture morning light and are cooler in the summer evenings (Level, 2015). However to do so would place the bedrooms in direct exposure to the railway corridor. Placing the bedrooms on the western façade exposed them to afternoon and early evening sun. To reduce low-angle glare and privacy from any new medium density developments nearby, the window sizes were reduced. To compensate for this, the western facade was iteratively altered (Figure 7.17) to angle outwards, creating more prominent views northward giving better daylighting.

To conclude and reflect upon the design of the terraced houses; recall that soundscape is influenced by context, and the individual is part of that context. Residents will be aware that by living in these terraced houses they will be partially exposing themselves to a railway environment; and as such have some expectations for noise. The body of research into soundscape indicates that the provision of a distinct 'quiet side' should enable these residents to physiologically and psychologically cope better than a house with no specific noise control design. With the prior established fact that noise annoyance is only up to 33% attributable to acoustical factors, this house's internal function for residents was not to solely reduce decibel measurements, but act as a well-designed context to generate a



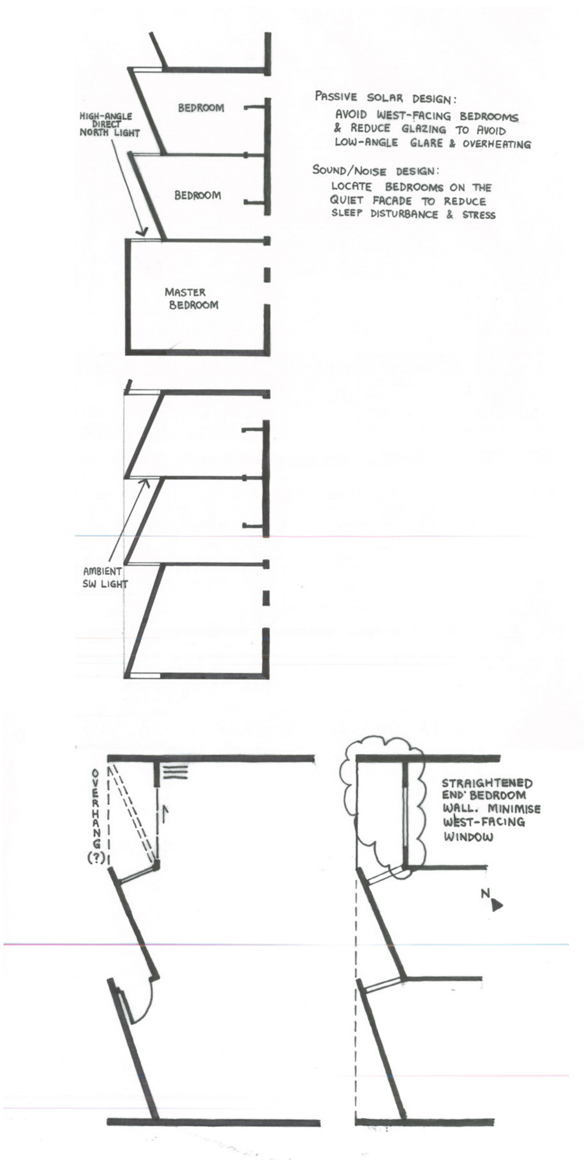


Figure 7.17 Iterative adjustment of the western facade to increase privacy and reduce afternoon sun glare.

positive perceptual soundscape that overlooks a revitalised railway corridor, train station and local centre. Externally, the houses improve the soundscape of Linden's residential areas, restoring a high-fidelity soundscape by allowing residential soundmarks to express themselves and the train noise to remain as an ambient keynote.

7.5 Mixed-Use Local Centre

The mixed-use local centre buildings (locatable in Figure 7.3) were developed after the focused-design of the terraced houses (Chapter 7.4); which took priority in the relatively noise-sensitive suburban residential programme. As discussed in Chapter 5, it was deduced and posited that programmes used within a vibrant mixed-use local centre would most likely be less susceptible to negative aural perceptions within the railway corridor. If anything, the encouraged indoor-outdoor interactions of retail and eating services introduces more 'human' and personally relatable sounds into the previously mechanically-dominated and impersonal railway soundscape (Figure 7.18).

The programme planning layout and developed plan of the mixed-use buildings were based upon the same principles and concepts that informed the terraced houses (Figure 7.19 and Appendices C-D). Programmes that would beneficially contribute to the soundscape composition between train station and local centre are suggested.

Figure 7.18 A variety of activities can occur in the mixed-use local centre through layers of spaces created by angled walls and building forms.

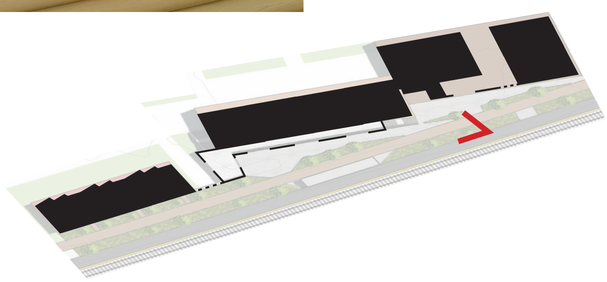
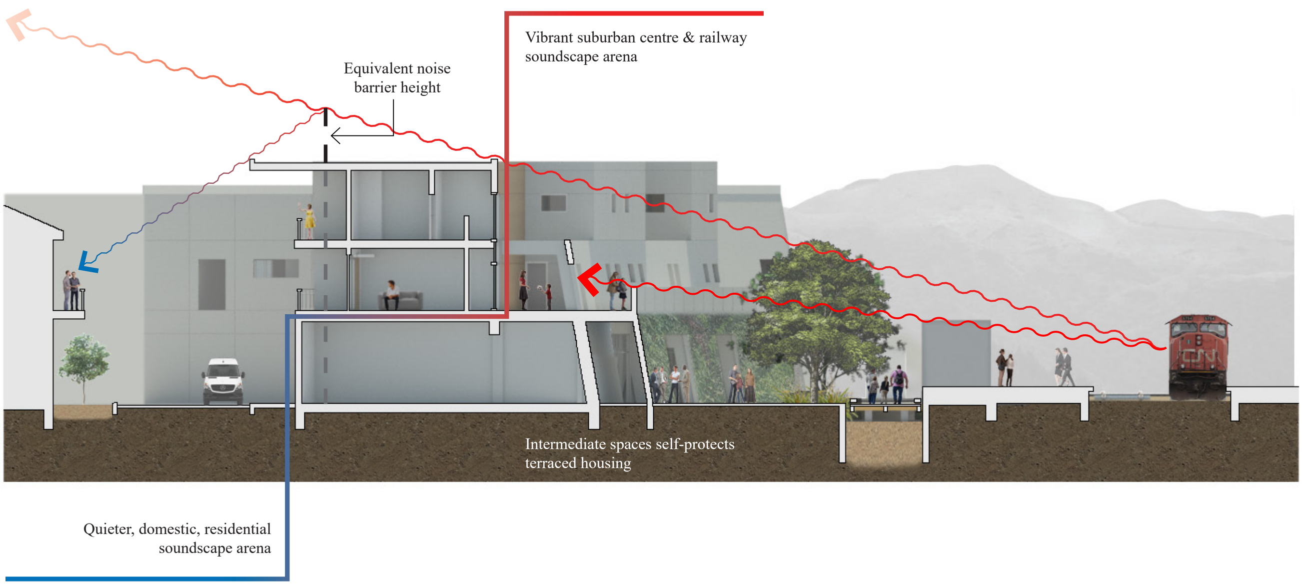


Figure 7.19 Programme layout and soundscape/acoustic design rationale of the mixed-use local centre. Some specific retail programmes are suggeseted based on their potential contribution towards the greater soundscape, noise masking potential, and prevalence in the original Linden centre (and other Tawa local centres).


Noise Sensitivity
high
moderate
low
physical permeability
visual permeability
DN
UP
Layering of spaces from
public balcony to shared yard
Layering of spaces for
public & retail to mix
Acoustic lock
entrance
Railway Corridor
Collins Avenue


Equivalent noise
barrier height
Vibrant suburban centre & railway
soundscape arena
Intermediate spaces self-protects
terraced housing
Quieter, domestic, residential
soundscape arena

7.6 Chapter Conclusion

The resulting developed design served as an interpretation of the literature and preliminary design when given a direction and soundscape context by a project site and programme. This was where the replicability of the preliminary design exploration came into play. Each developed design element had a clear history back to a preliminary acoustic design experiment or was inspired by a piece of psychoacoustic and soundscape literature. Some core concepts from the preliminary design process were shelved while others were developed further, adapting to the project requirements to achieve the portfolio's aims and objectives.

CHAPTER 8
PORTFOLIO CONCLUSION & REFLECTION

This portfolio investigated the application of soundscape principles in architectural design as a way of enabling sustainable densification and healthy inhabitation of noisy urban environments. The project was conceived in response to the developing worldwide design problem of increasing urban environmental noise levels, and its detrimental effects on human health. This portfolio proposed the use of psychoacoustics and soundscape philosophy as an alternative approach to acoustic design. This adds qualitative and perceptual design considerations to quantitative criteria.

By incorporating a range of research fields, it became evident that soundscape philosophy better enabled architectural design to engage with the design of the acoustic environment. Noises were broken down and treated as individual sounds to be carefully composed rather than a biproduct of urban densification. The resulting developed design reflected this by holistically incorporating acoustic design with psychoacoustics, soundscape manipulation, and the implications of context on spatial experience.

The portfolio heavily relied upon a developing body of research, some of which is ongoing and not fully established. This meant some areas of design exploration were more speculative than others and could be subject to further revision and development in the future.

The portfolio research and design process indicate a degree of replicability and adaptability. The site selection process showed that similar urban noise problems can be found elsewhere. Preliminary design experiments that were put aside for the developed design process can be used elsewhere, and adapted in their own way to fit the differing site and programme.

A limitation of the project was the lack of available school resources to model, closely examine, and evaluate the acoustic environments of the site and design concepts. If those resources were available, it would have greatly strengthened the design outcome, better enabling the integral use of acoustic and soundscape approaches. This was well compensated by thoroughly researching basic acoustic design principles, and the time spent exploring the complex but highly interesting proposition that people's aural experiences are a stronger determinant on environmental satisfaction. However, by focusing solely on acoustic and soundscape design, the visual dimension tended to be neglected where it did not interact with aural perception. Understanding people's visual and architectural form preferences would be another line of design exploration in itself, and were not central to this project's investigation. The final forms were mostly the result of aural, acoustical, and functional considerations and priorities. Synthesising a visual design agenda with soundscape design could be a way of improving and continuing the project beyond its original scope.

One of the important findings of this portfolio was the realisation that soundscape design has an inherent limitation: there remained several unknowns regarding the certainty of the developed design's success through soundscape, specifically the contexts of the unique person and person-place interactions. It was impossible to fully predict nor simulate the experiential results, whether through text or images. Even in a virtual-reality technology the user is not made to live in the environment, hence the context behind the soundscape responses and outcomes remained disjointed to reality. Therefore limitation cannot be overcome through architectural design process and methodology. The successful densification and sustainable inhabitation of Linden Station with the developed design solution will ultimately remain unknown until the project is built and post-occupancy reports and surveys are carried out. The portfolio's literature, site, and programme analysis only allowed the author/designer to tentatively predict and anticipate a typical user's attitude and reactions to sound.

The work acknowledged that there are many more facets of possible acoustic and soundscape considerations. This necessitates any master-level studies appearing somewhat limited in scope, and its inability to address everything within a single portfolio project. Even with the focus on place-context manipulation, many design scales (especially interior design) remain considered but not extensively explored. Just like research into psychoacoustics and soundscape, future projects could be built upon this portfolio in order to address soundscape design in its fullest capacity. One particular area of exploration outside of place in context that could be further explored is how a person's context (i.e. history, upbringing, personal preferences, cultural preferences, age-culture, etc.) affects the way his/her surrounding architectural environment generates his/her soundscape.

The implementation of soundscape principles into architectural and acoustics is a relatively new design approach. This portfolio and project design served as an example of its potential usage in an attempt to increase living density yet maintain a healthy, sustainable lifestyle. Noisy and challenging acoustic environments will continue to be a problem for designers as the urban context becomes more densely populated. By introducing soundscape research into design, it is hoped designers will engage with the alternative route of manipulating sound/noise perception through contextual design rather than purely through the increasingly louder acoustic environment.

LIST OF REFERENCES

Aletta, F., Kang, J., Astolfi, A., & Fuda, S. (2016). Differences in soundscape appreciation of walking sounds from different footpath materials in urban parks. *Sustainable Cities and Society, 27,* 367-376.

Aletta, F., Kang, J., Fuda, S., & Astolfi, A. (2016). The effect of walking sounds from different walked-on materials on the soundscape of urban parks. *Journal of Environmental Engineering and Landscape Management, 24*(3), 165-175.

ArchDaily. (2016, January 15). *Elizabeth II / Bates Masi Architects*. Retrieved from ArchDaily: https://www.archdaily.com/780342/elizabeth-ii-bates-masi-architects/> ISSN 0719-8884

Auckland Council. (2018, February 23). *E25 Noise and Vibration*. Retrieved from Auckland Council: http://unitaryplan.aucklandcouncil.govt.nz/Images/Auckland%20Unitary%20Plan%20Operative/Chapter%20E%20Auckland-wide/3.%20Built%20environment/E25%20Noise%20and%20vibration.pdf

Auckland Council. (n.d.). *Swales & Filter Strips Construction Guide*. Auckland: Auckland Council.

Aylor, D.E., & Marks, L.E. (1976). Perception of noise transmitted through barriers. *Journal of the Acoustical Society of America, 59*, 397-400.

Berglund, B. (1998). Community noise in a public health perspective. *Proceedings of Inter-Noise*. Christchurch, New Zealand.

Blesser, B., & Salter, L-R. (2007). *Spaces speak, are you listening?* Massachusetts: Massachusetts Institute of Technology.

Brown, A.L., & Muhar, A. (2004). An approach to the acoustic design of outdoor space. *Journal of Environmental Planning and Management, 47*, 827-842.

Brown, A.L., Gjestland, T., & Dubois, D. (2016). Acoustic Environments and Soundscapes. In J. Kang, & B. Schulte-Fortkamp, *Soundscape and the Built Environment* (pp.1-16). Boca Raton, FL, USA: CRC Press.

Brumm, H. (2004). The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology, 73*, 434-440.

Burgess, D. (2014, March 3). *Next stop Africa for Capital's well-used trains*. Retrieved from Stuff.co.nz: http://www.stuff.co.nz/business/industries/9781316/Next-stop-Africa-for-Capitals-well-used-trains

Carles, J.L., Barrio, I.L., & de Lucio, J.V. (1999). Sound influence on landscape values. *Landscape and Urban Planning*, 43, 191-200.

Carmona, M., Tiesdell, S., Heath, T., & Oc, T. (2010). *Public Places Urban Spaces - The Dimensions of Urban Design*. Abingdon, Oxon, UK: Routledge.

Christchurch City Council. (2016). *Rain Garden Design, Construction and Maintenance Manual*. Christchurch: Christchurch City Council.

Clare Cousins Architects. (2015). *Rail House*. Retrieved from Clare Cousins Architects: http://clarecousins.com.au/projects/rail-house/

Crafti, S. (2016, July 4). *What Architecture can Achieve*. Retrieved from Open Journal: http://openjournal.com.au/architecture-can-achieve/

De Kluizenaar, Y., Janssen, S., Vos, H., Salomons, E., Zhou, H., & van den Berg, F. (2013). Road traffic noise and annoyance: A quantification of the effect of quiet side exposure at dwellings. *International Journal of Environmental Research and Public Health, 10*(6), 2258-2270.

De Kluizenaar, Y., Salomons, E.M., Janssen, S.A., van Lenthe, F.J., Vos,H., Zhou,H., . . . Mackenbach, J.P. (2011). Urban road traffic noise and annoyance: the effect of a quiet façade. *Journal of the Acoustic Society of America, 130*(4), 1936-1942.

Dubois, D., Guastavino, C., & Raimbault, M.A. (2006). Cognitive approach to urban soundscapes: Using verbal data to access everyday life auditory categories. *Acta Acustica united with Acustica, 92*, 865-874.

Edwards, B. (1997). *The Modern Station: New approaches to railway architecture*. New York, USA: E & FN Spon.

Ermann, M.A. (2014). *Architectural Acoustics Illustrated*. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Finegold, L., & Hiramatsu, K. (2003). InterNoise: Linking soundscapes with land use planning in community noise management policies. *32nd International Congress and Exposition on Noise Control Engineering*. Seogwipo, South Korea: InterNoise - Covan International Corp.

