Remediation Architecture
A Spatial Approach to Bioremediation

Written by
Lewis Ellison

Supervised by
Maibritt Pedersen Zari

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Preface

I. Abstract

Phenomena such as industrialisation and urbanisation are associated with the built environment. Both contribute to pollution of urban soil, water and air in various ways. This in turn contributes in part to climate change and biodiversity loss. It is therefore the responsibility of the built environment, and the professionals associated with its design and functioning, to remediate the aforementioned effects.

This research investigates the spatial arrangement of bioremediation techniques (the process of using fungus, bacteria, and plants to break down and purify environmental pollutants) within architecture in order to remediate brownfield sites to a state where they contribute to a regenerative built environment.

This investigation utilises a design-led research approach of examining the spatial arrangement of bioremediation techniques within architecture and proposes a series of design interventions at one of New Zealand's most contaminated sites. This research proposes practical methods of applying restoration design to remediate brownfield sites to move towards a regenerative development model. The land and waterways that make up brownfield sites should be celebrated for their ecological significance, and remediated, rather than ignored so as to build positive human-nature relationships.

Research findings include that bioremediation and architecture cannot exist separately if brownfield site remediation and development is to contribute to a regenerative built environment. It is critical to use architecture itself as one means of educating users about the ecological processes of brownfield site bioremediation. This is important in order to establish a stewardship role within individuals and local communities as a way to work towards the protection and successful restoration of these degraded sites. This research also found that the restoration of brownfield sites towards regenerative development requires architecture and built environment infrastructure to be adaptive to future climate change conditions. The bioremediation techniques examined in this research could be used to retrofit existing buildings and designed into new additions and/or retrofits so that architecture can adapt to climate change impacts, particularly sea-level rise and increased storm surge.

II. Acknowledgements

Firstly, I would like to thank my supervisor Maibritt Pedersen Zari for her on-going guidance, encouragement, and inspiration throughout the year.

I want to express my gratitude to Joel and the Rock + Mineral club for allowing me to snoop around the clubhouse, and to Good Vibes Fungi for your generosity and knowledge on all things mushrooms.

I would also like to thank my friends and family for their support. Thank you to Connor for all your many differing inputs you have had on this thesis. Thank you to my Dad for your help with the soil experiments. Thank you to Alfred for your incredible graphic design guidance and help. And finally, a special thank you to Kate for all your love and support throughout the year and for always being there to workshop ideas with me.

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1. Introduction

1.1. The Design Issue

The built environment is currently a large contributor to humanity's environmental impact. It contributes to 30% - 40% of global energy consumption (UNEP, 2007) and 50% of global raw material consumption (Edwards & Hyett, 2001). Not only is this environmental impact contributing to climate change effects; industrialization and urbanisation are releasing pollutants into urban soils and waterways which in turn contributes to human and eco-system health degradation (Bisht et al., 2015; Dixit et al., 2015; Dubey et al., 2003).

It is critical for the built environment to identify and remediate these impacts, so climate change disasters and eco-system collapse is minimized in the future. To achieve these ambitious goals a shift in humanity's relationship with the natural world needs to occur from domination over nature to a state that recognises that humans and ecosystems are an equal part of the same whole. Regenerative design proposes a model for how the built environment could strengthen this relationship and support the co-evolution of humans and ecosystems together. The aim of regenerative design is for buildings to provide net positive ecological and social benefit as well as remediating previous damage caused by the built environment (Cole, 2012; Mang & Reed, 2015; Pedersen Zari, 2012; Pedersen Zari & Jenkin, 2010; Reed, 2007).

Urbanisation and industrialisation has degraded certain areas of land to a point at which they are now classified as brownfield sites; a site which is not available for immediate use without intervention due to its vacant, derelict or contaminated nature (Alker et al., 2000). These sites have been degraded to a point where ecological succession has failed and human intervention is required to remediate the land. Odum (2005) describes that ecological succession, the healing process that restores ecosystems, is effective in restoring damage caused by periodic catastrophes. When ecosystems are consistently abused however, this ecological succession fails and requires restorative design to remediate the living systems on these sites to a healthy state of self-organisation (Reed, 2007). In New Zealand, these brownfield sites usually consist of manufacturing plants (pesticides, fertilizers etc.), derelict industrial sites and contaminated sites. If these brownfield sites are to contribute towards a regenerative built environment, the onsite remediation needs to be effectively integrated into architecture in order to support both environmental and social ecologies.

1.2. Research Question

Given these issues, this design-led research asks the questions:

1) How can bioremediation techniques be spatially arranged within, and as architecture to restore ecosystems on brownfield sites back to a healthy state?

2) How can these architectural interventions contribute to a regenerative built environment?

1.3. Research Aims and Objectives

The aim of this research is to investigate bioremediation techniques as a method of remediating brownfield sites. As this research is architectural in nature, it will investigate a spatial design approach for how these techniques can be incorporated into architecture, or become architecture, to provide regenerative design. This research aims to:

- Explore bioremediation techniques in a New Zealand context to define a best practice for brownfield site remediation.

- Investigate how these techniques can be spatially arranged within architecture through two design interventions at two critically contaminated brownfield sites within New Zealand.

As well as these core aims of the investigations this research aims to investigate a secondary objective:

- Explore ways in which retrofitting bioremediation techniques for buildings in New Zealand could ensure that future development of New Zealand's built environment is regenerative.

1.4. Research Methodology

This research has initially utilised research about design in order to establish a background for this investigation and then a qualitative framework for assessing the effectiveness of design interventions. The framework is devised of qualitative measures that can be used to assess the effectiveness of different design interventions at regenerating degraded brownfield sites.

The next phase of this investigation utilised research through design in order to test spatial arrangement techniques for brownfield remediation. This process of research through design was conducted across two critically polluted brownfield sites in New Zealand.

A selection criterion has been devised in order to determine what sites this research has focused on. Due to the limitations of this type of research it was important to narrow down the scope. The selection criterion is as follows:

- Environmental ecosystem remediation: Sites chosen need to be some form of brownfield site that requires immediate environmental ecosystem remediation.

- Social ecologies remediation: Regenerative design seeks to repair the relationship between humans and ecosystems, therefore chosen sites need to have a component of social ecology that requires remediation.

- Funding: Potential funding for remediation projects allows for design interventions that are grounded. Therefore, sites chosen will be from the Contaminated Sites Remediation Fund (CSRF) priority list. The CSRF is a funding priority list that helps the Ministry for the Environment (MfE) distribute funds to remediation projects on sites that pose a risk to human health and/or the environment.

- Retrofit: Buildings in New Zealand are typically designed for an 80-year lifespan (Storey et al., 2004). Consequently, much of the current built environment will likely still be in place for at least the next 50 years. Continued sustainable development will need to consider retrofitting of the current building stock (Pedersen Zari & Jenkin, 2010). Therefore, part of the selection criterion requires each site to allow for a retrofit of an existing building.

Currently, bioremediation techniques are industrial in nature—they disrupt onsite activities until the site remediation is completed. This research uses architecture as the medium of remediation to develop methods that both strengthen the human nature relationship as well as restore the environmental ecosystems on site. This link between the technological approach of bioremediation and the architectural approach will allow for restorative design to take place without disruption of onsite activities as well as contributing to a regenerative built environment.

Start Project

Month 3 Milestone 1

Month 6 Milestone 2

Month 9 Milestone 3

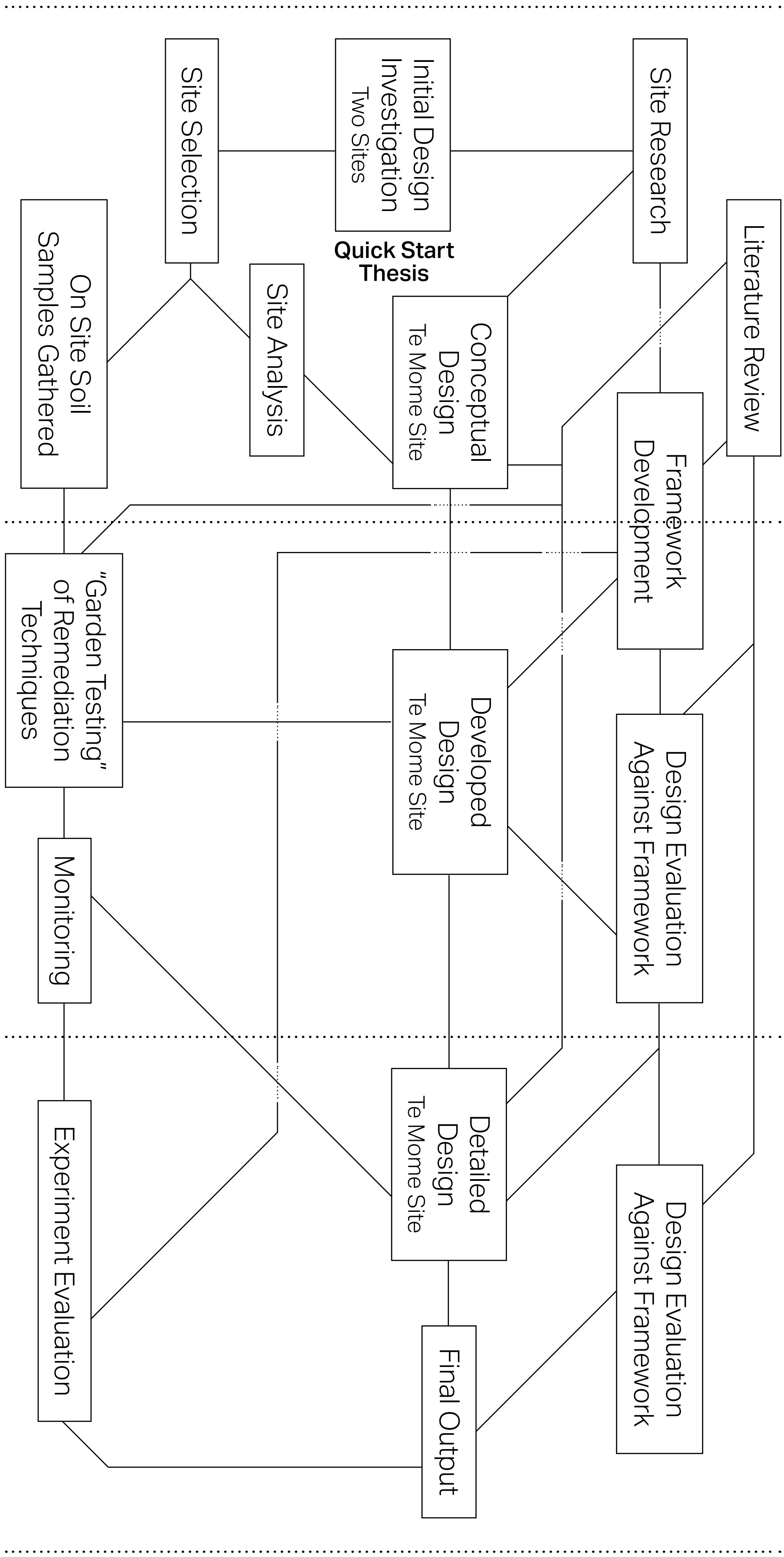


Figure 1.
Research Methodologies Diagram

2. Regenerative Design

2.1. Theory of Regenerative Design

Regenerative design is the core concept behind this research, it provides the aspirational goals that help focus the decisions made throughout this investigation. The following section presents the key aspects of regenerative design.

The term 'regeneration' was first related to land use by Robert Rodale who used it to symbolise the organic self-renewal of soil microbes in the absence of chemical agricultural processes (Lyle, 1994). He found that nature has an innate ability of self-organization and renewal when chemical agricultural processes are stopped; this phenomena is known as ecological succession. Lyle (1994) applied these principles to the built environment in order to acknowledge that sustainable development requires self-renewing inputs, He states:

> A regenerative system provides for continuous replacement, through its own functional processes, of the energy and materials used in its operation … Regeneration has to do with rebirth of life itself, thus with hope for the future (pg. 10–11)

More recently, regenerative design has been framed by various authors to describe the shift from a mechanised worldview to an ecocentric one that seeks to reframe the relationship of humans domination over the rest of the living world to one that supports a co-evolution between the two (Cole, 2012; Mang & Reed, 2015; Pedersen Zari, 2012, 2018; Pedersen Zari & Jenkin, 2010; Reed, 2007).

It has been used to reframe green building practices and expand upon their criteria. Instead of the 'do less harm' approach that green building practices currently take, regenerative design suggests that buildings should be designed to give back more than they take (Cole, 2012).

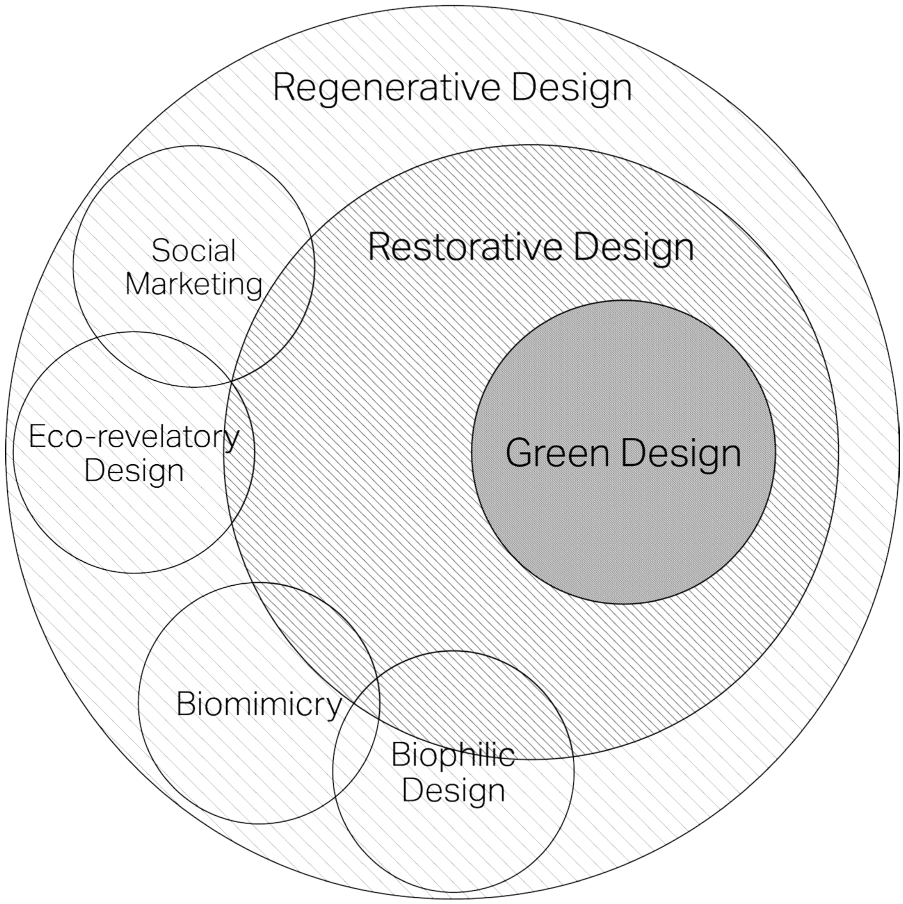
Reed (2007) explains that regenerative development follows a scale of different levels of the sustainable design trajectory that goes from conventional practice (a degenerative system) through to regenerative (co-evolution of humans and nature). He acknowledges that these levels are not exclusive of one another but are a progression. To truly reach regenerative development, the lessons of eco-efficiency learned from green building practice must be applied along with the philosophy behind regenerative design to achieve these goals. This paradigm shift is key if climate disasters and biodiversity loss is to be minimised.

2.2. Green Design

Green design or green building is the movement focused on creating the same design outcomes in designs and buildings while limiting the resources used and waste produced

(Pedersen Zari & Jenkin, 2010). Green building is focused on continually improving design towards the general ideal of doing no harm (Reed, 2007). It was born from the mechanical worldview that sees nature as a machine that can be managed and reducing it into components (Du Plessis, 2012). Because of this, green design has received criticism for not addressing the climate change and biodiversity loss in a holistic sense (Du Plessis, 2012; Mang & Reed, 2012). Green design requires a regenerative approach if the climate crisis and biodiversity loss are to be addressed by the built environment. Green design needs to be incorporated with the paradigm shift of regenerative design thinking in order to aim higher than the "do no harm" approach.

Figure 2.
Research Topic Interactions



2.3. Living Systems Approach

One of the main goals of regenerative design is to shift the current mechanical worldview to an ecocentric based worldview, this is often referred to as the living systems thinking or whole systems thinking (Reed, 2007). Capra (1987) explains that the current mechanical worldview has a dysfunctional relationship between humans and the rest of the living world. It views humans as above or outside nature and considers nature as a resource to be used; this contributes to the anthropocentric worldview. Anthropocentrism puts humanity as the most important thing in the world and views the rest of the living world as secondary. The ecological worldview contrasts this by recognizing the intrinsic value of all living things and seeing them as an interconnected web of relationships rather than isolated objects.

Reed (2007) describes how whole systems and living systems thinking can shift the green building practice from eco-efficiency to an approach that recognises the relationship of subsystems (hydrology, geology, plants, animals and humans). That these sub-systems are all interconnected and should support and evolve one another. A fundamental change needs to take place in the green building movement to focus on the life systems that they so heavily rely on and impact.

2.4. Place

Mang & Reed (2012) define place as “the unique, multi-layered network of living systems within a geographic region that results from the complex interactions, through time, of the natural ecology … and culture” (pg. 28). They explain that an important consideration when designing in the regenerative paradigm is to design from place. Designing from place is understanding the underlying patterns of the site, generating stories of place that individuals and groups can connect with, and understanding the potentials on site. This approach helps discover how the ecological systems work on site and how architecture can be nested within these. The goal of designing from place is to get individuals and groups to understand the importance and value of the area so they share in a collectively imagined future (Mang & Reed, 2012).

2.5. Social Marketing and Eco-revelatory Design

Social marketing is an application of marketing techniques used to achieve positive behavioural changes. This concept grew from the understanding that educating people on a subject is an ineffective way of enacting behavioural change, known as “the pamphlet approach” (Corner & Randall, 2011). A social marketing strategy will consider the individual, increase incentives, remove any barriers towards positive change, understand the factors that compete for one’s attention and understand one’s willingness to adopt a certain behaviour. Social marketing understands that an individual is most likely to adopt positive behavioural change when presented with opportunities to discover things on their own rather being told to make change. A social marketing initiative by the Australian government was able to reduce car use in a suburban area, a notoriously difficult task, by 14% within an 18 month period (Australian Department for Transport, Energy & Infrastructure, 2009). While social marketing initiatives have been achieving successful behavioural changes through marketing campaigns, social marketing principles have yet to be applied in an architectural context. This research will utilise social marketing principles in order to spatialise positive behavioural changes within architectural interventions.

Eco-revelatory design seeks to educate and illuminate about the ecological process that are present on any given site. It recognises that if one is aware of these ecological processes and phenomena, they are more likely to make decisions based on consideration of these (Brown et al., 1998). It centres around strategies of revelation and interpretation to give users the greatest opportunity to have an experience that promotes positive behavioural change for the conservation of these ecological processes. An example of eco-revelatory design in practical application is the above ground management of urban stormwater. By utilising techniques such as rain gardens, constructed wetlands and bio swales, cities are able to manage their stormwater ecologically while also contributing to the beauty and liveability of surrounding communities to enhance human wellbeing (Wenk & Gregg, 1998).

Similar to designing from place, social marketing and eco-revelatory design can be used to re-establish a steward role for the site in individuals and groups. Where designing of place achieves this through revealing the underlying narrative of the site, social marketing and eco-revelatory reveal the ecological processes on site as a targeted educational strategy. It is important for architecture to play this educational role and help promote positive behavioural change as this increases the community support for a successful restoration of the site.

2.6. Biophilic Design

Due to the interconnected relationship between humans and nature the regeneration of human and/or ecosystem health is an interconnected practice that supports both parties and is therefore mutually beneficial to both (Reed, 2007). In architectural practice, this can be achieved using the concept of biophilic design.

Biophilia is the human inclination to relate to nature and is one of the core concepts of regenerative design. It feeds humanity's biological drive for self-preservation through relationships with nature. Kellert (2005) explains that these relationships with nature have been increasingly disappearing in today's contemporary society. The role of nature in society has become confused—but with careful design these relationships can be facilitated once again. Biophilic design aims to create buildings and spaces which brings nature's role back into contemporary society for the measurable psychological benefits to human health and wellbeing. Biophilic Design is an example of one way in which regenerative design can relate to the human/nature relationship aspects.

2.7. Biomimicry

Biomimicry is a concept in architecture where specific characteristics of flora, fauna or ecosystems are emulated in building systems as a potential way to move the built environment to more sustainable systems (Pedersen Zari & Storey, 2007). This research will focus on ecosystem biomimicry as an inspiration point for designing bioremediation techniques. A key figure in ecosystem biomimicry is John Todd (1994, 1996, 2003, 2019) and his development of living machines. Living machines are designed to mimic the cleansing processes of wetlands in order to purify blackwater to drinking standards without any chemical processes and are an example of ecosystem-based biomimicry. Biomimicry is an example of one way in which regenerative design can be applied.

2.8. Regenerative Design Precedents

Living with Lakes Centre

Laurentian University in Sudbury, Ontario Canada built the Living with Lakes Centre for applied research in environmental restoration and sustainability as a regenerative building that not only reduces its ecological impact, but positively effects the surrounding environment. Designed by Perkins+Will, the Living with Lakes Centre is situated next to Lake Ramsey, an important drinking reservoir for Sudbury, which has had extensive ecological damage from the smelters and other industrial activities in the region. These smelters from the local mining industry raised the lake's pH to an acidic level that was disrupting local ecological functions that rely on the lake as their habitat, as well as being harmful to human health.

The Living with Lakes Centre was designed in collaboration with Laurentian scientists so that the building would not only minimise its own ecological footprint but also positively contribute to the restoration of Lake Ramsey. The building and landscaping were designed to incorporate Manitoulin Island limestone, an alkaline building material that will slowly assist with the neutralisation of acidic lake water as stormwater slowly wears away at the material. The building incorporates high performance green design strategies (such as; stormwater runoff management, a high-performance thermal envelope, passive heating & cooling, and a ground source heat pump) along with restorative design to achieve a truly regenerative building (Busby et al., 2011). This project is an excellent example of how remediation can be incorporated within a building so that it positively contributes to restoring the health of surrounding ecosystems.

