Master of Engineering in Management

Final Report:

3D environmental sound field auralisation – Feasibility, Development and Business Case (redacted version)

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Abstract

Environmental noise auralisation has the potential to improve communication between acoustic consultants and clients, project stakeholders and the community. This audible demonstration of the future sound environment enables non-technical stakeholders to experience proposed changes to the project site and surroundings realistically. Through the development of an environmental noise auralisation tool, context analysis, stakeholder interviews, and a business case, this report establishes that using environmental noise auralisation for community consultation is possible. For Marshall Day Acoustics' Christchurch office, there are potentially [redacted] projects per year that would use environmental noise auralisation. Auralisations are most accurate when presented in a controlled environment, so investment in a Listening Room would be necessary to provide this service to clients alongside further development of the prototype tool. Cash flow calculations for this investment incorporating [redacted] projects per year with a fixed fee of $[redacted], estimated a 20-year net present value of $[redacted] and a worst-case net present value of $[redacted]. The project has an estimated present value index of $[redacted], representing a $[redacted] return per dollar invested. Considering this financial return and the project's alignment with MDA's strategy and capabilities, the development of the environmental noise auralisation tool and the Listening Room is recommended.

Executive Summary

This report covers the prototype development and business case assessment of 3D environmental sound field auralisation for the Christchurch office of Marshall Day Acoustics (MDA). MDA has experience with auralisation, particularly for room and building acoustics, and has a Listening Room that it used for auralisation playback. However, these resources are limited to the Auckland and Wellington offices. Compared to standard acoustic reports, auralisation offers a more effective method of communicating how a future environment will likely sound to clients and their stakeholders. For environmental acoustics projects it is used so the client, their stakeholders, and the community can understand how proposed changes to an industrial site or other environment could affect the noise environment on-site and in its environs.

Auralisations are most effective when using ambisonic audio and played back through headphones or a speaker array. Including a visual component presented through virtual reality, such as a 360 video, also improves the realism of the auralisation. The process to create an auralisation has four key steps:

1. Determine the impulse response (IR) of the space involved.
2. Gather source audio (through recording or databases).
3. Convolve the input audio with the impulse response.
4. Decode the audio for the audio system (loudspeakers or headphones).

This process was used to establish the procedures and create template files based on MDA's previous auralisation work. These were tested with existing and raw data, then applied in a test case. The test case was of a rock crusher operating at a proposed quarry site, with the crusher auralised at two locations, both with and without a barrier. It consists of the audio and a 360 video presented through headphones and a virtual reality head-mounted device. The demonstration was shown to five stakeholders, who are often involved in environmental acoustics projects.

Analysis of the external environment, competition, market size and discussion with the stakeholders identified that the main competition for using environmental noise auralisation on projects is that clients would prefer to just have a standard report with no extra cost. However, the interviewees thought there is potential for using environmental noise auralisation in community consultation, although it would be complicated to use it in an environment court hearing. It is estimated that MDA Christchurch could have an average of [redacted] projects per year for the first 20 years of offering environmental noise auralisation as a service.

The business case identified that MDA could offer these auralisations as a service to clients with large or contentious projects for a fixed fee plus an hourly rate for consultant time. To provide this service, MDA would have to invest in the development of the tool and equipment. Charging a fixed fee of $ [redacted] for [redacted] projects per year, for 20 years, would cover the costs of this development with a 20-year net present value of $[redacted] representing a return per dollar invested of $[redacted]. As this development would also align with MDA's strategy and capabilities, this financial return indicates it is viable investment.

Assumptions were made in the market and economic analyses including the discount rate, number of projects per year and the available funding. Alongside cost and other estimates, these assumptions create uncertainty in the stated returns. Additionally, the large upfront costs increase the risk of the the investment having a negative return if risks, such as low project numbers and increased development time, are realised .

Contents

1 Introduction

This project is the development, feasibility, and business case for a 3D environmental sound field auralisation tool at the Christchurch office of Marshall Day Acoustics (MDA). MDA is a New Zealand acoustic engineering company founded 40 years ago, that now has offices across New Zealand and overseas. They design acoustic solutions for projects ranging from new theatre design to noise mitigation for industrial sites. Marshall Day Acoustics are well regarded in their field and aim to provide excellent solutions through innovation and creativity. This aim has fostered their research and development, leading to industry recognised software and an auralisation tool.

The auralisation tool allows MDA to simulate the noise response of different acoustic solutions and let the client experience it through a speaker array and accompanying visuals. The MDA Auckland office utilises a specially constructed room, called the Listening Room, to play their auralisations. These auralisations are sometimes accompanied by Virtual Reality (VR) visualisations through a head-mounted device and vibration simulation through a custom vibration rig. Auralisations have been used in a range of projects by Marshall Day Acoustics, but it was primarily established for room and building acoustics such as theatre design. Although the Auckland office predominately uses the Listening Room to play their auralisations, the Christchurch office does not have access to a Listening Room and is currently limited to headphones.

Environmental acoustics projects generally produce a report that communicates the predicted noise level, a comparison to the local requirements, and any potential mitigation actions. However, it is difficult for non-technical readers to understand what the noise levels sound like within the project context. Thus, auralisation provides a better method to communicate the reality of the noise levels to clients, their stakeholders, and the community.

This project builds on MDA's past development of auralisation and a literature review of auralisation processes to develop a tool specifically for environmental acoustics projects and carry out a test case with that tool. The test case will be demonstrated to stakeholders to gather information about the context and potential for the tool's use. The information and understanding of the tool will then be used to assess the business case of the tool through the commercial potential and the practicable feasibility of the required development for the Christchurch office.

This report is separated into four main sections: the literature review (Section 2), prototype development (Section 3), business context (Section 4), and the business case (Section 5). The literature review provides a background to the components and process of environmental noise auralisation and introduces some business case development methods. Next, the prototype development describes the tool's development process and test case, followed by the business context assessing the threats and opportunities for its commercial use. Finally, the business case assesses how it could be sold and developed, and if it is feasible for MDA considering their strategy and resources.

2 Literature Review

2.1 Introduction

The following literature review considers the various components and factors required for the implementation and commercial use of 3D environmental sound field auralisation. The review is broken into four main parts: the uses of auralisations, the auralisation process, the addition of VR to auralisations, and methods that could be used to develop a business plan. Where relevant, specific tools that are already in use at Marshall Day Acoustics or those that are available to the Christchurch office are considered in more depth to reflect the future needs of this project. For clarity, Marshall Day Acoustics primarily uses Max/MSP and Unity software to create their auralisations and VR. They use Soundfield microphones and sound level meters to record the audio required.

For consistency throughout this review the term "user" has been used to identify the person who is listening to an auralisation, viewing a Virtual Reality or other visualisation, or experiencing both simultaneously.

2.2 Applications of Auralisations

The term auralisation is broadly considered as the acoustic or aural version of visualisation but is often used to refer to a tool primarily used by the acoustic consulting industry to communicate with non-technical stakeholders by showing them how a situation or range of situations will likely sound. Originally, auralisations were based on a method to generate and evaluate the acoustical response of rooms before construction. The aim was to alter an audio signal's spatial characteristics by convoluting it with the room’s response so the audio can be listened to as if one is in the proposed space (Harriet, 2013). This allowed designers to verify the design and help the client decide on any acoustic treatments.

Nowadays, auralisations are used in various applications commercially and within acoustical research. Azevedo and Sacks (2014) describe multiple projects carried out by Acentech throughout the development of their auralisation processes including:

- auralisation of different types of performances heard from different seats of a proposed university recital hall,
- auralisation demonstrating different solutions for a new PA system for an existing multifunction hall, accounting for the background HVAC noise,
- auralisation of different room treatments to reduce noise in an aquarium "Touch Tank" hall,
- recreation of the soundscape during John Donne's 1622 Gunpowder Day sermon outside of St. Paul's Cathedral.

Research during this literature review identified many different uses of auralisation in research, including environmental acoustics, building acoustics, and historical studies. Examples of auralisation in environmental acoustics are a potential sound barrier for a park next to a busy road (Harriet, 2013), and the expected noise from a proposed motorway in a rural area (Ruotolo et al., 2013). In a similar field is a study involving the acoustic comfort inside various metro coaches (Iachini et al., 2012) while the simulation of a play (Poirier-Quinot et al., 2016), shows the application in building acoustics.

Although they are not yet in widespread use in the acoustics consulting industry internationally, there are two large acoustics companies who use auralisations: Acentech and Arup. Like Marshall Day Acoustics' Listening Room in Auckland, both companies have similar rooms used for experiencing auralisations, known as the 3D Listening studio (Acentech, n.d.) and SoundLab (Patel, n.d.) for Acentech and Arup respectively. Other companies, including Mueller BBM (Müller-BBM, n.d.) , AECOM UK (AECOM, n.d.), and Force Technology (Force Technology, n.d.) indicate that they have the capability to create auralisations, but do not have a significant number of varied past projects or examples listed on their website or otherwise advertised.

Thery et al. (2019) conducted a survey of acoustic consultants about their use of auralisation. They found that of the survey's 74 respondents, a third do not use auralisations and only 18% are regarded as intensive users, having used auralisations in more than 50 projects. Less than 30% of respondents had used VR and only 25% use some form of visualisation extensively, using it on more than 75% of their projects. Auralisations are used in both architectural and environmental projects, 96% and 75% of users respectively. The survey found that the acousticians regard auralisations as satisfying, compatible with their design projects and as a tool that improves or would improve their performance. However, it was considered hard to learn, requiring experience for accurate results, and so 80% of the non-users had no intention to use auralisation. The impact of the modelling software and sound recordings meant less trust in the reliability of auralisations but primarily, the time and cost required were limiting. Thery et al. (2019) note that smaller acoustic consulting practices (less than 10 employees) seem to be unable to afford the time, skills, and money required for reliable auralisations. For the firms that do use auralisations, they find auralisations useful for communicating with clients and other project actors. The extensive users were also those identified as coupling their auralisations with visual models and the rare users of VR, generally larger consultancies with greater than 50 employees. This reflects what is seen publicly.

To summarise, commercially, auralisations are used by acoustic consulting firms to communicate different situations to non-technical stakeholders through audio. Due to the cost of time, skills, and resources, auralisations are currently only in widespread use by larger acoustic consulting firms but are used in a variety of projects including environmental and building acoustics.

2.3 Auralisation Process

The process required for to create an auralisation is dependent of the specific requirements of the project but each auralisation follows the general process below to create the auralisation.

1. Determine the impulse response (IR) of the space involved.
2. Gather source audio (through recording or databases).
3. Convolve the input audio with the impulse response.
4. Decode the audio for the audio system (loudspeakers or headphones).

Impulse responses are generally calculated in one of two ways, by computer modelling or by direct measurement. Projects where the space does not yet exist, such as the design of a new concert hall, often use computer modelling to generate the impulse response of the proposed space. Commonly used software includes CATT-Acoustics, Odeon, Rhino, and SketchUp (Thery et al., 2019). The models are sometimes created by the acoustic consultant but may also be heavily based on models supplied by the architect (Thery et al., 2019). In contrast, projects in existing spaces, or where a similar space exists, use direct measurement, by exciting the space with a short sound like a clap or a test signal such as a sine sweep (Garí et al., 2017). Otherwise, the IR of the effect of a nearby event, such as a car passing, can be created from recordings of similar events (Ruotolo et al., 2013). Regardless of the method, IR are specific to a particular source and receiver positioning and therefore multiple IR may need to be recorded for one auralisation project (Harriet, 2013).

The source audio represents the standard audio that would be heard in the space. For a project like a new concert hall, the audio could be a performance recording. These recordings should be as "dry" as possible, that is without any effects from the recording space or elsewhere. Ideally, these are recorded in an anechoic room. There are databases, such as EigenScape (Green et al., 2017), with various anechoically recorded sounds that can also be used as a source input (D'Orazio, 2020). When the IR is not the IR of the space and instead of a nearby event, the source input audio is often an ambient noise recording (Harriet, 2013). Different methods and microphones are used to record the ambient noise, including binaural and ambisonic recordings. Binaural and ambisonic sound recording are advantageous over other forms as they provide spatial cues meaning the sound is heard more realistically and the listener can localise different sound sources. Binaural sound recordings are created through two microphones in a mannequin or headphones attached to a recorder (Iachini et al., 2012; Ruotolo et al., 2013). Ambisonic recording involves at least four microphones, generally from a combined Soundfield microphone, providing information about the sound in all three dimensions. The advantage of ambisonic over binaural audio is that ambisonic audio does not require the listener to be facing in the same direction as the recording, as it is recorded from one central position rather than the two microphones representing two ears (Harriet, 2013).