Forssen, J. (2009). *Road Traffic Noise Levels at Partille Stom after Gap Filling Building Constructions*. Gothenborg, Sweden: Chalmers University of Technology.

Frearson, A. (2014, August 12). *Gardens are interspersed with rooms inside House-K by K2YT*. Retrieved from Dezeen: https://www.dezeen.com/2014/08/12/house-k-indoor-gardens-tokyo-k2yt/

Gage, S., Ummadi, P., Shortridge, A., Qi, J., & Jella, P.K. (2004). Using GIS to develop a network of acoustic environmental sensors. *ESRI International Users Conference*, (pp.15-28). San Diego, CA.

Guski, R. (1998). Psychological determinants of train noise annoyance. *Proceedings of Euro-Noise*. Munich, Germany.

Halfwerk, W., Holleman, L.J., Lessells, C.M., & Slabbekoorn, H. (2011). Negative impact of traffic noise on avian reproductive success. *Journal of Applied Ecology, 48*, 210-219.

HEAD acoustics GmbH. (2015). *Soundscape 2015*. Retrieved from HEAD acoustics: https://head-acoustics.de/downloads/eng/workshop/Soundscape_2015.pdf

Huddart, L. (1990). *The use of vegetation for traffic noise screening*. Crowthorne, Berkshire, England: Transport Research Laboratory.

Hunt, T. (2017, March 1). *Going, going ... still here: Wellington rail work horses gathering graffiti with no departure date set*. Retrieved from Stuff.co.nz: https://www.stuff.co.nz/dominion-post/news/89914243/Going-going-still-here-Wellington-rail-work-horses-gathering-graffiti-with-no-departure-date-set

Jiang, J., Toward, M.G., Dijckmans, A., Thompson, D.J., Degrande, G., Lombaert, G., & Ryue, J. (2013). Reducing Railway Induced Ground-Borne Vibration by Using Trenches and Buried Soft Barriers. *11th International Workshop on Railway Noise* (pp.555-562). Uddevalla: Springer.

Job, R.F. (1988). Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. *Journal of the Acoustical Society of America, 83*, 991-1001.

Joynt, J.L. (2005). *A Sustainable Approach to Environmental Noise Barrier Design*. PhD dissertation, University of Sheffield, School of Architecture, Sheffield, UK.

Kang, J. (2006). *Urban Sound Environment*. New York: Taylor & Francis.

Kang, J., & Schulte-Fortkamp, B. (Eds.). (2016). *Soundscape and the Built Environment*. Boca Raton, FL, USA: CRC Press.

Kaplan, R., & Kaplan, S. (1989). *The Experience of Nature: A Psychological Perspective*. New York, USA: Cambridge University Press.

Kariel, H.G. (1980). Mountaineers and the general public: a comparison of their evaluation of sounds in a recreational environment. *Leisure Sciences, 3*, 155-167.

Kirk, S. (2016, December 21). *Kiwirail to dump electric trains and replace with diesel on North Island main trunk line*. Retrieved from Stuff.co.nz: https://www.stuff.co.nz/national/politics/87810900/Kiwirail-to-dump-electric-trains-and-replace-with-diesel-on-North-Island-main-trunk-line

KiwiRail. (2011?). *Matangi Fact Sheet*. Retrieved from KiwiRail: http://www.kiwirail.co.nz/uploads/Publications/Matangi%20Fact%20Sheet1.pdf

KiwiRail. (n.d.). *Narrow gauge railway a pragmatic concession to reality*. Retrieved from KiwiRail: http://www.kiwirail.co.nz/about-us/history-of-kiwirail/150yearsofrail/stories/narrow-gauge.html

KiwiRail. (n.d.). *Office power stuggle preceded introduction of diesel electric locomotives*. Retrieved from KiwiRail: http://www.kiwirail.co.nz/about-us/history-of-kiwirail/150yearsofrail/stories/introducing-diesel-electric-locos.html

Lee, P.J., & Griffin, M.J. (2013). Combined effect of noise and vibration produced by high-speed trains on annoyance in buildings. *Journal of the Acoustical Society of America, 133*, 2126-2135.

Lercher, P. (1998). Deviant dose-response curves for traffic noise in 'sensitive areas'. *Proceedings of Inter-Noise*. Christchurch, New Zealand.

Level. (2015, June 22). *Solar Orientation - What is ideal for different rooms*. Retrieved from Level: http://www.level.org.nz/passive-design/location-orientation-and-layout/room-layout/

Level. (2018, February 7). *Key features of designing a home with passive design*. Retrieved from Level: http://www.level.org.nz/passive-design/

Lynch, K. (1960). *The Image of the City*. Cambridge, Massachusetts, USA: MIT Press.

Maffei, L., Brambilla, G., & di Gabriele, M. (2016). Soundscape as Part of the Cultural Heritage. In J. Kang, & B. Schulte-Fortkamp, *Soundscape and the Built Environment* (pp.215-242). Boca Raton, FL, USA, FL: CRC Press.

Magrab, E.B. (1975). *Environmental Noise Control*. London, UK: Wiley Interscience Publications.

Menge, C.W. (1978). Sloped barriers for highway noise control. *Proceedings of Inter-Noise*, (pp.509-512). San Francisco.

Miedema, H.M., & Vos, H. (1998). Exposure-response relationships for transportation noise. *Journal of the Acoustical Society of America, 104*, 3432-3445.

Mindell, J.S., Watkins, S.J., & Cohen, J.M. (2011). *Health on the Move 2: Policies for health promoting transport*. Stockport, UK: Transport and Health Study Group.

Ministry of Business, Innovation and Employment (NZ). (1995, December 1). *Compliance Document for New Zealand Building Code Clause G6 - Airborne and Impact Sound*. Retrieved from G6 Airborne and impact sound | Building Performance: https://www.building.govt.nz/assets/Uploads/building-code-compliance/g-services-and-facilities/g6-airborne-and-impact-sound/asvm/g6-airborne-and-impact-sound-1st-edition-amendment-2.pdf

Ministry of Railways: Government of India. (2009). *Manual for Standards and Specifications for Railway Stations*. New Delhi, India: Land & Amenities Directorate.

Moehler, U. (1988). Community response to railway noise: A review of social surveys. *Journal of Sound and Vibration, 120*(2), 321-332.

Moehler, U., Liepert, M., Schuemer, R., & Griefahn, B. (2000). Differences between railway and road traffic noise. *Journal of Sound and Vibration, 231*(3), 853-864.

Murray, B. (2014). *A History of Tawa*. Wellington, NZ: Tawa Historical Society.

Murray, B., & Parsons, D. (2008). *Rails through the Valley: The story of the construction and use of the railway lines through Tawa*. Wellington, NZ: Tawa Historical Society.

Neufert, E. (2012). *Architects' Data* (4th ed.). Chichester, UK: Wiley-Blackwell.

NZ Transport Agency. (2010). *NZTA State Highway Noise Barrier Design Guide*. Wellington: NZ Transport Agency National Office.

Ohrstrom, E., Skanberg, A., Svensson, H., & Gidlof-Gunnarsson, A. (2006). Effects of road traffic noise and the benefit of access to quietness. *Journal of Sound and Vibration, 295*(1), 40-59.

Ong, W.J. (1991). *Orality & Literacy - The Technologizing of the World*. London, UK: Routledge.

Pallasmaa, J. (2005). *The Eyes of the Skin: Architecture and the Senses*. Chichester, UK: Wiley-Academy.

Paquette, D. (2004). *Describing the contemporary sound environment: An analysis of three approaches, their synthesis, and a case study of Commercial Drive*, Vancouver, BC. Retrieved from ProQuest Dissertations & Theses Global: https://search.proquest.com/docview/305073332?accountid=14782

Perfater, M.A. (1979). *Community Perception of Noise Barriers* (Vol. 1). Virginia, USA: Virginia Highway and Transportation Research Council.

Porteous, J.D., & Mastin, J.F. (1985). Soundscape. *Journal of Architectural and Planning Research, 2*, 169-186.

Rieper, A. (2013). *The Architectural Manipulation of Sound: Architecturally Articulating Urban Space to Protect and Enhance the Outdoor Acoustic Environment*. Wellington: Victoria University of Wellington.

Schafer, R.M. (1993). *The Soundscape: Our Sonic Evironment and the Tuning of the World*. Rochester: Destiny Books.

Schomer, P., Mestre, V., Fidell, S., Berry, B., Gjestland, T., Vallet, M., & Reid, T. (2012). Role of community tolerance level (CTL) in predicting hte prevalence of the annoyance of road and rail noise. *Journal of the Acoustical Society of America, 131*, 2772-2786.

Spencer-Hwang, R., Montgomery, S., Dougherty, M., Valladares, J., Rangel, S., Gleason, P., & Soret, S. (2014). Experiences of a Rail Yard Community: Life is Hard. *Journal of Environmental Health, 77*(2), 8-17.

Stewart, M. (2012, June 25). *After 74 years, English Electric trains retire*. Retrieved from Stuff.co.nz: http://www.stuff.co.nz/dominion-post/news/7166348/After-74-years-English-Electric-trains-retire

Tamura, A. (1998). An environmental index based on inhabitants' recognition of sounds. *Proceedings of the 7th International Congress on Noise as a Public Health Problem*. Sydney, Australia.

Truax, B. (1999). *Handbook for Acoustic Ecology* (2nd ed.). Burnaby, B.C., Canada: Cambridge Street Publishing.

Truax, B. (2001). *Acoustic Communication*. London: Ablex.

Turner, D., Hewitt, J., Wagner, C., Su, B., & Davies, K. (2004). *A report on Best practice in medium density housing design for Housing New Zealand Corporation*. Auckland: Unitec New Zealand.

Ulrich, S.R. (1993). Biophilia, biophobia, and natural landscapes. In S. R. Kellert, & E. O. Wilson, *The Biophilia Hypothesis* (pp.73-137). Washington DC, USA: Island/Shearwater Press.

Van Beek, A., Beuving, M., Dittrich, M., Beier, M., Zhang, X., Jonasson, H., . . . Ringheim, M. (2002). *Rail Sources: State of the Art*. European Commision.

Van den Berg, A.E., Koole, S.L., & van der Wulp, N.Y. (2003). Environmental preference and restoration: (how) are they related? *Journal of Environmental Psychology, 23*, 135-146.

van Kamp, I., Klaeboe, R., Brown, A.L., & Lercher, P. (2016). Soundscapes, Human Restoration, and Quality of Life. In B. Schulte-Fortkamp, & J. Kang, *Soundscape and the Built Environment* (pp.43-68). Boca Raton, FL, USA: CRC Press.

Van Renterghem, T., & Botteldooren, D. (2012). Focused study on the quiet side effect in dwellings highly exposed to road traffic noise. *International Journal of Environmental Research and Public Health, 9*(12), 4292-4310.

Varughese, J. (2011). *Birds in the City*. Ahmedabad: Landscape Environment Advancement Foundation (LEAF).

Viollon, S. (2003). Two examples of audio-visual interactions in an urban context. *Proceedings of Euro-Noise*. Naples, Italy.

Viollon, S., Lavandier, C., & Drake, C. (2002). Influence of visual setting on sound ratings in an urban environment. *Applied Acoustics, 63*, 493-511.

Vuchic, V.R. (2007). *Urban Transit Systems and Technology*. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Watts, G.R. (1996). Acoustic Performance of Parallel Traffic Noise Barriers. *Applied Acoustics*, 95-119.

Watts, G., Chinn, L., & Godfrey, N. (1999). The effects of vegetation on the perception of traffic noise. *Applied Acoustics, 56*, 39-56.

Wiacek, J., Polak, M., Filipiuk, M., Kucharczyk, M., & Bohatkiewicz, J. (2015). Do Birds Avoid Railroads as Has Been Found for Roads? *Environmental Management, 56*, 643-652.

Yang, W., & Kang, J. (2005). Soundscape and sound preferences in urban squares: A case study in Sheffield. *Journal of Urban Design, 10*, 61-80.

Yano, T., Yamashita, T., & Izumi, K. (1996). Social survey on community response to railway noise-comparison of responses obtained with different annoyance scales. *Proceedings of Inter-Noise*. Liverpool, UK: Inter-Noise.

Zhou, X., Ouyang, Q., Zhu, Y., Feng, C., & Zhang, X. (2014). Experimental study of the influence of anticipated control on human thermal sensation and thermal comfort. *Indoor Air, 24*, 171-177.

SOURCE OF FIGURES

ALL FIGURES NOT ATTRIBUTED ARE THE AUTHOR'S OWN.

Figure 2.1 Adapted from Brown, A.L., Gjestland, T., & Dubois, D. (2016). A conceptual diagram... [Flowchart]. In Acoustic Environments and Soundscapes. In J. Kang, & B. Schulte-Fortkamp, *Soundscape and the Built Environment* (pp.1-16). Boca Raton, FL, USA: CRC Press.

Figure 2.2 Adapted from Brown, A.L., Gjestland, T., & Dubois, D. (2016). Conceptual model of various contexts... [Flowchart]. In Acoustic Environments and Soundscapes. In J. Kang, & B. Schulte-Fortkamp, *Soundscape and the Built Environment* (pp.1-16). Boca Raton, FL, USA: CRC Press.

Figure 2.3 Adapted from van Kamp, I., Klaeboe, R., Brown, A.L., & Lercher, P. (2016). Conceptual framework for effects of high levels of sound on health [Flowchart]. In Soundscapes, Human Restoration, and Quality of Life. In B. Schulte-Fortkamp, & J. Kang, *Soundscape and the Built Environment* (pp.43-68). Boca Raton, FL, USA: CRC Press.

Figure 2.4 van Kamp, I., Klaeboe, R., Brown, A.L., & Lercher, P. (2016). A model on the need and whether people lead a busy life or not... [Flowchart]. In Soundscapes, Human Restoration, and Quality of Life. In B. Schulte-Fortkamp, & J. Kang, *Soundscape and the Built Environment* (pp.43-68). Boca Raton, FL, USA: CRC Press.

Figure 2.5 Data adopted from Aylor, D.E., & Marks, L.E. (1976). Perception of noise transmitted through barriers. *Journal of the Acoustical Society of America, 59*, 397-400.

Figure 2.6 Data adopted from Joynt, J.L. (2005). *A Sustainable Approach to Environmental Noise Barrier Design*. PhD dissertation, University of Sheffield, School of Architecture, Sheffield, UK.

Figure 3.5 Adapted from City of Santa Fe New Mexico (2002). Section Cut Through North Railyard Area [Map]. In *Land Use*. Retrieved from Master Plan - Santa Fe Railyard Community Corporation: https://sfrailyardcc.org/sfrycc-content/uploads/2015/01/LandUse_MP.pdf

Figure 4.1 Adapted from Brown, A.L., Gjestland, T., & Dubois, D. (2016). A classification scheme for categorizing sound sources... [Chart]. In Acoustic Environments and Soundscapes. In J. Kang, & B. Schulte-Fortkamp, *Soundscape and the Built Environment* (pp.1-16). Boca Raton, FL, USA: CRC Press.

Figure 4.3 Adapted from Carmona, M., Tiesdell, S., Heath, T., & Oc, T. (2010). Designing for mixed uses... [Diagram]. In *Public Places Urban Spaces - The Dimensions of Urban Design*. Abingdon, Oxon, UK: Routledge.

Figure 4.6 Data adopted from Murray, B. (2006). *An Historical Atlas of Tawa*. Wellington, NZ: Tawa Historical Society.

Figure 4.8 Stats NZ (2013). *2013 Census map - population and dwelling*. Retrieved from: http://archive.stats.govt.nz/StatsMaps/Home/Maps/2013-census-population-dwelling-map.aspx?url=/StatsMaps/Home/Maps/2013-census-population-dwelling-map.aspx.

Figure 4.10 Noise maps created in browser tool by Environmental Health Consultancy - MAS Environmental (n.d.). *MAS Environmental Tools - Noise Mapping / Sound Level Mapping*. Retrieved from Noise Tools by MAS Environmental: dbmap.co.uk.

Figure 4.11 Kang, J. (2006). Typical spectra of car and train noise [Graph]. In *Urban Sound Environment*. New York: Taylor & Francis.

Figure 6.6 Data adopted from Metlink (2017). *KPL-web-April-2017*. Retrieved from Metlink-Greater Wellington's Public Transport Network: https://www.metlink.org.nz/assets/OLD-Timetables/Train/KPL-web-April-2017.pdf.