Figure 3.
Living with Lakes Centre (Busby et al., 2011, p. 94)

Figure 4.
Living with Lakes Centre (Busby et al., 2011, p. 95)

Centre for Interactive Research on Sustainability

The Centre for Interactive Research on Sustainability (CIRS) was built by the University of British Columbia as a regenerative research lab. Located in Vancouver, British Columbia and designed by Perkins+Will the CIRS was not only designed as a high-performance green building, but to positively contribute to the natural resources it uses. The design of the CIRS takes an innovative approach to site opportunities; the building is able to utilise heat waste from a lab exhaust of the neighbouring Earth and Ocean Sciences building by using a heat recovery and heat exchanger to heat the building and supply additional energy back to the campus. This heat recovery system is able to recover 600 megawatt-hours back to the campus from what was a waste product and therefore is able to remove 170 tonnes of $CO2$-e emissions from the atmosphere annually. The building supplies 100% of its own water demands by capturing rainwater onsite and purifying in a solar aquatic biofiltration system (living machine); this system is able to treat up to 2,300 litres of water a day for re-use. By incorporating a fully timber structure the CIRS is able to sequester 600 tonnes of carbon and successfully offsets the carbon emissions associated with the construction and operation of the building (RAIC, 2015). This project highlights the importance of taking an innovative design approach that is effectively able to determine the onsite opportunities that can help move the building towards regenerative development.

Figure 5.
Centre for Interactive Research on Sustainability (Photo by Xicotencatl, CC BY-SA 3.0)

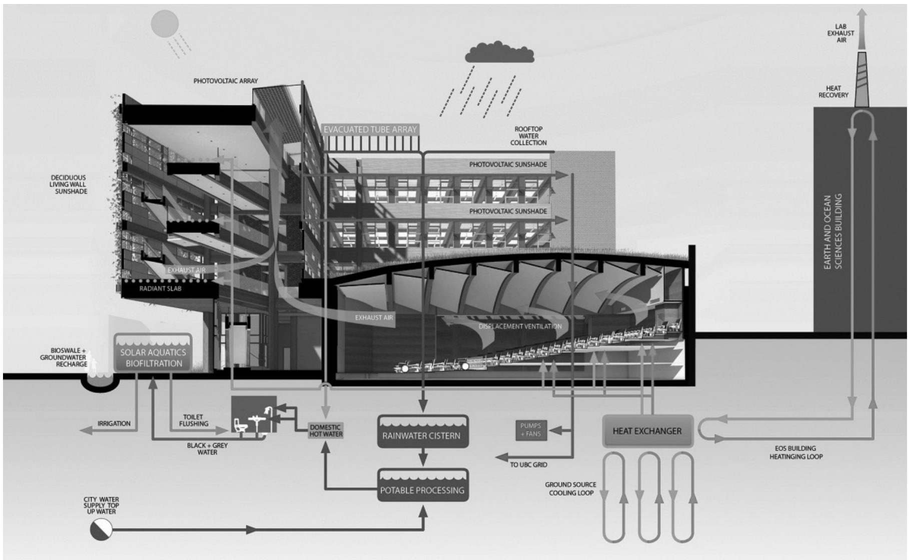


Figure 6.
Sustainability Strategies Diagram (RAIC, 2015, p. 33)

3. Bioremediation

3.1. Bioremediation Benefits

With the rise of industrialisation and urbanisation, the concern for human and ecosystem health has increased significantly. This is due to understanding the impacts of anthropogenic pollutants (petroleum hydrocarbons, polycyclic aromatic hydrocarbons, halogenated hydrocarbons, pesticides, solvents and heavy metals) being present in urban soils and waterways (CCME, 2001). These pollutants are damaging to ecosystem health by disrupting ecological succession. When the level of pollution on site disrupts ecological succession, it is categorised as a brownfield site and will require remediation. Conventional chemical remediation processes are often very expensive, energy intensive and not efficient for low concentrations of pollutants. There has been growing interest in bioremediation as a cheaper and more efficient alternative to conventional remediation processes (Bisht et al., 2015). Bioremediation utilises the strategies microorganisms have developed to survive in heavily polluted conditions. These microorganisms are able to survive in such harsh conditions by purifying their surrounding environments of pollutants (Dixit et al., 2015).

3.2. Bioremediation Techniques for Heavy Metal Pollution

Heavy metal pollutants have been increasing in industrial sites. Although some of these heavy metals are necessary for organic life processes, all of them are toxic to surrounding ecosystems at high enough concentrations (Velásquez & Dussan, 2009). This kind of pollutant requires different methods for remediation due to its non-biodegradable properties (Gupta & Rastogi, 2008). Conventionally, remediation methods for heavy metal pollutants usually consist of precipitation, coagulation, ion exchange, inverse osmosis, and absorption. Although effective at remediating high concentrations of metals, they are ineffective for lower concentrations and are energy / chemical intensive methods (Atkinson et al., 1998). Bioremediation methods are more effective at lower pollutant concentrations and are less energy intensive, therefore are a more effective and sustainable solution for the remediation of heavy metal pollutants.

3.3. Species Suited for Heavy Metal Bioremediation

A list of species that are best adapted for the bioremediation of heavy metal contaminants was gathered from literature and listed here along with the specific heavy metal(s) they are best adapted to. These species are:

Bacteria

- Bacillus sphaericus (As)
- Shinella Sp. NLS1 (Sb & As)
- Ensifer Sp. NLS4 (Sb & As)

(Nguyen et al., 2017; Velásquez & Dussan, 2009)

Fungi

- Aspergillus niger
- Trichoderma longibrachiatum (Cr)
- Aspergillus flavus
- Aspergillus terreus (Pb)
- Phanerochaete chrysosporium (Pb)
- Phanerochaete chrysosproium (Cd)
- Trichoderma viride (Cd)

(Joshi et al., 2011)

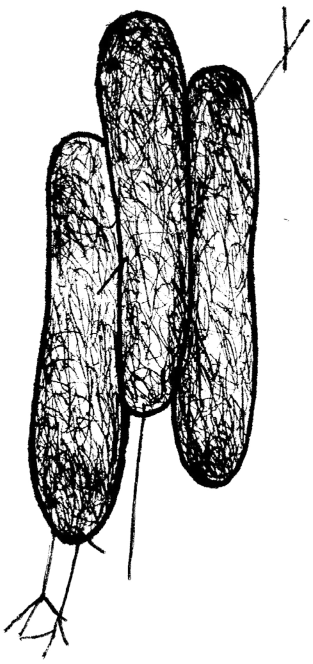
Plants

- Arabidopsis halleri (Cd)
- Solanum nigrum L. (Cd)
- Salix viminalis (Cd, Cu, Pb, Zn)
- Salix fragilis (Cd, Cu, Pb, Zn))
- Zea mays (Cd, Pb, Zn)
- Populus deltoides (Cd, Cu, Pb, Zn)
- Populus nigra (Cd, Cu, Pb, Zn)
- Populus trichocarpa (Cd, Cu, Pb, Zn)
- Jatropha curcas (Cd, Cu, Pb, Ni)

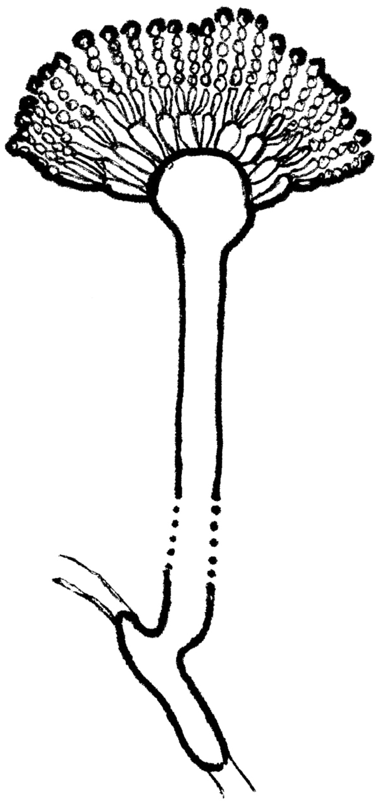
(Dixit et al., 2015)

Heavy Metal Remediation Species
(Turn to p. 28)

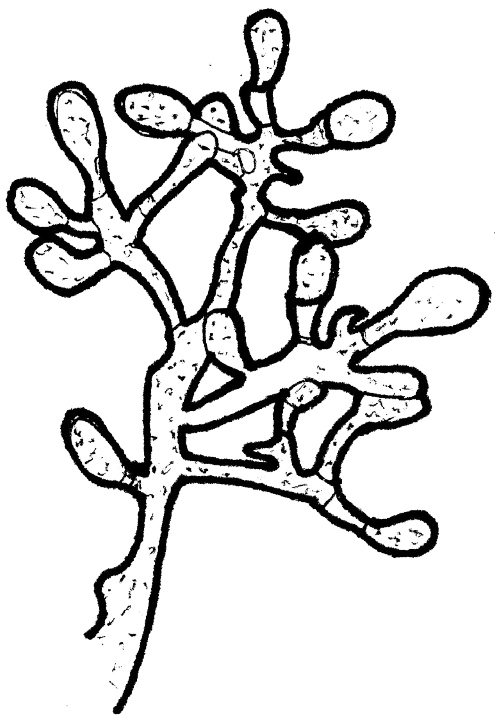
Heavy Metal Remediation Species
Bacteria and Fungi



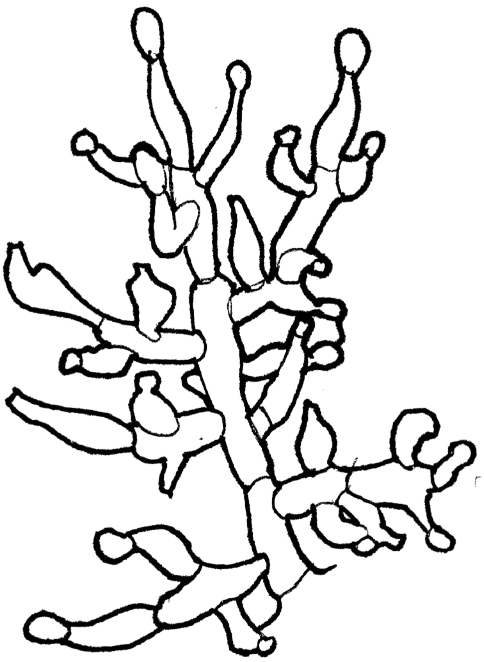
Bacillus sphaericus



Aspergillus terreus



Phanerochaete chrysosporium



Trichoderma longibrachiatum

Figure 7. (pg. 28–29)
Selection of Bioremediation Species

Salix fragilis

Zea mays

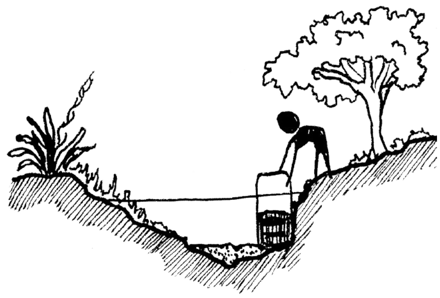
Salix viminalis

Populus deltoides

3.4. Bioremediation Techniques

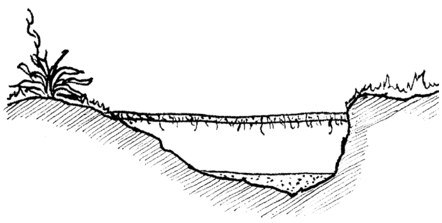
Next, a list of bioremediation techniques was gathered from literature and listed here. These techniques are:

1) In-Situ



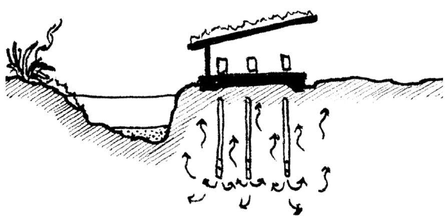
Bioaccumulation

The active uptake of heavy metal pollutants into the cell wall of the introduced microbes. This microbial living mater can then be harvested and disposed of safely (Dixit et al., 2015).



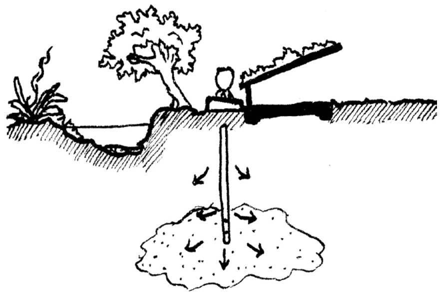
Biofilm

A concentrated film of microbes are created on the surface of contaminated soil or water in order to bioaccumulate heavy metal pollutants within the living matter of the microbes which can then be harvested and disposed of safely (Pepper et al., 2004).



Bioventing

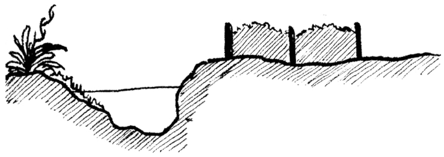
Oxygen is supplied to contaminated soil in order to stimulate aerobic biodegradation by existing soil microbes (EPA, 2001).



Bioaugmentation

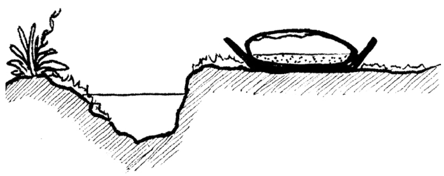
The introduction of microbes into contaminated soil or water that are specifically suited to break down pollutants in order to completely degrade a contaminated site (Das, 2014).

2) **Ex-Situ**



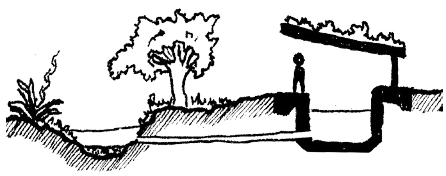
Composting

Contaminated mater is extracted from site and mixed with organic matter containing nitrogen and carbon to promote microbial activity (EPA, 2001).



Bioreactor

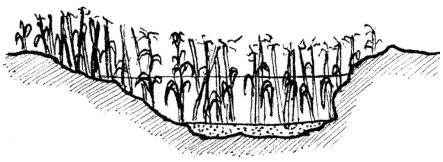
Contaminated soil or water are pumped into an engineered containment system which is then inoculated with microbes specifically suited to break down pollutants in order to completely degrade contaminated soil or water (Das, 2014).



Aqueous Reactor

Contaminated soil or water is pumped into an engineered containment system and mixed into an aqueous solution to increase its surface area. The solution is then inoculated with microbes specifically suited to break down pollutants, completely degrading the contaminant (Behkish et al., 2007).

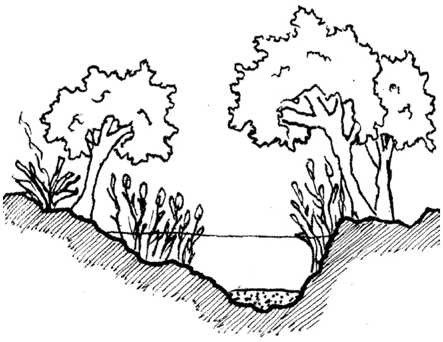
3) Phytoremediation



Accumulation

Plants known as “hyperaccumulators” are very efficient at accumulating metals in plant tissue. These plants are planted within a contaminated zone to take up heavy metal pollutants into plant tissue which can then be harvested from site and disposed of safely (Pepper et al., 2004).

Figure 8. (pp. 30–32) Bioremediation Techniques



Mineralisation

Plants stimulate the activity of contamination degrading microbes in their root zone to break down organic contaminates, this strategy does not require plant harvesting (Pepper et al., 2004).

3.5. Precedents

Kopeopeo Canal Remediation Project

Kopeopeo Canal is currently #2 on the CSRF priority list due to excess levels of dioxins. The contamination came from discharged water from the NZ Forest Products Ltd Sawmill and is very harmful to human and animal health. Due to the high risk to human health via the consumption of contaminated eel tissue gathered from the Kopeopeo Canal, remediation work was conducted to reduce the harmful levels of dioxins (Golder, 2019).

A 20-year bioremediation project has been undertaken on the canal to provide long-term containment and degradation of the toxic dioxins over time. The project uses a symbiotic colony of bacteria, fungi and plants to purify sediment dredged from the base of the canal contained with Geotube bags. It is a good working example of how bioremediation can be used to regenerate a degraded ecosystem.

Figure 9.
Kopeopeo Canal
(EnviroWaste, 2019)

Mapua Fruitgrowers Chemical Company Remediation Project

The Fruitgrowers Chemical Company (FCC) in Mapua was known as New Zealand's most contaminated site for many years and marks the first successful large-scale remediation project for New Zealand. From 1932 to 1988, the FCC operated on a coastal site in the small settlement of Mapua, Nelson. During those years, this plant produced many different varieties of toxic (and non-toxic) insecticides and anti-fungicides, which ultimately found their way into the soil on site, into local landfills and into the estuary. The full extent of contamination was not understood until 1997, 9 years after FCC was closed, when a resource consent was granted to remediate the site.

In 1999 the New Zealand government set up the Orphan Sites Remediation Fund, which later became the CSRF priority list, to fund remediation projects and at the time Mapua was at the top of the list. Through this initiative the Mapua remediation project received $3.1 million dollars to complete the remediation on site.

The site then underwent a 4-year remediation project using a mechano-chemical dehalogenation, a first in the world at this scale, and completed remediation in 2008 (Harris et al., 2011). Following the remediation project, 40% of site was dedicated to public park designed by Irving Smith Architects and Robin Simpson Design landscape architects. The design of the park is innovative in how it deals with the limitations of this being a once polluted site. Foundation work on site could not exceed the 500mm penetration cap underneath the surface of the ground therefore the above ground structures shared concrete plinths installed by the services upgrade project as foundations. This allowed the project to build above ground structures that usually require deep foundation work with minimal disturbance to this 500mm penetration cap.

This project is an excellent working example of how a site can be ecologically restored, as well as socio-ecologically restored. It also shows how a project can be staged out in construction phases to ultimately restore a once contaminated site to allow for re-habitation.

Figure 10.
Mapua Park Structures
(Reynolds, 2013)

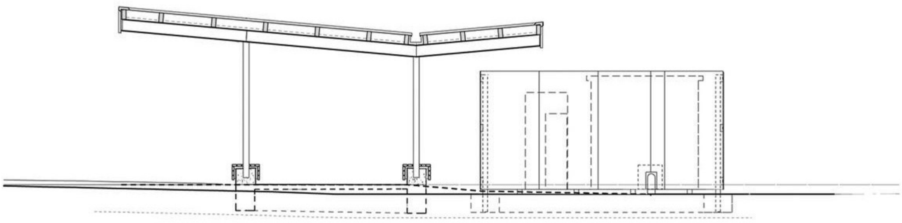


Figure 11.
Mapua Park Section
(Philip, 2013, p. 28)

4. Framework

4.1. Framework Development

A framework was developed to assess the effectiveness of the design interventions in this research which was then used to quantify the success of each design in this investigation.

It has been acknowledged by various authors that the checkbox nature of current green building assessment tools (e.g. LEED, BREAM, Greenstar etc.) does not capture a whole systems or living systems thinking approach (Cole, 2012; Cole et al., 2012; Plaut et al., 2012; Svec et al., 2012). Because of this, various regenerative design frameworks have been in development to help support projects moving from sustainability-based approaches to regenerative design ones.

There are a number of framework goals that restorative and regenerative design projects used to evaluate the effectiveness of their projects. As this research is looking only at the remediation of brownfield sites, the framework goals from the Perkins + Will framework (Cole et al., 2012), the REGEN framework (Svec et al., 2012), the Regenesis Group framework (Mang & Reed, 2012), and the Living Building Challenge (International Living Future, 2019) have been used as guidelines to develop three framework goals best suited to evaluate the design interventions proposed in this research. These three framework goals are the most critical to this research because of how they relate to bioremediation, as well as human/nature relationships.

4.2. Framework Goals

Net Positive Resource Goals

This research will use net water and material as one of the evaluation criteria and in assessing each intervention. The following question will be asked: "Is the proposed architecture able to produce a net positive amount, or contribute to resource flows, for the water and materials used by the project?".

Ecology of Place

As this research seeks to regenerate brownfield sites for the benefit of surrounding communities, when assessing each intervention, the following question will be asked: "Does the project contribute positively to the ecology of the place?".

Sense of Place

As this research seeks to re-establish a steward role for the communities surrounding brownfield sites, when assessing each intervention, the following question will be asked:
"Does the project enable individuals and groups to share in a collectively imagined future?".

4.3. Framework Application

This framework will be used in this research project to review the design interventions after each phase. This framework provides a consistent approach to the assessment of each intervention and allows for the different interventions to be compared and contrasted.

5. Design-led Research Phase One

Understanding Te Mome Stream and its Development Limitations

5.1. Quick Start Thesis

This research started with a “quick start” design exercise which focused on kickstarting the *research through design* process by attempting to complete the proposed thesis within one month. Following this quick start was a design review with feedback to provide a guide for the rest of the research.

Motivation

First, the background and motivation was established that brownfield remediation would be the aspect of regenerative design focused on for this quick start thesis and that three architectural interventions would be designed at sites throughout New Zealand in order to test brownfield remediation ideas. The purpose of these architectural interventions is to remediate the degraded ecosystems and the social communities surrounding the site, in order to reinvigorate local socio-ecologies.

Sites

Two brownfield sites were chosen for this quick start thesis, the sites chosen are:

- **Te Mome Stream**, a stormwater catchment arm for the Hutt River in Petone, Lower Hutt New Zealand. Te Mome Stream is currently #8 on the Contaminated Sites Remediation Fund (CSRF) priority list due to the Exide Battery reprocessing plant discharging toxic wastes into the stream.