Thirdly, the IR and source audio are convolved. Convolution is a mathematical process that combines the impulse response and the source audio signals (Smith, 1999). This applies the IR to the source audio creating an audio track that sounds as if it is being heard in the project's space, or with the event in the background. This is commonly done through software such as Max/MSP (Poirier-Quinot et al., 2016).

Finally, the convolved audio needs to be listened to through a sound system. To reap the full benefits of the auralisation the audio should be rendered for a sound system that accurately represents the audio. Auralisations can be heard through standard headphones from an audio track on a website, which has the advantage of reaching many more people, such as auralisations of road noise on Danish motorways (Force Technology, n.d.). However, the aim of an auralisation is to hear the sound as if one is in the space and listening to the audio source live. Thus, it is important for the sound system to be decoded to a system that does not remove or affect the spatialisation cues during the listening experience.

The preferred method for sound quality and experience is an ambisonic speaker system such as used in the Listening Room (Harriet, 2013). Although there are other methods, such as surround sound, and newer methods, the ambisonic system is favoured because it allows for 3D formats, can be modified for any number of loudspeakers, and can be used for many different forms of acoustics. The other methods do not meet all three of these criteria, as surround sound systems only reproduce sound in 2D and newer methods such as Spatial Impulse Response Rendering, although they are perceived to be more natural than ambisonics, are not yet applicable to environment sound projects (Harriet, 2013). However, ambisonic systems have a high cost of implementation due to the cost of an anechoic room and the equipment.

To avoid the costs of ambisonic speaker systems the most common audio system used by acoustic consultants is either stereo or binaural headphones (Thery et al., 2019). Using headphones avoids the cost of constructing and equipping a Listening Room, but further computational steps must be used to account for the different listening experience. When humans hear sound, the spatial information for sound source localisation is determined from the timing and loudness differences between our two ears, identifying if the sound is on the left or right side of the head. The soundwaves interact with our outer ear (pinnae), head, and torso changing the sound frequency which our brain subconsciously recognises and provides the remaining localisation cues (Berger et al., 2018). When listening through headphones these spatial cues must be recreated within the audio if localisation is desired. Stereo headphones alter the loudness at each ear which allows the listener to identify if the sound is coming from the left or right. Binaural sound allows for 3D spatialisation by incorporating a Head Related Transfer Function (HRTF), to account for the frequency changes from the pinna, head and torso. To further complicate things, individuals' different ear, head, and torso shapes means an accurate HRTF must be modified for each individual (Armstrong et al., 2018; Harriet, 2013).

2.3.1 Head Related Transfer Function

Experimenting with audio and desktop-based visuals, Larsen et al. (2013) compared the use of standard VR audio systems, which alter sound levels according to the orientation and distance of a source from each of the users ears but do not consider vertical positioning of the source, to binaural synthesis with a generic HRTF. They concluded that binaural audio results in better human localisation performance in an exclusively audio environment compared to panning systems.

Calculating an individual's HRTF is technically complicated and challenging, for example, Jenny and Reuter (2020) required 60 minutes for each individuals measurement procedure, measuring 1550 positions with 22 custom made loudspeakers, in ear microphones, and an electromagnetic head tracking system among other components. Clearly, the resources and time required to calculate an individual's HRTF makes it impracticable for most auralisations, so there is much research into the differences between an individualised HRTF and a generic HRTF from a standard mannequin. The most common generic HRTF's are the KEMAR and KU100. As Xu et al. (2007) summarise and Geronazzo et al. (2018); Jenny and Reuter (2020); Orduña-Bustamante et al. (2018) also state human localisation performance is better with individual HRTF's, as non-individual HRTF's can cause a user to have high error rates when localising a sound source. However, these studies are carried out in an exclusively auditory environment (without any visual component) and focus on localising the sound.

Considering localisation, Oberem et al. (2020) compared individualised HRTFs with static audio to generic HRTF's with dynamic binaural audio. Dynamic binaural audio utilises head orientation tracking to adjust the audio as the user rotates their head. Oberem et al. (2020) concluded that for static audio the individual HRTF did improve the user's localisation ability compared to the generic HRTF. However, dynamic audio caused a much larger improvement of their ability, and thus the benefit of using dynamic audio is greater than the benefit of using individualised HRTF's for localisation.

Armstrong et al. (2018) noticed the strong focus on localisation in research and so considered other components of the sound, evaluating the difference between individual and generic HRTF's impact on sound brightness, richness, externalisation, and preference. Their experiment showed no clear preference for the individual HRTF's, with a range of different responses between individuals. However, they did find an overall preference for one of the generic mannequins HRTF's, specifically the KU100. A lack of extreme or consistent results showed that neither the generic nor individualised HRTF's markedly outperformed the other. Notably, none of the participants preferred their own individualised HRTF over the generic KU100 or KEMAR HRTF's.

Berger et al. (2018) investigated the impact that visual cues have on users' abilities to localise sounds. They considered that humans auditory systems have been shown to be highly adaptable and investigated this adaptability. This means that exposing a user with a generic HRTF to a synchronised audio and visual cue, indicates to their auditory processing system the subtle differences from the headphones and temporarily shifts their processing to account for the difference. However, as Berger et al. (2018) mention, more research on the cue requirements and timeline of the shift is needed.

Therefore, although much research recommends using individualised HRTF's over generic HRTF's in an exclusive auditory environment, recent works (Berger et al., 2018; Oberem et al., 2020), show that the plasticity and multimodality of humans senses mean supplementing the audio with dynamic audio and visual cues can have a larger impact on localisation than an individualised HRTF. Additionally, considering the entire listening experience, users preferred generic HRTF's over their individual HRTF's.

As covered in this section, the auralisation process is comprised of four key steps: getting the IR, recording audio, convolution, and decoding for playback. The exact process for each of these steps differs depending on the project but for environmental sound this is likely to include recordings of the IR and ambient sound. These recordings should be done with a Soundfield microphone. Once the audio is convolved the best practice for playback is to use an ambisonic system. Using dynamic audio and visual cues can improve the listening experience, especially to overcome the decreased localisation ability if using a generic HRTF with headphones.

2.4 Auralisations and Virtual Reality

Although there is not much research into the impact of visual cues on spatialisation with binaural audio and HRTF's, there is a growing amount of research around the impact of VR on auralisations. VR has grown in popularity in the past five years as high-quality, low-cost VR tools have become readily available. Hence the research around various applications of VR has also grown. Within that research there is many interpretations of the term virtual reality due to the various tools available to display an audio-visual presentation. This report employs the term VR to refer to an image, video, or activity presented to the user with a head mounted display (HMD) with accompanying audio (through speakers or headphones), a system also known as immersive virtual reality. The aim of VR is to give the user a sense of presence and immersion in the environment. An effective VR experience can provoke responses and behaviours similar to those provoked in a real environment (Ruotolo et al., 2013).

Poirier-Quinot et al. (2016) describe the process of creating an auralisation and concurrent VR video of a play in a theatre. The paper proposes a framework for the creation of these VR experiences so they can be used to assess the "ecological validity" of an auralisation. This can be understood as assessing the models applicability to real life situations. Poirier-Quinot et al. (2016) framework was a part of a larger research project to use auralisation for the assessment of room acoustic quality by non-acousticians. To create the VR experience and auralisation they followed the following steps:

1. Created an acoustic model of the theatre and simulated the room impulse responses with CATT-Acoustic and Max/MSP.
2. Created a visual model from the acoustic model, in 3dsMax and BlenderVR.
3. Recorded the performance audio and video with close mic headsets and a Kinect 2 sensor for the audio and visuals respectively.
4. Presented the recordings via a VR cave or HMD with binaural headphone or ambisonic loudspeaker rendering.

Real-time auralisation is a term used to describe an auralisation where the user can move about to different source and receiver positions within the scene, as this requires the source audio to be convolved with the specific source-receiver IR each time the user changes position. The signal that the user has moved within the VR environment is sent to the audio processing programme, such as Max/MSP, through the Open Sound Control (OSC) protocol (Poirier-Quinot et al., 2016).

In the field of environmental acoustics, Ruotolo et al. (2013) created a VR auralisation to research the impact of a proposed motorway on people nearby. As they summarise, traditional noise annoyance assessment is carried out through the self-reporting, social surveys, or listening to pre-recorded traffic noise in a lab. These processes do not consider the influence of the visual environment on the noise annoyance despite many studies proving that visual information influences auditory responses and vice versa. They created aural and visual models of an area in rural Italy for two scenarios, one with and one without a proposed motorway. Binaural recordings were made of traffic noise from a similar motorway and of the ambient noise in the environs of the proposed motorway. These were applied to a SoundPlan model of the site to create the auralisation. A 3D model was created of the environs from GIS data and photos. The presentation was made with headphones and an HMD, alongside real-time auralisation. Users were asked to perform cognitive tasks and rate their annoyance in three different positions for each scenario. The results found that the users felt present and that the VR was realistic. They were more annoyed, and their short-term verbal memory was worse in the scenario with the motorway. This aligns with some of the research on the impact of traffic noise and concludes that concurrent visual and aural stimulus should be used to assess the impact of environmental noise (Ruotolo et al., 2013).

Iachini et al. (2012) carried out a study assessing response differences from exclusively audio and concurrent audio and visual stimulus. They simulated the experience of sitting in a metro coach in various cities through binaural audio recordings from inside the metro coaches and a visual 3D model of a coach. An HMD was used in the concurrent scenario and headphones were used for both scenarios. Iachini et al. (2012) found that cognitive performance was worse when experiencing the concurrent model particularly for the more demanding cognitive tasks and the intelligibility of spoken words. However, despite the larger impact, the users rated the noise in the concurrent task as less annoying. This research shows that visual context impacts the effect of noise on people and that VR creates a sense of immersion and can improve the impact assessment of different scenarios.

However, creating visual models like Iachini et al. (2012); Poirier-Quinot et al. (2016); Ruotolo et al. (2013) used can be time consuming and require new skills and resources. Cranmer et al. (2020) used a 360-degree video presented on an HMD to assess if VR is ecologically plausible enough to impact social acceptance of wind turbines. They combined the 360 video and audio recorded at a coastal wind turbine site to create a VR experience presented to the users through an HMD and headphones. The users rated the experience as immersive and representative of the real world. They found that the opinion of users who had never seen or were not knowledgeable about wind farms had larger changes in opinion than those who had, concluding that the 360 video VR can, to some extent, replicate the experience of being there in real life. Cranmer et al. (2020) do state, however, that further work is required on the sound recording and playback.

As VR headsets have become readily available, research into VR and auralisation has increased. As discussed, this research has shown that the combination of VR and auralisations renders the auralisations more realistic, improving the assessment of noise effects. The use of 360 videos instead of visual models could reduce the time required to create the VR scenarios, however, they should be used with ambisonic auralisations instead of the basic audio recordings used by Cranmer et al. (2020).

2.5 Developing a Business Plan

This literature review is for a project on the feasibility, development, and business case of 3D environmental sound auralisation for Marshall Day Acoustics. To assess the feasibility and develop the business case for the tool various factors must be considered. Models such as the Lean Canvas for entrepreneurship and the Five Case model for business cases cover these factors. As the auralisation tool is being developed within a well-established company this project will consider both the Lean Canvas and Five Case Model to determine the best commercialisation strategy, and then develop the business case for that strategy. Two factors that are of particular importance for this project are the market and opportunity, and the stakeholders. This section describes the Lean Canvas, the Five Case model, and identifies methods to understand the market size and stakeholders.

2.5.1 Lean Canvas and Five Case Model

The Lean Canvas is a business model template primarily used in digital technology entrepreneurship. It considers nine components necessary for successful entrepreneurship: the problem, customer segments, unique value proposition, solution, channels, revenue, costs, success metrics, and the unfair advantage (LeanStack, n.d.). A Lean Canvas template is included in Appendix A: Lean Canvas Template.

The Five Case model is the basis of the Better Business Cases expected by the UK and New Zealand Governments (The Treasury, 2021). This model forms a business case around five key cases: the strategic case, the economic case, the commercial case, the financial case, and the management case. The strategic case discusses the benefits of the proposed changes while the economic case determines the best option. The commercial and financial cases assess if the project is commercially viable and how it could be funded. Finally, the management case discusses the plan for the project delivery.

2.5.2 Market and Opportunity

One of the first steps in developing a commercialisation model is ensuring that there is a sufficiently sized market for the tool. Once determined, the market information forms the basis for the customer component of the Lean Canvas. Evaluating the market must also consider the external environment and identify factors that could impact the tools success. A common model to analyse the external environment is a PESTLE analysis. PESTLE stands for political, economic, social, technological, legal, and environmental. A PESTLE analysis simply considers the different aspects relevant to the tool that influence these six factors. This process reduces the risk of a known factor unexpectedly impacting the product later on (Turner et al., 2010).