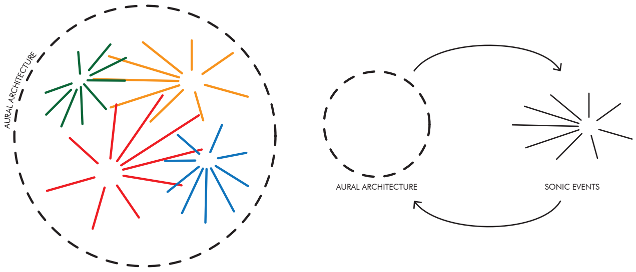
Figure 6.12 Expanded from Kang, J. (2006). Principles and examples of self-protection buildings, cross sectional view [Diagrams]. In *Urban Sound Environment*. New York: Taylor & Francis.

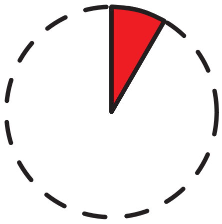
Figure 6.15 NZ Transport Agency. (2010). Effective height of an earth bund [Diagram]. In *NZTA State Highway Noise Barrier Design Guide*. Wellington: NZ Transport Agency National Office.

Figure 7.2 Noise maps created in browser tool by Environmental Health Consultancy - MAS Environmental (n.d.). *MAS Environmental Tools - Noise Mapping / Sound Level Mapping*. Retrieved from Noise Tools by MAS Environmental: dbmap.co.uk.

APPENDIX A
Additional portfolio material related to Chapter 2

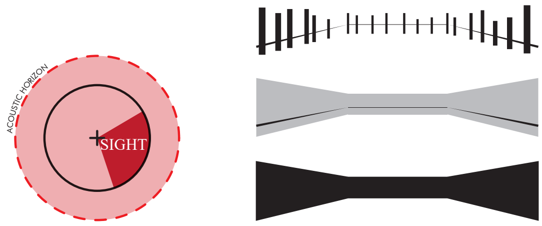
AURAL ARCHITECTURE & SOUNDSCAPE





Aural architecture & sonic events
[Cathedral|Recording Booth] [Singer]

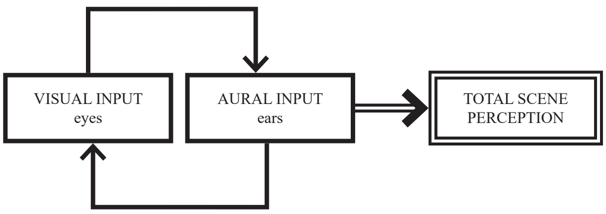
Visuals instantaneously affected by light
Aurals endure after noise source removal

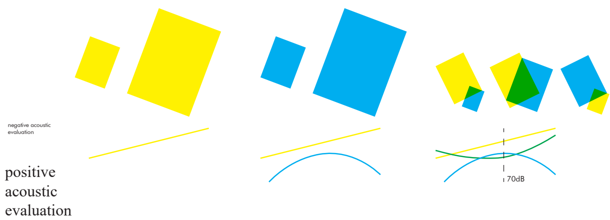


Separation and consistencies of visual and aural boundaries

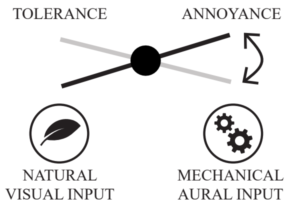
Physical/visual separation
Aural and acoustic binding

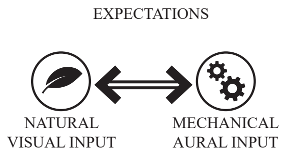
VISUAL-AURAL RELATIONSHIP RESPONSES





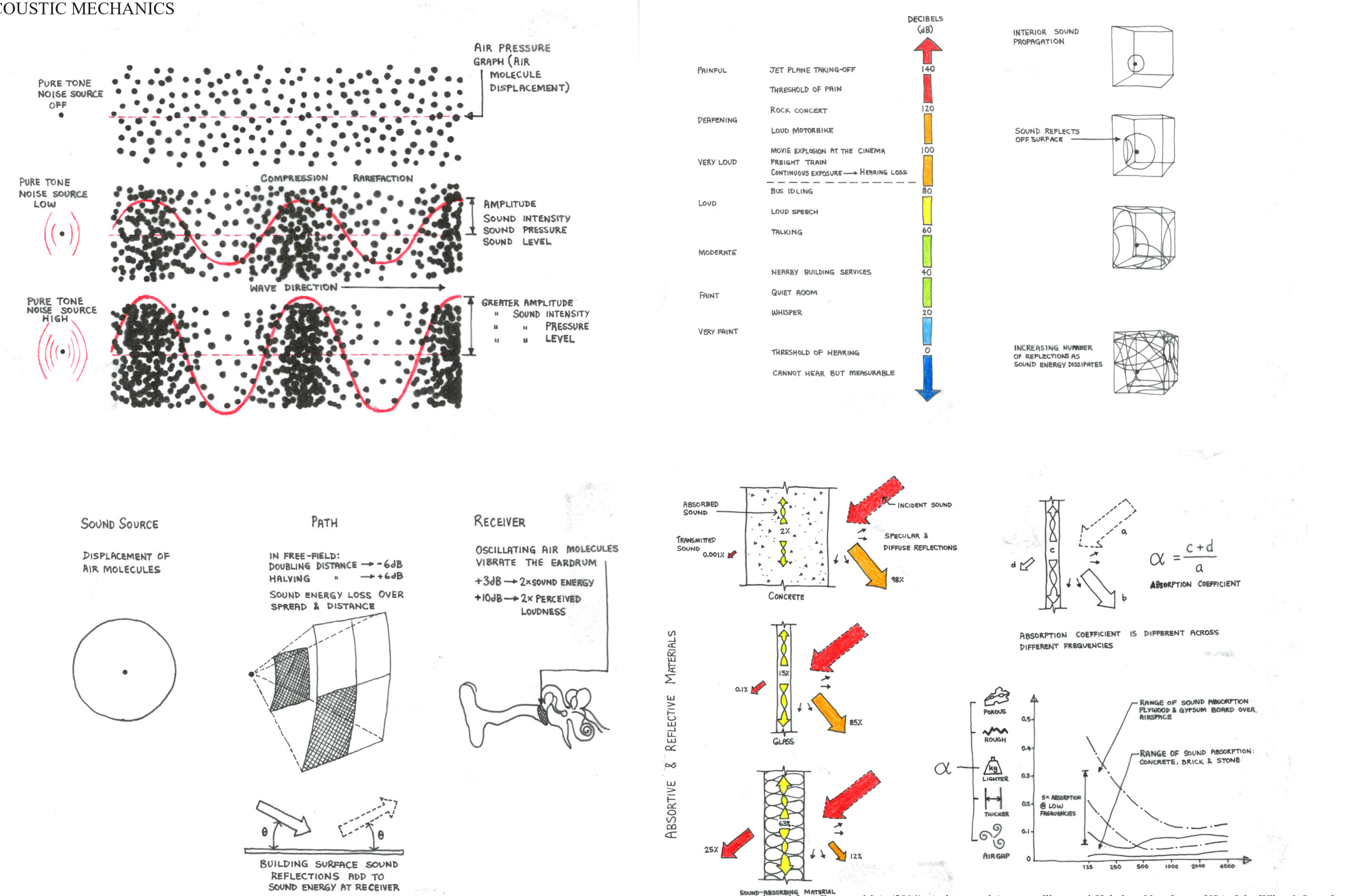
People have a high tolerance for natural sounds.
A loud natural sound can be used to mask over an unpleasant mechanical sound.





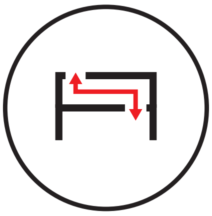
Is the aural input plausible given the visual setting?

ACOUSTIC MECHANICS



Adapted from Ermann, M.A. (2014). *Architectural Acoustics Illustrated*. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

SUMMATIVE DESIGN PRINCIPLES



Offset Openings & Indirect Transmission

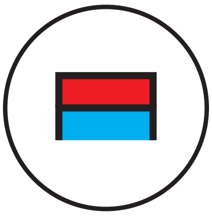
Offset physical permeability at various scales where movement through is needed.

Applicable at a range of scales from wall construction to urban block layout.

Loud & Quiet Facades

Distinguish soundscapes and establish higher quality acoustic environments.

Selectively filtering sounds to create correlation between visual and aural.



Program Hierarchy & Layering Spaces

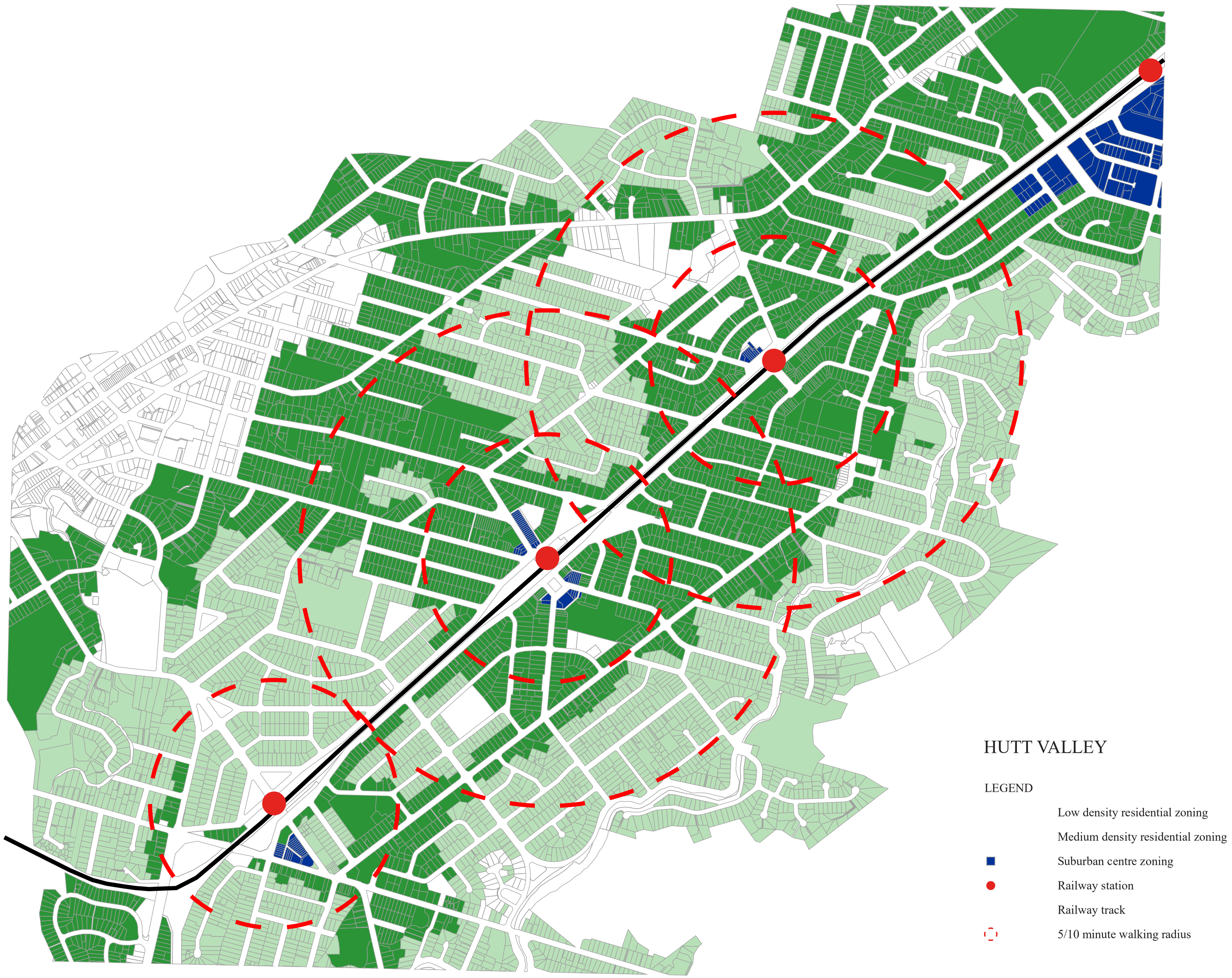
Evaluate programs' sensitivity to noise, protecting others by airgap and masking.

Selecting the program for maximum productivity and soundscape contribution.

Maximise Acoustic Shadow

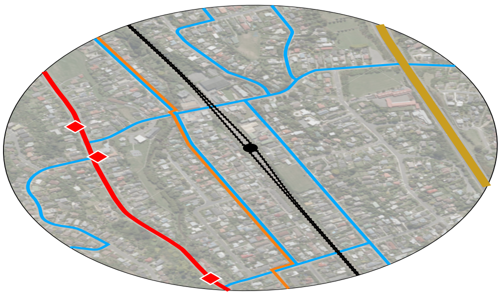
Increased height on the loud facade give better protection to elements behind.

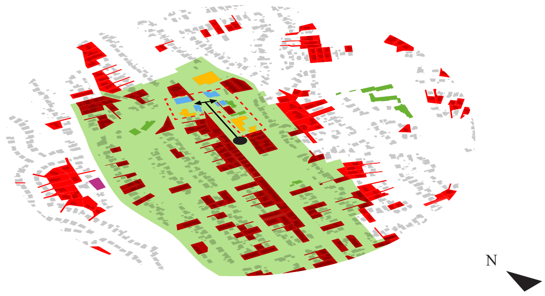
Lower surface height for a similar shadow proportional to the noise source distance.


HUTT VALLEY
LEGEND
Low density residential zoning
Medium density residential zoning
Suburban centre zoning
Railway station
Railway track
5/10 minute walking radius

Recreational Spaces

Porirua Stream





State Highway

Main Road/Bus Route

Collector Road

Kapiti Pedestrian/Bike Route

Kapiti Railway Line & Station

Industrial Establishment

Retail Establishement

Community Establishment

Cultural/Heritage Site

Current Residential

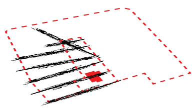
Medium Density Residential Area

Medium Density Typology

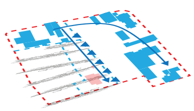
Suburban Centre

ENABLING DENSIFICATION

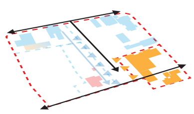
East-west orientation of housing maximises sunlight but enables noise to permeate deep into the suburban blocks



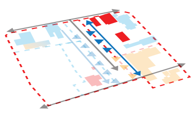
Introduction of retail-residential mixed-use along the railway line. North-south development acts as a buffering sacrificial program.



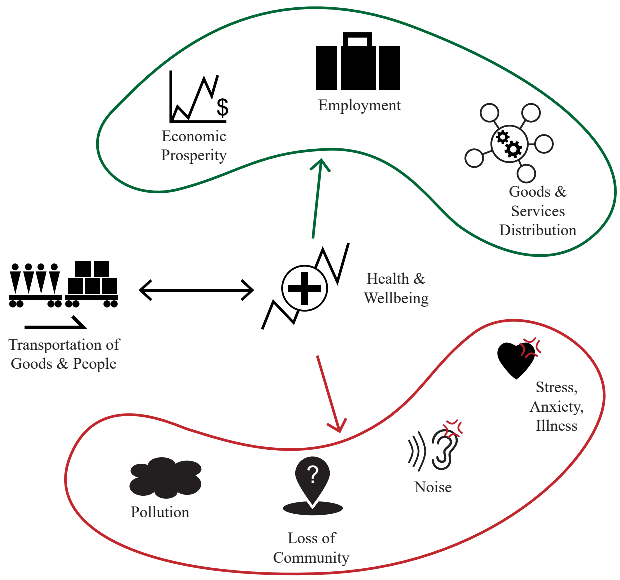
New suburban centre frontages encourages reorientation of existing services on the opposite side. New routes frame and increase permability.



The current stormwater ditch can be further utilised as public green space acting as a psychological noise mitigator.