Figure 12.
Halford Place Before

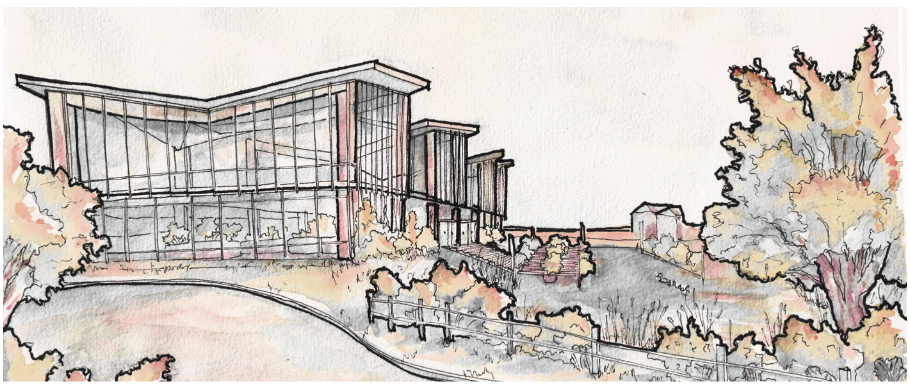


Figure 13.
Halford Place Community Center (authors own)

- **Mataura Paper Mill**, a now decommissioned paper mill along the Mataura river in the town of Mataura, Southland New Zealand. Mataura Paper Mill currently houses 22 tonnes of Ouvea premix, a toxic material when combined with water creates ammonia gas and ammonium which could leak into waterways and surround soils.

Figure 14.
Mataura Paper Mill
Before

Figure 15.
Mataura Paper Mill
Retrofit
(authors own)

Programme

The programme for the design investigation at Te Mome Stream is a community centre that houses the community groups currently on the existing site as well as a bioremediation research and monitoring centre.

The programme for this design investigation at Mataura Paper Mill is a local history museum and a bioremediation research and monitoring centre.

Design Review

The main feedback from the design review was to incorporate more overlapping programmatic uses for each design intervention. This would result in a set of spaces that are more effective in engaging with social and environmental ecosystems as well as providing a multifunctional architectural intervention. The feedback from this design review also suggested that re-evaluating timeframe limitations is important when picking research sites. It was suggested that focusing on one site would allow for a practical amount of work to be completed within the proposed time frame of the thesis. Therefore, the next phase of research focused solely on

Te Mome stream rather than Mataura Paper Mill.

Quick Start Thesis Findings

The main findings from this quick start design exercise was that bioremediation was both the most sustainable and economic way of remediating brownfield sites. Rather than traditional remediation, consisting of methods which rely heavily on chemical processes and are often energy intensive, expensive, and intrusive on site, bioremediation can provide remediation methods that are low impact and include potential to be effectively integrated into architecture. Moving forward, this research will focus on bioremediation as the remediation method to explore.

5.2. Te Mome Stream

Te Mome stream is a small tidal stream that runs alongside Halford Place in Petone, Lower Hutt, Wellington, New Zealand. Halford Place is a council owned section of land that contains various community club buildings, as well as a water treatment plant.

Site Analysis

Te Mome stream is a catchment arm for the Hutt river in Petone, Lower Hutt, New Zealand. Te Mome is a 'dead arm' tidal stream, meaning it relies on mostly on tidal movements to cycle the water. It is a 1.4km long, 1.4m deep stream that runs along the suburb of Ava in Petone and discharges into the Hutt River close to Wellington Harbour (GWRC et al., 2005). Te Mome stream is currently #8 on the Contaminated Sites Remediation Fund (CSRF) priority list due to pollutants captured from the 110 hectares of stormwater that is discharged into the stream.

The main pollutant on site is concentrated heavy metals in the sediment and water of Te Mome stream. Following contamination incidents from the Exide Battery Recycling Plant on the 4th of November and the 15th of December in 2004, an investigation was conducted by Greater Wellington Regional Council (GWRC et al., 2005) into the contamination impacts of these incidents. This investigation found a significant concentration of heavy metals commonly associated with battery recycling activities in both the sediment and water of Te Mome stream. It was determined that while there is evidence of historical pollution build up, the main contamination came from battery wastes being discharged from the Exide site into the stormwater system which subsequently found its way into Te Mome Stream. This investigation found concentrations of iron, antimony, arsenic, cadmium, and lead which all exceeded guidelines for concentrations of these heavy metals (the concentration of lead exceeded the acceptable guidelines by 1300%).

Remediating heavy metal pollution brings a set of challenges and considerations that need to be factored into the design of a purification program. Unlike heavy organic pollutants, which can be broken down by microbes into non-toxic compounds, heavy metal pollutants cannot be chemically transformed into a non-toxic version and therefore need to be bioaccumulated taken off site to be disposed of safely. By focusing on Te Mome Stream, which contains heavy metal pollution, a set of bioremediation techniques have been developed which best suit the remediation of heavy metal pollutants.

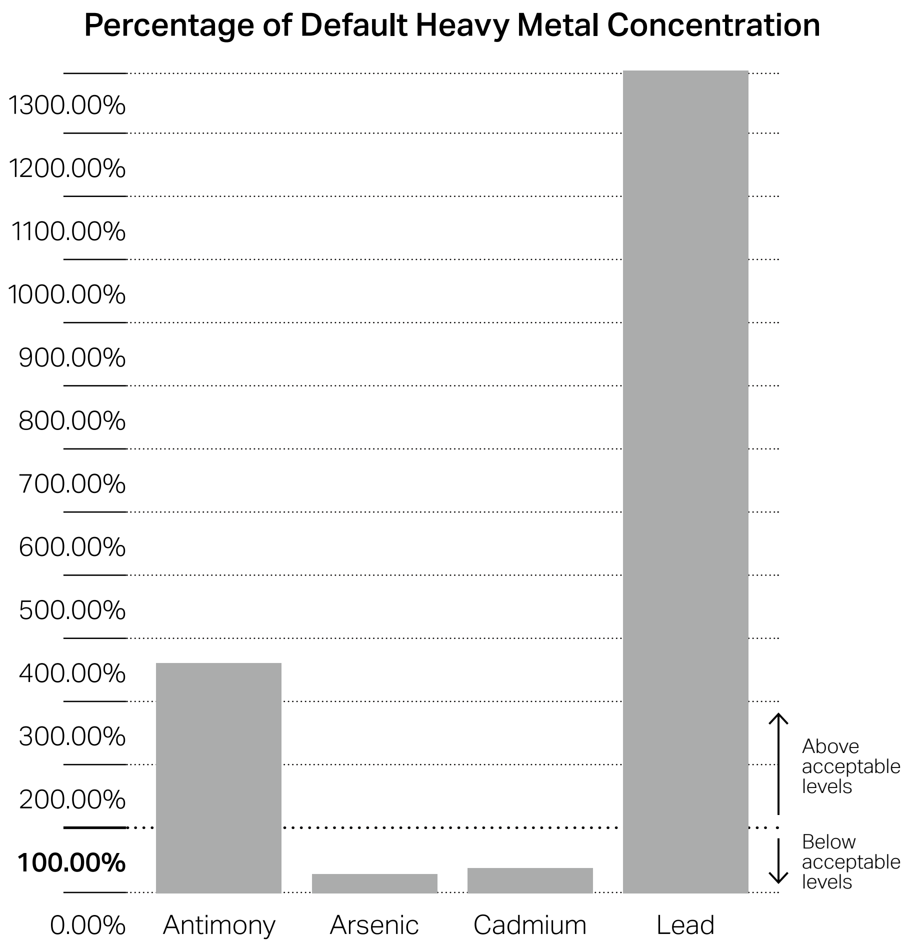
Halford Place and Te Mome Stream are in a coastal region. Therefore, they will be prone to the impacts of climate change induced sea level rise so this should be factored into the design process of any design interventions on the site. An average sea level rise has been calculated by Bell et al. (2017) for three different climate change scenarios. This will be the basis of projected sea level rise used in this investigation. These three scenarios are based on the representative concentration pathways (RCP) of global CO_2^{-e} levels as detailed in the Intergovernmental Panel on Climate Change's fifth assessment report (IPCC, 2015):

> RCP2.6 (best case) is where drastic reductions of global CO_2^{-e} are achieved and is likely to keep global warming temperatures under 1.5° Celsius; RCP4.5 (moderate case) is where moderate reductions of global CO_2^{-e} are achieved and is likely to result in a global temperature rise between 2°–3° Celsius; RCP8.5 (worst case) is continuing business as usual with no drastic reductions in global CO_2^{-e} and is likely to result in a global temperature rise between 3–5 degrees Celsius. The following table depicts the predicted sea level rise in NZ overtime for each scenario.

Median Sea Level Rise (m)			
Year	**RCP2.6**	**RCP4.5**	**RCP8.5**
2020	0.08	0.08	0.09
2030	0.13	0.13	0.15
2040	0.18	0.19	0.21
2050	0.23	0.24	0.28
2060	0.27	0.30	0.36
2070	0.32	0.36	0.45
2080	0.37	0.42	0.55

This research will use the scenario RCP8.5 as an assumption that prepares for the “worst case scenario”. shows the effects of the predicted sea level rise on site for RCP8.5 using GWRC’s sea level rise and storm surge modelling tool.

Figure 16.
Heavy Metal Concentrations of Te Mome Stream




1
2
3
4
Sports Field
Sports Field
Golf Course
Te Mome Stream
Industrial Area
Ex Battery
Recycling Plant
Site
Te Awakairangi / Hutt River
Wellington Harbour

1.

2.

3.

4.

Figure 17. (pp. 46–47)
Location Map of
Te Mome Stream

Figure 18.
Site Analysis of Halford Place

Figure 19. (pp. 49–51) 2020
Sea Level Rise of Halford Place

2050

2080

5.3. Design Exploration

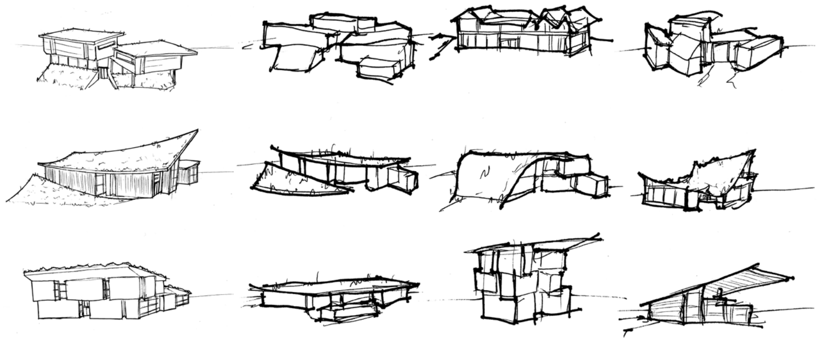
This design investigation started with the idea of re-orientating the existing buildings in order to optimise the space on site and maximise the passive solar potential of each building on site. Currently the buildings on site are placed in a disorganised and disorderly way that is not best optimised for passive solar architecture and the most efficient use of space. The reorientation idea takes advantage of the ability of light timber framed buildings to be picked up and moved by truck or crane. Most of the clubhouse buildings on site will be able to be moved in this manner.

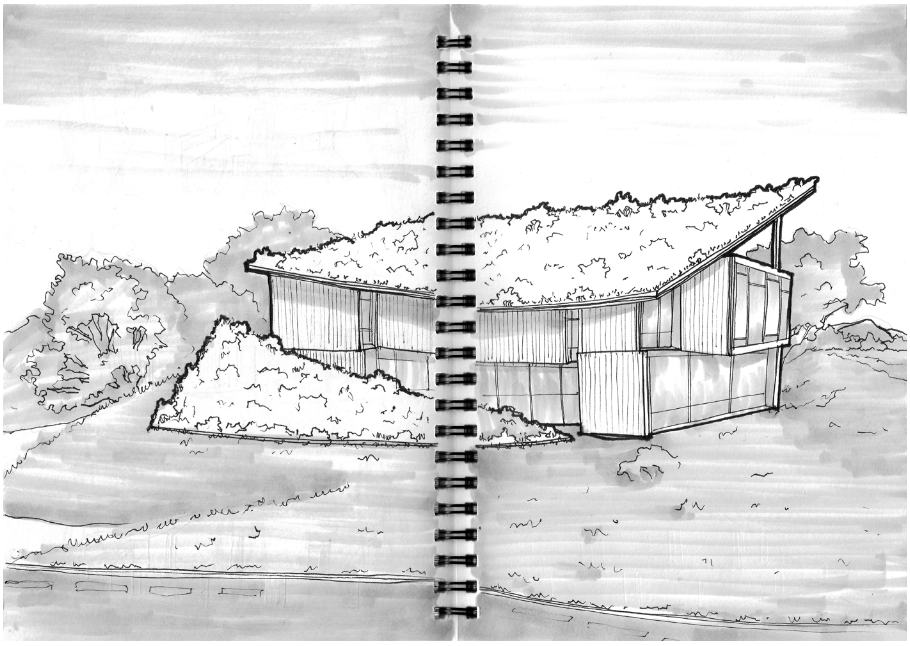
To kickstart the design process for the intervention at Te Mome Stream a 20-20-20 minute design exercise was conducted. This is where nine different sketch concepts were developed in the first 20 minutes, then three concepts were chosen to further develop in the next 20 minutes, and finally one concept chosen from those three to be developed in the final 20 minutes, the sketchbook pages from the exercise are shown in figure 20. The concept developed in the final 20 minute phase explored the idea of repurposing the existing buildings on site into one cohesive building by arranging them together where they would best fit and covering with a green roof; a "jigsaw" approach. A review of this conceptual design provided some insight on how to move forward.

Consideration of the core principles of this research had to be made to justify why these buildings were being moved so significantly. The idea to mass all of the existing buildings into one form was reconsidered to limit the resource and energy usage for the intervention. The design could be more playful when using the existing buildings and to let them guide the design rather than restrict it. Therefore, future design interventions would try to limit the amount of building movements to best utilise what is already on site.

Next, the buildings were re-orientated into two L shapes (shown in figure 21) and covered with a green roof. This was for two main reasons; to increase the riparian edge along the Te Mome side of the site by bringing that riparian edge vegetation up onto the roofs of the buildings and to create an internal courtyard between the two main L shapes. shows this design exploration.

Figure 20. (pp 52–53) Design Phase One Exploration Sketches





Proposed Programme

The programme for the design investigation at Te Mome Stream is a bioremediation education and community centre as well as incorporating the existing community club buildings currently on site. This was proposed in order to best retain the original activities on site and bring more community focused projects onto the site. This engagement with the community is imperative in order to foster a stewardship role for the site. Establishing this stewardship role in the community is one of the main ways of ensuring that the remediation plan is continued in the future and successful restoration of the site is continued.

The spaces required for the proposed programme are:

Community Clubs

- Rock and Mineral Club – 8.2m × 14.0m (93.3m^2)
- Tai Chi Club – 16.8m × 9.5m (152.4m^2)
- Judo Club – 20.1m × 8.3m (160.9m^2)
- Motor Club – 18.3m × 8.7m (143.1m^2)
- Rifle Range – 42.3m × 8.5m (308.0m^2)
- Fijian Club – 15.2m × 7.9m (99.2m^2)
- Vintage Car Club – 35.9m × 16.4m (432.0m^2)

Gear Island Water Treatment Plant

- Shed – 13.9m × 6.6m (93.1m^2)
- NE Building – 12.0m × 9.0m (108.0m^2)
- S Building – 24.3m × 16.9m (283.2m^2)

Bioremediation Centre

- Classroom / Teaching Space – 10m × 10m (100m^2)
- Lab Space – 10m × 10m (100m^2)

Site Constraints

Through this initial design investigation, site constraints were discovered which helped contribute to the design thinking for each of the following design iterations.

While investigating the idea to move buildings on site to best suit site conditions and bioremediation methods, a limitation was discovered; while most of the buildings on site are light timber framed with timber subfloors, the Vintage Car Club and the Gear Island Water Treatment buildings are built on concrete slabs and therefore cannot be easily moved. Because of this, the following design iterations had to work around these buildings and treat them as "anchor points" to design around. It was also discovered that the rifle range was too long of a building to be picked up in one piece by a crane and therefore will need to be separated into two parts if it is to be moved.

An important consideration to take into account when designing for this site is the pollution type existing there and the necessary precautions that need to be taken with it. Because the site is polluted with heavy metals, with the highest concentrations being found in the sediment of the river next to the site, particular care needs to be taken when proposing design interventions in order to keep the disruption of sediment to a minimum. As a result, no piles can be placed within the stream and/or near the stream edge. This particular limitation has to be adhered to when proposing design interventions and will require inventive solutions in order to remediate the site whilst not disrupting stream sediment.

Another limitation discovered through this first design intervention was the need to provide vehicle access for the Vintage Car Club and the Motor Club. Design for car-centric space is often limiting for the potential use of the site due to the large amount of space required to provide vehicle access. Therefore, extra care and consideration will be taken when designing this vehicle access as to not dominate the outdoor space of the site.