Porter's five forces is a tool to assess the economic potential of an industry. It considers the power of buyers, entry barriers, rivalry, potential substitutes, and power of suppliers for a particular industry as seen in Figure 2-1. This analysis informs on whether there is any hurdles or major drawbacks of operating in the industry (Grundy, 2006). This ensures that potential hurdles, such as large financial barriers to entry or many different substitutes for the product. As Grundy (2006) identifies, this model is less relevant nowadays when industry boundaries are less clear. However, it still provides a structure to base an analysis of the competitiveness of the business area a tool will be applied in.

Looking more internally at the project or company through a SWOT analysis means the company or projects strengths can be considered and ultimately related to the external and industry environments. A SWOT analysis simply lists the strengths, weaknesses, opportunities, and threats related to the project or company and is used for a wide variety of scenarios (Helms & Nixon, 2010).

Estimating the available market is also an important step to ensure that it is large enough for the project to be profitable (Fairbanks & Buchko, 2018). A basic method is to estimate the total market, reduce this by a fraction to the serviceable market and then to the obtainable market. This market segmentation may then continue to customer segmentation to identify groups for a targeted approach. The market value can also be identified from the size estimate. There are two main methods for estimating market sizes. "Top-down" uses research and reports while "bottom-up" uses internal information from early sales or expressions of interest (Fairbanks & Buchko, 2018). As the auralisation tool is already used within Marshall Day Acoustics the bottom-up process will be used.

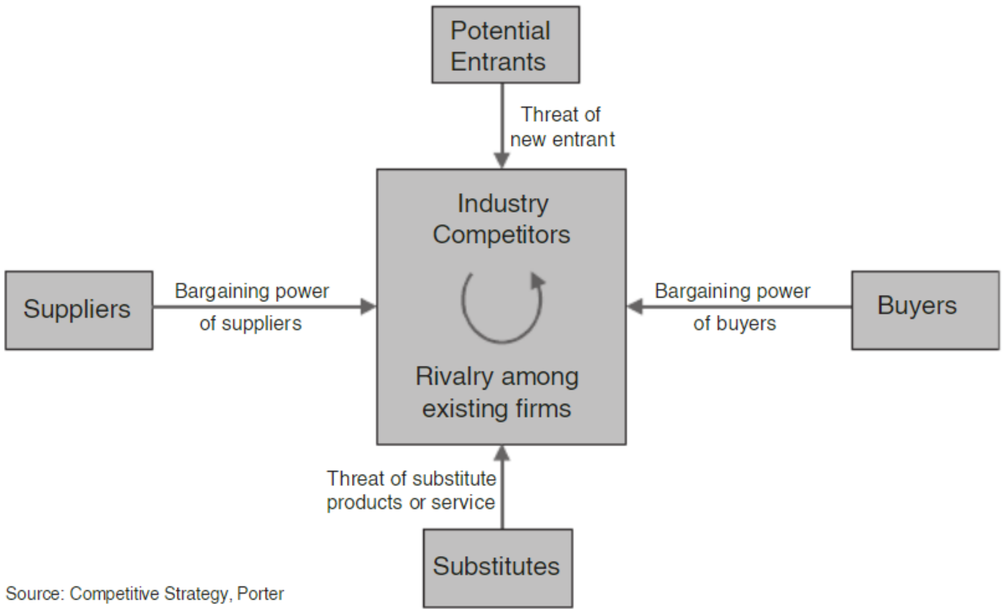

Figure 2-1: Porter's Five Forces model (Grundy, 2006).

2.5.3 Stakeholders

Stakeholders are particularly important to this project as environmental acoustics projects are often reviewed by external experts or involved in legal proceedings. Hence, a lack of trust from external stakeholders could render a project's auralisation pointless. By identifying the stakeholders and their requirements early, problems can be prevented through awareness and management of the stakeholders' positions toward the project.

Freeman et al. (2007) discuss mapping stakeholders as primary and secondary stakeholders, where primary stakeholders are typically a company's suppliers, shareholders, employees, customers, and others directly linked to the project, while secondary stakeholders are those with interest in the project such as advocate groups and competitors. The stakeholders can also be mapped on various matrices such as power vs interest in vs position towards the project. These maps can identify which stakeholders are the most likely to cause problems, whose opinion could be changed with some engagement and which stakeholders may be able to influence other stakeholders. In complex projects this can then be used to inform a stakeholder register and determine the engagement requirements for different stakeholders. Figure 2-2 shows an example of these matrices considering organisational power and influence on the projects outcome and showing how the stakeholders are grouped for engagement (Martinelli & Milosevic, 2016).

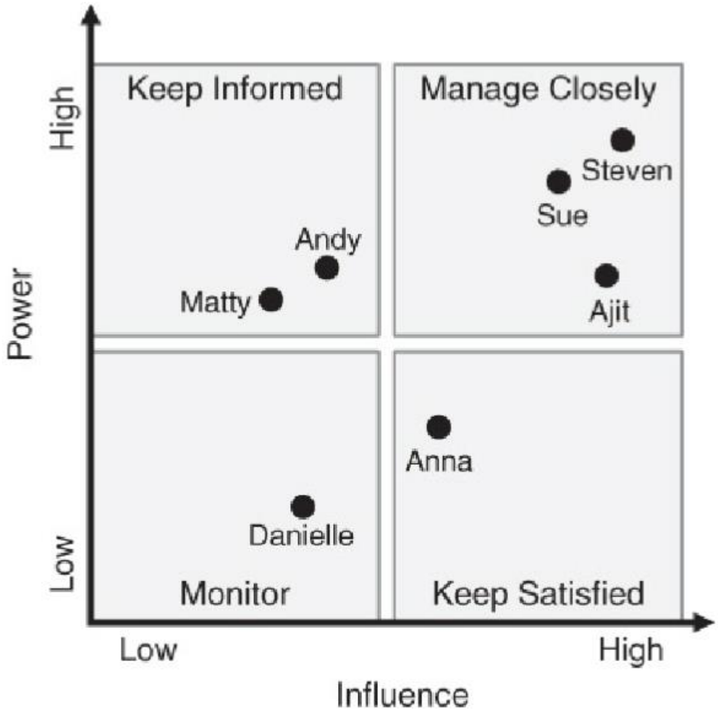

Figure 2-2: Example stakeholder matrix for power and influence (Martinelli & Milosevic, 2016).

2.6 Conclusions

This literature review considered four key components necessary for the feasibility, development, and business case of 3D environmental sound auralisation for Marshall Day Acoustics. The review found the following conclusions:

- Commercially, auralisations are used to communicate different situations to non-technical stakeholders. They are used in a variety of projects including environmental and building acoustics but are only in widespread used by large acoustic consulting firms.
- The exact process for each of the four key steps for auralisation differs depending on the project but for environmental sound this is likely to include recordings of the IR and ambient sound. These recordings should be done with a Soundfield microphone. Once the audio is convolved the best practice for playback is to use an ambisonic system. Dynamic audio and visual cues can improve the listening experience, especially when using headphones.
- Research in combining VR and auralisations has shown that it renders the auralisations more realistic, improving the assessment of noise effects. The use of 360 videos with auralisations instead of visual models could reduce the time required to create the VR scenarios.
- Many factors need to be considered when developing the business case for 3D environmental sound auralisation. Utilising both the Lean Canvas and Five Case model will consider all the factors. The market and opportunity for the tool can be estimated through various tools and a bottom-up approach while stakeholders can be grouped through stakeholder mapping.

3 Prototype Development

3.1 Introduction

Informed by the literature review results, the next step was to combine the current software and processes from the Auckland office to create a tool for environmental noise auralisation in Christchurch. This aims to show proof of concept, to be a demonstration for stakeholders, and create a basic template and process, reducing the time required to develop an auralisation. The development was carried out by collating the techniques used by the Auckland office and adapting them to the Christchurch system.

3.2 Method

The prototype development followed the design process outlined in Figure 3-1. This process follows the order of: understanding the tool – implementing and checking – carrying out a test case. The goal was to be able to complete the test case without having to make any adjustments to the process, thus gaining a realistic estimate of the time required for a basic auralisation.

The first step was to establish what was necessary to run already created auralisations in the Christchurch office and secondly how to modify those auralisations. The initial focus was on getting the audio processing to work as there is a wider variety of methods for the visual component of the auralisations. Once the audio processing was adapted to the Christchurch system, the previous files were used to build a new template for environmental noise auralisation. The visual component was built in Unity using an old 360 video, and the communication protocols between the VR headset and audio processing environment were established. Once the entire system was operational, it was tested with raw data. This data was also used to develop the processes to prepare the raw data, including trimming and matching the video and audio files. Once the entire process was established, a test case was devised and created. Finally, a user guide was written to guide MDA's acoustic consultants through recording files and creating an environmental noise auralisation. The existing calibration process for a headphone set-up was adapted for the Christchurch system.

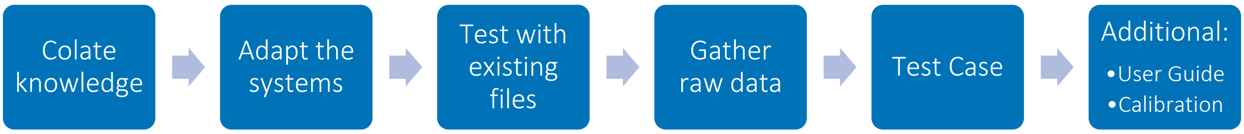

Figure 3-1: Prototype development process.

3.3 Prototype

The tool prototype that was developed consists of the auralised sound combined with a 360 video, because this improves the realism of auralisations, as discussed in Section 2.4. Different impulse reponses can be selected to auralise the noise source from different locations or with different mitigation options. An visual indicator is included in the video to represent the general location of the noise. The auralisation is presented via headphones and VR headset with the capability to be presented via a loudspeaker array. The audio is processed and controlled through Max, a visual programming software for audio created by Cycling '74, and the video rendered through Unity, a game engine from Unity Technologies. Based on the steps in Section 2.3, the environmental noise auralisation consists of four main processes:

1: Determine the Impulse Response of the event.
2: Gather source audio.
3: Convolve the IR and source audio.
4: Process the audio for output.

The first process is not explicitly included in the auralisation tool as this is a decision made from acoustics knowledge of the specific project. Once a decision is made, the noise level change is modelled with standard acoustic modelling practices. Finally, the level change in dB over a frequency range of 10 Hz to 10 kHz is inputted into the impulse response generator and converted into an audio file.

Secondly, the raw data of the ambient environment and the changing noise source is recorded. The source audio, such as the sound of operating machinery, only needs to be a single channel “mono” audio file and can be recorded with any appropriate microphone. The ambient environment is captured by simultaneously recording with a 360-degree camera and ambisonic microphone, as shown in Figure 3-2. The recording should be long enough for at least one minute of footage when trimmed, and more importantly, long enough to accurately represent the environment over time. The ambient noise level is also measured simultaneously with a sound level meter, following the standard practice for acoustic site surveys. It is possible to record this data before the impulse response is calculated to coincide with other site visits as long as the auralisation location has been chosen.

Figure 3-2: 360-degree camera and microphone recording the ambient environment.

Once the raw data has been collected, the ambient audio and video are synced and trimmed. Next, both the ambient and noise source audio are added to the Max file, where they are processed and controlled. Finally, the source audio is convolved with the wave impulse response file to create the auralised component in Max.

The final audio output is converted from the four-channel ambisonics to the relevant output channels through a Max plugin called Harpex-X that retains the spatial sound information in the output audio, so the user still experiences the auralisation in 3D. This live processing enables the audio to be changed during a demonstration, such as switching between impulse responses. Likewise, for headphone playback, the users head orientation is fed to Harpex-X and used to adjust the audio as they move their head.

The video is rendered for playback through the VR headset by building it into a Unity video. This video sends information to and from the Max patch allowing it to be controlled simultaneously with the audio.

3.4 Test case

The job of the test case is twofold. It was used as a comprehensive test of the system and as a demonstration to stakeholders. This allowed them to understand better what an environmental noiseauralisation would consist of and provide a more informed opinion on its commercial use. The project chosen for the test case is a well known local project that had a hearing in the local environment court. This meant that the project sponsor and most stakeholders could compare the auralisation to their knowledge and experience of the project site. The project also had an existing noise source recording and easy access for recording the ambient audio and 360 videos as the project site has not yet undergone any development.