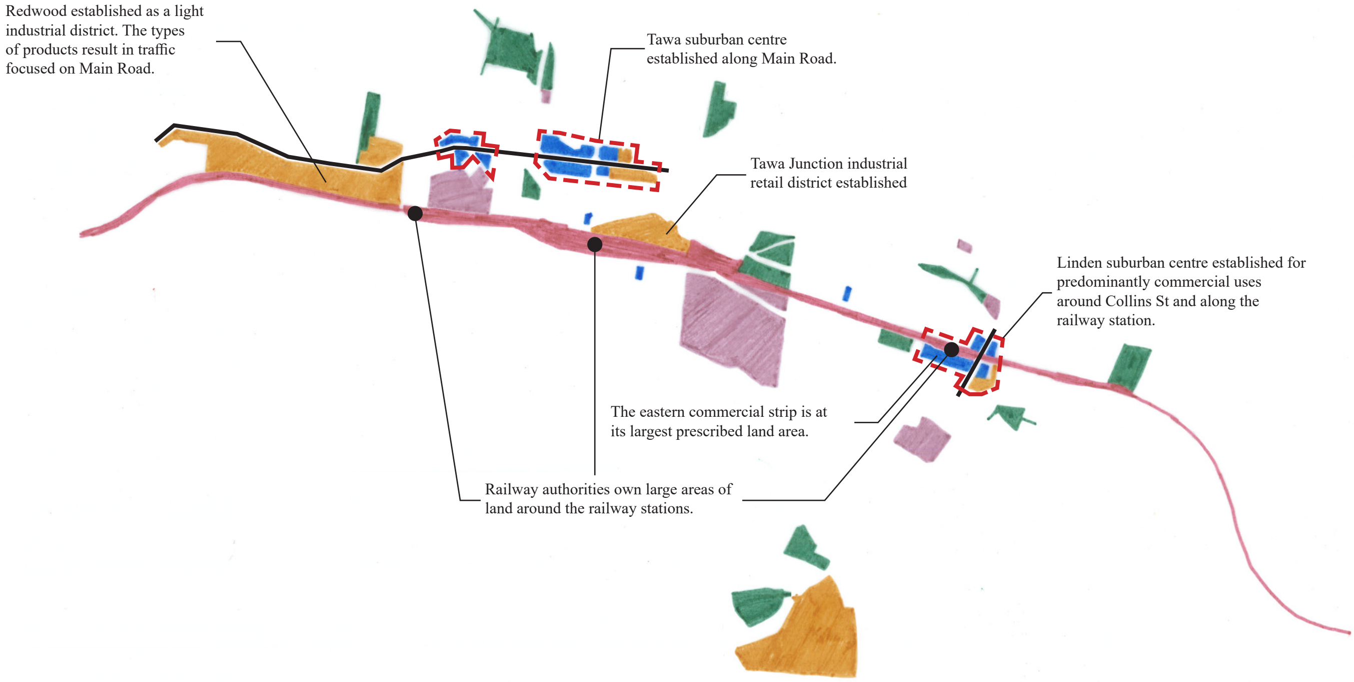


IMPORTANCE OF RAILWAY TO COMMUNITIES

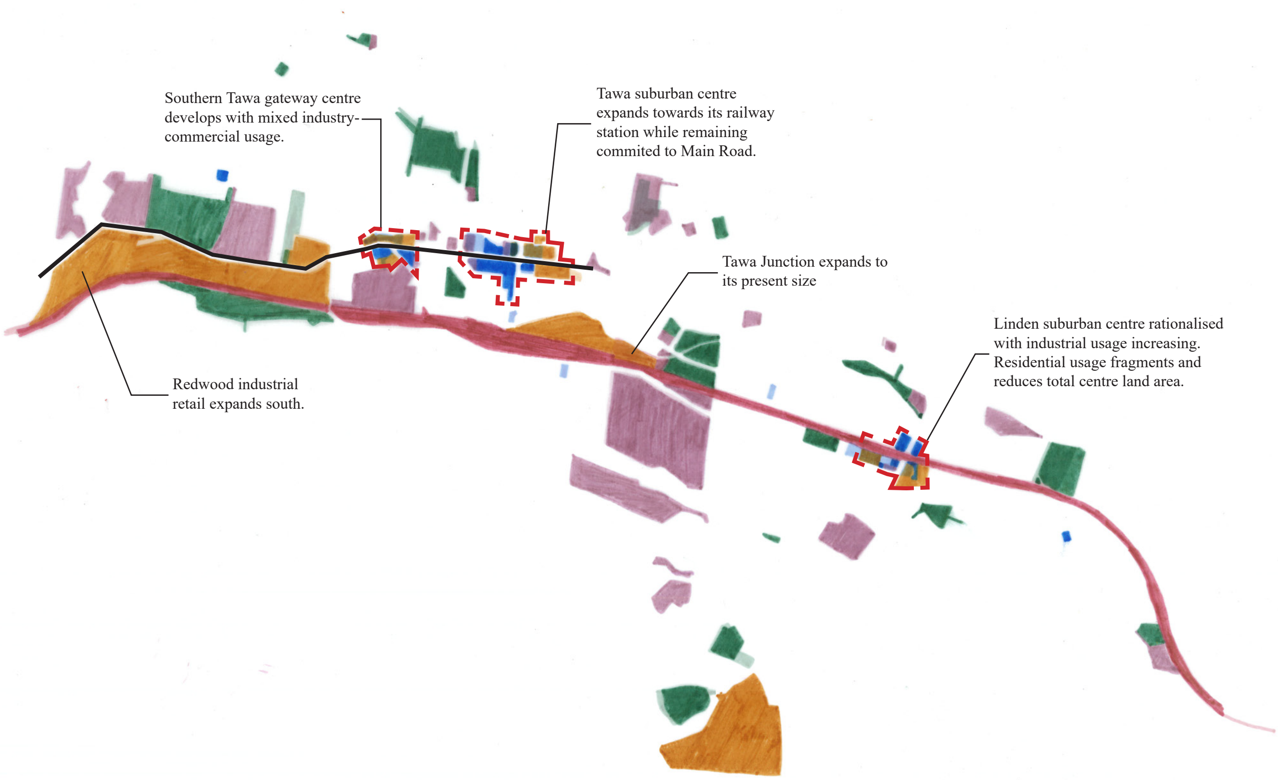


HISTORICAL DEVELOPMENT OF TAWA

1960



1968



1986

CURRENT

ADDITIONAL SITE CONSIDERATIONS

BUILDING CONTROLS

ARCHITECTURAL

- # of household units
- Building height
- Building recession planes

SITE

- Site coverage
- Minimum landscaping
- Front yard

PROVISION

- Vehicle parking

LAND USE

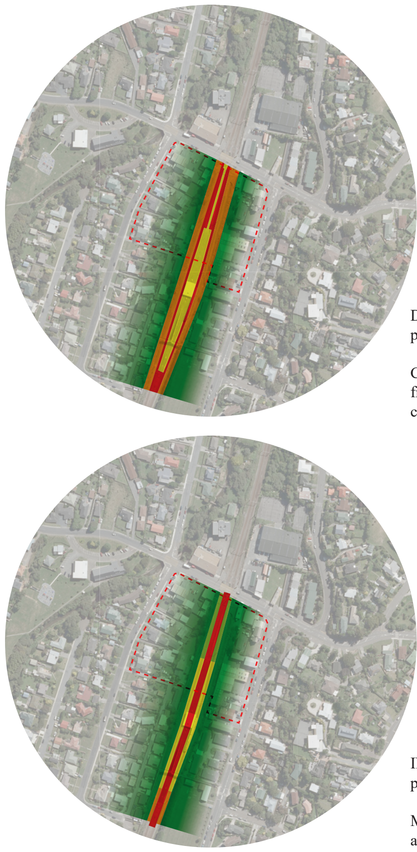
- Recreation/Park
- Community
- Retail
- Medium density residential

SITE ISSUES

- Noise annoyance
- Privacy

TRANSPORTATION MODES

- Walking
- Bicycle
- Train
- Bus



DIVISIVE - Island platform configuration

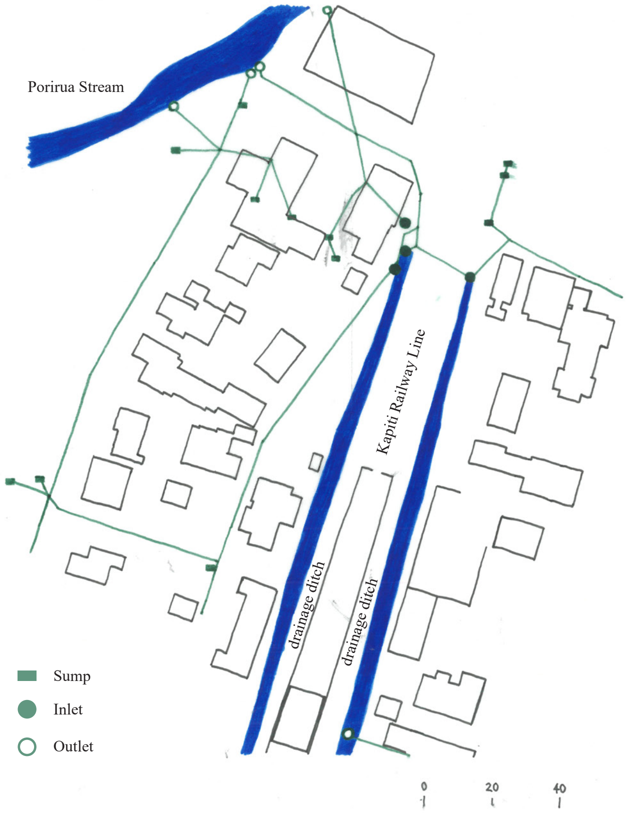
Commuters isolated from potential suburban centre activity

INTEGRATED - Side platform configuration

More land-use opportunities and connectivity between sides

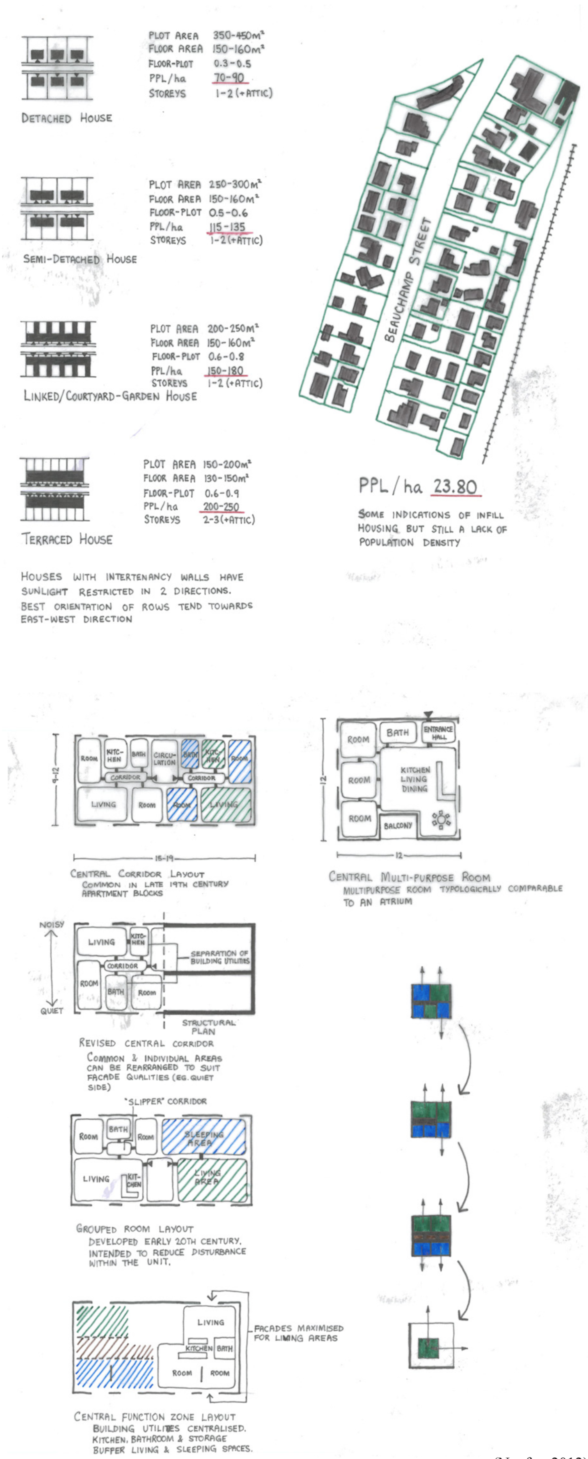
- Public access prohibited
- Public access restricted
- Commuter space
- Developable space

LINDEN STORMWATER SYSTEM

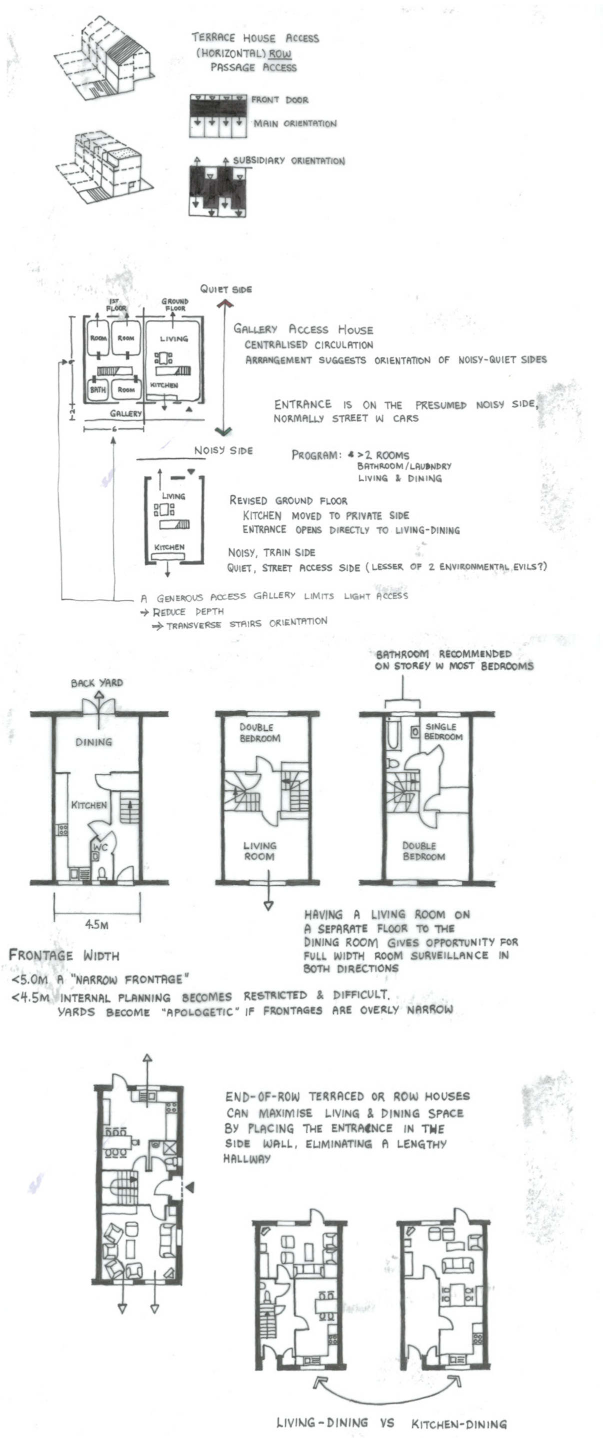


APPENDIX C
Additional portfolio material related to Chapter 6

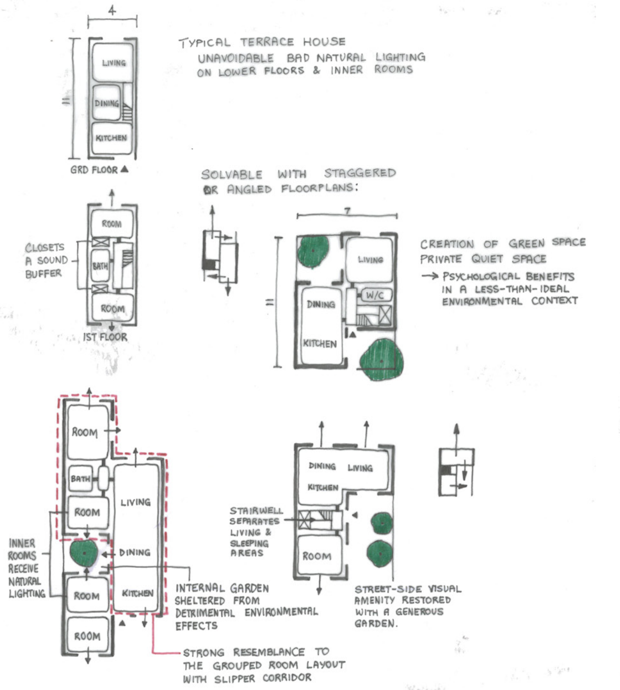
EVALUATION OF DWELLING DESIGN & PLANNING



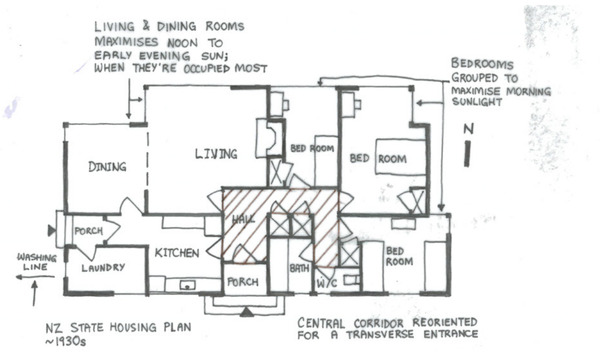
(Neufert 2012)