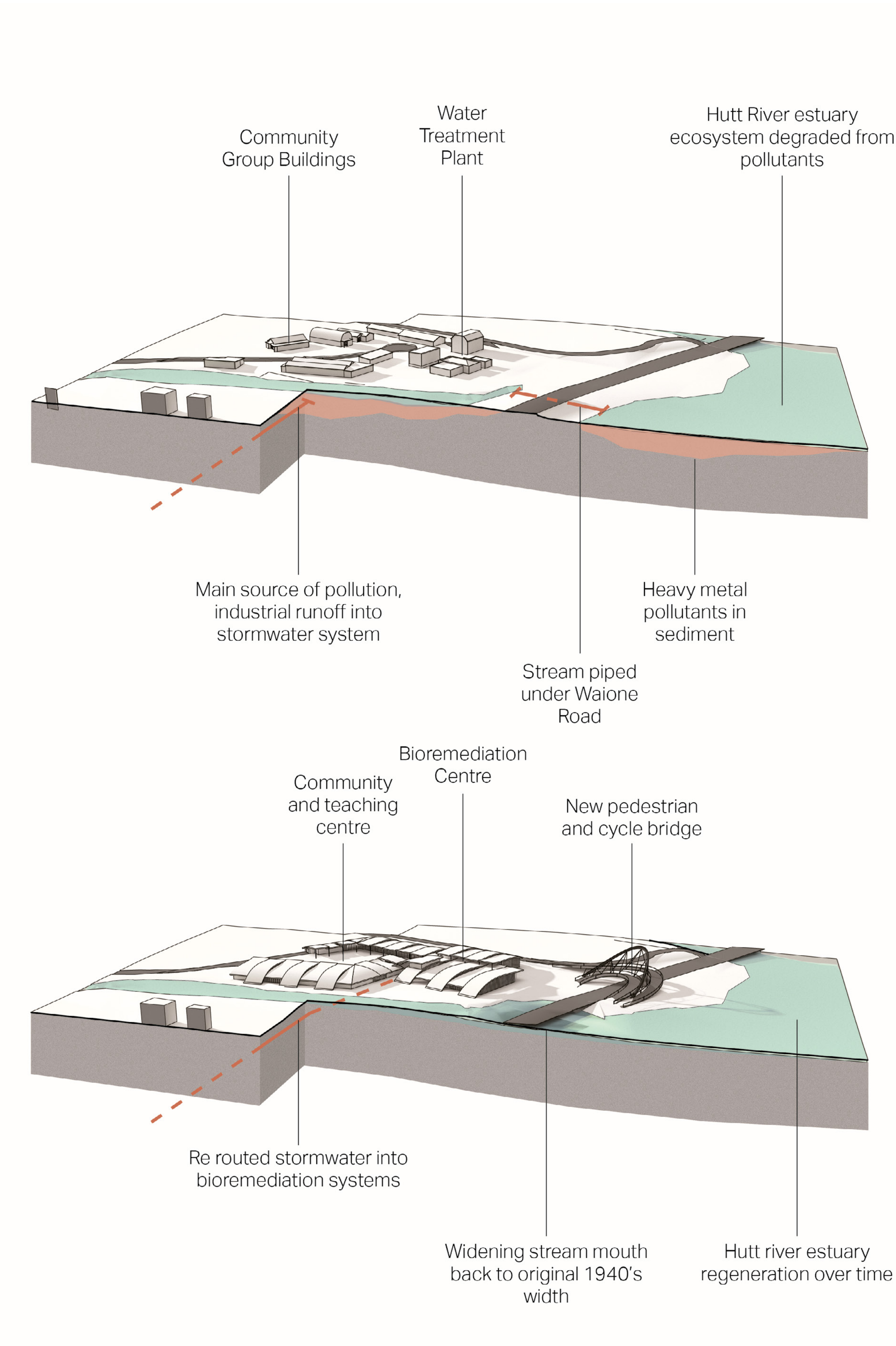


Figure 21.
Axonometric of Existing and Phase One Design

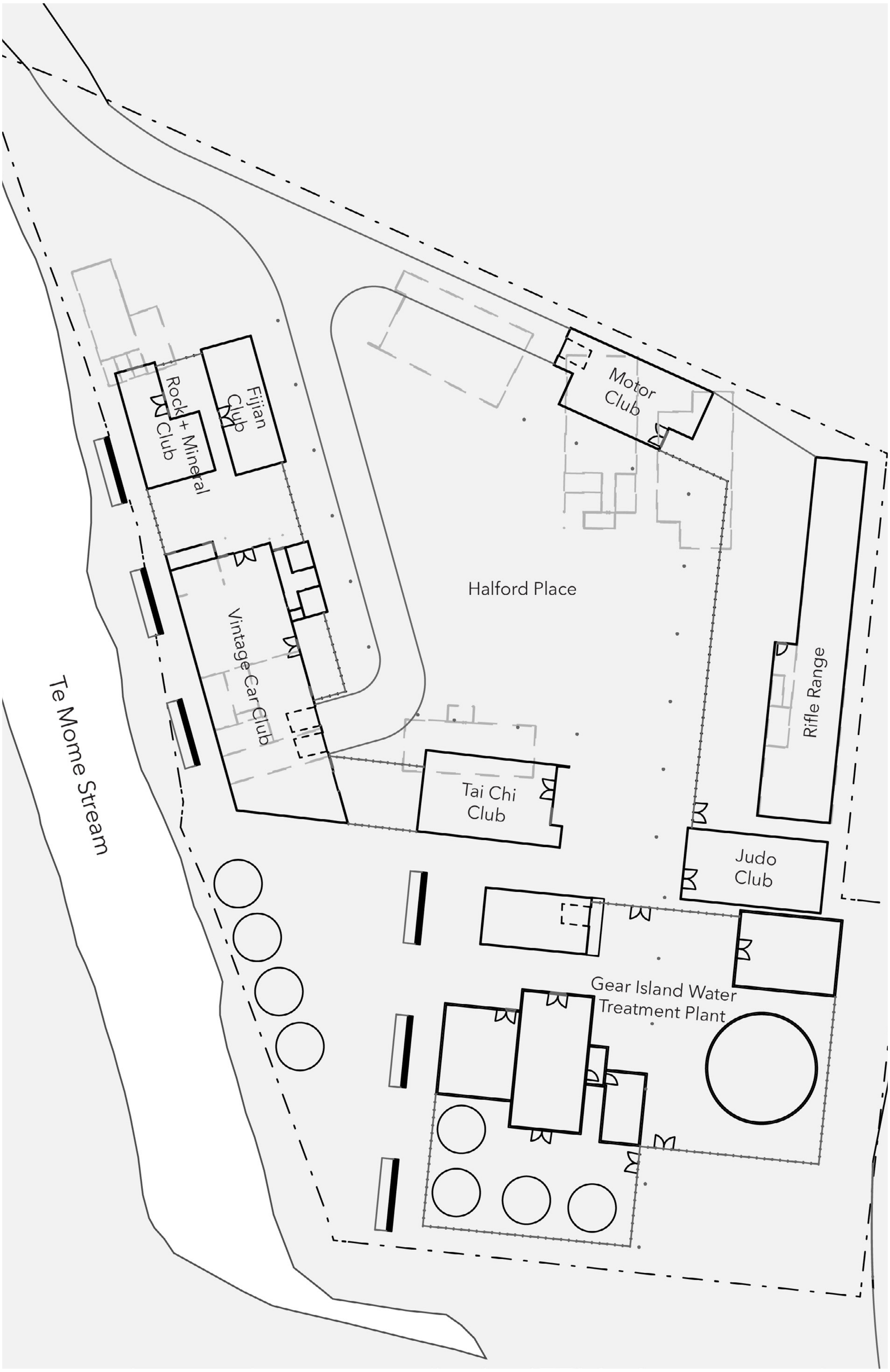


Figure 22.
Plan of Phase One Design

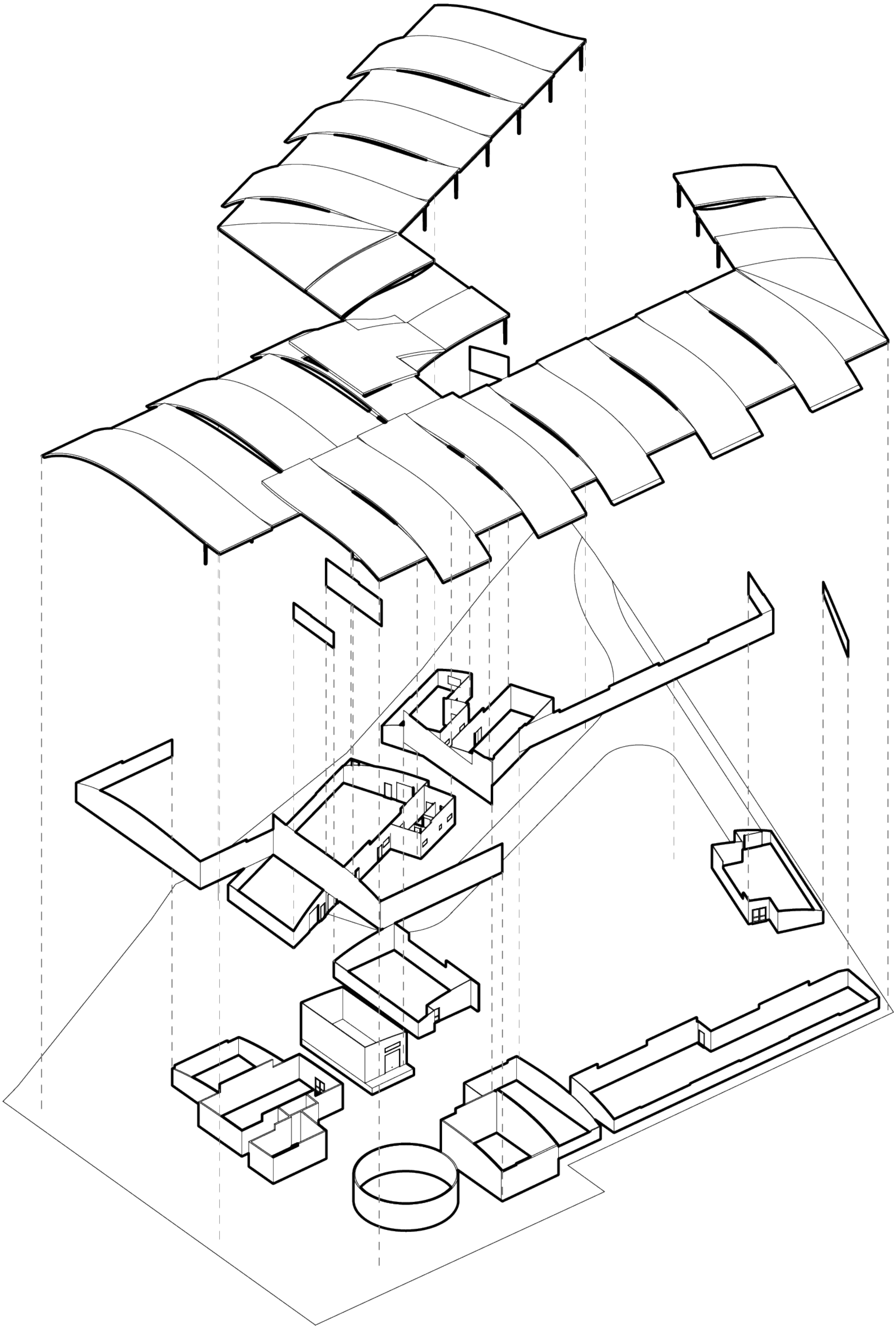


Figure 23.
Exploded Isometric of Phase One Design

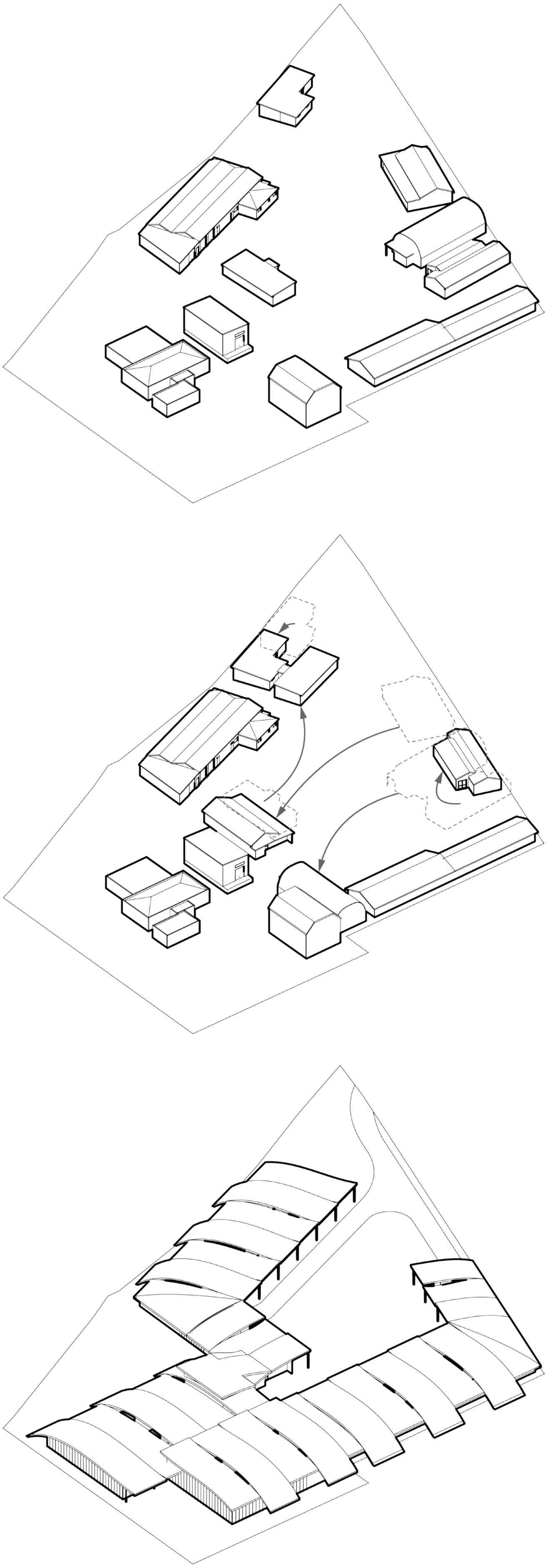


Figure 24.
Diagram of Phase One Design Building Movement

Figure 25.
Exterior Perspective of Phase One Design

5.4. Phase 1 Review

Design Review

After three months, a design review was conducted of all work completed within phase one of this investigation. The feedback from this review was mainly about three aspects of the research: firstly, how does the architecture bring awareness of contamination to those who inhabit it? Moving forward, the decision was made to re-focus on designing experiences rather than buildings-as-objects when designing architecture for the site.

Secondly, how does the architecture respond aesthetically to this type of redevelopment for the site? The reviewers were interested in how the retrofit of existing buildings could celebrate the existing condition rather than be heavily altered. This research needs to investigate what the architectural response is to the site conditions, while ensuring that it continues to fit within the sustainable parameters set out earlier, and not contribute to the current architectural waste economy (cradle to grave, resources are extracted to be used once on a building and landfilled following demolition).

Finally, what is the role of architecture within these bioremediation techniques? The reviewers were interested in how architecture could be used to participate in bioremediation techniques to regenerate the surrounding ecosystems. This gave a clear direction for how to focus subsequent research on designing experiences. Moving forward, this research investigates a selection of bioremediation techniques spatially, and will evaluate each investigation independently of site before returning to the design of architectural interventions that combine each technique together on site through the medium of architecture.

5.5. Phase 1 Framework Review

Net Positive Resource Goals

Is the proposed architecture able to produce a net positive amount for water and materials?

The design of phase one does re-use the existing buildings in part; however, by altering the external envelope so heavily and adding a green roof, which have high embodied energy and require extra structure to be installed, the design is not able to produce a net positive effect for the resources it uses. Moving forward, this research will investigate ways in which the existing buildings do not have to be altered so heavily in order to keep the embodied energy of the project low.

The design of phase one does not address any of the onsite demands for water usage, and therefore does not produce a net positive for the water used onsite. Moving forward, this research will investigate ways in which stormwater and blackwater could be treated onsite and be able to produce a net positive for water usage.

Ecology of Place

Does the project contribute positively to the ecology of the place?

By introducing green roofs that sweep from the ground up to the roof of the existing buildings, the design of phase one increased the riparian edge of the stream. By increasing this riparian edge, the design interventions are able to increase habitat provision onsite, and therefore contribute positively to that aspect of the ecology of place. However, the design of phase one does not contribute to the reduction of contaminants in the existing habitats onsite, and therefore does not contribute positively to that aspect of the ecology of the place. Moving forward, this research will focus on ways to purify the existing habitats onsite whilst also continuing to increase habitat provision onsite by increasing the riparian edge of Te Mome stream.

Sense of Place

Does the project enable individuals and groups to share in a collectively imagined future?

While the design of phase one does re-develop the existing community clubs onsite, it does not provide any more value to the current public space amenities onsite. The design of phase one also does not provide any educational opportunities for users to learn about the ecological processes happening on site, and therefore does not enable individuals and groups to share in a collectively imagined future. Moving forward this research will investigate ways in which public space amenities and educational space can be provided onsite to install a sense of place for the users of this space.

6. Design-led Research Phase Two

Spatial Exploration of Bioremediation Techniques

6.1. Spatial Explorations of Bioremediation Techniques

This phase of design-led research focuses on understanding the technical aspects of three bioremediation techniques and explores potential spatial arrangements for each technique. The three techniques chosen were bioventing, riparian edge phytoremediation, and aqueous reactors. These specific techniques were chosen in this phase of the design-led research because they can provide remediation for the soil, water and stormwater on site, as well as providing potential for integration within the architecture on site.

Bioventing

Bioventing, as mentioned in chapter 3.2, is the process of providing oxygen to contaminated soil to promote indigenous microbial activity to remediate the soil onsite. This is achieved by drilling a pile hole into the ground, just below the level of contaminated soil, and installing a biovent pipe so that air can be blown (either passively or mechanically) from the surface into the contaminated soil and dispersed throughout. The pipes used are the same used for plumbing or drainage in the construction industry - in this case a 100mm diameter HDPE pipe. A diagram of this can be seen in figure 26. This method is a low cost, non-intrusive method of remediating degraded soil as it does not require contaminated soil to be excavated and then treated. It can be installed in-situ and remediate soil overtime with minimal disruption to surrounding activities.

The specifications for designing a passive bioventing system for this research were sourced from Larson (2006). A passive bioventing system utilises the difference between atmospheric and subsurface air pressure to passively aerate contaminated soils. Larson states that a passive venting system is more effective in certain situations than a conventional system because of its reduced reliance on mechanical blowing systems, and therefore lower operational and maintenance costs. Using a passive bioventing system better aligns with the regenerative design goals of this research and thus, moving forward this research project will focus on passive bioventing rather than mechanical bioventing.

The spacing of vent wells is dictated by the estimated radius of influence for the site. The factors that determine this radius of influence are:

- Magnitude of air pressure change
- Frequency of air pressure change
- Soil permeability (soil type, soil porosity, soil moisture)
- Respiration rate of indigenous micro-organisms

For the purpose of this research project, it was assumed that the radius of influence at the Te Mome site would be similar to that presented in Larson's (2006) passive bioventing design.

So, based on this we have taken the Te Mome site to have an approximate area of influence of 2.5m radius for each biovent.

Conventionally, biovents are not designed to interact with users of the space, neither do they indicate their function to the users of the space. This research first investigates ways in which biovents could indicate their function to users of the space and secondly, investigates ways in which users could interact with these biovents to participate in the remediation process. These investigations explored the eco-revelatory design potentials for biovents.

Shown in figure 27, the ideas explored were:

- Indicating the activation state of a biovent by a change in lighting, such as incorporating a transparent material that can light up when the biovent is active.

- Allowing interaction by inviting users into a field of biovents. This deepens user interaction by allowing users to walk through the intervention.

- Turning an industrial process into an architectural one by using each biovent in a sculptural way, engaging users through aesthetic interest.

The technique of indicating activation state was explored further. Figure 28 is an animation that examines the shifting activation states throughout a day and night cycle as a result of the changing atmospheric and subsurface air pressure. User interaction would be dependent on the shifting barometric pressure cycles throughout different days and therefore adds a sense of chance when users interact with these biovents.

Figure 26.
Biovent Diagram

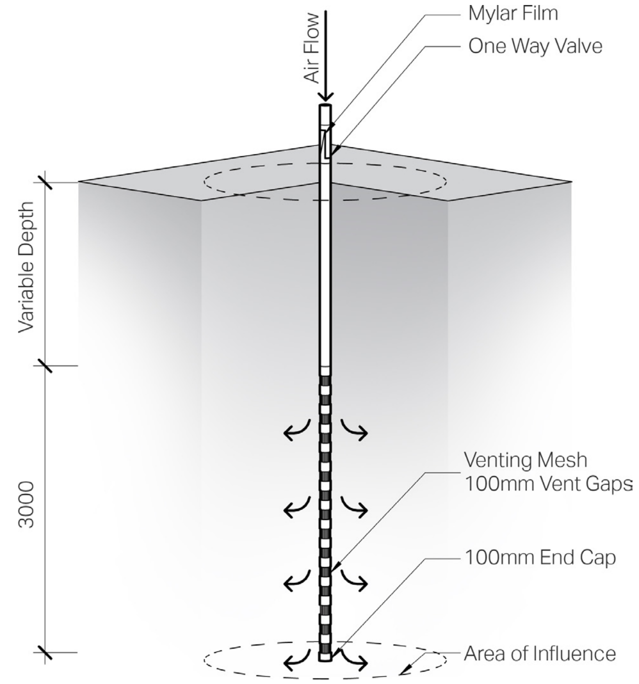


Figure 27.
Bioventing Ideas Explored

Figure 28.
Still from Biovent Animation (find animation @ http://tiny.cc/jab2tz)

Riparian Edge Phytoremediation

The next bioremediation technique examined was a combination of phytoremediation methods and extensions to the riparian edge of Te Mome stream in order to restore the soil and water ecology on site.

The soil in Halford Place requires both bioaccumulation and mineralisation, previously mentioned in chapter 3.2, due to the contamination from heavy metal pollutants and a degraded soil ecology. In addition to phytoremediation, this part of the research investigated an extension of the riparian corridor to aid in soil restoration.

The riparian edge is the space that runs alongside watercourses and water bodies; this zone supports a different kind and amount of vegetation compared to adjacent areas due to more water being supplied to these plants. The riparian edge plays an important ecological role for the health of the water body through nutrient cycling, hydrological function, and providing habitat for both aquatic and terrestrial plants and animals (USDA, 1996).

By supporting and restoring the riparian edge alongside Te Mome stream, significant positive contribution would be made to the ecological health and function of the stream. To achieve this, the riparian edge of Te Mome stream would need to be replanted with species indigenous to the area and increased in size so that this riparian edge can adapt to climate change effects (such as coastal squeeze).

Coastal squeeze is the reduction of the intertidal zone from the high tide mark being fixed by seawalls and the low tide mark moving closer to the high tide mark due to sea level rise (Pontee, 2013). This phenomenon negatively effects species who inhabit this intertidal and/or riparian zone. As Te Mome stream is a tidal stream, the riparian corridors along its edge are also affected by coastal squeeze. To avoid this, the seawalls designed at Halford Place must mitigate the effects of coastal squeeze and support the increase in riparian edges along the shorefront.

When investigating this technique spatially at Halford Place the main design challenge to overcome was allowing for the increase in riparian zone whilst still retaining the space needed on site to continue the existing activities. The site is fairly small, so this presented an interesting challenge to overcome. It was identified that the phytoremediation and riparian edge extension would need to be used together to overcome these site challenges and in addition special arrangement techniques were investigated so that users could interact with this type of remediation.

Shown in figure 29, the ideas explored were:

- Floating phytoremediation pads, where a hyperaccumulator and/or a mineraliser could be planted aqueously in order to bio-accumulate heavy metals and/or mineralise other contaminants from the stream.

- Timber structures / boardwalks as a growth medium for bio-accumulating microbes, providing structures that users can walk on as well as providing a medium for beneficial microbial growth. Materials used would require inoculation offsite before installation.

- An environmentally friendly seawall with microbial inoculant. This is a seawall that has soil inoculated with beneficial microbes during construction. This seawall will be able to mitigate the effects of sea-level rise and storm surge on land by increasing the riparian edge / intertidal zone while also increasing remediation potential by utilising phytoremediation.

- Extending the riparian edge onto a building. By utilising a green roof that starts from the ground and extends up and becomes the roof of one of the existing buildings, the riparian edge could be extended past a point which is usually dedicated by a building.

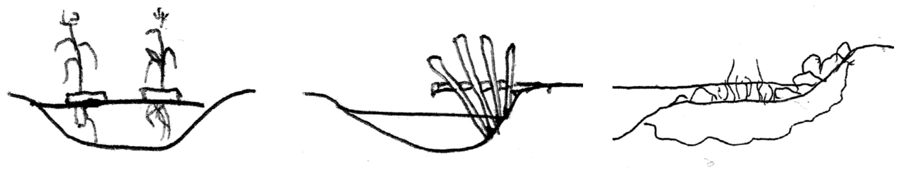


Figure 29. Riparian Edge Phytoremediation Ideas Explored

After these initial explorations, each method was further researched to determine if it would be suitable to support plant / microbial growth and if each method would provide beneficial remediation. Floating phytoremediation was determined to be beneficial based off a pilot study completed by Phytotech in 1996, who bio-accumulated caesium and strontium by using sunflowers on floating pods in Chernobyl (Phytotech, 1996). This technique is further explored in phase three of this research project.

Timber structures / boardwalks as a growth medium for this site was determined to be un-suitable as the type of fungi suited to heavy metal remediation would not survive in an aqueous environment.