The chosen test case is a proposed quarry development, where the ambient environment is an empty field. A kerbside spot on the most residential side of the site was chosen as the receiving location where the auralisation was centred, shown as the blue dot in Figure 3-3. A similar crusher was auralised as if operating 100 and 300 meters directly in front of the receiving location, shown as the red dots in Figure 3-3. An audio recording and sound level measurement of the similar crusher were available from previous work and used for the auralisation. The measurements provided the crusher's sound power, which was applied to the 100 and 300-meter locations in an acoustic calculation software, Minerva, both with and without a barrier. The calculated sound level differences between the locations and receiving locations created four different impulse responses.

Figure 3-3: Auralisation and receiver locations.

When an impulse response is selected in the Max patch, it is convolved with the crusher audio recording. This recording is 12 seconds long and set to loop continuously. The convolved audio was given an azimuth and elevation angle and converted from a single channel to ambisonic audio. As they were located directly in front of the receiver and at ground level, these angles were designated as 0 degrees for all four impulse responses. The ambient audio and video included events such as cars and planes passing and natural sounds such as bird calls. The files were recorded on a clear, calm, and sunny late morning. Next, the ambisonic microphone and 360-degree camera files were trimmed and synched; then the video file was built into a Unity file for VR playback. The prepared audio and video are just under 2 minutes 44 seconds long, also set to loop; however, the demonstration is generally completed before the end of the track.

Using the Max and Unity files from the previous trials as a template, it took 4 hours to create a working auralisation from the raw files, including importing the files. The time required for recording the ambient environment depends entirely on the project and location, however for this test case, the site visit, including transport from the office, took around 3 hours. Each recording took 15 minutes so that a full-length sound level measurement could be done alongside the video and audio recordings. Multiple recordings were made to increase the likelihood of a good recording. Setting up the equipment, including adjusting the ambisonic microphone gains, and playing audio files for quality checking, also used up time on site. The test case is run for demonstrations through an HTC Vive VR Headset and Sennheiser HD600 headphones while controlled through Max/MSP. Further information on the creating the auralisation is included in the environmental noise auralisation user guide in Appendix B: Environmental Noise Auralisation User Guide.

3.5 Conclusions and Limitations

A working prototype tool for environmental noise auralisation was successfully created and used for a test case and demonstrations. The tool consists of template files and the processes for creating an auralisation, including recording, processing, and outputting audio and video files. The test case is an auralised crusher at a proposed quarry site, with the ability to hear the crusher at two different distances from the receiver, with and without a barrier. Excluding the planning time, the recording and processing for the test case took seven hours, which can be used as a time estimate for similar auralisations.

The tool is limited to four impulse responses and one ambient audio and video combination. The number of impulse responses and ambient audio tracks can easily be increased; however, adding videos would require more development time. The test case playback through headphones can be calibrated using the existing system from the Auckland office once it is adapted to the Christchurch system. This calibration verifies that the headphone output is the same level as was measured on-site with the sound level meter. If the exterior noise environment of the demonstration space is not controlled, the everyday noise can impact what the user is hearing, and the calibration levels cannot be guaranteed. In this situation, the overall levels are no longer accurate, but the difference between impulse responses is accurate, and the auralisation can be used as an “A-B comparison”. The visual indicator of the crusher location is currently limited to the single static dot; however, further development could improve the visuals.

4 Business Context

4.1 Introduction

Understanding the context in which the auralisations would be used is necessary to know how they can be used commercially by considering the factors that can impact its success. The prototype and literature review developed an understanding of the time, equipment, processes, and limitations of environmental noise auralisation. This knowledge is used in the following section to understand the potential of environmental noise auralisation and the threats its development faces. This section is divided into external factors, competition, stakeholders and potential market size.

The two potential applications of auralisations for environmental acoustics projects are to communicate and educate the community through community consultation and to assist in Resource Management Act (RMA) hearings as evidence of the potential future noise environment. RMA hearings are local environment court procedures where a panel and commissioners determine if a proposed activity or development is acceptable under the terms of the local district plans and resource consent requirements. These district plans are based on the Resource Management Act (1991) which states that activities and occupations shall use the best practicable options to avoid unreasonable noise levels.

4.2 Method

The Porter's and PESTLE analyses discussed in Section 2.5.2, were used to understand the market and the environment environmental noise auralisation could be used in and identify any threats and opportunities. As explained in Section 2.5.2, a bottom-up approach was applied to job lists from MDA's project management software to identify the number of projects with potential for environmental noise auralisation. A technology adoption rate factor was then used to determine the number of potential projects.

Five major stakeholder groups for the use of environmental noise auralisation in community consultation and RMA consent hearings were identified by understanding the RMA consent and hearing process. A member of each group was contacted by the project sponsor and asked if they would participate in a demonstration and interview. The demonstration was of the developed test case. It started with the ambient environment before introducing the crusher auralised at two distances from the receiver, both with and without a noise barrier. After the demonstration, the questions followed a semi-structured interview format adapted slightly for the different participants' roles. The stakeholders' influence, interest, and opinion towards using environmental noise auralisation for consent hearings and community consultation were mapped as discussed in Section 2.5.3. The interviewee's responses were summarised for each question, and additional points were noted. Their responses informed the potential market size and which components would be necessary for future development of the tool, such as if a portable system is required.

4.3 External Context: PESTLE Analysis

As discussed in Section 2.5.2, a PESTLE analysis provides an understanding of the project's external environment. An analysis of the tool, community consultation use and RMA hearing environments identified the following key externalities that could impact environmental noise auralisation:

Political:

Few political changes would have a direct impact on environmental noise auralisation. The most likely effect would be from significant changes to the excessive noise section of the Resource Management Act (Resource Management Act, 1991) and regional council plans. Although the RMA is under review and redesign, there has been no indication that the noise emissions section will change (Ministry for the Environment, 2021). Other political changes could affect the number of major environmental projects available for MDA and consequently the number of potential auralisation clients; however, the changes are unlikely to be significant.

Economic:

Post COVID-19 recovery and inflation could reduce the number of projects, constrain budgets, and make clients less willing to pay for additional services like auralisations. Supply issues on other components of the projects, such as the current delays in the construction sector (Radio New Zealand, 2021), could delay starting dates or prevent projects from going ahead. However, the impact on MDA is reduced as their expertise is sought during the project planning and design stage before many supply issues are realised.

Social:

Increasing exposure to environmental noise combined with increasing health consciousness is leading to more consideration of noise levels by the general public (IBIS World, 2021). This may impose more restriction on and increase negative opinions towards noise emitters. There will potentially be higher rates of community consultation. This increased community consultation will likely lead to environmental noise auralisation being a key tool for more clients.

Technological:

Improving quality, increasing availability, and decreasing prices of technology such as VR headsets, 3D microphones and 360 cameras will probably benefit the quality and cost of auralisations as well as improve clients' opinions of and comfort with the technology (Allday, 2021). Development of spatial and dynamic audio in the gaming and music industry indicate how the technology is becoming more widespread and accessible; such as Apple's recent addition of spatial sound to Apple Music and sensors for dynamic audio in their headphones (Apple Inc., 2021). However, these benefits also reduce some of the barriers for new entrants to the market.

Legal:

There are no legal changes that could significantly affect the use of the technology, except changes to the RMA as discussed in the political section. The widespread use of auralisations in general means it is highly likely that the technology and process are too common to be considered novel so there is no risk of patent infringement.

Changes to laws about audio and visual recording laws, particularly in public spaces, could complicate the ambient sound and visual recording process however, these changes are unlikely and may be irrelevant if recordings are carried out inside private site boundaries.

Environmental:

The sole environmental effect that could impact the auralisation part of environmental noise auralisation is changing weather patterns affecting the timing of site visits. However, many factors could impact the number and type of environmental acoustic projects in general. In particular growing awareness and increasing impacts of climate change and environmental sustainability will affect how the environment is used and the projects being carried out. MDA will need to adapt as these changes happen, however, the broad range of projects they work on, and the slow pace of change will likely mitigate the impact of these changes. Additionally, company-level economic incentives for protecting the environment are growing, as one of the interviewees (See Section 4.5) stated, "*getting consent is not getting easier*". This may increase the public scrutiny on projects making the case for environmental noise auralisation easier.

4.4 Competition: Porter's Five Forces analysis

As discussed in Section 2.5.2, Porter's Five Forces analyses assess the competitiveness of a service or product, ensuring that the less obvious components are known and prepared for. The five competitive forces considered are shown in Figure 2-1. The following section describes how these forces affect the commercial use of environmental noise auralisation.

Competition:

MDA has very little existing environmental noise auralisation competition as environmental acoustics requires local knowledge and positioning and the other acoustics teams and companies in Christchurch do not appear to have used auralisation in any current or historical projects. Similarly, there is no public record of other companies in New Zealand creating auralisations for a project, nor using any facilities similar to the Listening Room. Acoustic consulting firms overseas, including but not limited to those listed in Table 4-1, have created auralisations and may have Listening Room equivalents. Although a lot of these projects are for building acoustics, the three most relevant examples for environmental noise auralisation are Force Technology's (Force Technology, n.d.) traffic noise comparisons and Aecom's work with traffic noise around Stonehenge and with different noise mitigation treatments for high-speed rail (AECOM, n.d.). Although these companies are doing environmental noise auralisations, they operate from the UK, Europe, or USA, and are not a competitor to MDA in Christchurch. There is one New Zealand company, Earcon, that indicates they can create auralisations, however, they specify its use for room and building acoustics only and operate out of Auckland. Consequently, the strongest competition for MDA Christchurch is if the local offices of Aecom or WSP apply their company's international expertise locally. This finding reflects what was identified in Section 2.2, that auralisations are only in consistent use by large consultancies (greater than 50 employees).

Table 4-1: Acoustics consultants with a public record of auralisation use.

Company	Location	Expertise	Listening Room
Earcon	Auckland	Room/Building acoustics only.	No
ARUP	UK, USA & Australia	Room, Building, Environmental and VR.	Yes
AECOM	UK	Room, Building, Environmental and VR.	Yes
Acentech	USA	Room/Building acoustics only.	Yes
Force Technology	Denmark	Road noise only.	No
Müller-BBM	Germany	Room/Building acoustics only.	Yes
Venta Acoustics	UK	Room/Building acoustics only.	No
WSP	UK	Room acoustics only.	No

Potential entrants:

The main barrier for entry for companies interested in using environmental noise auralisation is expertise. The technology required to create auralisations, such as 3D microphones and 360 cameras, has become common and affordable. Although the cost of creating a Listening Room is higher than the other equipment such as headphones or a VR headset, it is not prohibitive nor strictly necessary to enter the auralisation market. Similarly, the software required is not limited, technically demanding, or high cost. Thus, the technology is not a barrier to entry for companies. However, acoustic expertise is required to understand and create accurate auralisations, and gain clients' trust; as the clients themselves do not normally have the expertise to verify the reliability and accuracy of the auralisation. There is a level of signal processing expertise required to create the auralisations, however, with more acoustics software introducing the capability to create auralisations, the expertise required will diminish. This means that all local acoustics firms have the potential to be new entrants to the local environmental noise auralisation market if they wish.

Supplier Power:

The auralisation process has no recurring suppliers as all the components used are multi-use (e.g. 360 camera, microphones). The only recurring payments would be for subscription style software. There are two applications with annual licenses that are used in MDA's process and are only used for auralisation. These applications are not designed primarily for auralisation (audio processing and game engine), and alternatives are available. Thus, if the price or quality becomes unacceptable MDA could switch to other options with some effort. There is some slight supplier power here as the auralisations created with one combination of software would likely have to be rebuilt from scratch for a different combination of software.

Buyer power:

Considering a buyer who needs an environmental noise auralisation in Christchurch, they have very low power as MDA would be their only option. The broad range of environmental noise clients means they do not have any group power from them all being a part of the same industry, similarly, only a small proportion of environmental noise projects are for recurring (more than one project per year) clients so none of the clients have a high individual power. However, a large proportion of environmental projects will likely have a tight budget both in general or for acoustics specifically, so the buyers may have high price sensitivity. High price sensitivity could mean lower revenue per project or less projects agreeing to an auralisation.

Substitutes:

There are no complete substitutes for auralisation; solely different methods of calculation or presentation of the auralisation. The major substitute for buyers is to simply not use auralisation and to continue with the current method of reports. Tying in with price sensitivity and considering the lack of direct competition, the "do-nothing" option is the strongest competition for environmental noise auralisation. MDA should ensure that their pitch for the additional benefits of environmental noise auralisation is strong to encourage more adoption of the tool on projects but continue providing the option without auralisation to prevent losing clients to other consultancys.