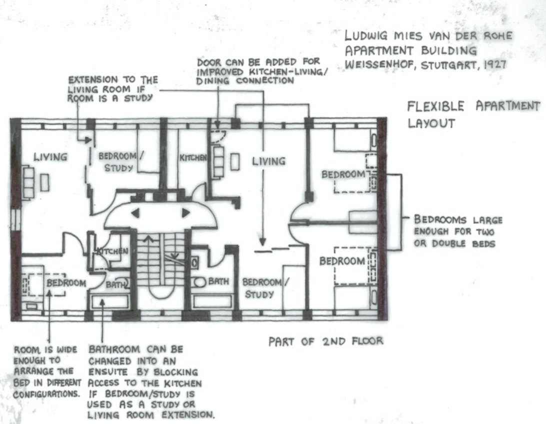


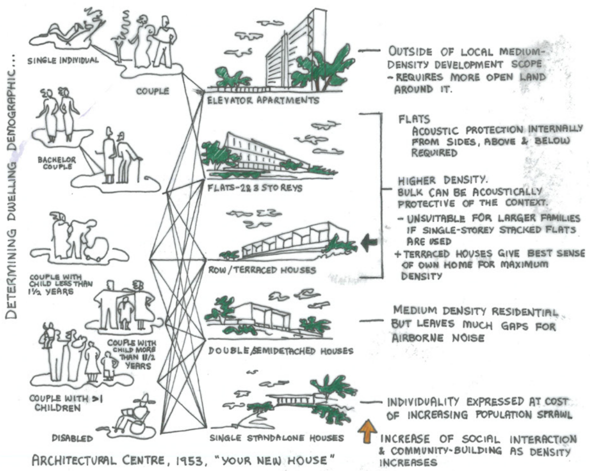
(Neufert 2012)

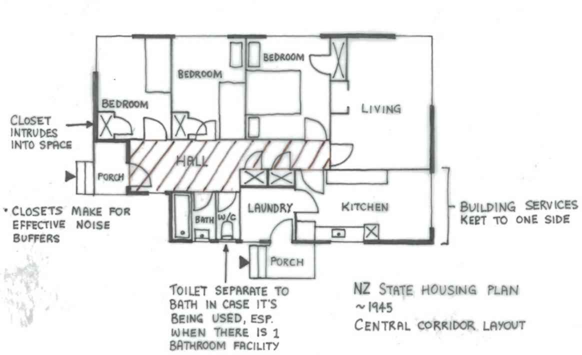


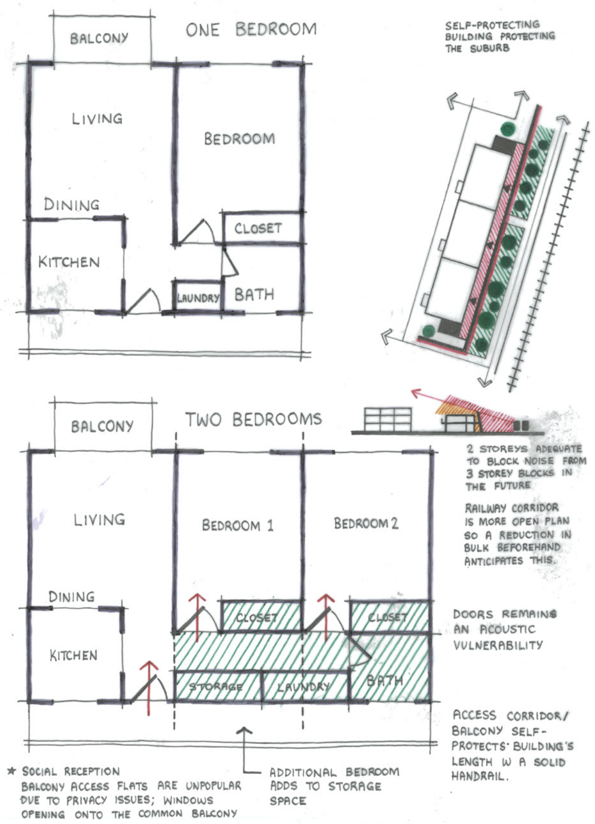
(Neufert, 2012)

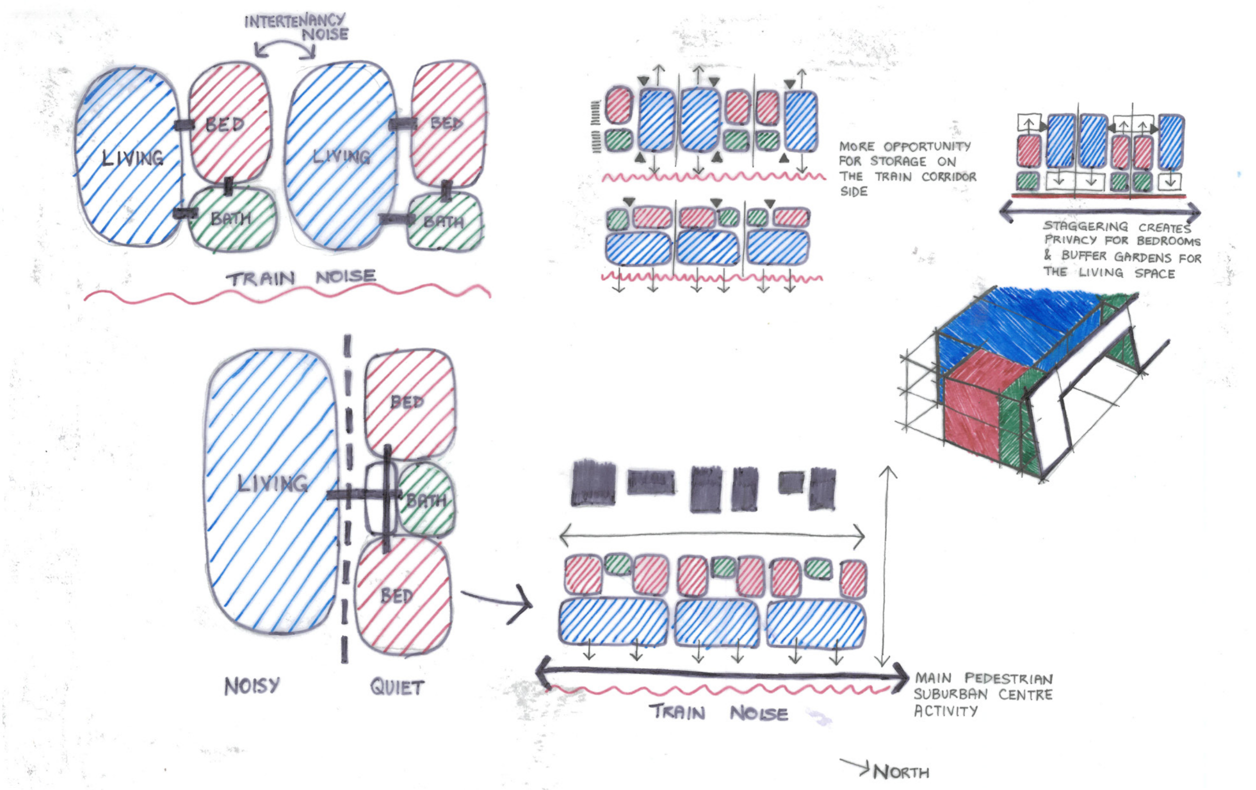


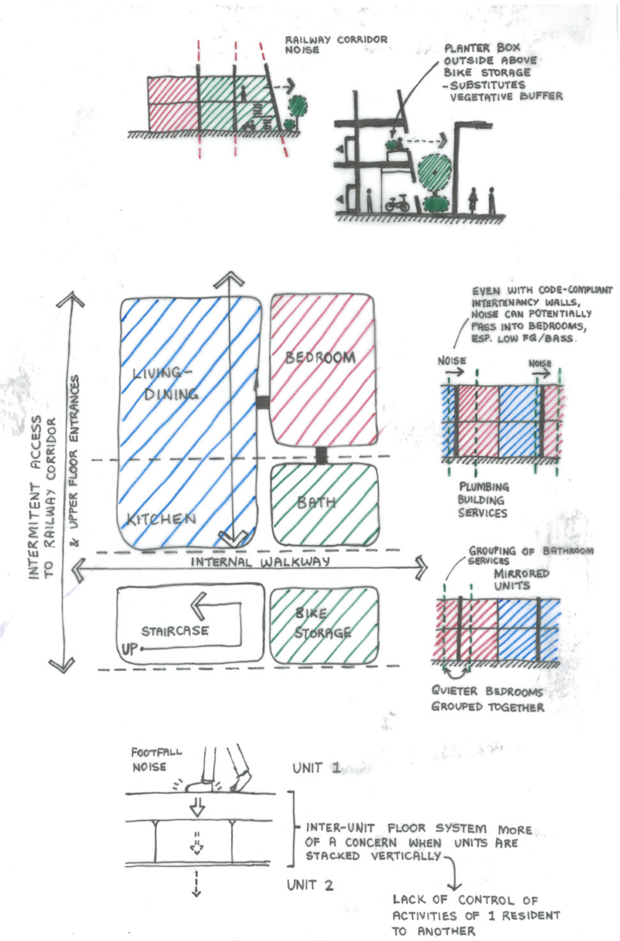


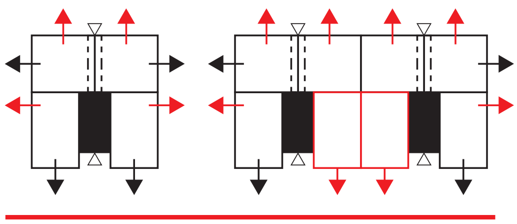






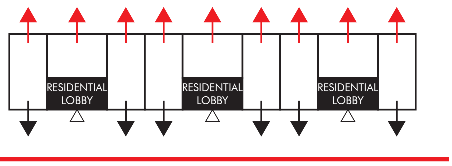




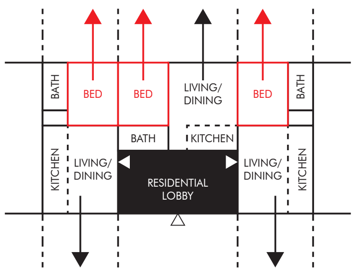


Dual aspect units around a central lobby

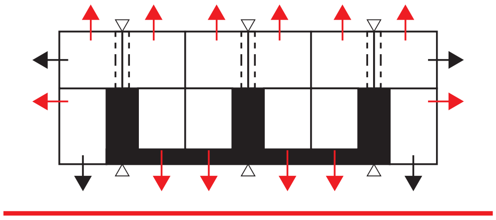
A row of the same creates single aspect units with bedrooms on the noisy side



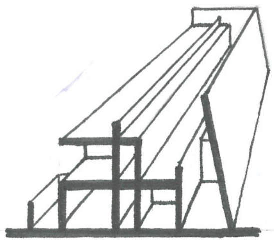
Depending on scale we can arrange dual and single aspect units or rooms around regular residential lobbies
A truly quiet building is unfeasible without excessive measures
Type 2 (loud-quiet sides) restoration will be the main method of residents coping

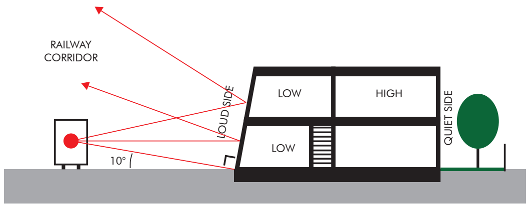


Single storey unit space constraints require mixing moderate and low noise-sensitivity programs
Living/dining noise disturbance is dealt with Type 2 aural restoration and a visual-aural connection to the noise source

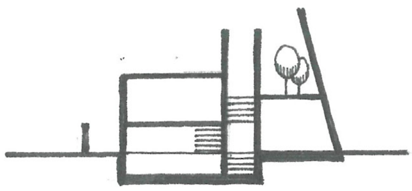


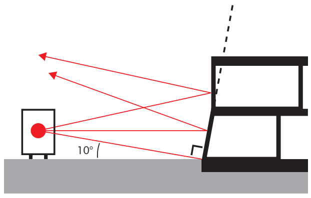
Adding balconies self-protects single-aspect rooms or single-aspect residential units
Separate residential units on different facades undesirably subjects inhabitants to more noise than others.



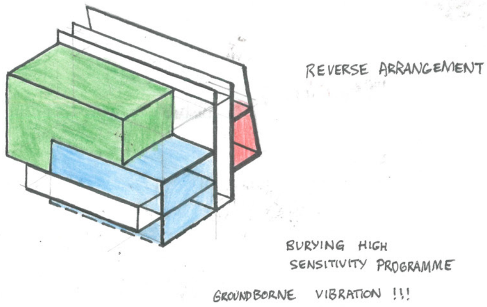


A barrier at right-angles to the noise source effectively eliminates second-order reflections off the ground.
Slope gestures openess in the rail corridor
Slight reduction in rail corridor width-height ratio

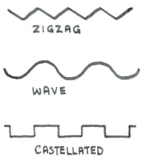




Noise reflections are less of an issue once the surfaces are above the noise source

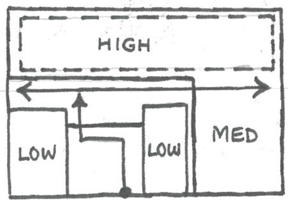


DISPERSIVE BARRIERS

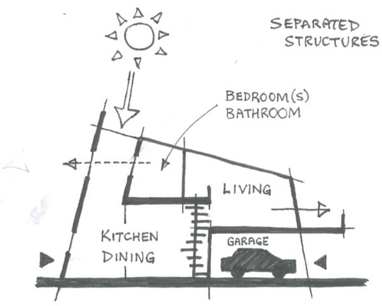


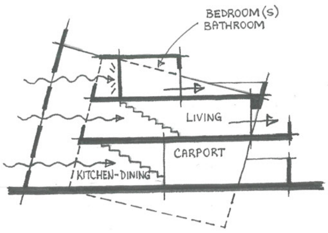
EXAMPLES OF DISPERSIVE BARRIERS / FACADES IN PLAN VIEW.
INCREASED SPACE REQUIRED BUT STRUCTURALLY BETTER THAN A STRAIGHT LINE.
POCKETS OF OPEN SPACE IN FRONT CAN BE FILLED WITH VEGETATION TO INCREASE DISPERSION OR ADD TO AESTHETIC PLEASANTNESS AT VERY LEAST.

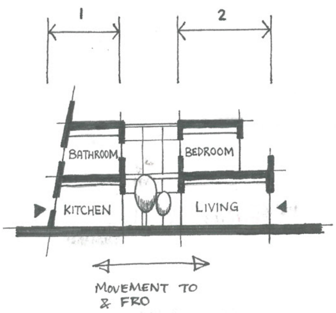
NOTE: LESS EFFECTIVE FOR LINE SOURCES. REFLECTIONS CAN FOCUS & REINFORCE IN AREAS, ESPECIALLY IN CONCAVED CURVE FORMS.