The environmentally friendly seawall with a microbial inoculant and extending the riparian edge onto a building roof were explored further; shows stills from an animation that

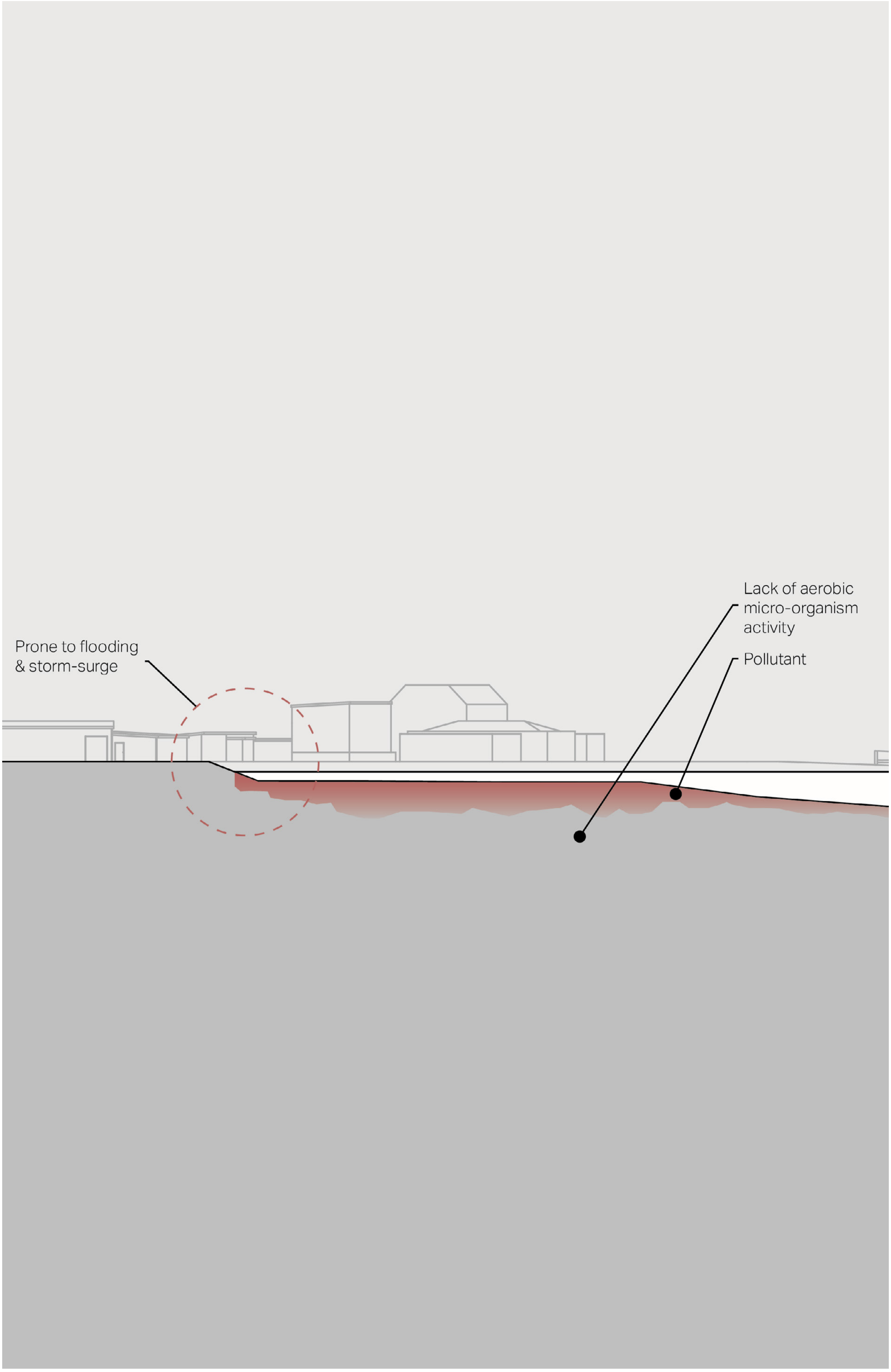


Figure 30. (pp 68–69)
Seawall Animation Stills (find animation @ http://tiny.cc/jab2tz)

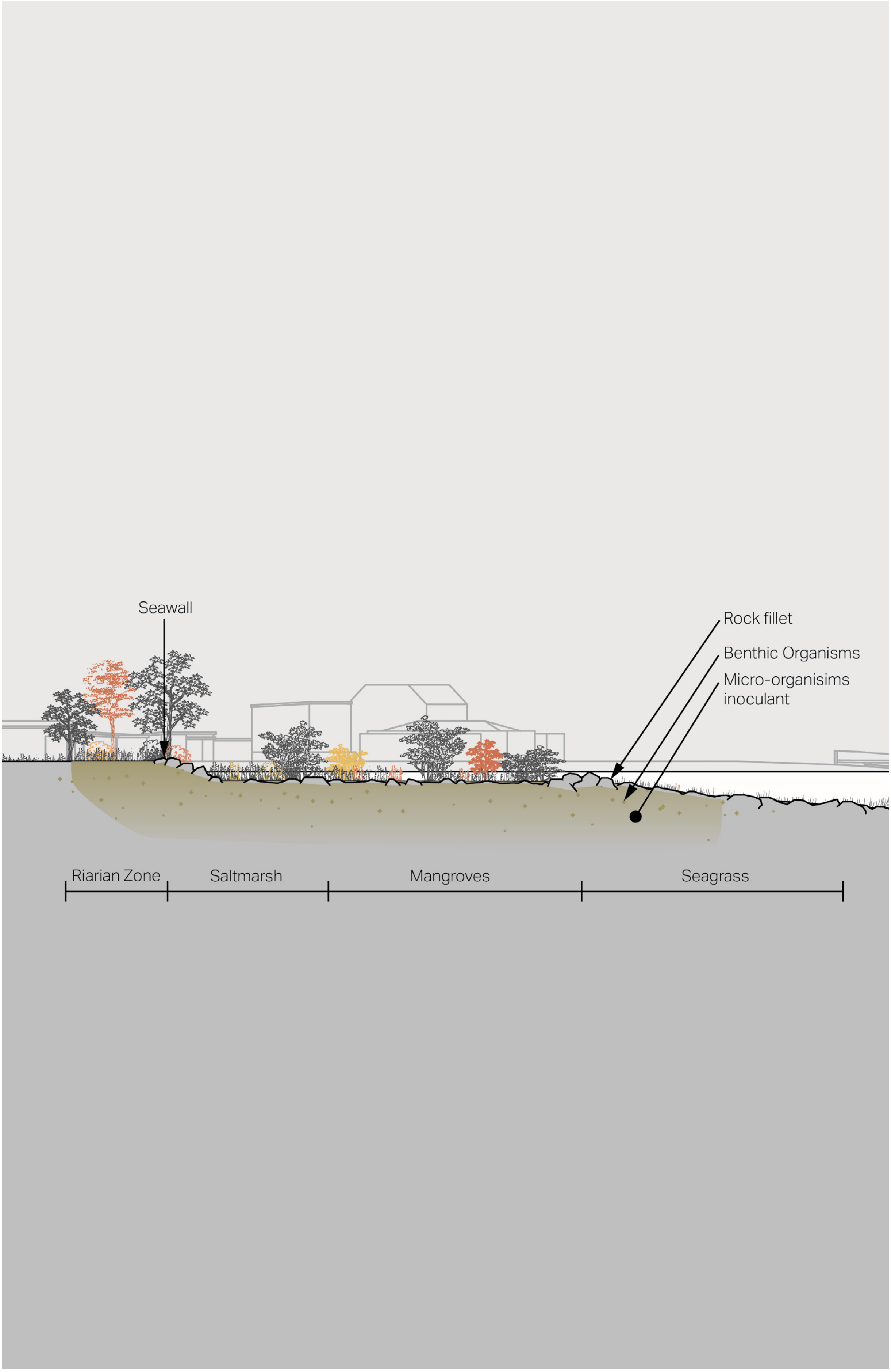

Seawall
Rock fillet
Benthic Organisms
Micro-organisims inoculant
Riarian Zone
Saltmarsh
Mangroves
Seagrass

Figure 31.
Seawall Perspectives

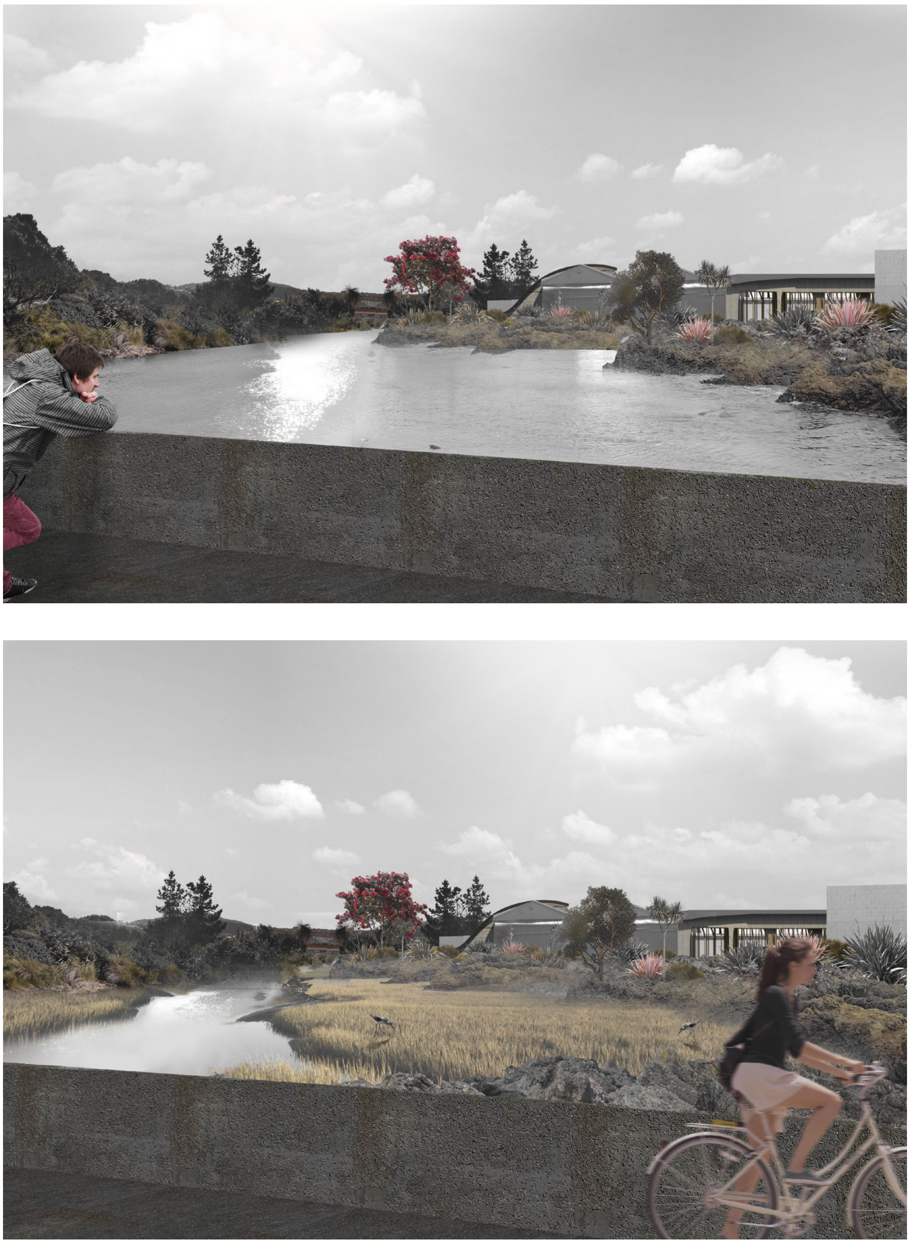


Figure 32.
Riparian Edge
Extension Perspective

explores the construction and growth of the microbial seawall technique through time whilst also exploring how it interacts with changing tides. Figure 32 is an image that explores the idea of extending the riparian edge on top of a building by utilising a green roof.

Aqueous Reactor

The final technique examined in this phase of design-led research is an aqueous reactor. Aqueous reactors, as previously mentioned in chapter 3.2, use the process of pumping contaminated water into an external vessel so that a microbial inoculant can be added to aid in the remediation of contaminants.

This bioremediation technique was explored onsite so that contaminated stream water could be treated in an external vessel as well as providing capacity to treat all (or some) stormwater from the surrounding catchment area before it is discharged back into Te Mome Stream. The reason for providing the capacity for the treatment of the surrounding catchment stormwater is to ensure that there are systems in place to stop any future contaminants being discharged into the stream. The design of this aqueous reactor is based on an ecological model developed by John Todd called a living machine (Todd, 1994, 2019; Todd et al., 2003; Todd & Josephson, 1996). The premise of a living machine is to utilise ecological succession (nature's ability to self-organise and move from disturbed to healthy states in ecosystems) within several different external vessels by inoculating each vessel with a variety of plants, animals, bacteria, and fungus and running wastewater through each. Over time, each vessel evolves a unique ecosystem so that the whole system can best purify the contaminants being run through it.

First, this research investigated ways in which a living machine could be used onsite for the purpose of treating contaminated stream water and stormwater from the surrounding catchment. The design of the living machine for Halford Place was based on the living machine in Oberlin College, Ohio, United States of America. The specifications of this working example of a living machine were used as the basis for the proposed system at Halford Place and also provide an estimation for the capacity of the system.

- Underground Processes: 1× 5,600L (2.5m × 1.6m) Anaerobic Settling Tank → 1× 5,600L (2.5m × 1.6m) Anaerobic Reactors → 2× 5,600L (2.5m × 1.6m) Aerobic Reactors

- Greenhouse Processes: 3× 2,700L (1.8m diameter × 1.1m high) Open Aerobic Reactors → 1× 2,700L (1.8m diameter × 1.5m high) Clarifier

- Outdoor Processes: 1× 17,000L Constructed Wetland □ 1× 9,500L Holding Tank & 1× 160L Pressurised Tank

Second, this research investigated ways in which eco-revelatory design techniques could be used in conjunction with the design of this living machine to allow for users to interact with the ecological processes of this system. Shown in figure 34, the ideas explored were focused on communicating the complex ecological interactions of the living machine in a simplified manner. The process could be simplified down by showing the contaminated, dirty water going into the system and the purified, clean water coming out and being returned to the environment. Figures 35 and 36 explore this technique of eco-revelatory design through the design of an extension to one of the existing buildings to house this living machine.

Figure 33.
Aqueous Reactor Detail

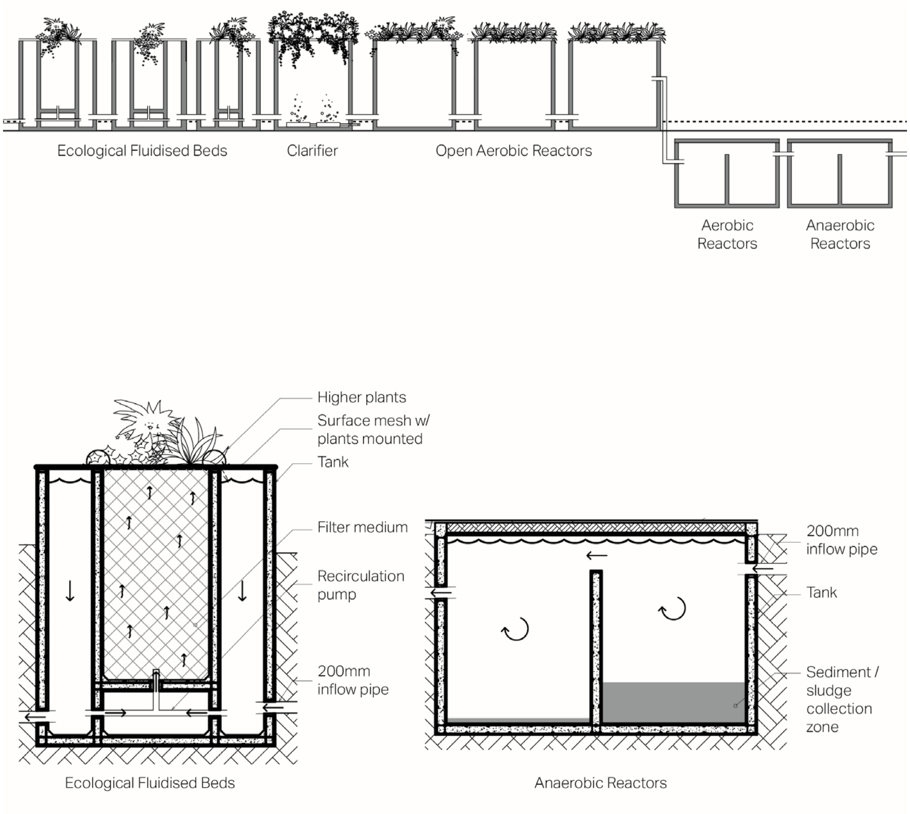


Figure 34.
Aqueous Reactor Idea Explored

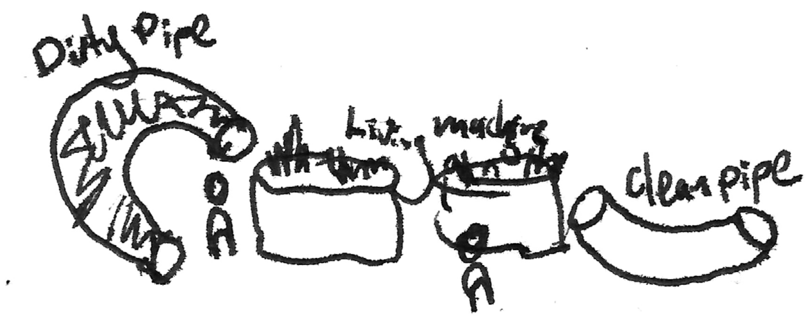


Figure 35.
Interior Aqueous Reactor Perspective

Figure 36.
Exterior Aqueous Reactor & Constructed Wetland Perspective

6.2. Site Planning

This phase of design-led research re-examined the master plan on site and further developed the spatial arrangement of the master plan from phase one. The revised master plan aims to aid in the remediation on site more effectively as well as focusing more on user experience. The concept behind this updated master plan was to rearrange the site into spatial corridors (riparian, bioremediation, and circulation) and fit the buildings in between. Each corridor was aligned to best suit the orientation of the buildings that cannot be moved on site (those made of concrete or placed on concrete pads). This also provided a framework for where the moveable buildings on site could be situated. This site re-orientation can be seen in figure 37. The idea behind arranging the site into corridors was to dedicate space to both bioremediation and the users of the site while still working with the orientations of the buildings that cannot be moved.

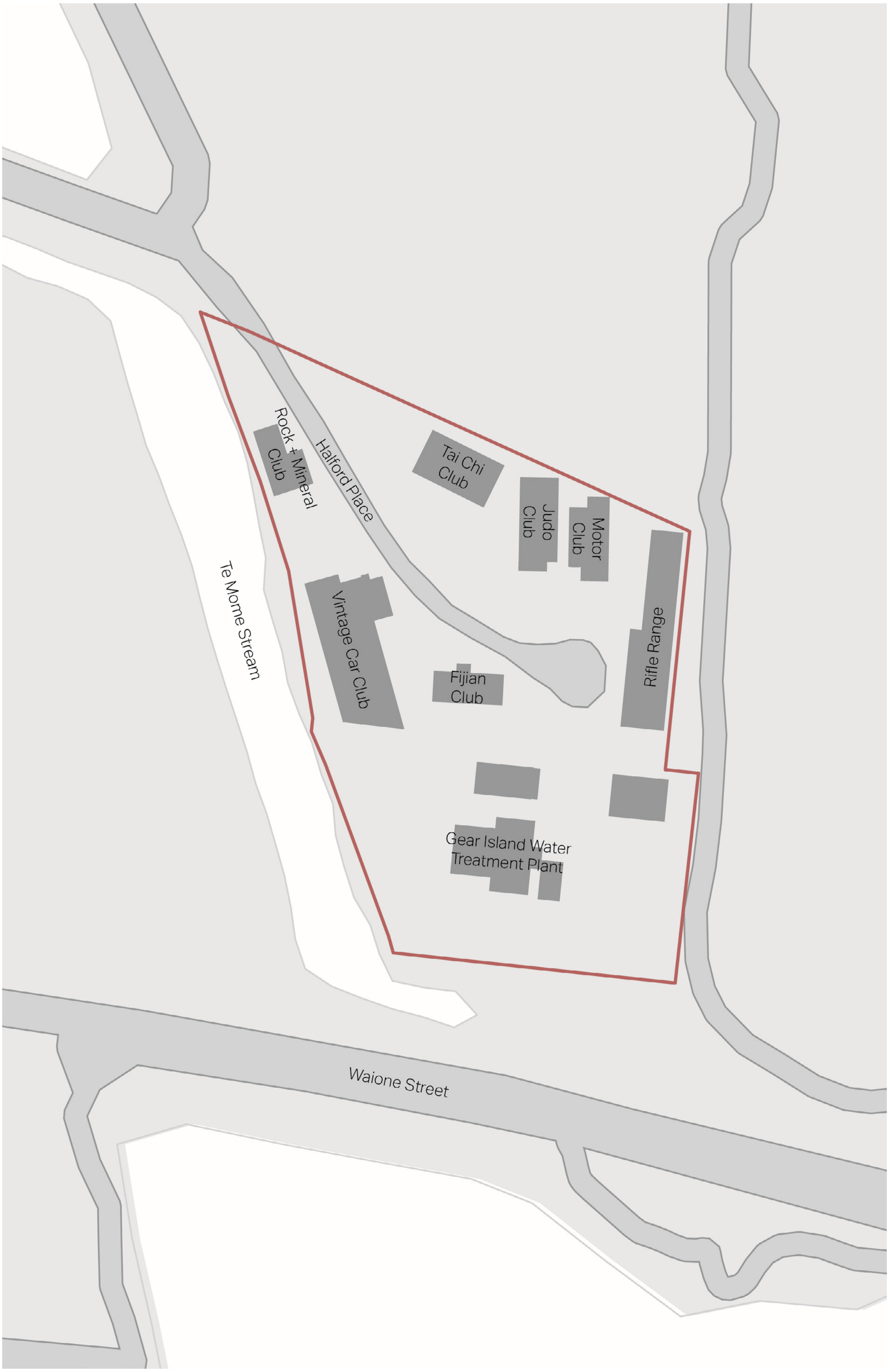


Figure 37. (pp. 74–75)
Site Re-orientation


Circulation Corridor
Remediation Corridor
Te Mome Stream
Riparian Corridor
Remediation Corridor
Circulation Corridor
Remediation Corridor
Waione Street

6.3. Design of Vintage Car Club Extension

An extension to the vintage car club was designed during this phase of design-led research to house the proposed aqueous reactor and to provide a new atrium/entrance for the vintage car club. The structure of this extension was designed out of glulam timber members to mimic the structural fins of an oyster mushroom. Figure 38 shows the structure and envelope of this extension in an exploded axonometric view as well as showing the extension of the riparian edge of the stream onto the green roof of the vintage car club.