Additional Competition:

Some acoustic software programs, such as Odeon (n.d.), allow the user to create "auralisations" within the software. This creates competition in the potential entrants and substitutes sections. In general, the auralisation in this software is only possible for room or building acoustics, with a source audio and impulse response, occasionally accompanied by a 3D model of the space. This is missing the background audio and spatial sound that provides the context necessary for environmental noise auralisations. As environmental and room acoustic software are generally separate due to the different calculation methods, the risk that these features could become available for environmental acoustics is low. However, if it does, it will likely decrease the expertise required and consequently the barrier to entry for environmental noise auralisation. It could also become a substitute with clients opting for a quicker and cheaper one-click auralisation and not a fully developed one with VR and spatial sound.

4.5 Stakeholders

Understanding the needs of the clients and others who would interact with the environmental noise auralisation tool is essential so that it is valuable and practical for them. In addition, engaging with these stakeholders early in the tool's development means any necessary changes to the tool or its ongoing development is easier and cheaper. Engaging early also provides the opportunity to determine when the stakeholders would use the tool, informing the market size estimate.

The five stakeholder groups were identified as:

- Environmental acoustics clients.
- Other acoustic experts.
- Environmental planners and commissioners.
- Resource management lawyers.
- Local council environmental health officers (EHO's).

Although there is only one "client" of MDA in the interviewee pool, the other interviewees, aside from the acoustic expert, speak on behalf of clients to guide them through the RMA process and recommend MDA or engage MDA on behalf of their clients. Similarly, the council may engage MDA on new infrastructure projects and peer reviews. Additionally, the EHO interviewed can recommend that MDA and environmental noise auralisations be used. Therefore, all stakeholders were asked if they would recommend auralisations to their clients or use it themselves.

The feasibility and business case project sponsor and other MDA staff were also considered primary stakeholders, and the community is a secondary stakeholder. These three stakeholders were not interviewed as they were engaged with otherwise, or the group was too broad for interviews.

Human research ethics approval for these interviews was granted by the Engineering Management Programme based on the blanket approval for the Master of Engineering in Management projects by the University of Canterbury Human Ethics Research Committee. In accordance with the approval, all interviewees provided informed consent before participating and all results have been anonymised.

The semi-structured interview questions revolved around if and when the participant would use or recommend an auralisation for either community consultation or in a consent hearing process and what improvements they would like or need to see. An example run sheet is available in Appendix C: Interview Run Sheet. The interviewees' responses showed a positive reaction to using it for community consultation. However, one stressed that accurate communication of its abilities and limitations would be necessary. The RMA lawyer advised caution of the selection and timing of what the community hears to prevent counter-productive interpretation of the audio. Aside from the acoustic expert, all interviewees would recommend it to clients or use auralisation themselves in the right context.

Considering environmental noise auralisations use in RMA consent hearings, the responses were positive but conditional. The only negative response was the acoustic expert's response that it should not be used in hearings for decisions as it represents a small moment and is therefore not suitable to assess the long-term health effect. The lawyer raised how the different noise sensitivity of individuals could impact the hearing panel's decision. The planner/commissioner noted that it would require strict, well-documented procedures to ensure consistency across different hearings and that it could only be an accompaniment to the standard acoustic reports at this point. The complex logistics for a hearing situation was also discussed by multiple stakeholders, considering the process transparency and logistics of demonstration. It was emphasised that because of natural justice, everyone involved in the hearing process must have an opportunity to use the auralisation.

The stakeholders were all generally positive about the quality of the presentation, stating that they had not noticed anything to improve during the demonstrations. On further discussion, a few points for improvement were noted:

- Higher screen quality for the headset for auralisations with detailed videos.
- Better method of communication as they could not hear the interviewer during louder parts of the auralisation.
- Improved visual representation of the auralised components. Such as adding a picture of machinery or barriers when they are auralised.
- Some people, particularly those with mobility or balance issues, may be more comfortable seated.
- The headphone and headset cables could be a hazard if there were multiple demonstrations running simultaneously.

When discussing how many people it would be shown to in community consultation, the stakeholders identified that community consultations can have hundreds of people involved and that community meetings sometimes lack structure. Additionally, demonstrations at community events are likely to have uncontrollable external noise environments, so the accuracy would be limited to an A-B comparison. Therefore, it was suggested to identify the people most affected by the noise, offer them an auralisation and then provide a basic auralisation or online video for the community. The client pointed out that auralisations are still helpful at community events to educate the wider community and remind them of the ambient noise in the site's surroundings. The entertainment during the community events reflects positively on the client and MDA. Offering individual demonstrations for the identified people means they can be in a controlled noise environment and experience a more accurate and realistic demonstration than at a community event.

Due to the stakeholders' general requirement for a portable system, a headphone calibration rig is necessary to replace the one currently borrowed from the Auckland office as the portable system must be run through headphones. Similarly, projects outside the Canterbury (or Auckland or Wellington) region would have to be presented with headphones and as much external noise control as possible.

Throughout all the interviews, the challenges of using environmental noise auralisations in a consent hearing were discussed. Some of the main points identified were:

- Protocols and procedures around measurement and file processing will need to be developed and clearly communicated, including documented and agreed prescriptions around how the measurements are taken compared to the ambient noise level and the calibration process.
- It would be good to know how the permitted baseline compares to the auralisation in addition to the current ambient environment.
- Need to be able to defend the model from a noise perspective: e.g. showing that the auralised options are chosen because they are the best practicable options.
- Playback order would have to be carefully chosen to avoid jarring changes.
- Need to answer:
    - What are you ultimately using it for?
    - How does it fit into the trial sequence?
    - How does the demonstration get recorded for the case files?
- As evidence, the demonstration must be available for everyone but could be analogous to a site visit and could be available to just the panel.
- It would need a flexible hearing panel to do demonstrations in the Listening Room rather than the court room.

Post interviews, the stakeholders were mapped on interest vs influence maps for environmental noise auralisation in community consultation and hearing environments, shown in Figure 4-1 and Figure 4-2, respectively. The maps are coloured according to their attitude to the respective auralisation usage. This identified no stakeholder barriers and consequently no opposition to using environmental noise auralisation for community consultation. However, the acoustic expert is a barrier that would need to be addressed to use auralisations in environment court hearings. As the acoustic expert has high interest, high influence, and is against the use, they are likely to oppose any use in the environment court. Therefore, environmental noise auralisation has no value in a hearing environment until this barrier is overcome. The lawyer and commissioner also have high influence and a conditional attitude towards the use in hearing, so their conditions would also need to be considered and mitigated.

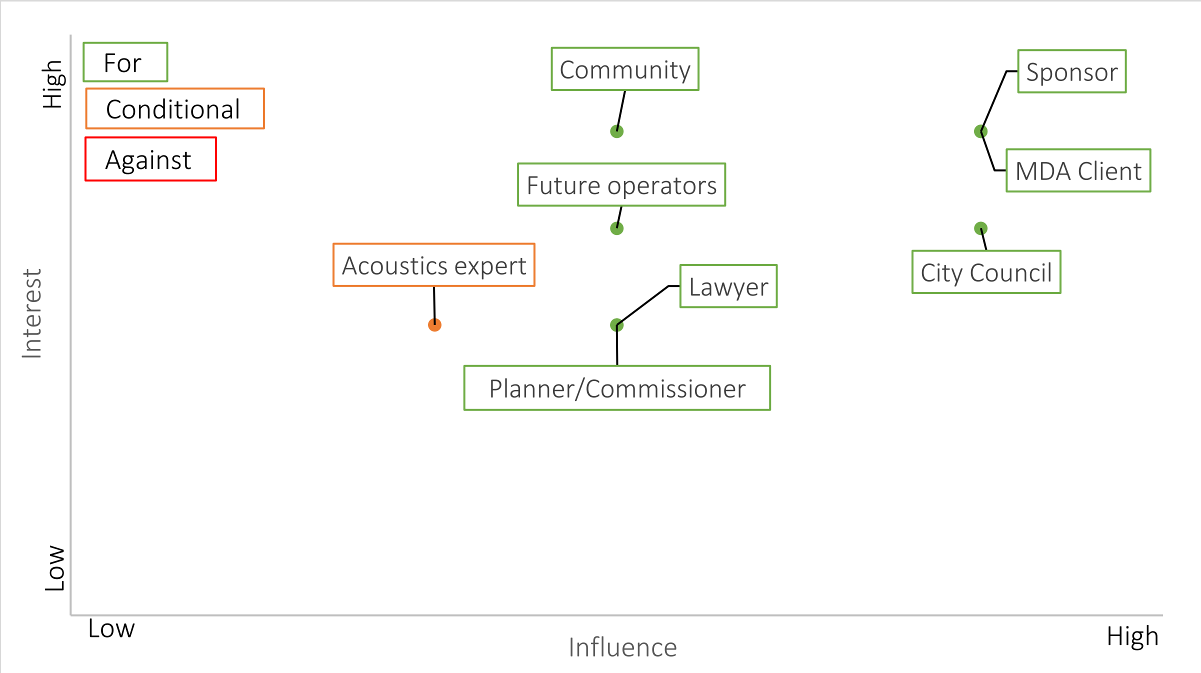

Figure 4-1: Stakeholder map for using environmental noise auralisation in community consultation.

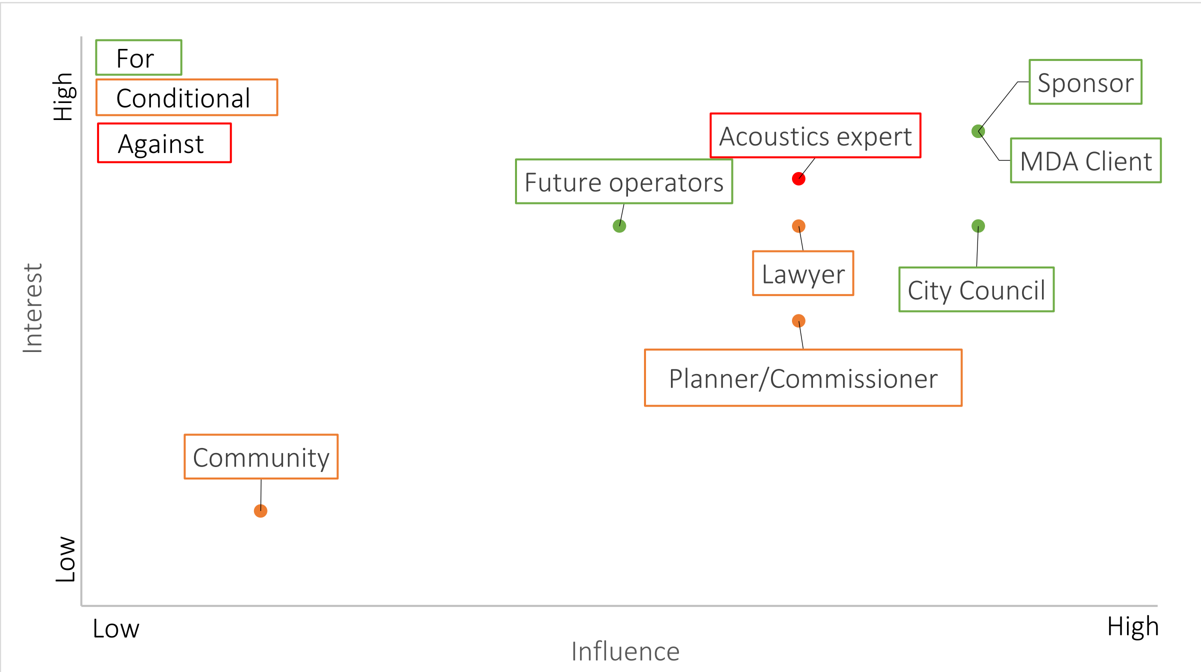

Figure 4-2: Stakeholder map for using environmental noise auralisation in hearings.

4.6 Market Size

A key component to the feasibility and business plan for environmental noise auralisation is the number of projects it is expected to be used on, as this is a driver of the financial feasibility. Therefore, the environmental projects initiated between 1st December 2020 and 1st December 2021 were analysed to estimate the number of projects environmental noise auralisation could be used on each year.

Not all environmental acoustic work is suitable for auralisation; there are two factors required for auralisation:

- There must be a proposed change to the existing noise environment at the project location.
- The acoustics project must provide information to help decision-makers decide if or how the proposed change will go ahead.

With these criteria, environmental acoustics projects that are always unsuitable for auralisation include noise level monitoring and peer reviews. There is the potential for vibration simulation within a Listening Room set up, as in the MDA Auckland Listening Room. However, this is outside this project's scope and not feasible for the Christchurch office in the short term; thus, any primarily vibration-based projects are also excluded from the potential market.