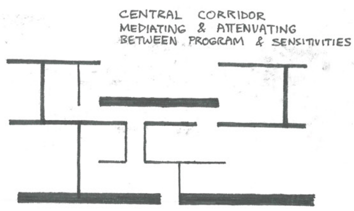


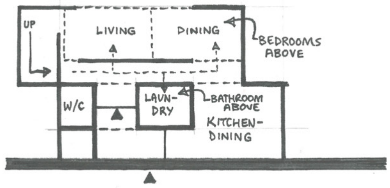
(Kang, 2006)





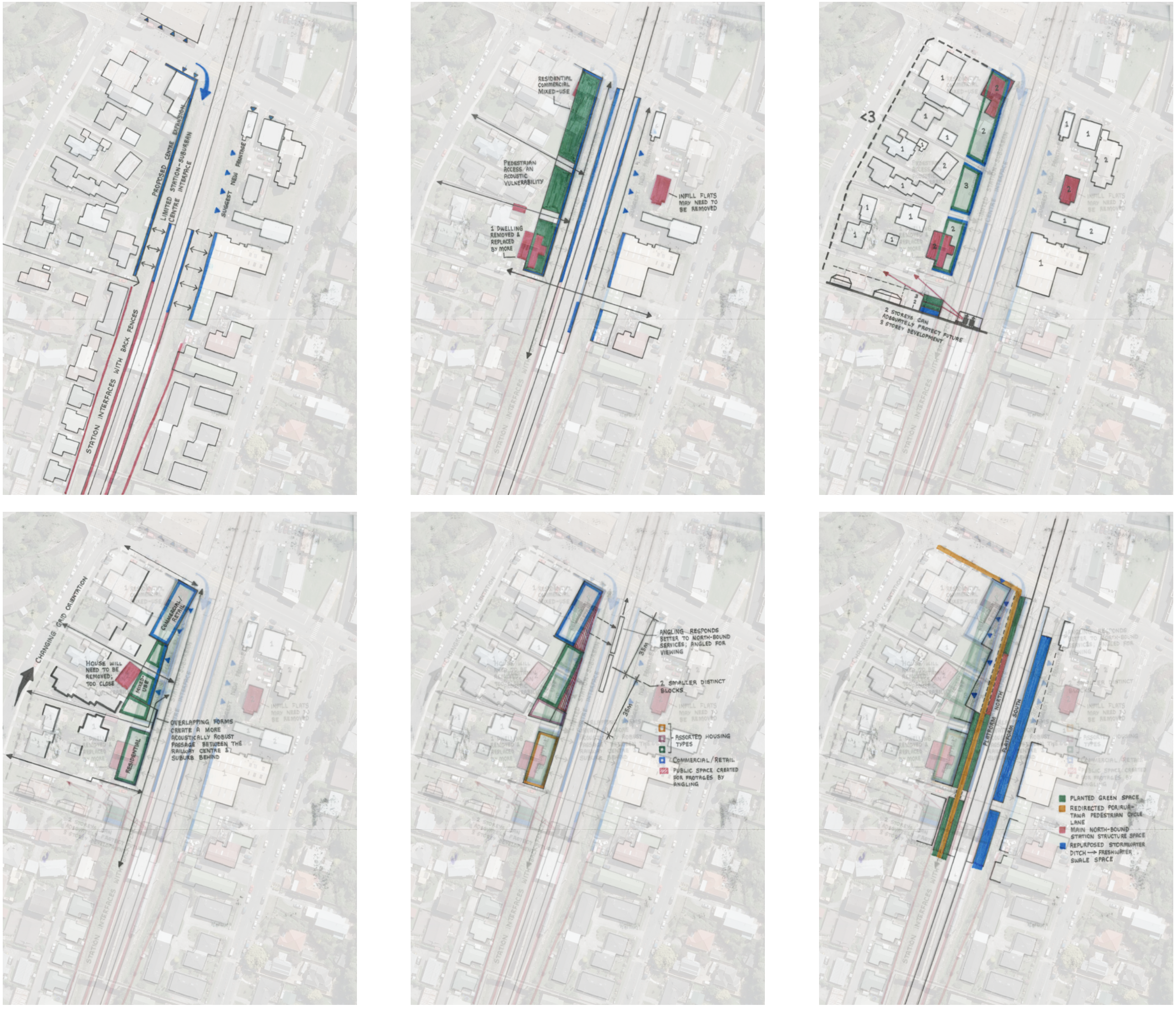




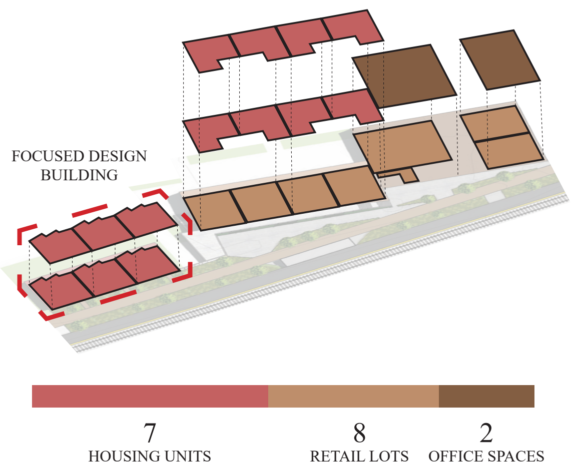


APPENDIX D
Additional portfolio material related to Chapter 7

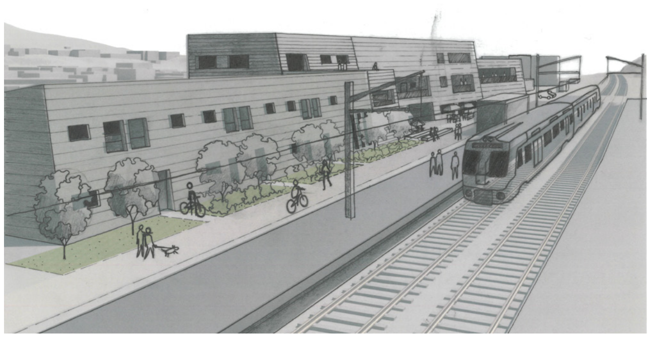
DEVELOPED MASTERPLAN DESIGN

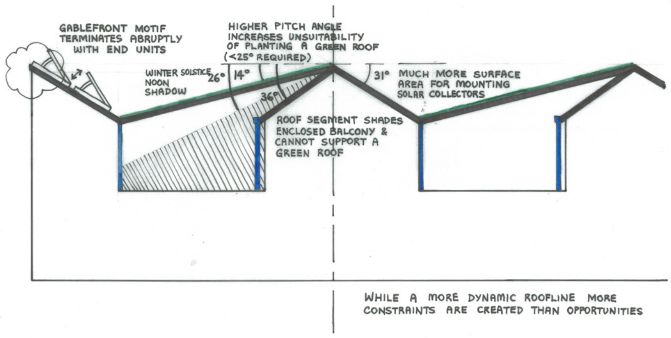


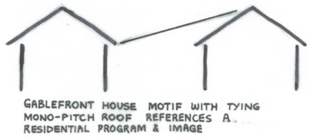
FLOOR AREA BREAKDOWN

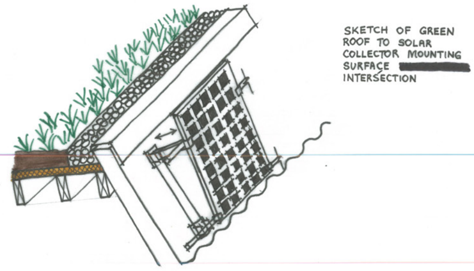


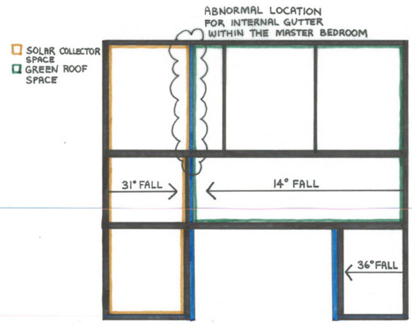
EARLY RENDER OF THE LIVING BARRIER

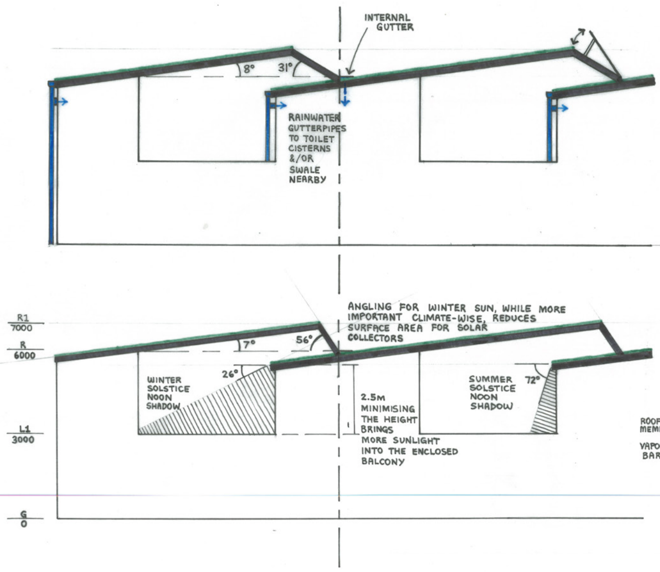


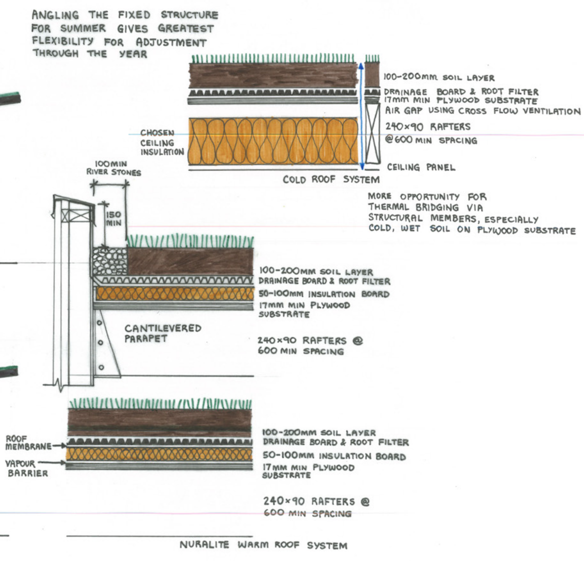

GABLEFRONT MOTIF TERMINATES ABRUPTLY WITH END UNITS
HIGHER PITCH ANGLE INCREASES UNSUITABILITY OF PLANTING A GREEN ROOF (<25° REQUIRED)
WINTER SOLSTICE NOON SHADOW
26°
14°
36°
31°
MUCH MORE SURFACE AREA FOR MOUNTING SOLAR COLLECTORS
ROOF SEGMENT SHADES ENCLOSED BALCONY & CANNOT SUPPORT A GREEN ROOF
WHILE A MORE DYNAMIC ROOFLINE MORE CONSTRAINTS ARE CREATED THAN OPPORTUNITIES


GABLEFRONT HOUSE MOTIF WITH TYING MONO-PITCH ROOF REFERENCES A RESIDENTIAL PROGRAM & IMAGE

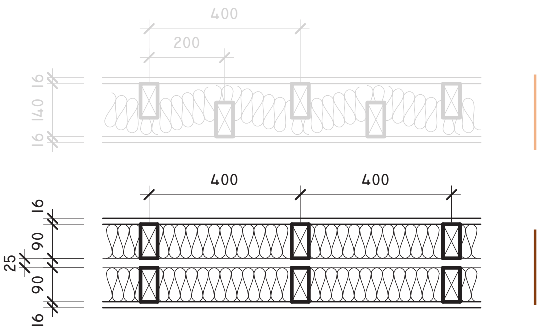

SKETCH OF GREEN ROOF TO SOLAR COLLECTOR MOUNTING SURFACE [redacted] INTERSECTION


ABNORMAL LOCATION FOR INTERNAL GUTTER WITHIN THE MASTER BEDROOM
SOLAR COLLECTOR SPACE
GREEN ROOF SPACE
31° FALL
14° FALL
36° FALL

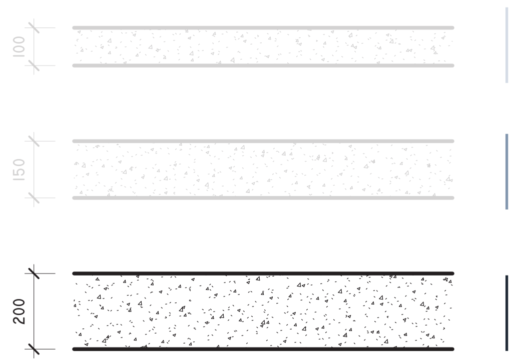

INTERNAL GUTTER
8°
31°
RAINWATER GUTTERPIPES TO TOILET CISTERNS &/OR SWALE NEARBY
R1 7000
R 6000
L1 3000
G 0
7°
56°
ANGLING FOR WINTER SUN, WHILE MORE IMPORTANT CLIMATE-WISE, REDUCES SURFACE AREA FOR SOLAR COLLECTORS
WINTER SOLSTICE NOON SHADOW
26°
2.5M MINIMISING THE HEIGHT BRINGS MORE SUNLIGHT INTO THE ENCLOSED BALCONY
SUMMER SOLSTICE NOON SHADOW
72°


ANGLING THE FIXED STRUCTURE FOR SUMMER GIVES GREATEST FLEXIBILITY FOR ADJUSTMENT THROUGH THE YEAR
100-200mm SOIL LAYER
DRAINAGE BOARD & ROOT FILTER
17mm MIN PLYWOOD SUBSTRATE
AIR GAP USING CROSS FLOW VENTILATION
CHOSEN CEILING INSULATION
240×90 RAFTERS @600 MIN SPACING
CEILING PANEL
COLD ROOF SYSTEM
MORE OPPORTUNITY FOR THERMAL BRIDGING VIA STRUCTURAL MEMBERS, ESPECIALLY COLD, WET SOIL ON PLYWOOD SUBSTRATE
100MIN RIVER STONES
150 MIN
100-200mm SOIL LAYER
DRAINAGE BOARD & ROOT FILTER
50-100mm INSULATION BOARD
17mm MIN PLYWOOD SUBSTRATE
CANTILEVERED PARAPET
240×90 RAFTERS @ 600 MIN SPACING
ROOF MEMBRANE
VAPOUR BARRIER
100-200mm SOIL LAYER
DRAINAGE BOARD & ROOT FILTER
50-100mm INSULATION BOARD
17mm MIN PLYWOOD SUBSTRATE
240×90 RAFTERS @ 600 MIN SPACING
NURALITE WARM ROOF SYSTEM

TYPICAL WALL CONSTRUCTION & EVALUATION

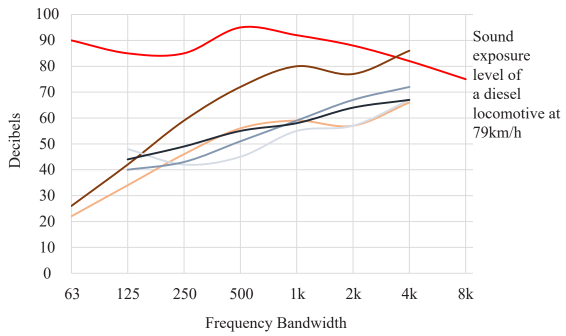


LIGHT TIMBER FRAMING



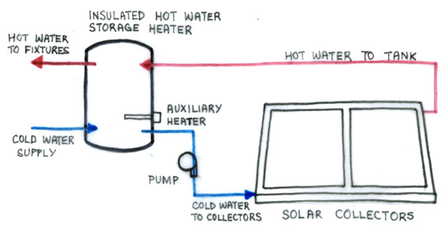
REINFORCED CONCRETE

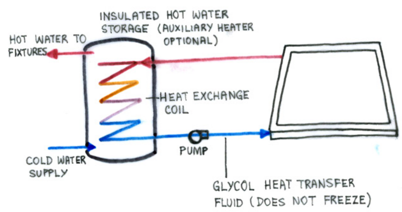
SOUND EXPOSURE & TRANSMISSION LOSS COMPARISON



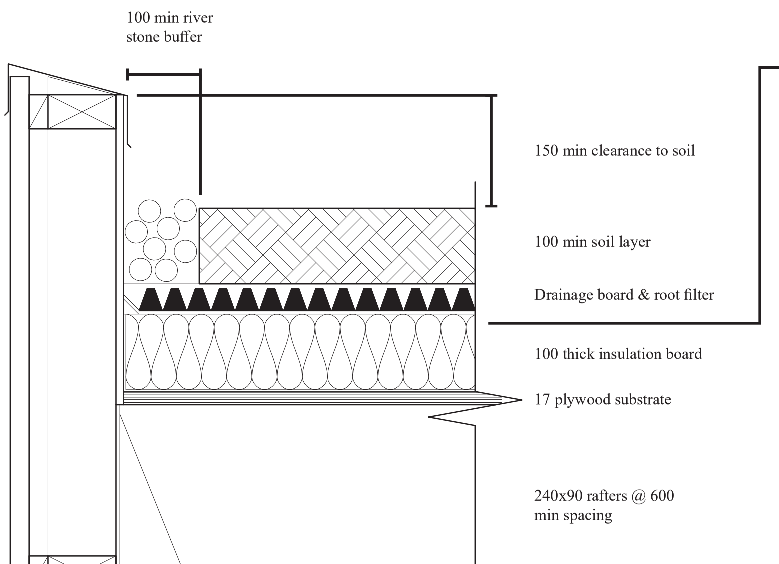
Data adopted from Kang (2006) and Ermann (2014)