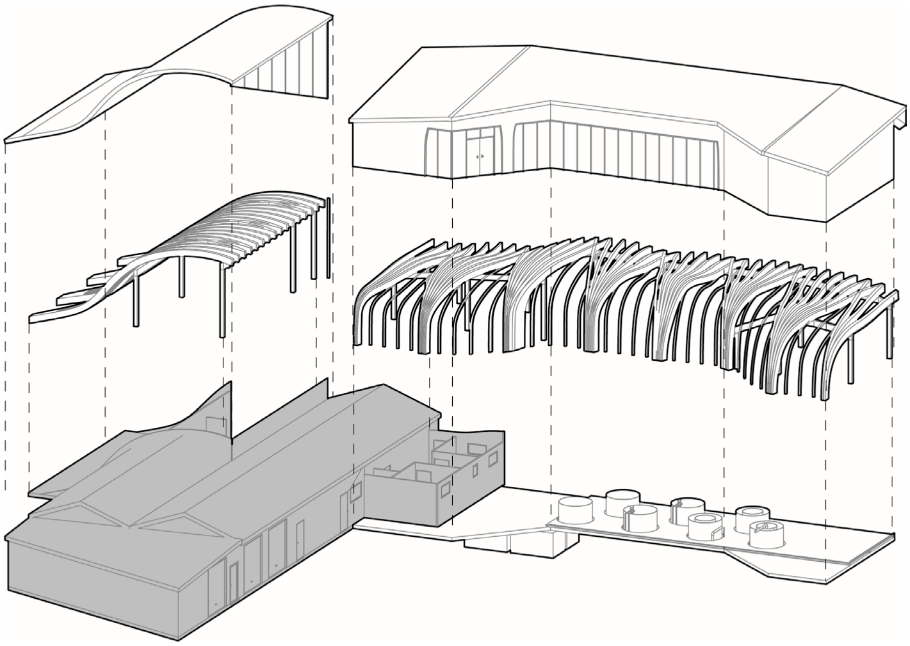


Figure 38.
Vintage Car Club Extension Exploded Isometric

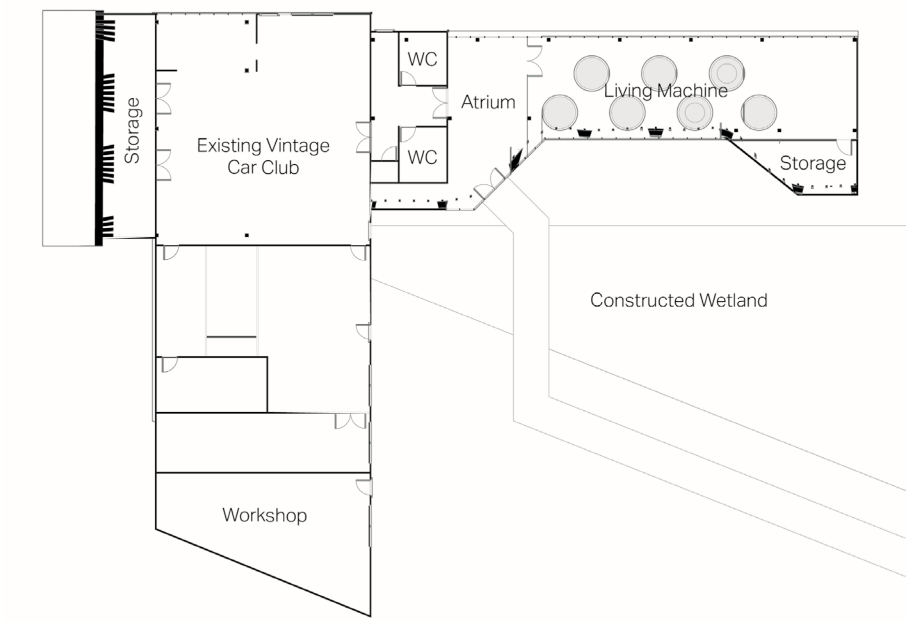


Figure 39.
Vintage Car Club Extension Plan

6.4. Phase 2 Review

Six months into this research, another design review of all work completed within phase one and two of this investigation was undertaken. The feedback from this review brought up four key questions:

1) How does the project come together as a whole to make the bigger connections between the different remediation methods?

2) How can the system adapt to future conditions?

3) How can the project strengthen the water connections?

4) How can the project stay true to the original regenerative design principles?

The reviewers mentioned that the investigation was comprehensive in some areas of the project but felt fragmented as a whole. They suggested reconsidering why design decisions were being made and what the design driver was for orientating the site into corridors. They also suggested considering how the design makes a bigger connection between each bioremediation technique. A point for further investigation was reconsidering the relationship between bioremediation and architecture in the restoration of a site more explicitly or overtly.

The future of the site will change drastically due to climate change, so the reviewers suggested that the project should respond to future site conditions in order to provide adaptive, resilient architecture on site. Future investigations will be centred around this idea of adaptive architecture and consider how the project can be arranged into a timeline of phases to ensure an effective response to sea-level rise and climate change.

As this research is focused on Te Mome stream, water has become a connecting factor for different aspects of the project. The reviewers picked up on this design connection but suggested that it could be strengthened. As a follow on to the previous point, they suggested that widening the stream from its current condition (piped under the road) back to its original state could become part of the project timeline.

The investigation so far has been focused on producing some form of building as part of the architectural output. The reviewers suggested to think beyond these ideas, and ask is this an architectural intervention that does not have conventional architecture perhaps? Moving forward, this research will focus on investigating retrofitting examples first and then new buildings that do not contribute to the waste economy of the current built environment. The reviewers also suggested that adding, or showing, another layer of programme to the intervention would help the project stay true to regenerative design principles. To progress, this research will investigate architectural opportunities to engage with the community and asks: how can users interact with the designs? What educational opportunities can the designs provide? And how can the architecture use social marketing and eco-revelatory design strategies to encourage a sense of stewardship in users?

6.5. Phase 2 Framework Review

Net Positive Resource Goals

Is the proposed architecture able to produce a net positive amount for water and materials?

Timber was used as the main construction material in this project so the design on phase two would offset its overall carbon footprint through the carbon sequestered in this timber. The project used approximately 59.6m^3 of timber to sequester 39.5tCO_2 (Alcorn, 2010). To ensure that the development at Halford Place is able to produce a net positive for the materials used, this research will focus on the adaptive re-use of the existing materials onsite to keep the overall embodied energy of the development low.

The proposed design was also able to manage all the onsite black and stormwater by using a living machine. The living machine designed on this site is able to treat approximately 9500 litres of black and stormwater per day, and therefore provides a net positive for the water used on site.

Ecology of Place

Does the project contribute positively to the ecology of the place?

By remediating site contaminants, increasing the riparian edge and increasing soil ecology health, the proposed design is able to positively contribute to the environmental ecology of the site. By revitalising the existing community clubs onsite, the proposed design is also partially able to positively contribute to the socio-ecosystems of the site as well. Moving forward this research will focus on fully revitalising the socio-ecosystems onsite to positively contribute to the overall ecology of the place.

Sense of Place

Does the project enable individuals and groups to share in a collectively imagined future?

The design of phase two aims to stimulate community and individual investment in the successful remediation of this site and to re-establish a sense of stewardship for this site.

The design of phase two achieves this, in part, by utilising eco-revelatory design to reveal the ecological processes being used to remediate the contaminants on site to users. In order to enable individuals and groups to share in a collectively imagined future, the development at Halford Place needs to provide more educational opportunities for users alongside these eco-revelatory design moments. Therefore this research will further investigate providing educational opportunities for users in the following phases.

7. Field Tests of Bioremediation Techniques

Two field testing experiments were undertaken to examine a selection of the bioremediation techniques proposed for the project site. This was undertaken to evaluate the effectiveness of the chosen bioremediation methods in a context that simulates, as close as practical, the onsite conditions. The two field test experiments that were undertaken were the phytoremediation method and the fungi bioaccumulation method.

7.1. Phytoremediation Field Test

This field test examined the effectiveness of phytoremediation methods for remediating soil ecology on site. Three different approaches to phytoremediation were examined by planting a fast-growing crop (Raphanus sativus) using each method and testing the soil for biological activity after one month of growing. The setup of this field test is shown in figure 40. The three methods used were:

1) **Baseline:** the soil gathered from the site without any additives to establish a baseline for this field test.

2) **Microbial Inoculant:** 50% of the soil was gathered from site with 50% of a microbial inoculant mixed in. The microbial inoculant consists of: Bacillus subtilis, Beauveria bassiana, Arbuscular mycorrhiza, and Azotobacter chroococcum

3) **Stimulated Indigenous microbial additive:** 50% of the soil is gathered from site with 50% compost mixed in. Installing a biovent onsite was outside the scope of this investigation so the compost was used to simulate what biovents would do to onsite soil. Composting is the process of aerating a soil pile to promote indigenous microbial activity for the breakdown of organic matter. The assumption has been made here that this is a very similar process to bioventing the soil on site.

Method

Soil was gathered from the site near the edge of Te Mome Stream and near the stormwater outlet where most contaminants are discharged from. This soil was then used to set up the three tests in an offsite location. After the experiment methods were set up, Raphanus sativus seeds were planted into each test and were left to grow for a month-long period. After the growing period, soil samples were taken from the plant root areas for each of the three experiments and sent to a lab for a Solvita test. This is a measure of soil ecology health as measured by the amount of soil respiration (CO_2).

Figure 40. (pp. 82–83)
Setup of
Phytoremediation
Field Tests

Results

Initially there was no noticeable difference between seed germination times for each sample but by the end of the growing period there was a noticeable difference between the size of plants, the amount of germination, and leaf defects in the plants. Figure 41 shows a time-lapse of this field test. Shown within these images are the leaf defects and constricted plant growth potential for both the baseline and microbial inoculant experiments.

Figure 42 shows the results of the Solvita test. These results clearly show that the stimulated indigenous microbial additive was the most effective method of improving the health of the soil ecology; this is also backed up by the visual analysis of the plants.

A hypothesis for the observed result is that this was the most effective method because these indigenous microbes have already best adapted to the site conditions due to ecological succession. Therefore, they have the greatest chance to improve soil ecology health when stimulated.

Based on these results, it was determined that biovents are likely to be the most effective method for remediating the soil onsite and therefore this method is explored further in phase 3 of this project.

Figure 41. (pp. 85–86) Growth of Phytoremediation Field Test


1:1 COMPOST
1:1 MICROBE
Raphanus Sativus
BASELINE


1:1 COMPOST
Raphanus Sativus
1:1 MICROBE
Raphanus Sativus
BASELINE


1:1 COMPOST
Raphanus Sativus
1:1 MICROBE
Raphanus Sativus
BASELINE

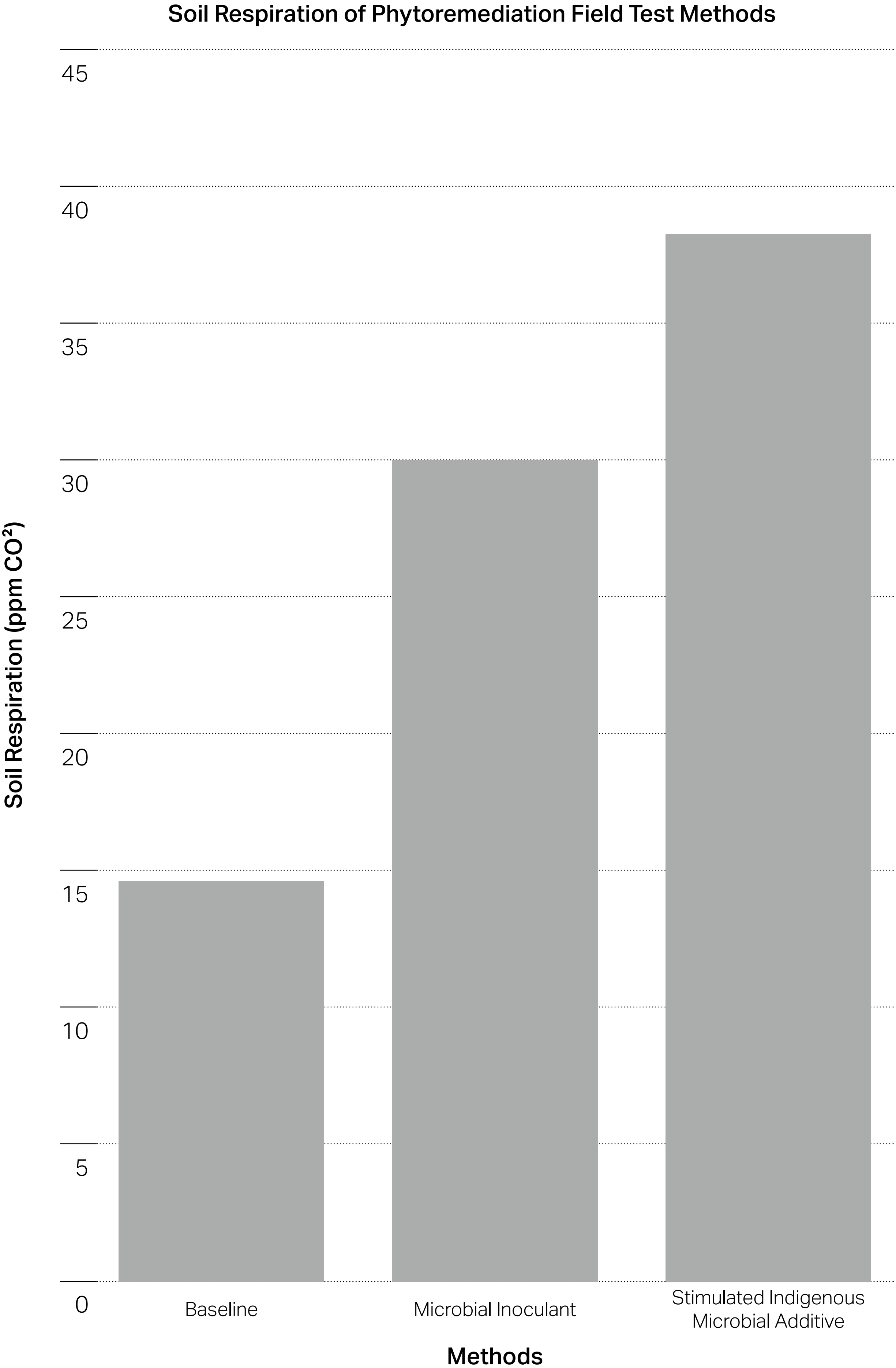


Figure 42.
Soil Respiration of Phytoremediation Field Tests

7.2. Fungi Bioaccumulation Field Test Fungi Bioaccumulation Field Test

This next field test investigated the possibility of using mycelium as a building material. The purpose of this field test was to determine if it were possible to grow a brick out of mycelium that could be used in the architectural interventions at Halford Place. By examining the findings of Dahmen (2017) and the findings from examining different fungi specie's functions, it was hypothesised that mycelium could be used to remediate the contaminated sediment onsite by combining a proportion of this sediment with construction waste sawdust and inoculating with mycelium. Due to resource, time, and access limitations of this research, the remediation potential of fungi for the sediment of Te Mome Stream could not be tested in this field test. Instead, this field test focuses on the re-use of construction waste as a food source to grow mycelium into a building material.

Method

First, brick moulds were made using a vacuum former so that the mycelium would have a structure to grow into. Next, the growing substrate was prepared. This field test used radiata pine pellets to closely resemble the type of construction waste that could be used as a mushroom growing substrate. This field test used a cold pasteurisation method, combining the growing substrate with a hydrated lime solution, to sterilise the pine pellets. Once the substrate is sterilised it was combined with a fungi inoculant, in this case Pleurotus Pulmonarius, at a 20% spawn rate. This mixture of growing substrate and fungi inoculant was then packed into the sterilised brick moulds and left in an incubation chamber held at 27°C to provide optimum growing conditions. After the mycelium have grown to fully incorporate all of the substrate within the brick mould, they can be taken out of the moulds and baked at 90°C to harden the brick and stop any future growth from the mycelium.

Figure 43.
Setup of Fungi Bioaccumulation Field Test

Figure 44. (pp. 90–91)
Growth of Fungi Bioaccumulation Field Test

Results

This field test was the first exploration into this method of creating mycelium bricks as a building material, and thus it was unknown how long the incubation process would take. The incubation period was expected to take 2-3 weeks but at the time of writing the incubation is still ongoing at 7 weeks. As the results of this field test are not yet available, this research will continue further investigations on the assumption that this field test was successful in growing a mycelium brick for use as a building material. Figure 45 shows the preliminary result of one of these bricks

Figure 45. (pp. 92–93) Bioaccumulation Field Test Preliminary Results

8. Design-led Research Phase Three

Integration of Bioremediation and Architecture

8.1. Site Planning

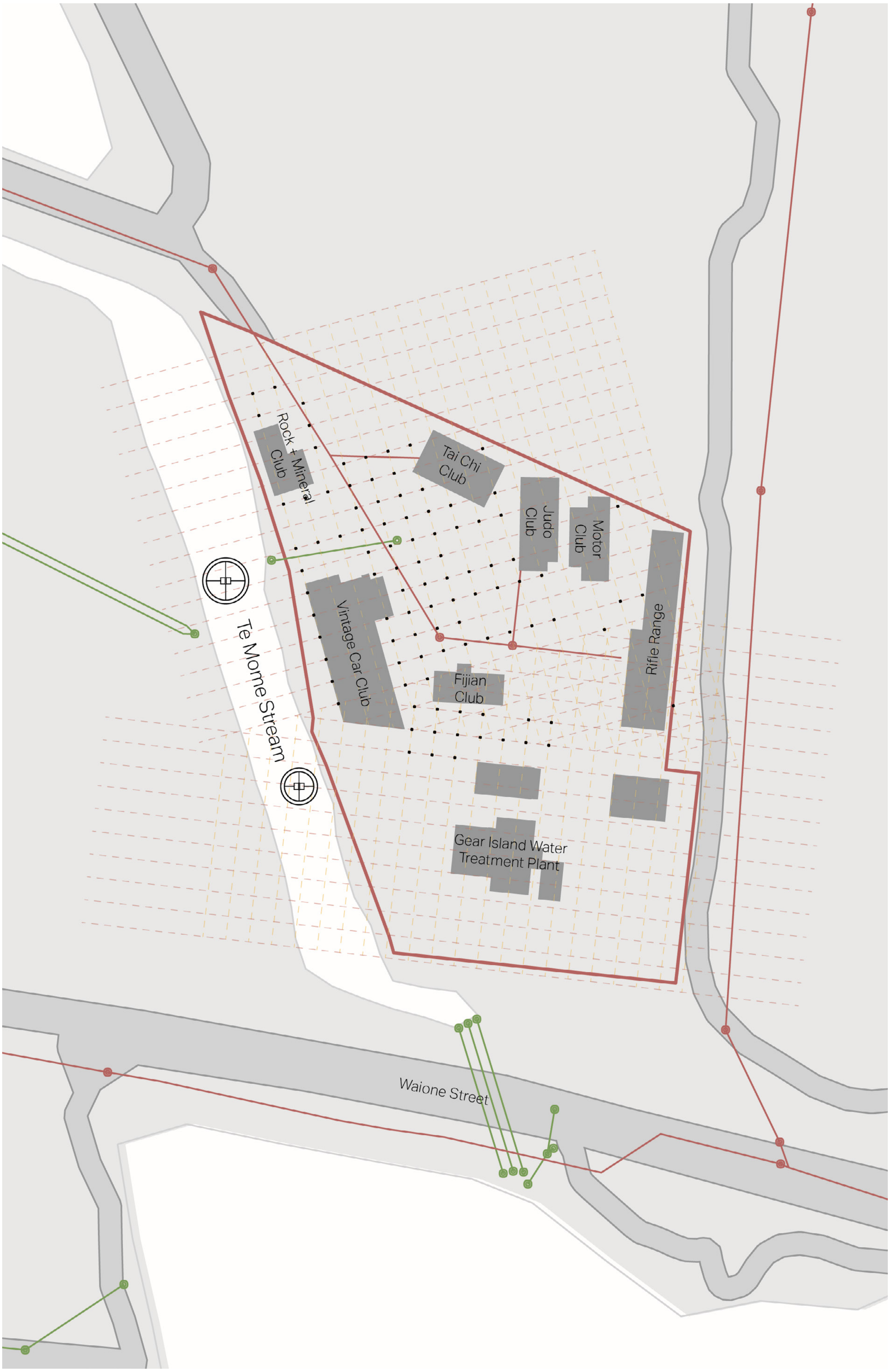
This phase of design-led research again looked to revise the master plan of the site and propose a more effective spatial arrangement. This revised master plan aims to retrofit the buildings onsite so that they are adaptive to future climate change conditions. The site was re-organised into two 5 × 5m grids, shown in figure 46. This was for 3 reasons:

1) To align with the two orientations, two orthogonal planes rotated at 22.2°, that the non-moveable buildings on site are aligned with,

2) The gridlines are spaced 5m apart due to the radius of influence for the biovents onsite, and

3) To adapt the existing and new buildings into this 5 × 5m grid so that buildings can be moved in the future to best adapt to changing site conditions.

Figure 46. (pp. 96–97)
Design Phase Three Site Re-organisation



Rock + Mineral Club
Tai Chi Club
Judo Club
Motor Club
Rifle Range
Vintage Car Club
Fijian Club
Te Morne Stream
Gear Island Water Treatment Plant
Waione Street

8.2. Integration of Bioremediation and Architecture

This phase of design-led research investigated ways in which the spatial explorations of bioremediation techniques in the previous phase of the design-led research could be incorporated into architecture to work towards regenerative design. This integration with architecture is an important step in ensuring that the remediation onsite contributes to both biological ecosystem health as well as socio-ecological revitalisation.

Biovent Columns

After determining that the technique of lighting up the biovents to indicate activation was an effective spatial and visual way to involve people in the process of bioremediation, this research investigated how such vents could then be integrated into architecture. First, the opportunity to integrate these biovents into the structural elements for buildings on site was explored.

The timber column element of the Pure South Dining building by Gray Puksand in Southbank, Melbourne was examined as a precedent for the integration of a downpipe into a structural element as shown in figure 47. The stormwater system in the Pure South Dining building is integrated into the columns that sit on the façade of the building by nestling them between the double glulam timber elements of the columns.

This idea was adopted in this project by nestling the biovent in-between two glulam timber members to make an overall biovent column that would act as a structural element as well as a soil remediation element. This biovent column would indicate its function to users by utilising a transparent tube and lighting while also providing vertical structural elements for the buildings and structures on site. Figure 48 shows details of the concept design for the biovent column.

These biovent columns were designed to be modular so that the biovent could be installed ahead of time to start the soil remediation process. The biovent column would first be installed onsite by drilling a pile hole, fitting the biovent tube into the pile hole and setting it in place with a concrete foundation pad at ground level. This biovent could then be fitted with the glulam timber elements and a pole extender that is pinned in place to the foundation block with a steel plate and steel pin joint to create the biovent column. When the soil remediation is complete and the column is to be moved, the biovent column can be unpinned at the steel pin joint to allow all of the elements to be re-used. The step by step process of constructing and deconstructing this biovent column is shown in figure 49.

This biovent column concept has been implemented into the retrofit of the existing buildings as a way of adapting to the new 5 × 5m grids onsite. Biovent columns are to be installed on the external edge of each existing building and would become the new gravity loadbearing structure. The purpose of this was to allow each building to be raised by 600mm (the maximum amount of storm surge projected for New Zealand (MfE, 2017)) to ensure that the existing buildings onsite will be adaptive, at least in part, to climate change conditions.