During the stakeholder interviews (see Section 4.5), the type and size of projects that the stakeholders saw auralisation being used on were discussed. They identified that of the suitable projects, only large or controversial projects would benefit from auralisations due to their increased likelihood of a hearing and community interest. Therefore, only these projects have commercial auralisation potential.

From the [redacted] jobs classed as environmental acoustics, [redacted] were identified as in progress or complete, with proposals accepted by MDA and the client. Of those [redacted] projects, [redacted] were identified as unsuitable for auralisation. Another [redacted] were identified as too small or routine to have any auralisation potential. These were primarily projects applying or reapplying for consents that are unlikely to be controversial. The remaining [redacted] projects are then said to have auralisation potential. However, without in-depth knowledge of each project, this number is an estimate, as many factors such as project size and location can affect the potential of an individual project. This segmentation of the jobs is shown in Figure 4-3.

According to NBS Research (2018), 35% of UK architects are currently using virtual reality technology, and a further 29% expect to start using it in the next five years. Similarly, Jalo (2021), surveyed small and medium enterprises in manufacturing in the European Union and found that 25% of the companies were using mixed reality technologies occasionally and 15% were using them often. Without the barrier of investment in VR, auralisation clients are likely to be more open to using VR on projects compared to investing in the costs and development themselves. Therefore, an adoption rate factor of 25% is a reasonable estimation of the adoption of auralisation by MDA's clients. This was applied to the [redacted] potential projects, resulting in an estimated [redacted] projects per year.

In addition to the estimations, there is uncertaintly in this estimated [redacted] projects per year as the overall number of projects per year differs each year as does the proportion of different types of projects. The average size of the technically suitable segment for the five years from 2017-2021 was [redacted] projects with a range from [redacted] in 2017 and 2019 to [redacted] in 2018. Each smaller segment introduces more uncertainty and there is no clear pattern to the number of jobs, even considering the COVID disruption over the past two years. Therefore, this uncertainty must be considered if the development is to go ahead.

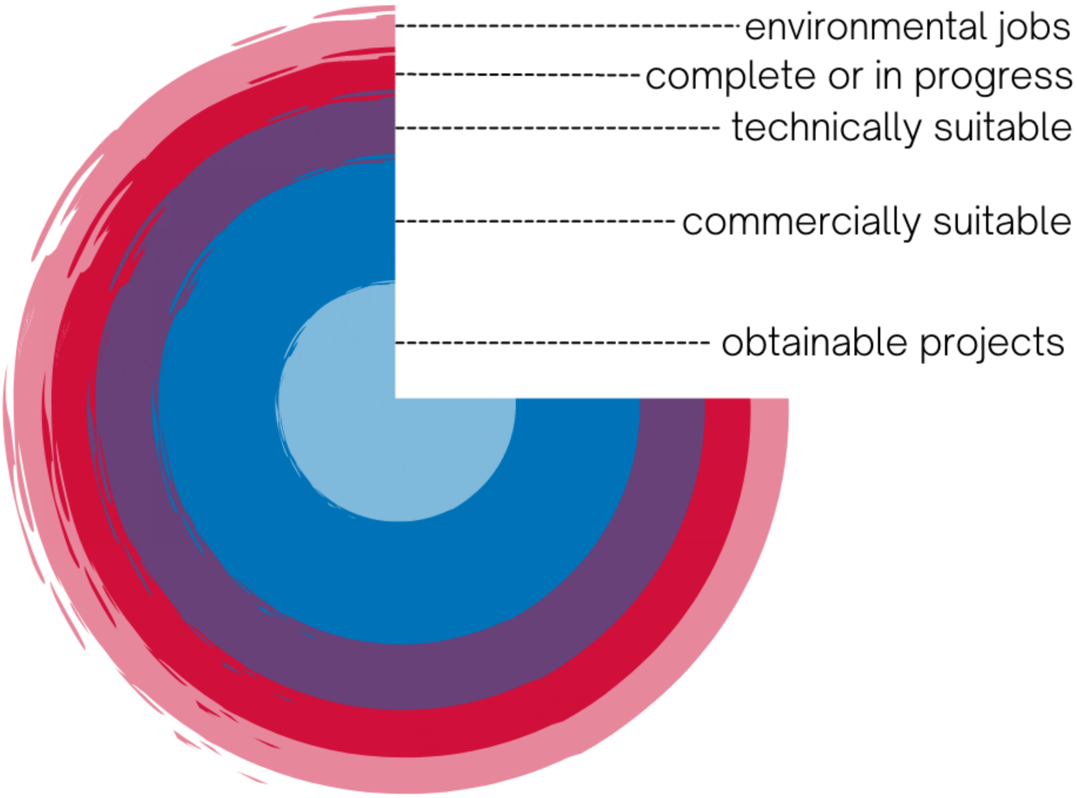

Figure 4-3: Segmentation of 2021 environmental acoustics jobs by auralisation potential.

4.7 Conclusions

Understanding the context in which the development and use of environmental noise auralisation exist is vital to understanding its threats and potential. A PESTLE and Porter's analysis were used to assess the external environment and competition. Information from stakeholders and a market size estimate were used to determine environmental noise auralisation's potential.

The PESTLE analysis concludes that no external factors are likely to have a significant impact. Porter's Five Forces analysis established there is no direct competition currently operating in Christchurch, and the suppliers and buyers also have very little influence. There is some risk of new entrants, which would be amplified if auralisation capability is introduced into the environmental acoustics software. However, this is unlikely in the short term, and MDA would continue to be strong competition with new entrants because of their expertise, higher quality auralisations and Listening Room. The strongest competition force is substitution as there is a high risk that clients would choose the "do nothing" option, preferring a standard acoustic report. The only mitigation for this is to ensure that the communication of the benefits is persuasive. MDA should also continue to offer the standard report option alongside auralisation, so the client remains with MDA and does not go to another consultant for the report.

Five key stakeholder groups were identified, and a group or individual of each was invited for a demonstration of the test case. Discussions with those interviewees found that they all thought that environmental noise auralisation could be used for community consultation as long as the tools abilities and limitations are communicated to the user. As running demonstrations for large groups of people is complicated, it was suggested that a full demonstration is provided to the key stakeholder, and a video or uncalibrated auralisation is used for the bulk of the group. On the other hand, the discussions identified that most interviewees thought many hurdles need to be overcome before environmental noise auralisation can be used in an environment court hearing. The key hurdles are determining what it is for and how it fits within the hearing, developing clear protocols and documentation for the entire process, and ensuring the auralisation location and audio selections are defensible during the hearing.

The market size was estimated by analysing the previous year's environmental acoustic jobs and segmenting the jobs into those technically viable for auralisation, then those commercially viable. The approximately [redacted] commercially viable jobs were then divided by a technology adoption rate factor, giving around [redacted] jobs per year where the client would be open to the new technology and would choose to pay for an auralisation.

Overall these analyses showed a small market for environmental noise auralisation as a community consultation tool. If the hurdles are overcome, there is potential for its use in hearings in the long term.

5 Business Case

5.1 Introduction

With an understanding of the tool, market, and context, it is possible to understand how the environmental noise auralisation tool could be sold as a service and what investment would be required to provide the service. As mentioned in Section 2.5, environmental noise auralisation is considered under the commercialisation of a new product and the feasibility of the required development. So both the Lean Canvas and Five Case model can be used. The Lean Canvas considers how the environmental noise auralisation product can be sold, such as who are the customers and what is its unique value proposition. This is important to understand why, how, and who will pay for the service. Conversely, the Five Case model considers the capital and ongoing costs of providing the service compared to the benefits and if the project is compatible with MDA's strategy and abilities.

5.2 Methods

This business case uses two common models. First, the Lean Canvas is used to summarise the commercialisation of environmental noise auralisation as a service for acoustic consultants. Secondly the Five Case model is used to assess the feasibility of the continuing development, Listening Room construction and 20 years of projects. This was done by forecasting 20 years of cash flows for a set number of projects per year at a set fee per project. The number of projects per year was chosen from the estimated market size from Section 4.6. An estimation of equipment and development costs was used to select the project fixed fee and estimate the costs throughout the 20 year forecast. Generally, the values used in the estimation calculations were gathered from MDA's previous Listening Room development projects and other internal data, The calculation sheet is included in Appendix D: Economic Analysis Calculation Sheet.

5.3 Lean Canvas

As described in Section 2.5.1, the Lean Canvas is a way to summarise the different aspects necessary for successful commercialisation and how this project addresses them. The Lean Canvas shown in Figure 5-1 considers the key components required for a successful product. This includes the problem being solved, the existing solution, the unique value of the concept, the customers, the unfair advantage, costs, revenue and more.

The information gathered during the stakeholder interviews and context analysis was used to understand how auralisation could be sold to clients, identifying how and when the environmental noise auralisation tool has the highest value for clients. It also identified the various costs and potential revenue streams such as an auralisation fee added to standard project rates, and other projects it could be used on such as machinery operator training. In summary, the Lean Canvas establishes that environmental noise auralisation solves the problem of communicating technical information to non- technical stakeholders. The customers are environmental acoustics clients who MDA provides with clarity of the future noise environment so they can make the best decision for their project and the community.

Problem

Communication of technical reasoning to stakeholders is difficult due to their lack of conceptual understanding such as the difference between X dB and Y dB.

Communication of how noise will sound, including the frequency spectrum is difficult and not included in the overall levels reported.

Existing Alternatives

Currently written and verbal explanations are provided, sometimes assisted by diagrams and graphs, such as noise contours.

Solution

Audible demonstration of the expected sound. This auralisation presents the sound level differences and the overall character of the noise by incorporating audio representing the full spectrum of the sound.

Key Metrics

Number of projects using or requesting environmental auralisation at MDA Christchurch.

Time spent creating an auralisation compared to the revenue.

Unique Value Proposition

We provide clarity so you can hear the future and make the best decision for your client.

High Level Concept

Visualisation for sound.

Unfair Advantage

MDA's acoustic expertise, reputation, and client base.

MDA's experience with auralisations and listening room development.

Channels

Reach out to past and potential clients to inform them how the new tool can be applied to their projects.
Run demonstrations to show them the difference.
Offer auralisation in project proposals.

Customer Segments

Paying customer:
Environmental acoustics clients that are changing the noise environment, with projects that are:
- large
- contentious
- need clear communication with the stakeholders or community

Early Adopters

Forward thinking and open to change.
Value communication
Work on large projects, prioritise $ over cost.

Cost Structure

Capital costs of new equipment, Listening Room build, and initial development and marketing. Ongoing costs of development, software, and equipment.
Variable costs of consultant time per auralisation.

Revenue Streams

Charge each project that uses an auralisation where the fee is a fixed auralisation fee + hourly rate for the consultants time. The fixed fee is a perceived value price above a minimum value that covers the capital and ongoing costs.

Figure 5-1: Lean Canvas for Environmental Noise Auralisation

5.4 Five Case Model

As discussed in Section 2.5.1, the Five Case model separates a business case into five sections: strategic, economic, commercial, financial, and management. For a stand alone project such as this one, the most important section is the economic section that discusses the economic feasibility of the project. The strategic case ensures the project is a right fit for the company while the commercial, financial, and management cases discuss if the project is competitive and profitable, if it can be funded, and if it can practicably be implemented.

5.4.1 Strategic Case

MDA's mission is to deliver exceptional acoustic designs by valuing technical excellence, innovation and strong client relationships as well as a respectful work environment, the highest ethical standards, fiscal responsibility, and exceptional people. The objectives of developing and using environmental noise auralisation on projects are to:

- Improve MDA's capability to communicate the impact of different acoustic scenarios to clients and other stakeholders.
- Ensure that clients receive fitting, high-quality solutions through better comprehension of the acoustic factors.
- Showcase MDA's innovation and expertise.
- Increase capability for innovative projects.

These objectives align with MDA's strategy as they foster innovation, improve client relationships, demonstrate and improve technical excellence, and conform with the other values. Therefore, a successful investment in the initial and ongoing development of environmental noise auralisation would look like:

- Better decisions made on environmental acoustic projects due to clearer communication of the effects.
- Happier and more likely to be return clients due to better results on their projects
- A broader reputation as an innovative company with excellent technical expertise, as community consultations create a wider outreach.
- Competitive advantage in environmental acoustics proposals leading to more work won.
- More resources to provide innovative, specialised solutions on any project.

The main benefits of environmental noise auralisation are that it provides better communication with clients and their stakeholders and therefore, better decisions and results for their projects. Better communication and results for clients will likely lead to higher customer satisfaction and clients are more likely to return and recommend MDA. As the only company in NZ with auralisation it also provides a point of difference and competitive advantage when MDA are competing for work. Wider scale demonstrations such as community consultation events would introduce MDA to a range of people and broaden MDA's reputation.