OPEN AND CLOSED LOOP SOLAR WATER HEATING SYSTEMS

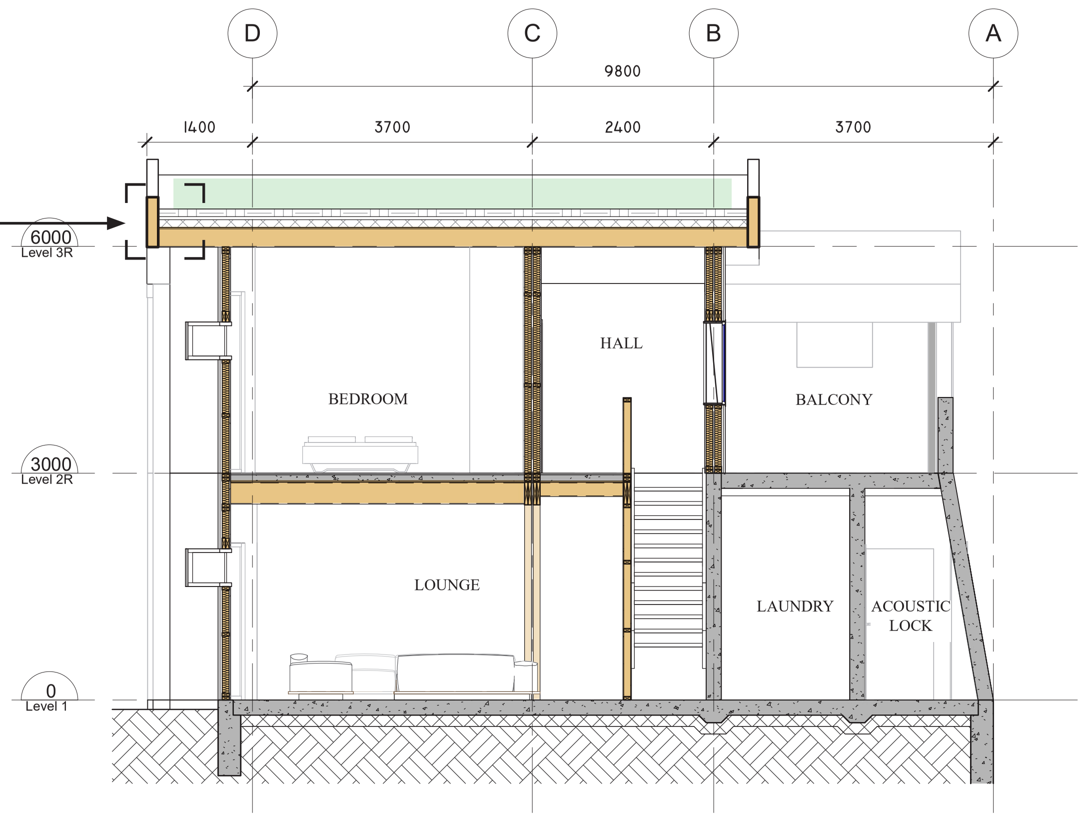


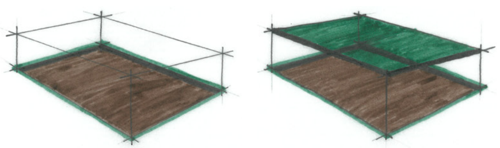


SECTION THROUGH THE TERRACED HOUSE

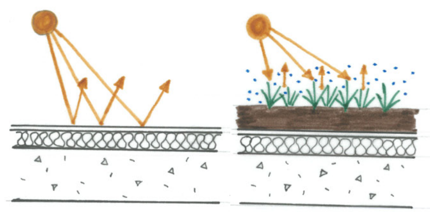


Green Roof Parapet Detail
(all dimensions in mm)
warm roof system



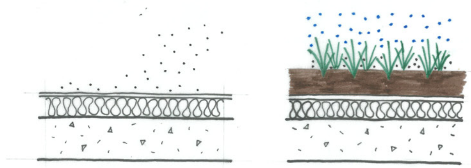


Reclaiming lost landscape



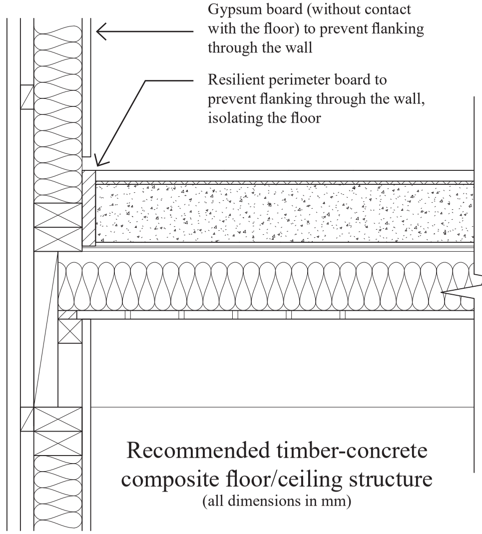
Reduce environmental temperature

Increased soft surfaces; less sound reflection

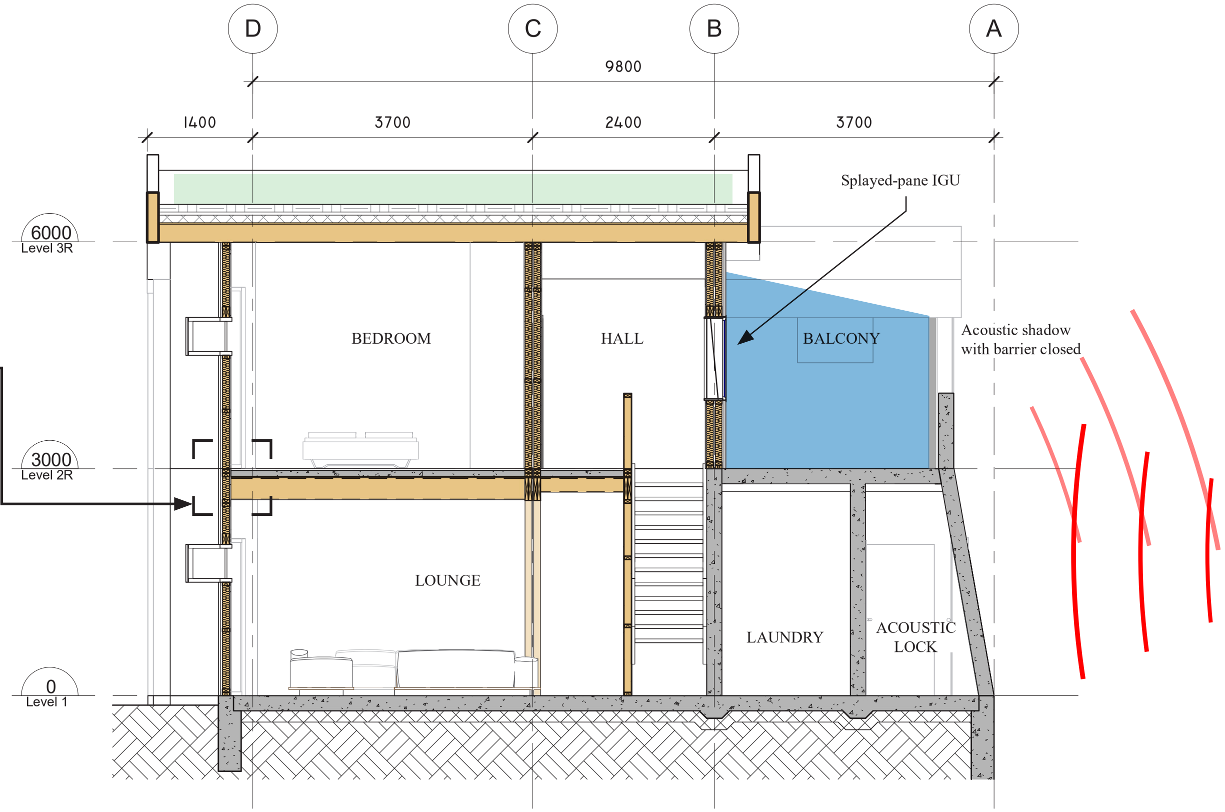


Improving air quality

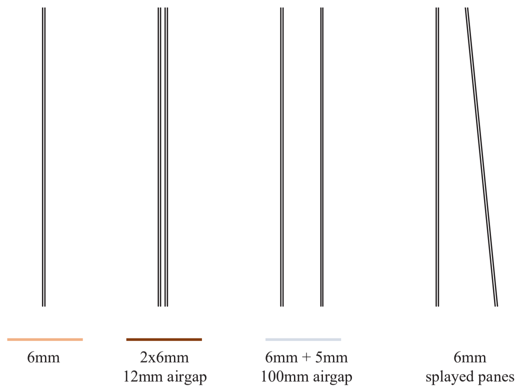
CONVENTIONAL ACOUSTIC CONSIDERATIONS



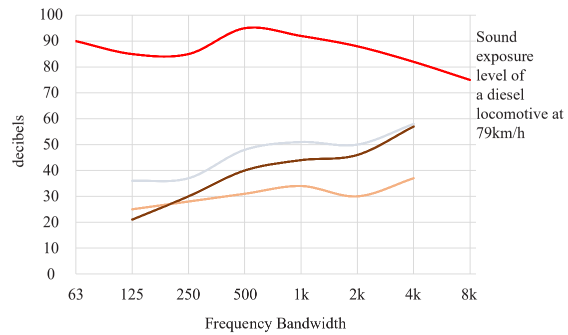
Recommended timber-concrete composite floor/ceiling structure
(all dimensions in mm)



GLASS NOISE INSULATION PERFORMANCE



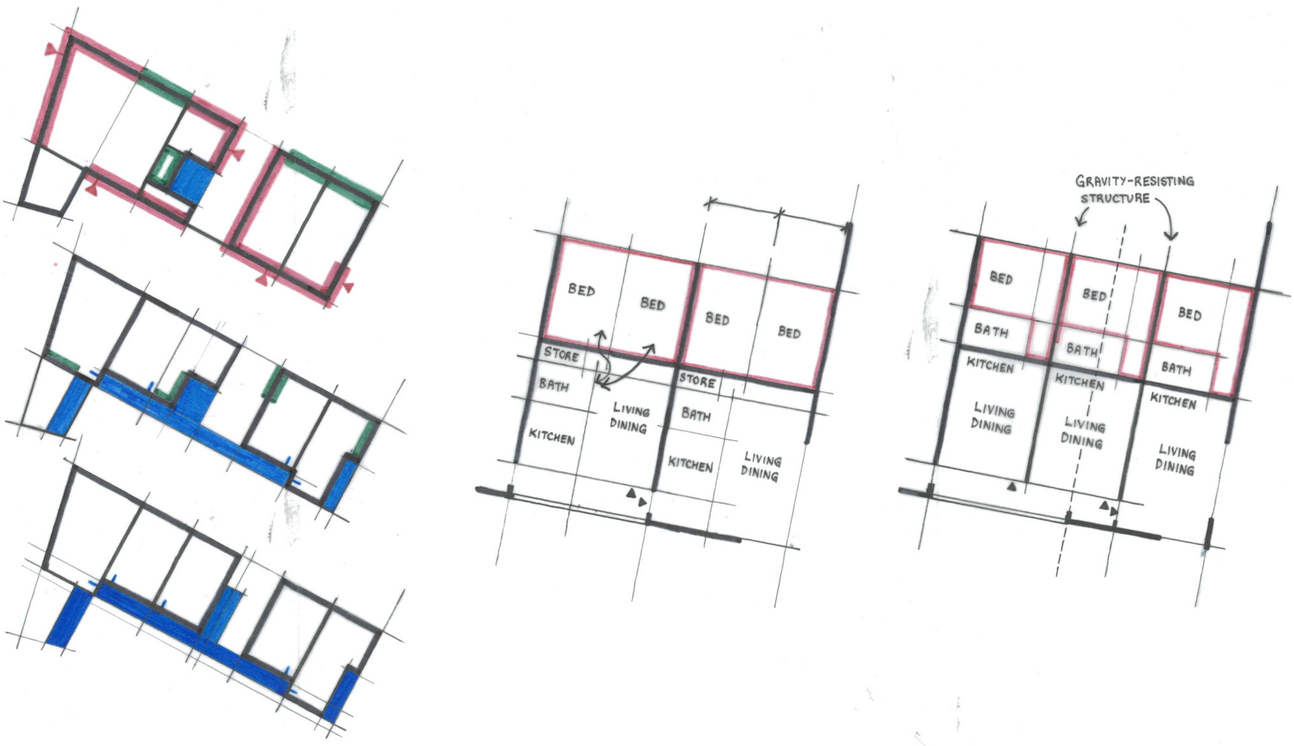
Splayed panes reduce resonance build up within the airgap, improving performance beyond that of parallel panes. Low acoustic performance compared to solid walls means glazing should be used sparingly and strategically for aural-visual connections.

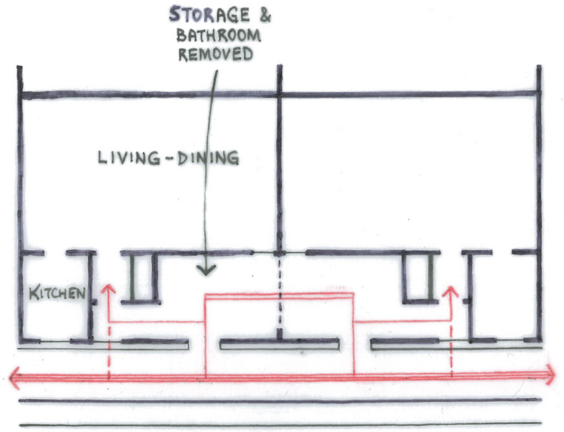


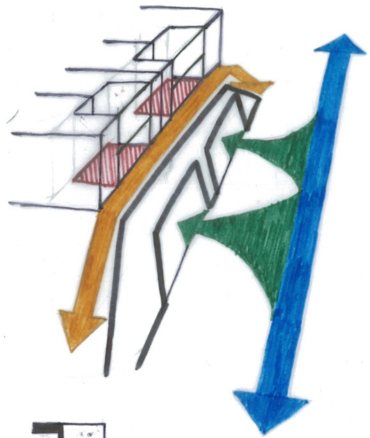
Data adapted from Kang (2006) and Ermann (2014)