Figure 47.
Pure South Dining Column Detail (Vicbeam, 2016)

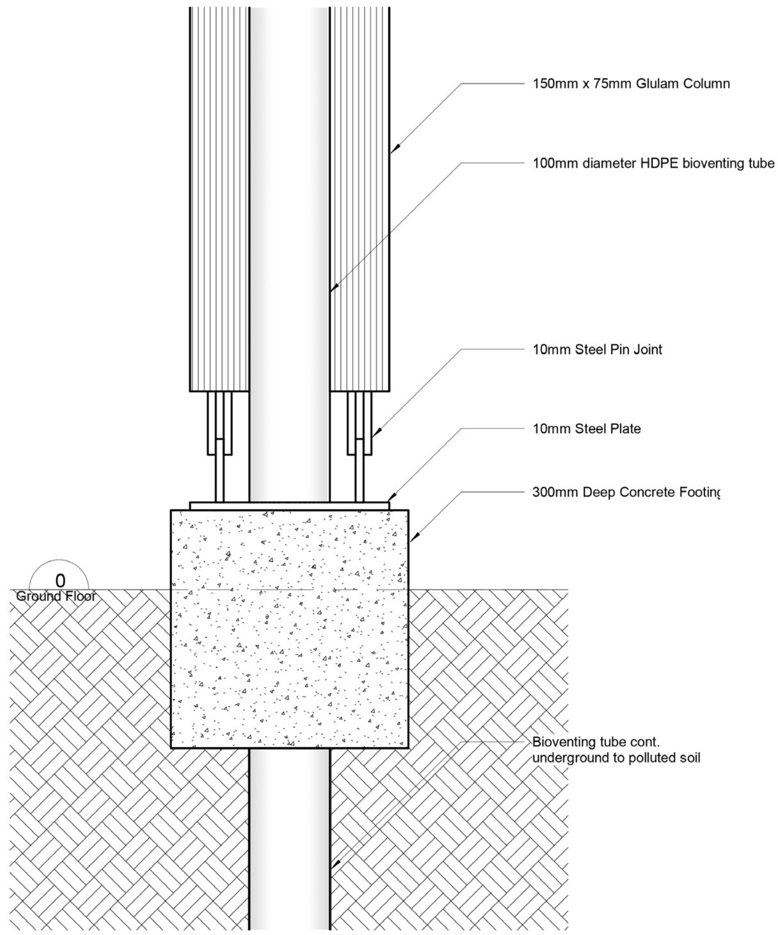
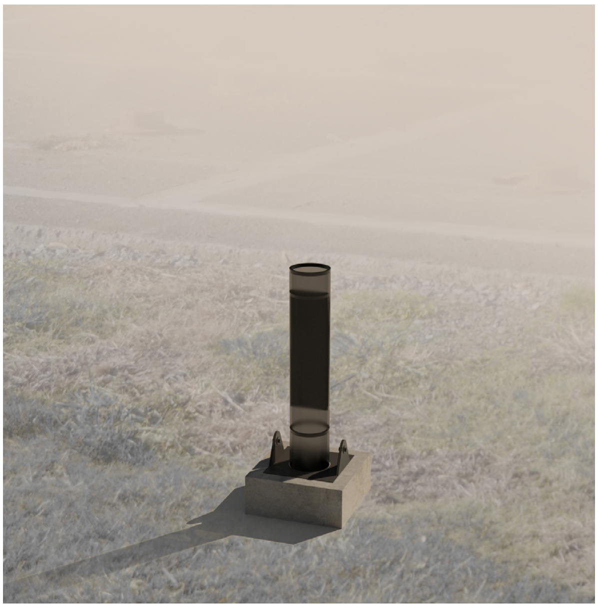
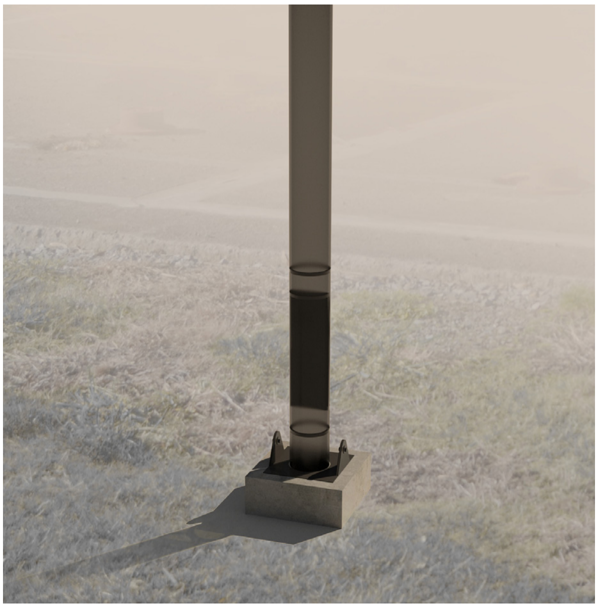
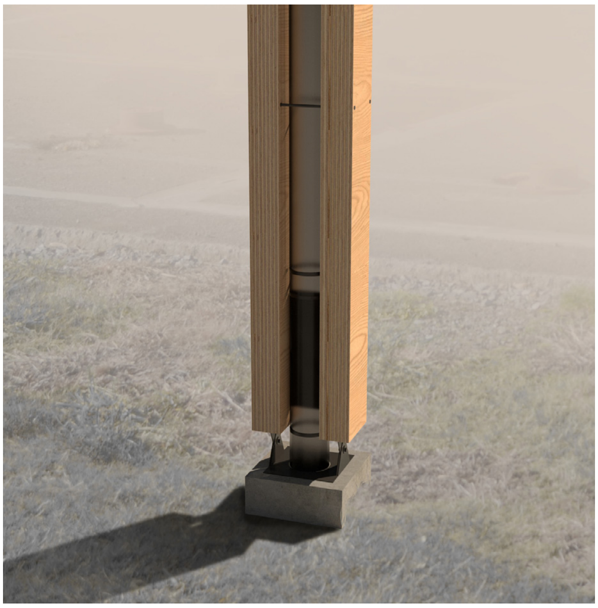


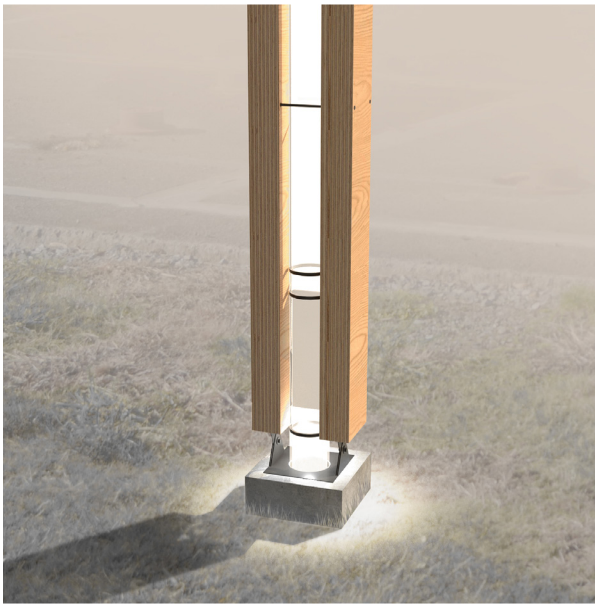
Figure 48.
Biovent Column Detail

Figure 49. (pp. 100–101) Biovent Construction Sequence (find animation @ http://tiny.cc/jab2tz)









Floating Phytoremediation Pads

After determining through the field tests that using a microbial inoculant as a phytoremediation method would not be the most effective solution for remediating soil and sediment near Te Mome Stream, floating phytoremediation pads were re-examined in this phase of design-led research. Floating phytoremediation pads would consist of two remediation techniques: bioaccumulation pads and floating purifiers. These are designed to achieve two purposes for the remediation of Te Mome Stream. Bioaccumulation pads would uptake heavy metals from the water (and small amounts from the stream sediment) into the living matter of the plants, which could then be harvested and disposed of safely at an offsite facility. Floating purifiers would mineralise other non-heavy metal contaminants and increase the stream's biological health by encouraging beneficial microbial activity.

The bioaccumulation pads designed here are based on the previously mentioned Phytotech precedents (Phytotech, 1996), which grow hyperaccumulator plants in floating grow pads to bioaccumulate heavy metals out of stream water and into plant matter. The floating purifiers used in this technique are based on the Flax Pond restorer and Floating Park restorers by Todd (2019), which utilise solar power to circulate contaminated water over plants being grown on a floating grow substrate to mineralise stream water, shown in figure 50.

The Baima Canal Restorer precedents by Todd (2019), shown in figure 51, were examined as a method to allow users to interact with and walk through the remediation techniques while not disrupting the remediation process. The Baima Canal Restorer is a boardwalk constructed with floating pads planted with beneficial plant species that help remediate the degraded canal water. By utilising eco-revelatory design techniques, the plants alongside the floating boardwalk can help to reveal the complex ecological process of remediating stream water to users in a simplified manner while also allowing users to move through and get close to the remediation process itself. This method has been adapted to the project site by incorporating bioaccumulation pads and floating purifiers into the floating boardwalk concept. The detailed design of these boardwalks was based off of the floating boardwalk design guide by Neese (2002). The design of this floating boardwalk is shown in figures 52, 53 and 54.

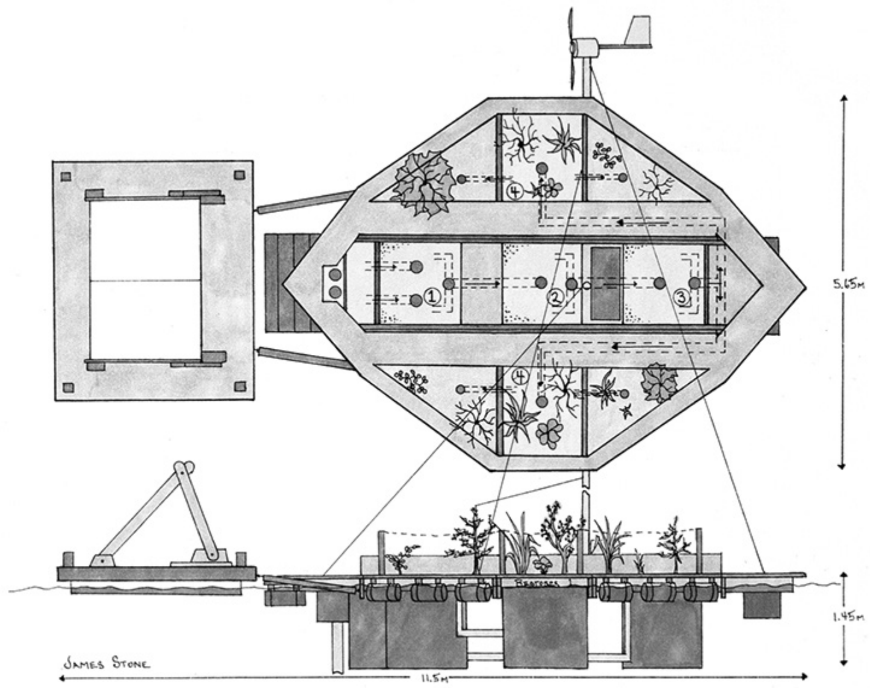


Figure 50.
Flax Pond Restorer
(Todd, 2019)

Figure 51.
Baima Canal Restorer
(Todd, 2019)

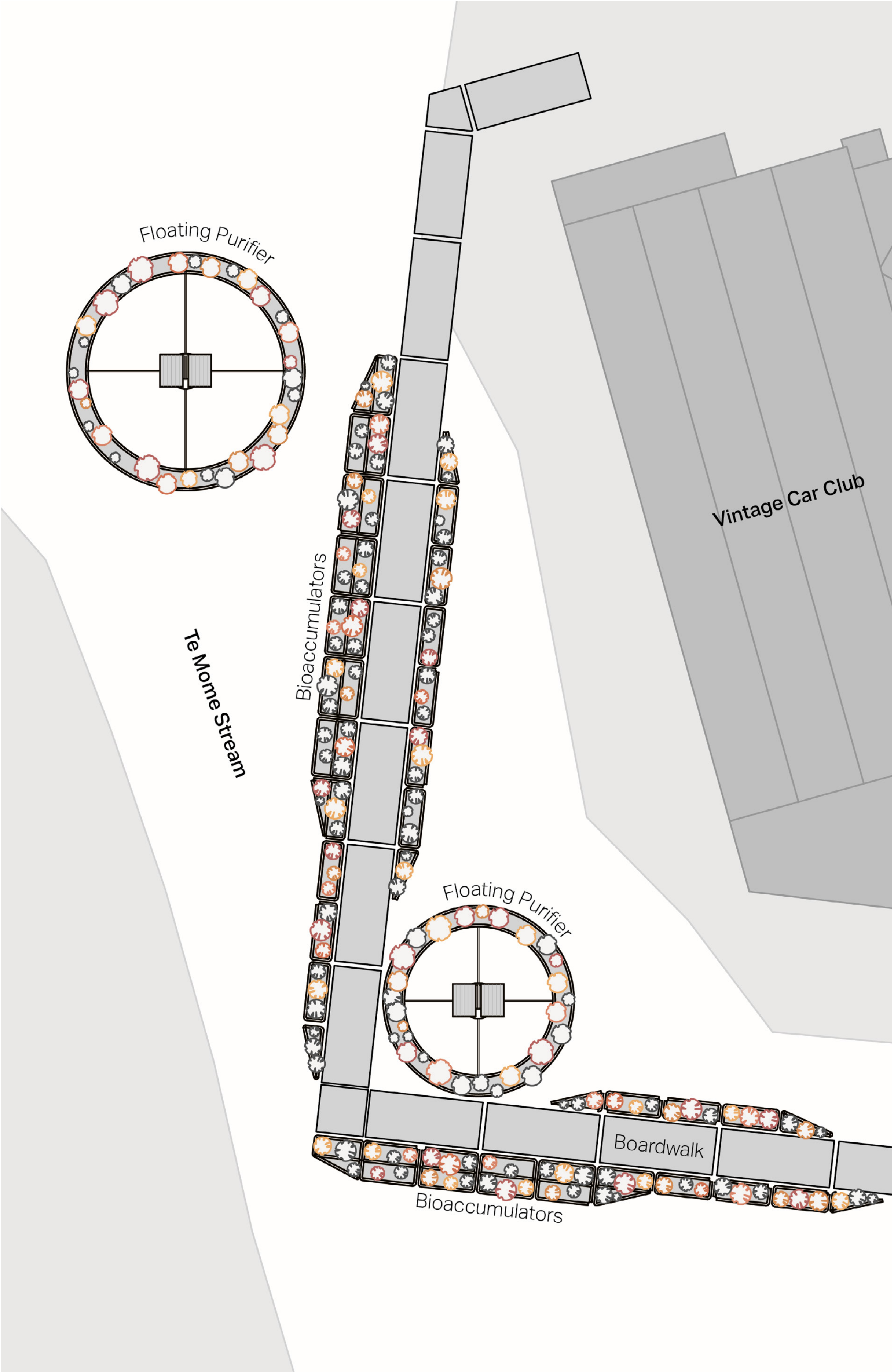


Figure 52.
Floating Boardwalk Design

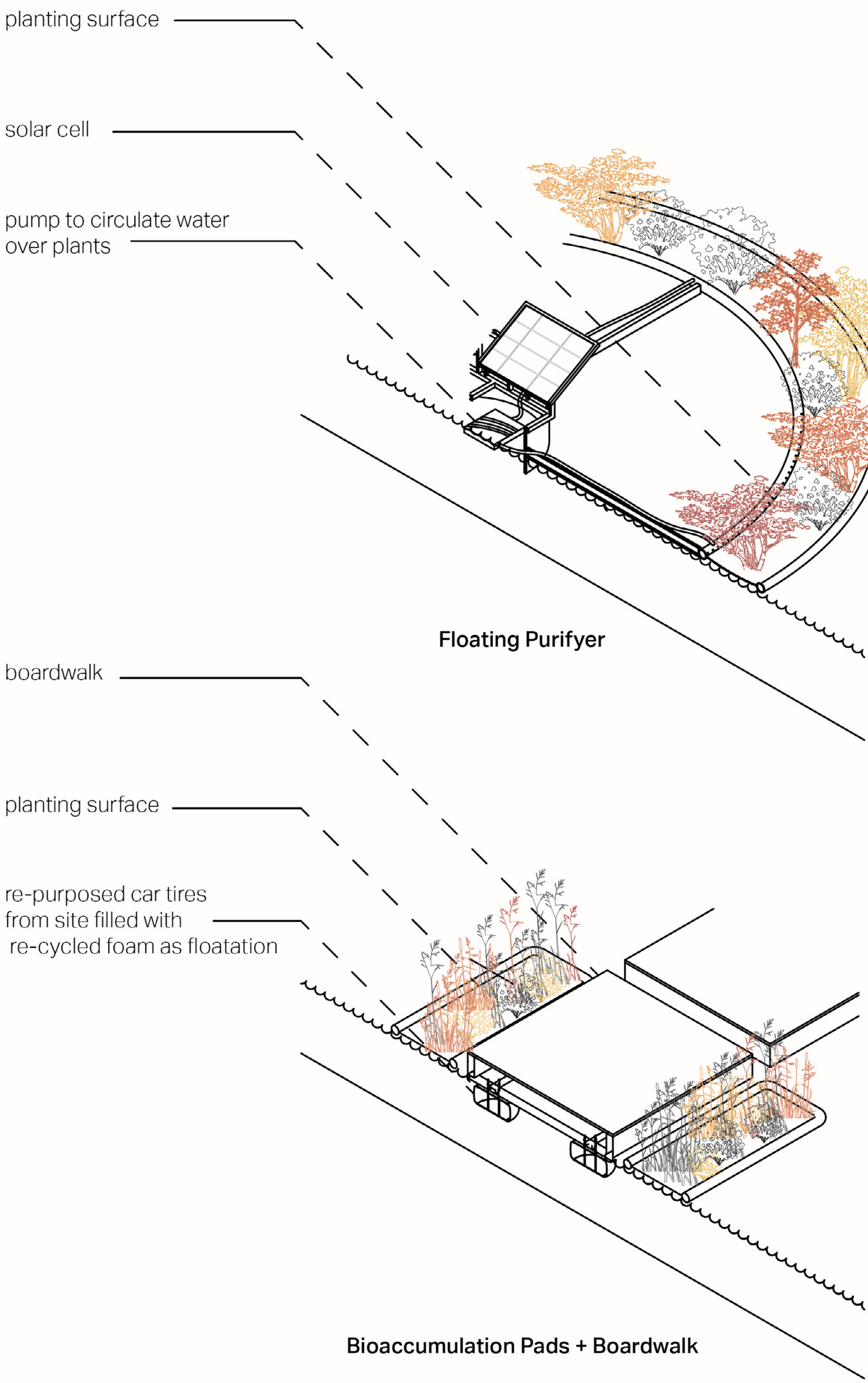


Figure 53.
Boardwalk Details

Figure 54.
Floating Boardwalk Perspective

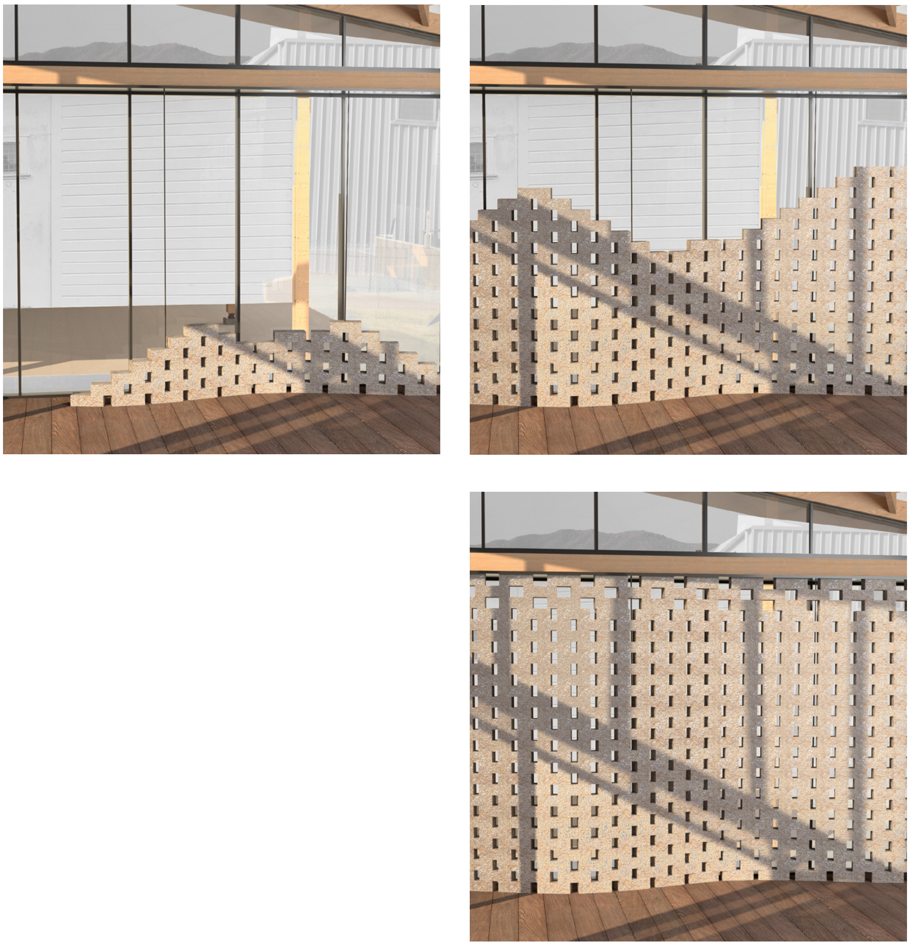
Mycelium Bricks

As previously examined in chapter 7.2, this method utilises fungi to remediate dredged contaminated sediment from Te Mome Stream by combining stream sediment with construction wastes (growing substrate) and a microbial inoculant to create a mycelium brick that can be used as a building material. The spatial arrangement of the mycelium bricks was investigated to reveal to users the ecological process that are used to remediate stream sediment.