5.4.2 Economic Case

This case assesses different options for the development and use of environmental noise auralisation. The options are assessed against the objectives from Section 5.4.1 and the critical success factors outlined in Table 5-1. The costs, benefits, and risks are also assessed for the options to determine a preferred development method.

Table 5-1: Critical success factors for environmental noise auralisation at MDA.

Critical Success Factor	Key considerations:
Strategic fit and business needs	Meets the project objectives and MDA strategy. Fits with other MDA development and projects.
Value-for-money	Optimises value-for-money (best mix of benefits, costs and risks) providing an appropriate reward to stakeholders.
Potential affordability	Can be implemented from available funding.
Potential achievability	Can be delivered with the organisation's abilities and available skills. Can be effectively utilised on projects with the organisation's resources and expertise.

There are five options for the development of environmental noise auralisation that were considered against the objectives and factors discussed in the project context.

1. Represents the status quo; in this option there is no further development of environmental noise auralisation for the Christchurch office and noise level communication continues through written reports.
2. This is solely a portable system; development continues and auralisations are used for environmental acoustics projects; however, there is no development of a Listening Room. This significantly reduces the required capital investment but limits the accuracy of audio playback and limits future innovation potential.
3. This option is the full development of environmental noise auralisation for both portable use and a Listening Room. The Listening Room introduces more costs but provides more accuracy and potential for use on other projects.
4. This option is for the full development as in option 3, using a partnership to help fund the investment. This could involve developing a separate entity for the auralisation projects or sharing the use of the Listening Room with another consultancy.
5. Finally, option 5 is for the full development as in option 3 but with focussed development on using the auralisations in environment court hearings. This would broaden the usage of auralisations faster but increase the amount of initial development required and introduce the risk that the barriers to use it in hearings cannot be overcome.

Table 5-2: Comparison of success factors for environmental noise auralisation development options.

Reference to:	Option 1	Option 2	Option 3	Option 4	Option 5
Description of option:	Status Quo	Portable system	Listening Room and portable system	Joint venture	Focus on RMA hearing use
Project objectives					
1. Improved communication	x	√	√	√	√
2. Ensure high quality solutions	?	√	√	?	√
3. Showcase innovation and expertise	x	√	√	?	√
4. Increased capability for innovation	x	?	√	√	√
Critical success factors					
Business need	x	?	√	?	√
Strategic fit	x	?	√	?	√
Value-for-money	?	√	√	?	?
Potential achievability	√	√	√	?	?
Potential affordability	√	√	?	√	?
Summary	x	√	√	?	√

KEY:	
Red – does not meet	x
Yellow – partially meets	?
Green – Fully meets	√

Option 3 is the preferred option as it best meets the objectives and critical success factors, as shown in Table 5-2. The status quo option does not meet most objectives and factors because it is not contributing any development. Option 2, although it is affordable, achievable, and good value-for-money, does not increase the capability for innovation. A portable system also does not offer the same quality or fit with other MDA developments as a Listening Room. Engaging in a joint venture would make the project more affordable but also complicates aspects such as the Listening Room's location and the ability for future innovation with the room. Involving another acoustic consultancy would also decrease the MDA's competitive advantage and could require compromises that affect the quality of the results. Option 5 would significantly increase the cost of initial development without a guarantee of successful use in hearings or a larger market size. Option 3 mitigates this increased risk and cost with a gradual development of hearing use once the community consultation use is established. This also allows time for the clients, community, and hearing panel to see auralisations in use before encountering them in a hearing environment.

The financial affordability and cost benefits of Option 3 were assessed by determining the costs and future cash flows for a 20-year forecast. The project's costs were divided into capital, fixed and variable costs. The capital and fixed costs cover the equipment, software, and development required to make auralisations, while the variable costs cover the consultant time spent on an individual project plus any other project-specific costs. Initial development time and equipment expected to have a lifetime of 20+ years are considered capital costs. Equipment with a shorter lifespan, including software, is considered fixed costs as they would need to be replaced within 20 years. As proven by the working prototype and stakeholder demonstrations, the equipment does not need to be purchased initially for the set-up to function as MDA Christchurch already owns or has access to this equipment and software. However, some would need to be bought in the first few years to replace aging equipment or return borrowed equipment.

The variable cost per project is driven by the number of receiver positions in the auralisation and partly by the number of demonstrations. Therefore, the preferred option would be to estimate the minimum charge by combining the minimum fixed fee and the estimated variable cost. Then the project fee can be above the minimum amount by a percentage increase or an increase representing the value the auralisation will likely bring to the client. The profit from the variable costs was not included in the model or calculations as it is dependent of the time taken and particular consultant for each auralisation, and because this profit is earned whatever the consultant is working on.

Currently, tethered headsets are required when using headphones as the headset sends the head position data back to the PC to adjust the audio spatialisation. Untethered headsets are currently unable to do this without converting them to tethered headsets at an additional cost. In addition, tethered headsets require a single PC per headset, so running multiple demonstrations simultaneously would require capital investment.

Ongoing development costs were kept separate from the fixed costs as the number of development hours per year is at MDA's discretion and can be increased or reduced as required. For the calculations, it was assumed that there would be 90 hours of ongoing development per year, based on the Auckland office's average time spent per year. The development hourly rate represents a higher proportion of graduate level work and is reduced by 20% to remove the markup.

The number of projects per year was modelled as slowly increasing from 0 to [redacted] over the first five years and then between [redacted] and [redacted] projects per year for the remaining 15 years. This gives an average of [redacted] projects per year over the 20 year period, based on the estimation from Section 4.6. For simplicity, an average of [redacted] projects per year was used for the calculation of the of the minimum fixed fee. The estimated number of projects for individual years is included in Appendix D: Economic Analysis Calculation Sheet.

The project's economic viability is assessed using its net present value (NPV) at the end of its life. NPV accounts for the time value of money, as due to borrowing costs, expected shareholder returns, and many other factors, cash is worth more in the present than the future. This is accounted for by adjusting future values to their equivalent amount today with a discount rate. Projects with a positive NPV are financially viable and can be accepted. For companies, the discount rate represents either the cost of borrowing money or the return expected by shareholders; however, without the company's discount rate, the rate was set at 8%, 2% higher than recommended by the treasury for state-sector R&D projects. An increase in the discount rate decreases the value of future transactions, generally delaying the breakeven point for the project. Fortunately, the nature of this project means the fixed fee per project can be increased to account for a higher discount rate if necessary.

The variables shown in Table 5-3, based on data from the test case and the Auckland and Wellington Listening Room projects, were used to calculate the cash flows and 20-year forecast. The development and equipment costs of the rooms in Auckland and Wellington were also used to estimate the capital costs. With these variables, the capital investment is $[redacted], with approximately $[redacted] of ongoing development and fixed costs per year. This resulted in a minimum fixed fee of $[redacted] per project for a 10-year payoff period. The actual price per project must be higher to account for the time value of money. Therefore, using a fixed fee of $[redacted] per project, the NPV after 20 years is $[redacted], with a present value index (PVI) of $[redacted]. This means the project is economically viable and would return $[redacted] for every dollar of capital investment. This 20-year forecast is shown in Figure 5-2, where the light bars represent the yearly cash flow from the auralisation fees and costs. The dark line represents the cumulative cash flow adjusted to the NPV, giving the NPV of the project over time. For this fixed fee of $[redacted], a similar project to the test case would have a total price of $[redacted], including the consultant time cost.

Table 5-3: Cost and forecast variables.

General Variables		
Number of projects	[redacted]	/year
Staff rate	$[redacted]	/hr
Development cost	$[redacted]	/hr
Ongoing development time	90	hrs/year
Capital costs		
Pay off period	10	years
Initial development time	300	hrs
Funding	$[redacted]	
Variable costs		
Meeting with client	2	hrs
Site visit	0	hrs
Processing time	4	hrs/position
Demonstration time	0.25	hrs/person
Project specific costs		
Number of receiver positions	1	
Demonstrations	4	people
Other costs	$0	

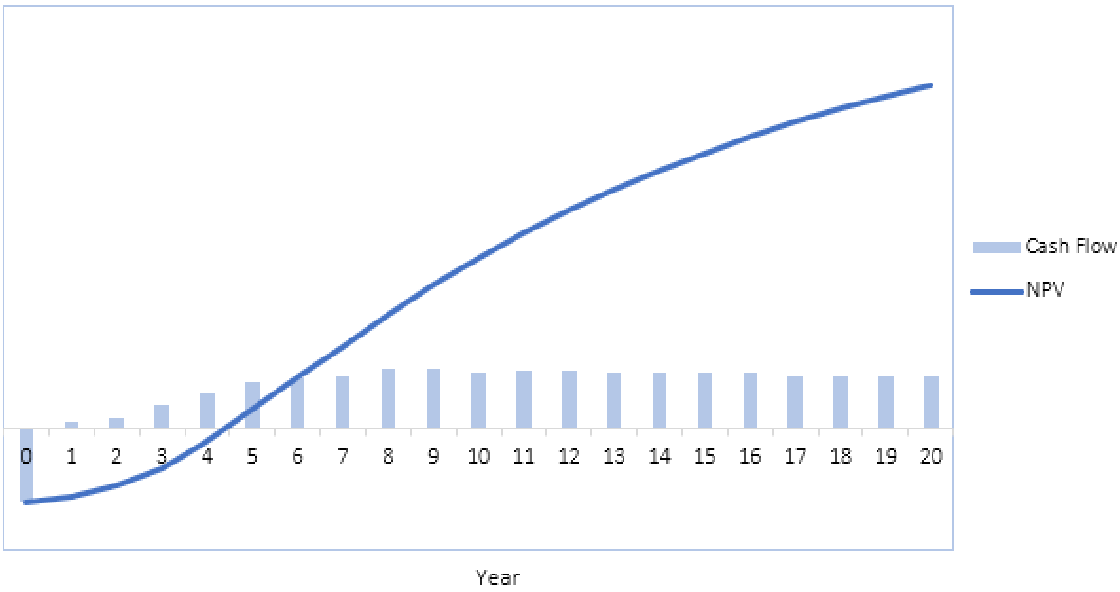

Figure 5-2: 20-year forecast for environmental noise auralisation cash flows for a $[redacted] fixed fee per project.

The key variables were tested in a sensitivity analysis and a worst-case analysis to ensure the project is financially viable. The funding, number of projects per year, discount rate, and overall costs were selected as the key variables to compare. The results are shown in Table 5-4. For each sensitivity analysis, all the other variables were held constant, as in Table 5-3, with a fixed fee of $[redacted]. The overall cost sensitivity was assessed by adding a sensitivity factor to the overall capital and fixed costs so the combined cost could be increased or decreased by a percentage. The results show that halving the number of projects each year has the most significant impact of all the sensitivities, followed by the discount rate.

Compared to the number of projects and discount rate, the overall cost and funding impact is small. Fortunately, if the number of projects per year is lower, the remaining projects are more likely to be larger or more controversial, making the auralisation worth more. In that case, a higher price can compensate for the lower numbers. The discount rate could be higher than expected but is unlikely to reach 20%, as with the number of projects raising prices could combat higher rates if necessary. The worst-case scenario shows the impact of a bad result for all the sensitivity variables. The worst-case was selected as no funding, 25% decrease in the number of projects, 50% increase in costs and a 12% discount rate. The NPV for this case is $[redacted], which is low but still a positive return on the investment without adjusting the fixed fee. This shows that the project is economically viable even in the worst case.

Table 5-4: Sensitivity analysis results.

Sensitivity Variables	Altered Value	NPV
Baseline	*N/A*	$[redacted]
Funding ($[redacted])	$0	$[redacted]
	$[redacted]	$[redacted]
Average number of projects per year ([redacted])	50%	$[redacted]
	75%	$[redacted]
	125%	$[redacted]
Discount rate (8%)	10%	$[redacted]
	12%	$[redacted]
	20%	$[redacted]
Overall cost	+ 10%	$[redacted]
	+ 50%	$[redacted]
	+ 100%	$[redacted]
Worst Case - Funding - Number of projects - Discount rate - Overall cost	 $0 15 12% + 50%	$[redacted]

5.4.3 Commercial Case

As discussed in Section 4.5, potential clients have stated that they are excited by the technology and would use it on their projects, even suggesting it for other uses such as staff training. Therefore, commercial use of the environmental noise auralisation tool is likely. Once the development is complete, projects and marketing could begin with the portable system, even if the Listening Room is still under construction. If the noise environment of the demonstration spaces cannot be controlled, the auralisations may be limited to A-B comparisons rather than a replication of the exact levels.