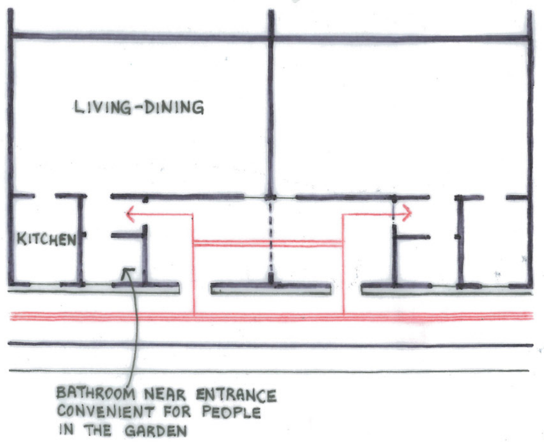
INSIDE THE TERRACED HOUSE

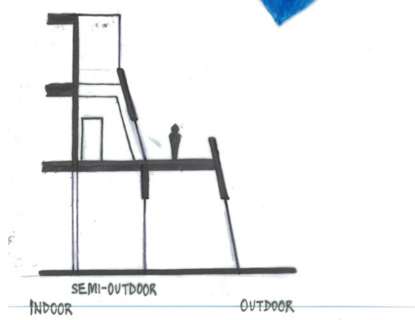
RESIDENTIAL MIXED-USE DESIGN EXPERIMENTATION

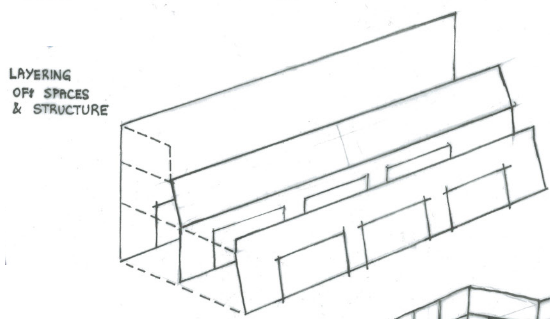


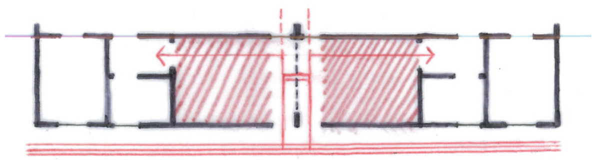




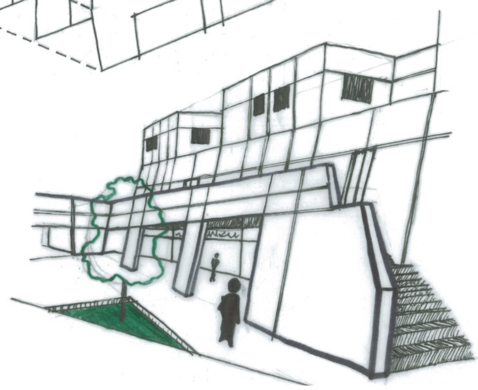


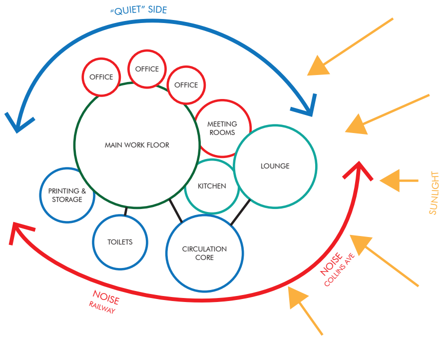


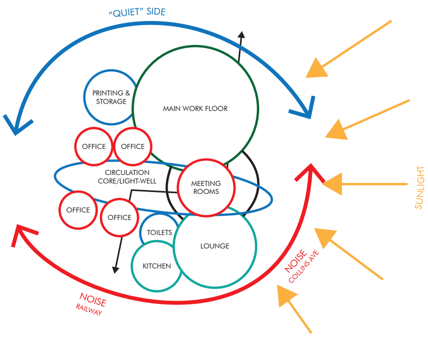




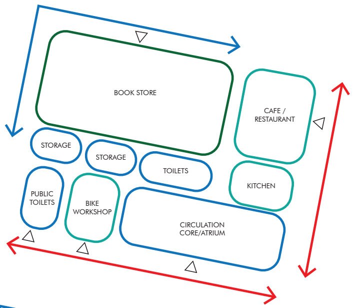
LIMITING THE AMOUNT THE COMMUNAL GARDEN IS EXPOSED, BOTH VISUALLY & ACOUSTICALLY

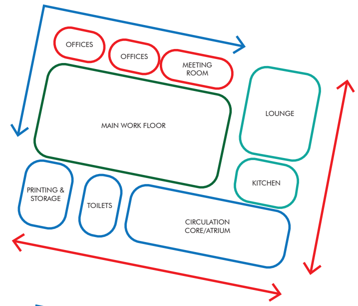


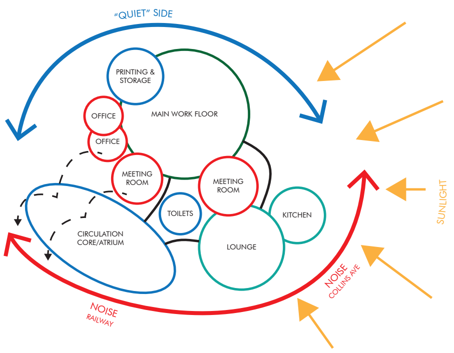


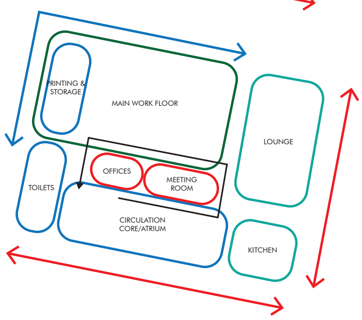


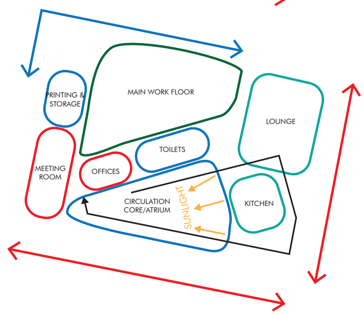
Low noise-sensitivity programs are back-of-shop. Articulating program purely on acoustics creates poor facade visuals



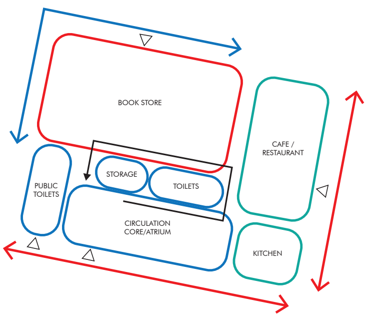


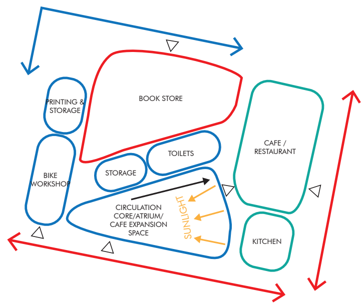


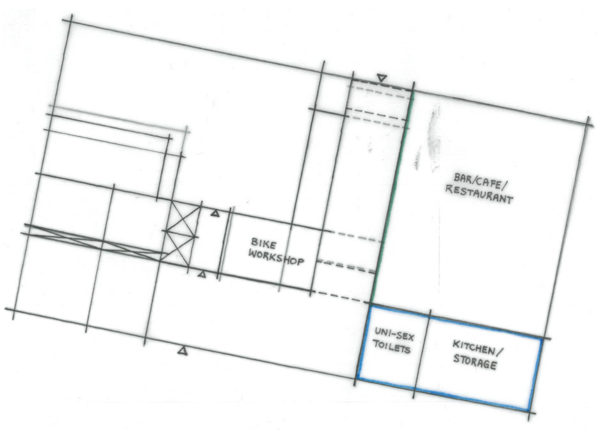


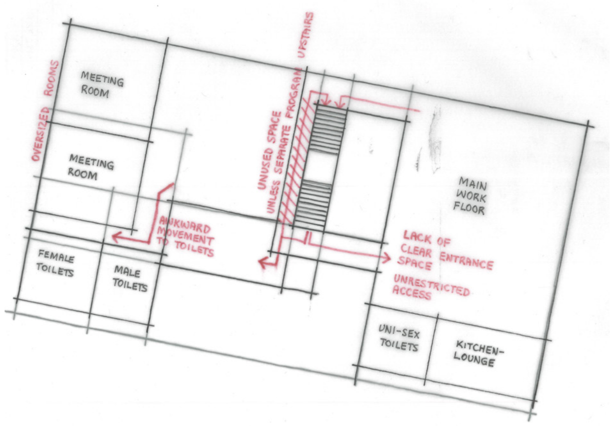


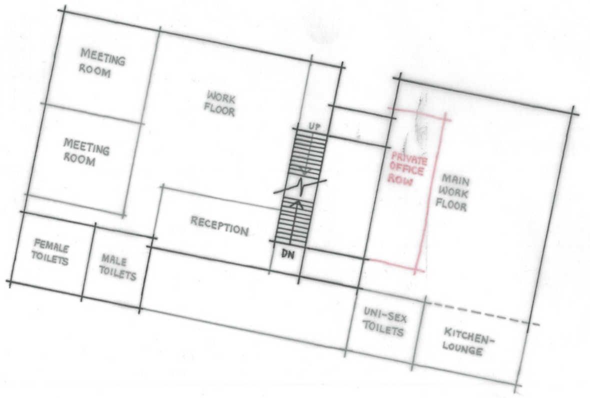
To maintain active frontages, compromises have to be made with moderately noise-sensitive social programs taking prominence

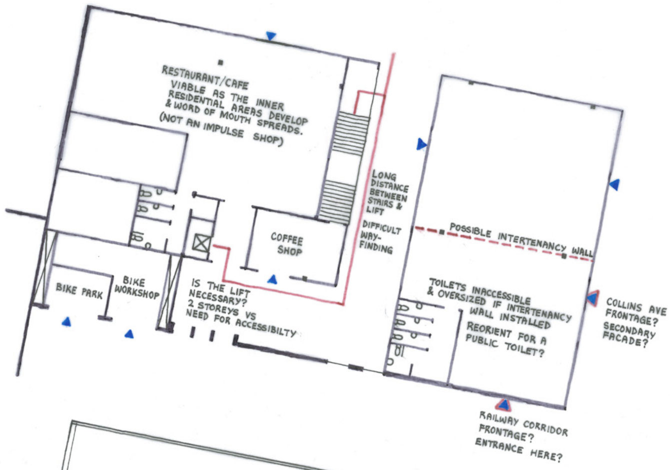


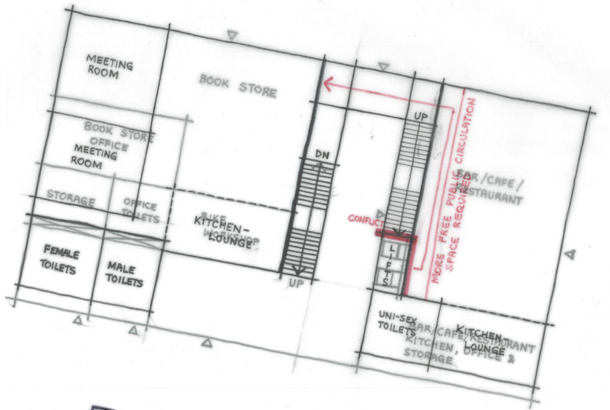


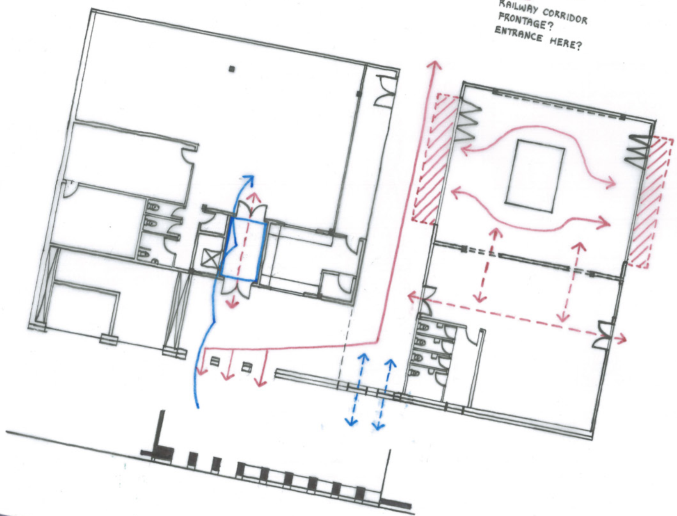


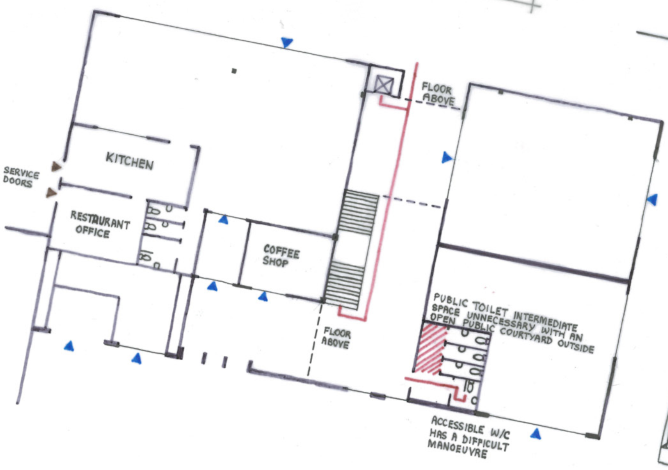


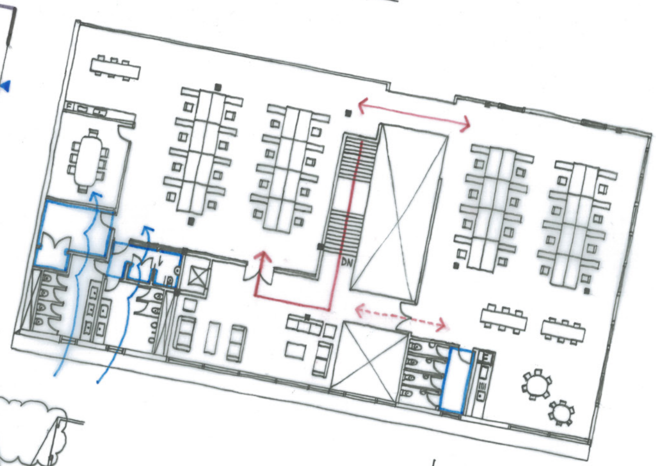

MEETING ROOM
MEETING ROOM
WORK FLOOR
UP
RECEPTION
DN
PRIVATE OFFICE ROW
MAIN WORK FLOOR
FEMALE TOILETS
MALE TOILETS
UNI-SEX TOILETS
KITCHEN-LOUNGE

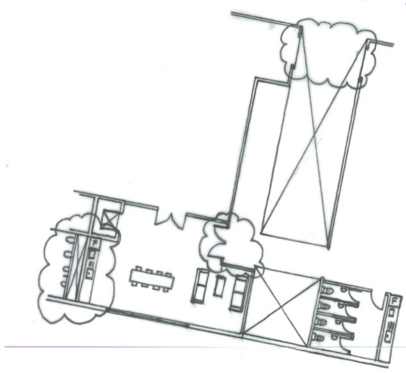

RESTAURANT/CAFE VIABLE AS THE INNER RESIDENTIAL AREAS DEVELOP & WORD OF MOUTH SPREADS. (NOT AN IMPULSE SHOP)
LONG DISTANCE BETWEEN STAIRS & LIFT
DIFFICULT WAY-FINDING
COFFEE SHOP
POSSIBLE INTERTENANCY WALL
BIKE PARK
BIKE WORKSHOP
IS THE LIFT NECESSARY? 2 STOREYS VS NEED FOR ACCESSIBILTY
TOILETS INACCESSIBLE & OVERSIZED IF INTERTENANCY WALL INSTALLED
REORIENT FOR A PUBLIC TOILET?
COLLINS AVE FRONTAGE? SECONDARY FACADE?
RAILWAY CORRIDOR FRONTAGE? ENTRANCE HERE?

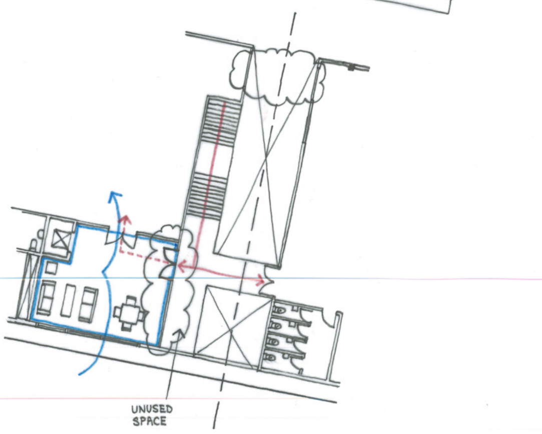

MEETING ROOM
BOOK STORE
BOOK STORE OFFICE
MEETING ROOM
STORAGE
OFFICE TOILETS
KITCHEN-LOUNGE
FEMALE TOILETS
MALE TOILETS
DN
UP
MORE FREE PUBLIC CIRCULATION SPACE REQUIRED
BAR/CAFE/RESTAURANT
UNI-SEX TOILETS
KITCHEN, LOUNGE
STORAGE



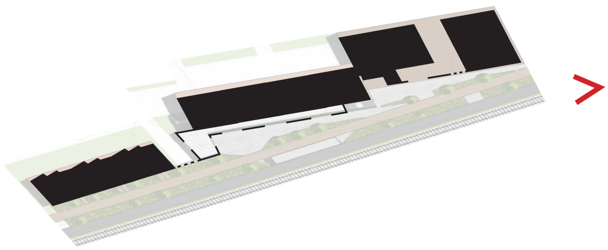

SERVICE DOORS
KITCHEN
RESTAURANT OFFICE
COFFEE SHOP
FLOOR ABOVE
FLOOR ABOVE
PUBLIC TOILET INTERMEDIATE SPACE UNNECESSARY WITH AN OPEN PUBLIC COURTYARD OUTSIDE
ACCESSIBLE W/C HAS A DIFFICULT MANOEUVRE


DN




UNUSED SPACE


KiwiRail



EXPERIMENTAL PLATFORM BARRIER VISUALLY DISPLAYING THE TEMPORALITY OF SOUND