There are some remaining factors to consider and include in the ongoing work and development, should the project go ahead. Currently, the office space required for a Listening Room has not been considered in the costs and development as the Christchurch office is considering moving offices regardless of if the Listening Room goes ahead. However, if circumstances change, the space required may become a necessary consideration. After the initial development and room construction is complete it is advised that MDA host demonstration events of auralisations for prospective clients so they can understand what they are being offered. Similarly, materials to market the tool will need to be prepared. Throughout the stakeholder interviews it was suggested that MDA collaborates with landscape architects for the visual component, so some investigation should be carried out into this possibility. The recording, processing, and calibration procedures will need to be established for quality guarantees between different projects, even more so as the hearing use is investigated later on.

5.4.4 Financial and Management Cases

The development of environmental noise auralisation and a Listening Room in Christchurch has a one-off capital cost of $[redacted] for the build costs, equipment, and a further 300 hours of development. There are ongoing costs of $[redacted] for fixed equipment and around $[redacted] for ongoing development, although this is likely to decrease after the first five years. MDA can use its internal grant, the Keith Ballagh research fund, to cover some of the capital costs, as it has previously been used for the development of the other Listening Rooms. $[redacted] from this fund was included in the economic assessment, reducing the capital investment to $[redacted]. Some funding may be possible for specific development projects through Research and Development and Student Grants with Callaghan Innovation (Callaghan Innovation, n.d.). The remaining funds would have to be raised through the business or other sources.

As MDA has two other Listening Rooms that have been successfully built and have auralisation expertise, this project can be internally managed at MDA Christchurch with the assistance of the nationwide MDA offices as necessary.

5.5 Conclusions

The environmental noise auralisation tool addresses the difficulty in communicating technical reasoning and how noise level changes will likely sound by providing an audible demonstration of the changes. This would be a service provided to environmental acoustic clients for a fixed fee plus hourly rate. Auralisation is ideal for projects that need clear communication with stakeholders and the community. The recommended development method is to develop both the Listening Room and a portable system focussing on community consultation and develop it for use in hearings after its other services are established. The Listening Room construction and initial development costs are estimated to be $[redacted]. After 20 years of an average of [redacted] projects per year, with a $[redacted] fee per project, the estimated NPV is $[redacted]. A sensitivity analysis showed that the NPV is positive even in the worst case, so this investment is financially viable. The stakeholder discussions indicated that there are potential sales and that projects can be carried out with the portable system before the Listening Room is constructed. Some funding is possible from internal and external innovation grants, while the experience of other MDA offices indicates that the development can be managed internally. Other factors that would need to be considered before and during the development are the required office space, demonstration events for prospective clients, marketing, and development of the visual component and procedures.

6 Conclusions and Recommendations

Continued development of 3D environmental sound field auralisation in the Christchurch office of Marshall Day Acoustics would allow auralisation to be offered to environmental acoustics clients and provide the office with more opportunities for innovation. Environmental noise auralisation helps clients better understand and communicate the impact of proposed noise changes through an audible demonstration of the future sound. Adding 360 videos presented in Virtual Reality to the auralisation improves the realism experienced by the user.

Having identified the process required to create an auralisation through a literature review and MDA's previous work, an environmental noise auralisation tool was developed. This tool follows the process of:

1. Identifying the noise changes to be auralised, known as Impulse Responses.
2. Recording the source audio for the impulse responses and audio and video of the ambient environment.
3. Convolve the source audio with the impulse responses to create the auralisation.
4. Process the audio and video for playback.

MDA Auckland's previous files were adapted to environmental projects and the Christchurch setup. Template files for environmental noise auralisation were created then tested with existing and raw data. This template was then applied to a test case of a crusher operating at a proposed quarry site. The auralisation shows the ambient environment of the proposed quarry site and how the crusher would sound operating 100 meters and 300 meters from the receiver, both with and without a barrier.

This test case was demonstrated to key stakeholders who identified that it could be used in community consultation but using it in the environment court for resource management hearings is much more complicated and would require many hurdles to be overcome. For community consultation, they could see it being used on larger or contentious projects. They would need a portable demonstration system for larger groups, although key individuals could come to the MDA office for more accurate demonstrations. Analysis of the external operating environment and competition did not identify any threats; however, the strongest competition is the "do-nothing" option, where clients prefer the traditional acoustic report with no extra cost. An analysis of the previous year's environmental acoustic jobs identified around [redacted] that were technically and commercially feasible for auralisation. An adoption rate factor of 25% determined that there could be [redacted] environmental noise auralisation projects each year.

Environmental noise auralisation could be provided to these clients for a fixed fee + hourly rate. Further development of the tool and equipment is needed to provide this service. A fixed fee of $[redacted] for [redacted] projects per year is estimated to provide a net present value of $[redacted] at the end of [redacted] years, including initial and ongoing development costs. The development of the tool for community consultation as a portable system and a Listening Room agrees with MDA's strategy and capabilities; additionally, a sensitivity analysis showed that it would be financially viable with a worst-case net present value of $[redacted]. Thus, the development and use of environmental noise auralisation for MDA Christchurch is viable.

It is recommended that Marshall Day Acoustics develop the environmental noise auralisation tool for use in community consultation with a portable and Listening Room set up. Use within the RMA hearing process could be investigated but should not be prioritised in the short term.

7 Limitations & Risks

This report has some limitations due to the time and resources available and the scope of the project.

The stakeholder demonstrations and interviews were limited due to time constraints to one person or group from each stakeholder group. This limits the applicability of the results to their stakeholder groups. However, the overall sentiments were similar, indicating that the results could be consistent with a wider group of interviewees.

The economic analysis relies on many estimations that are as accurate as possible with the available information. This includes the cost of the Listening Room build, which is affected by the circumstances of each build. In the model, the fixed costs for equipment are evenly distributed throughout the project life for simplicity. However, as the individual equipment costs vary, the actual fixed costs are likely to be much higher in some years and lower in others.

No in-depth research was carried out into the accuracy and reliability of the software used for the audio processing relying on the premise that it behaves as advertised.

As with any large investment there is risk inherent in proceeding with the development. Optimism bias could have impacted the business case by assuming better values or results than what is likely. As this projects costs are primarily upfront, before environmental noise auralisation projects begin, there is a risk of not generating enough income to compensate for the investment. This risk could be realised if there is not enough projects or a low perceived value by clients. Similarly, if the tool cannot move from the first clients, who would likely be innovative and adaptable, to the majority of clients, who are more skeptical of change, the number of projects could be limited. Resource constraints, such as limited staff or equipment availability, could reduce the number of projects that MDA is capable of providing. Increased time spent on initial development could increase the capital costs and also delay the income stream. There is no method to eliminate these risks, however monitoring of the factors mentioned can allow for control measures such as price increases or more resource allocation to be implemented. Finally, there is the opportunity cost, the risk that the investment money could be better spent on a different project. MDA should consider the costs and benefits of other potential projects to ensure they invest in the best possible project.

8 Future Work

There are plenty of factors that could be developed further as the environmental noise auralisation tool is taken from a working prototype to a service. This work includes but is not limited to :

- Finalise and document the calibration process for both the headphone set up and Listening Room.
- Add visual cues to the demonstration so the user knows when the impulse response is changed.
- Add the capability to switch between different locations, including different videos.
- Finalise and document the procedure for creating and demonstrating auralisations to maintain consistency between projects.
- Investigate methods for demonstrations to large groups and publishing online.
- Investigate collaboration with landscape architects for the visual component.
- Develop marketing materials, including an introduction to auralisation for potential clients, possibly with demonstrations.

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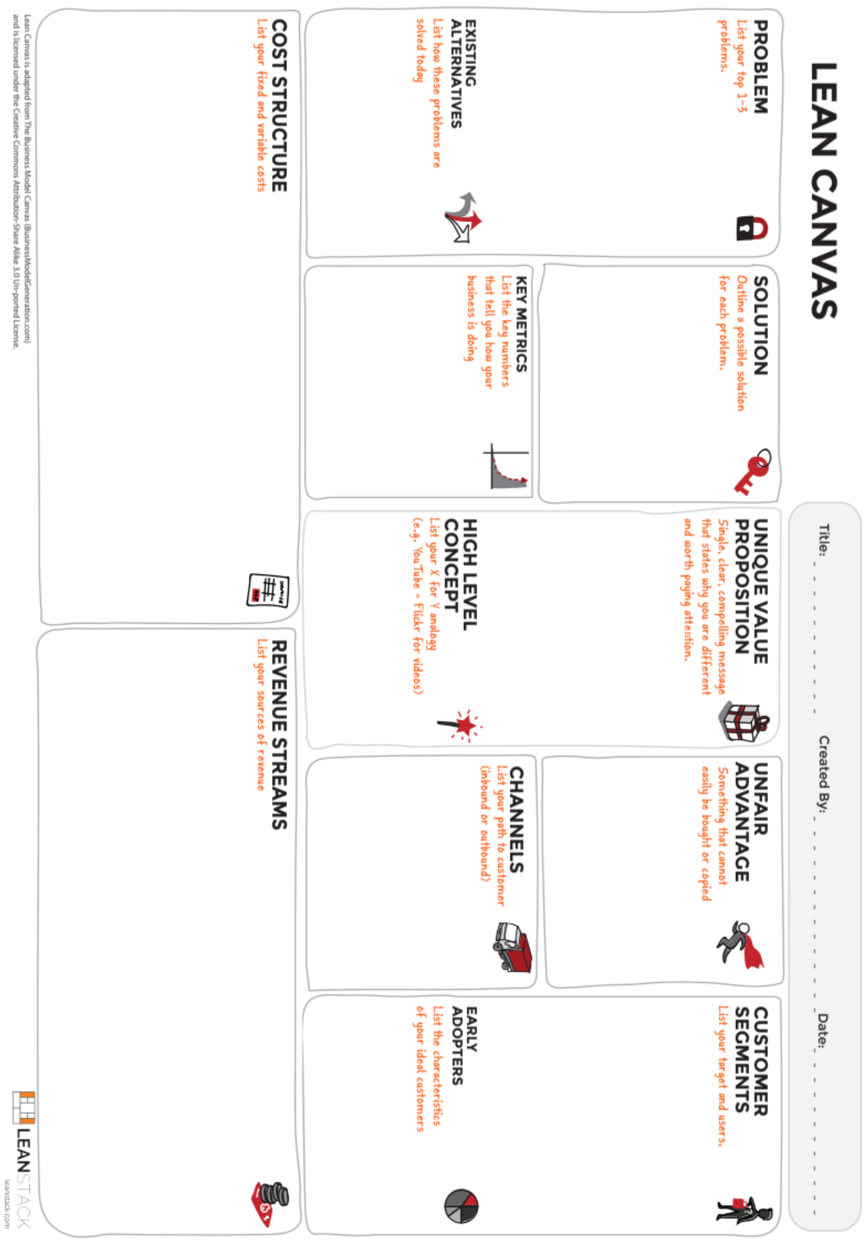
11 Appendices

11.1 Appendix A: Lean Canvas Template



Template from LeanStack (n.d.)

11.2 Appendix B: Environmental Noise Auralisation User Guide

11.3 Appendix C: Interview Run Sheet

RUNSHEET FOR SEMI-STRUCTURED INTERVIEWS: Environmental sound field auralisation

1. Welcome and self-introduction (by the student)
2. Reciprocal introductions by the interviewee
3. Summary of ethical protocols and confirmation of consent
4. Demonstration of the environmental noise auralisation
5. Questions
    a. Have you seen or used auralisation before?
        i. Specifically in an environmental noise context?
    b. Would you use it, recommend it or accept it?
        i. In which projects?
        Size, location, budget?
        ii. As an accurate replication of the sound or as an education comparison?
        iii. How regularly would you use it?
        iv. Do you think it is useful?
    c. What do you think can be done to improve the auralisation experience?
        i. Is one sound source sufficient?
        ii. Would you need to be shown to multiple people at once? (Specific stakeholders or large community groups)
    d. What would you pay for an auralisation on a project?
    e. Can you see it in regular use within your profession in the future?
    f. Would it make you more likely to engage MDA on a project?
6. Probing questions
    a. Why?
    b. Can you be more specific?
    c. Can you provide an example of that?
    d. What is your best estimate?
    e. Which would be closer?
    f. Which answer comes closest to how you feel/ think?
    g. If you had to pick one answer, what would you choose?
    h. Is there anything else you can think of?
    i. What do you think would needed to be changed?
    j. Do you think that is right/wrong? Why?
    k. What do you think about that?
    l. Why do you think that is?
7. Closing questions
    a. Is there anything you would like to add?
8. Student thanks participants, and describes next steps
    a. Email transcription within the week

11.4 Appendix D: Economic Analysis Calculation Sheet