This research examined the precedent Hi-Fi by The Living, shown in figure 55, as a way of using mycelium brick to build a structure that users can interact with. Hi-Fi was a mycelium brick pavilion that was constructed within three months in 2014 to host several public events and then was composted to return the materials back to the carbon cycle (Stott, 2014). This structure was effective in getting users to inhabit and interact with this new form of material. This project uses the concept of user interaction with building materials by constructing parametric mycelium brick walls within a pavilion structure so that users can understand the ecological process behind remediating stream sediment. The mycelium brick walls will be built over time as the sediment remediation process takes place so that users can see the evolution of sediment remediation over time. The design of these parametric mycelium brick walls can be seen in figure 56, which shows the build-up of mycelium bricks overtime.

Figure 55.
Hi-Fi Mycelium Pavilion (Graves, 2014)

Figure 56.
Mycelium Brick Wall Construction Over Time



Aqueous Reactor

The aqueous reactor design from chapter 6.4 has been reworked in this phase of design-led research to ensure that the site is able to produce net positive effects for the water used onsite and ensure that no contamination discharged into the surrounding stormwater catchment will enter the stream. Shifting the function of this bioremediation technique from actively contributing to the remediation of the site, to becoming a preventative method for more stream pollution was done because the other bioremediation techniques were determined to be better suited to the type of remediation an aqueous reactor provides. Instead of redirecting part of the stream into the aqueous reactor, all of the onsite black and greywater and the onsite stormwater, as well as the local catchment stormwater, where feasible, will be redirected into the living machine to be purified before being returned to Te Mome stream. A diagram of this is shown in figure 57.

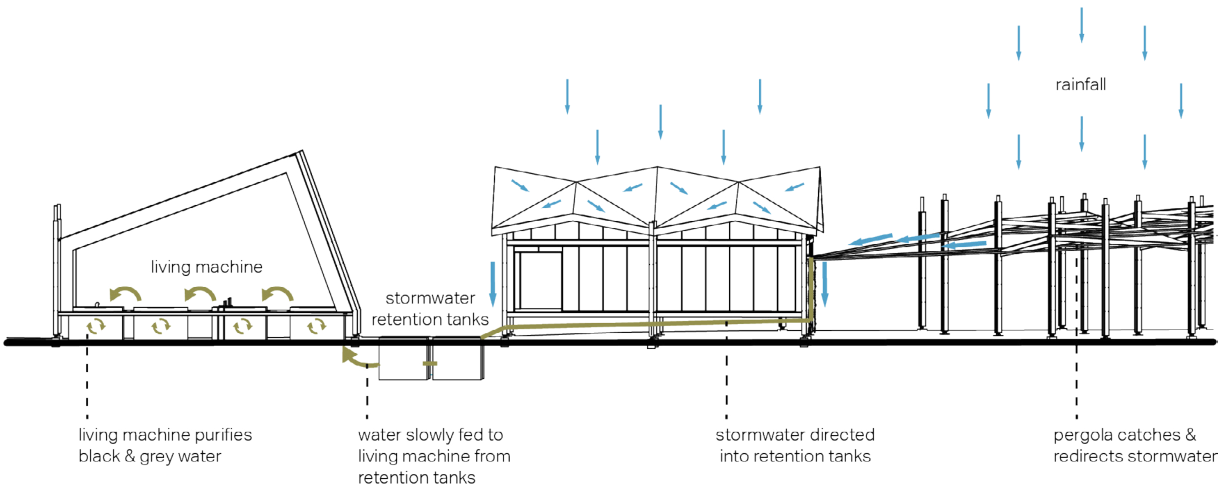


Figure 57.
Water Redirected to
Living Machine Diagram

8.3. Site Additions

Boardwalks

As the existing buildings and new additions to the site are being raised 600mm above the ground for future storm surge adaptation, the design of a boardwalk was necessary for each building to remain easily accessible. The design of this boardwalk presented an opportunity to design the spaces between the buildings as outdoor public space that users can dwell within. The boardwalk design includes space for people to sit, dwell, and move through. The design of this boardwalk is shown in figure 58.

Pergola

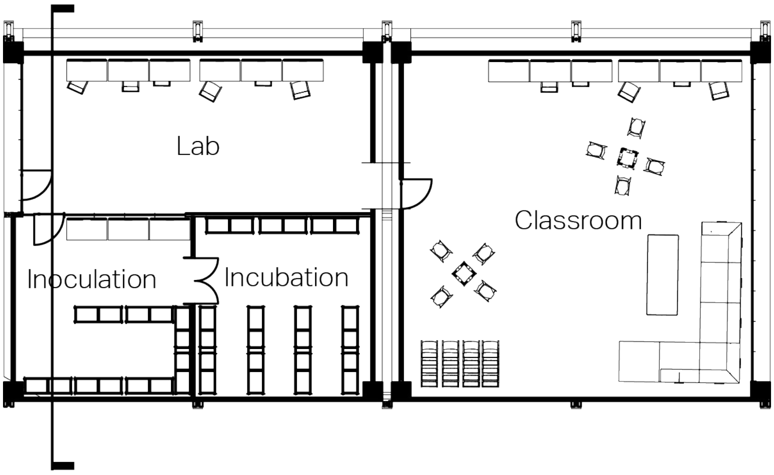
A pergola over this outdoor public space was designed to tie the site elements together (which are aesthetically fragmented due to the differing ages and styles of the existing buildings). It was also designed to capture a portion of stormwater and provide a continuous supply of water to the living machine on site. The pergola is designed at a 5° slope towards the pavilion so that all stormwater captured can drain into the retention tank located underneath the pavilion; this detention tank then slowly feeds water to the living machine to ensure a constant flow during dryer periods and also to ensure that the living machine does not overflow in periods of increased rain. The pergola is designed to attach to the biovent columns onsite and is constructed with glulam timber members and sheet metal roofing. The design of this pergola is also shown in figure 58.

Figure 58.
Boardwalk & Pergola Perspective

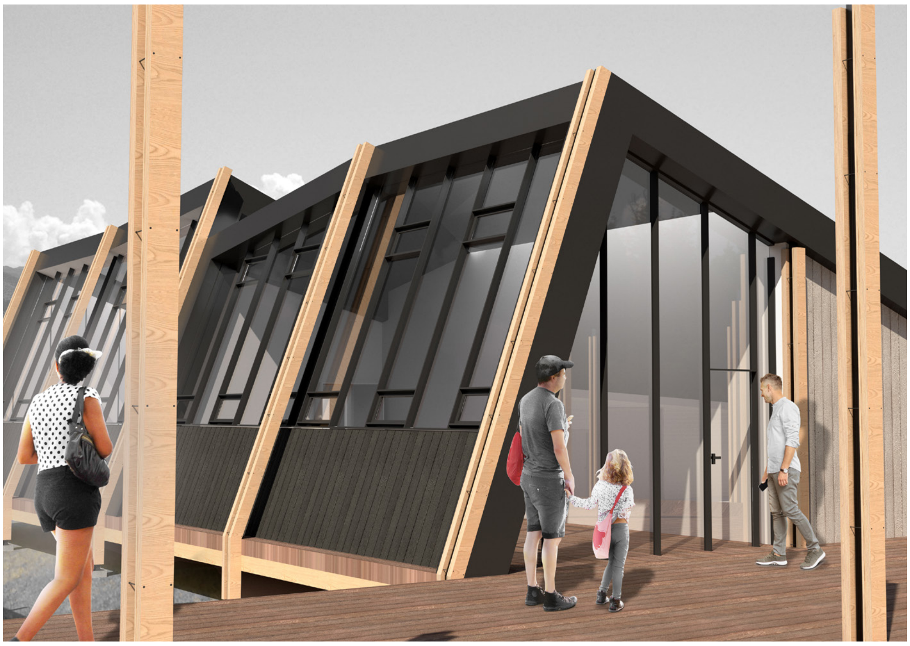
Classroom / Lab

A classroom and bioremediation lab building were designed together to provide space for mycelium brick production, bioremediation technique monitoring, and an indoor teaching / gathering space. These buildings were designed to incorporate biovent columns as the gravity structure so that the soil underneath would be remediated through the building's lifespan; the building could then be moved by unpinning the base of the columns and shifting to another location. The lab building consists of: office space for bioremediation monitoring; space for the construction and inoculation of mycelium bricks; and a space for the incubation of these mycelium bricks. This incubation room requires temperature, humidity and light controlled conditions for optimal mycelium brick cultivation. The classroom space was designed as an open plan space so that it could be adapted to best suit the needs of the users of the space. Both buildings were designed for passive heating/ cooling and passive ventilation by designing the north façade as 80° sloped glass to maximise passive solar gain. The design of these buildings can be seen in figure 59.

Figure 59.
Classroom / Lab Design



Classroom / Lab Plan 1:200



Pavilion / Outdoor Classroom

A pavilion was designed to act as a physical nexus point between all the bioremediation techniques being used onsite, and to function as an outdoor teaching space. The pavilion was designed as an axial change point between the two orientations of grids, an end/start point of the floating phytoremediation boardwalk, and a building to showcase the mycelium brick bioaccumulation methods used to purify the stream sediment. This building provides an important function for the site as it is the space that combines the various different bioremediation techniques happening onsite and presents these to the users of the building so that they can understand the ecological processes at work on this site.

The pavilion features parametric mycelium brick walls on the interior so that users can interact with this bioremediation method. This parametric wall features a double curve which, according to Dahmen (2017), helps retain stiffness within the wall. Even though the mycelium bricks are self-supported, steel ties are included throughout the wall to resist seismic loads as shown in figure 60. The pavilion roof is designed as a folded plate that comes to a 20° pitched gable at the front; this mimics the existing structures onsite and contributes to the new design aesthetic being added to the site. The design of this pavilion is shown in figure 61.

Figure 60.
Mycelium Brick Wall Structure

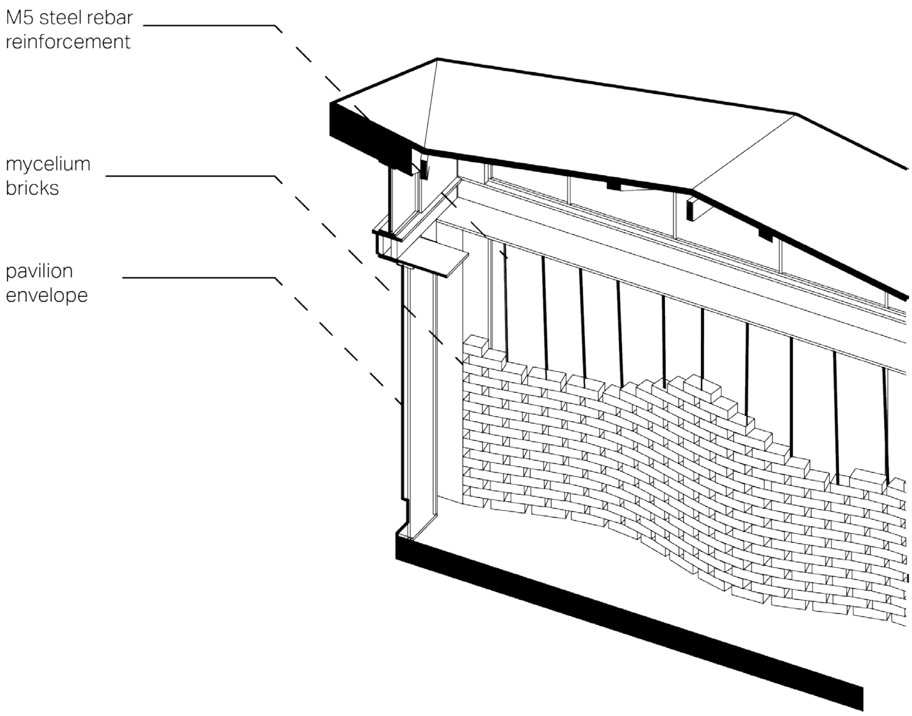
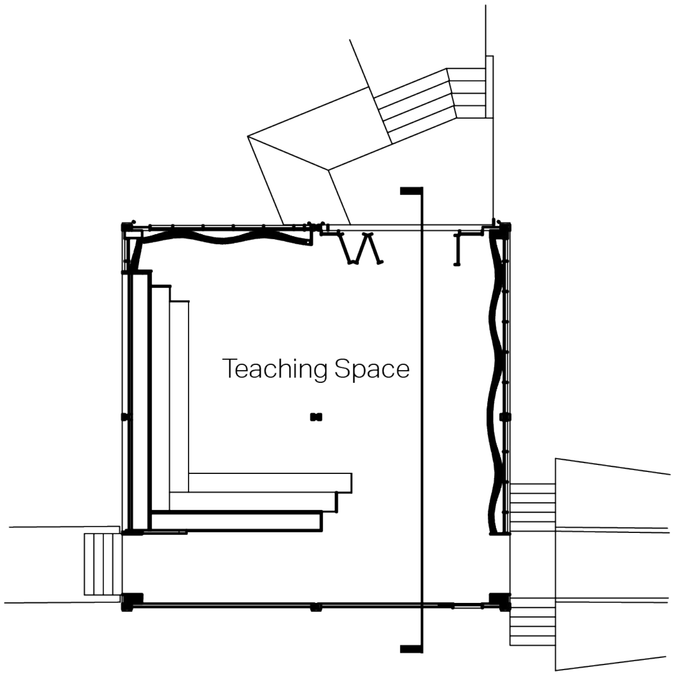
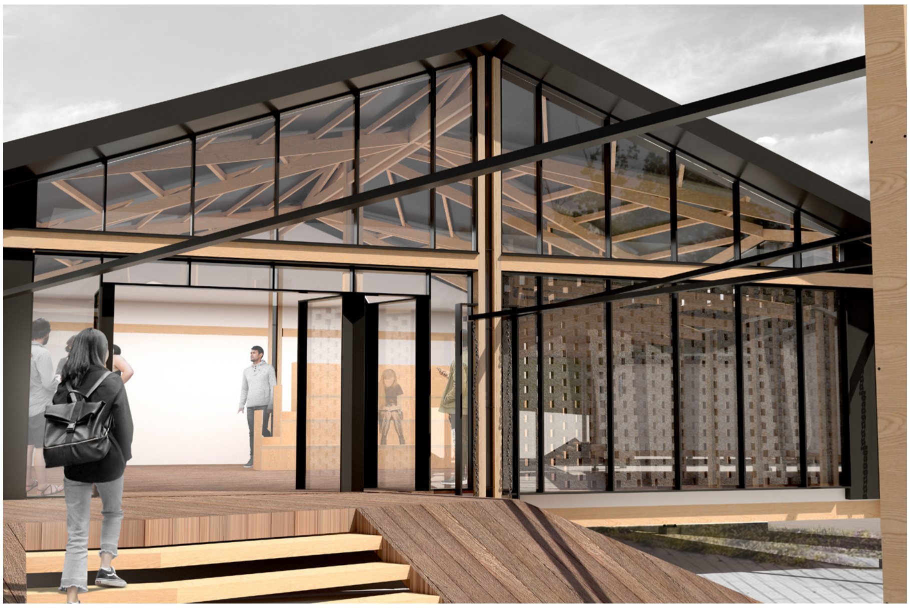


Figure 61.
Pavilion Design



Pavilion Plan 1:200



Additions to Existing Buildings

Additions have been made to the existing buildings onsite so that they will fit within this new modular 5 × 5m grids, and so they perform as passive solar buildings more effectively. Similar to the classroom/lab buildings, an 80° sloped glass façade has been added to the north face of these buildings to allow more passive solar gain, passive ventilation, and 100% daylit interiors. The Rock + Mineral Club retrofit is shown in figure 63.

Figure 62.
Existing Rock + Mineral Club Exterior

Figure 63.
New Rock + Mineral Club Design

8.4. Construction Phases

The project was set out in three construction phases to ensure that the programmatic activities on site could still take place while remediation is being undertaken. As these remediation processes are heavily dependent on time, it was important to develop a plan to set out how the site will be managed into the future and to ensure that this site will be fully remediated. An animation of these construction phases can be found at http://tiny.cc/jab2tz.

Phase 1

Phase one starts with the re-organisation of the site into two 5 × 5m grids and the installation of biovents at grid intersections where buildings will be shifted to in phase two of construction. Biovents are installed in this phase to kick-start the soil remediation on Halford Place before any large site developments take place, and to provide the platforms that the existing buildings and new additions will be built upon. The stream's floating phytoremediation pads are also installed in this phase to kick-start the remediation of Te Mome's water and sediment. Figure 65 shows a site plan for this phase of construction.

Phase 2

Phase two is when most of the site development takes place. The existing building retrofits take place and buildings are moved to their new positions. The classroom/lab building, pavilion, boardwalks and pergola are constructed. The remediation of Te Mome's water and sediment are increased, and Te Mome Stream is restored back to a pre-piped condition. Any sediment that is excavated by the re-widening of the stream back to a pre-piped condition can be treated onsite through the mycelium brick bioaccumulation method. Figure 66 shows a site plan for this phase of construction.

Phase 3

Phase three is the monitoring stage of the bioremediation that has taken place onsite, and the reclaiming of Te Mome Stream back to the original 1940's condition as far as possible. The site will be determined as "remediated" when levels of contamination are no longer a concern for human and/or environmental health. Once this has been determined, the bioremediation techniques / structures will be deconstructed and moved to another contaminated site that requires remediation, and the onsite activities can continue as the site is now free from harmful contaminants. Due to the fact that future site conditions are so variable because of changes in sea-level rise and increases in storm surge, the buildings may need to adapt once again to changing conditions onsite. This phase of construction would consist of another review of site conditions and would determine a new plan to ensure that activities onsite can continue and that the buildings remain adaptable to future site conditions.

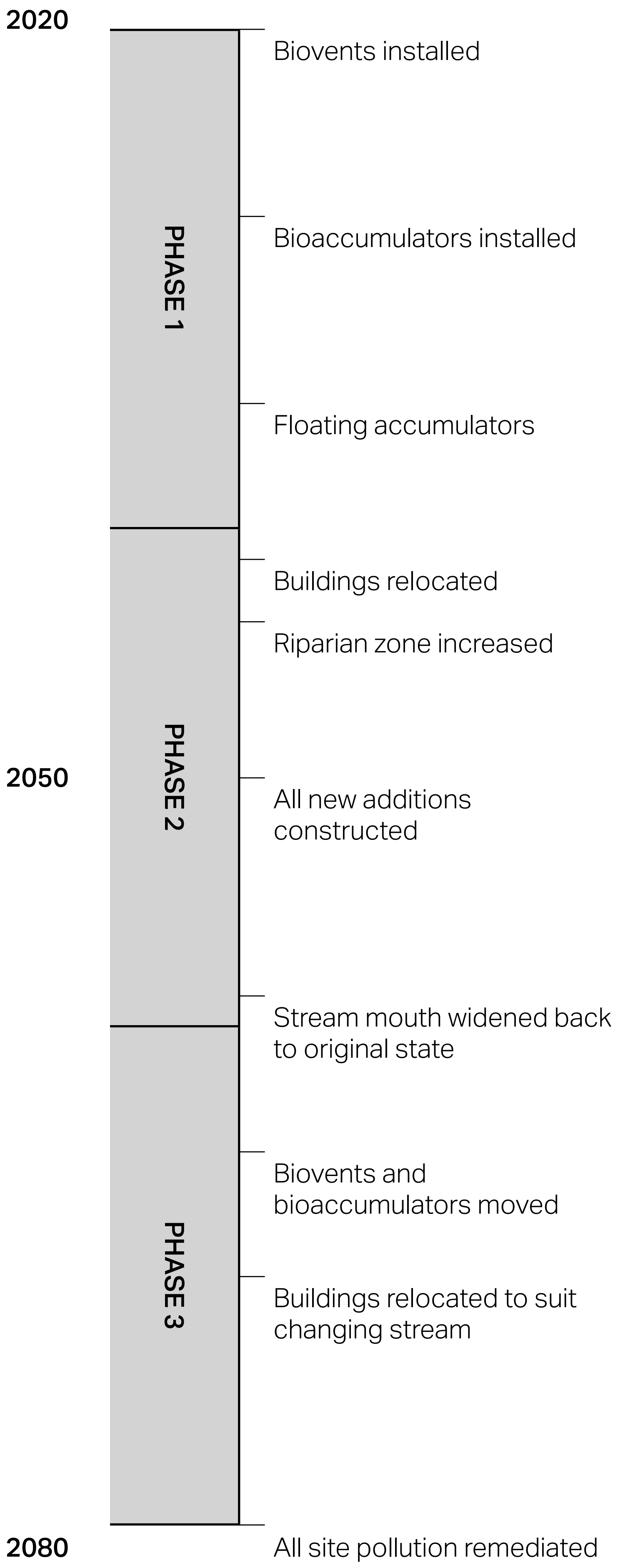


Figure 64.
Project Timeline Diagram

8.5. Phase 3 Framework Review

Net Positive Resource Goals

Is the proposed architecture able to produce a net positive amount for water and materials?

Timber was used as the main construction material in this project so that the project would offset its overall carbon footprint through the carbon sequestered in this timber. The project used approximately 33.3m3 of timber to sequester 22.1tCO2 (Alcorn, 2010). By reusing the existing buildings onsite and redirecting construction waste from landfills, the project would be able to keep the overall carbon footprint as net positive.

The design would also manage all the onsite black and stormwater, as well as providing capacity to treat some of the local catchment's stormwater, using a living machine. The living machine designed on site is able to treat approximately 9500 litres of black and stormwater per day, and therefore provides a net positive for the water used on site.

Ecology of Place

Does the project contribute positively to the ecology of the place?

By remediating site contaminants, increasing the riparian edge, increasing soil ecology health, and restoring the river back to a close to original condition, the final design is able to positively contribute to the environmental ecology of the site. By bringing new education opportunities, creating public open space, and revitalising the existing community clubs onsite, the project is able to positively contribute to the socio-ecology of the site as well.

Sense of Place

Does the project enable individuals and groups to share in a collectively imagined future?

The final design aims to get communities and individuals invested in the successful remediation of this site and to re-establish a sense of stewardship for this site. The final design will achieve this by utilising eco-revelatory design and providing educational opportunities to reveal the ecological processes being used to remediate the contaminants on site to users. This final design also re-invigorates the existing community groups onsite through the developments planned and provides a space for the community by bringing usable public outdoor space to the site.

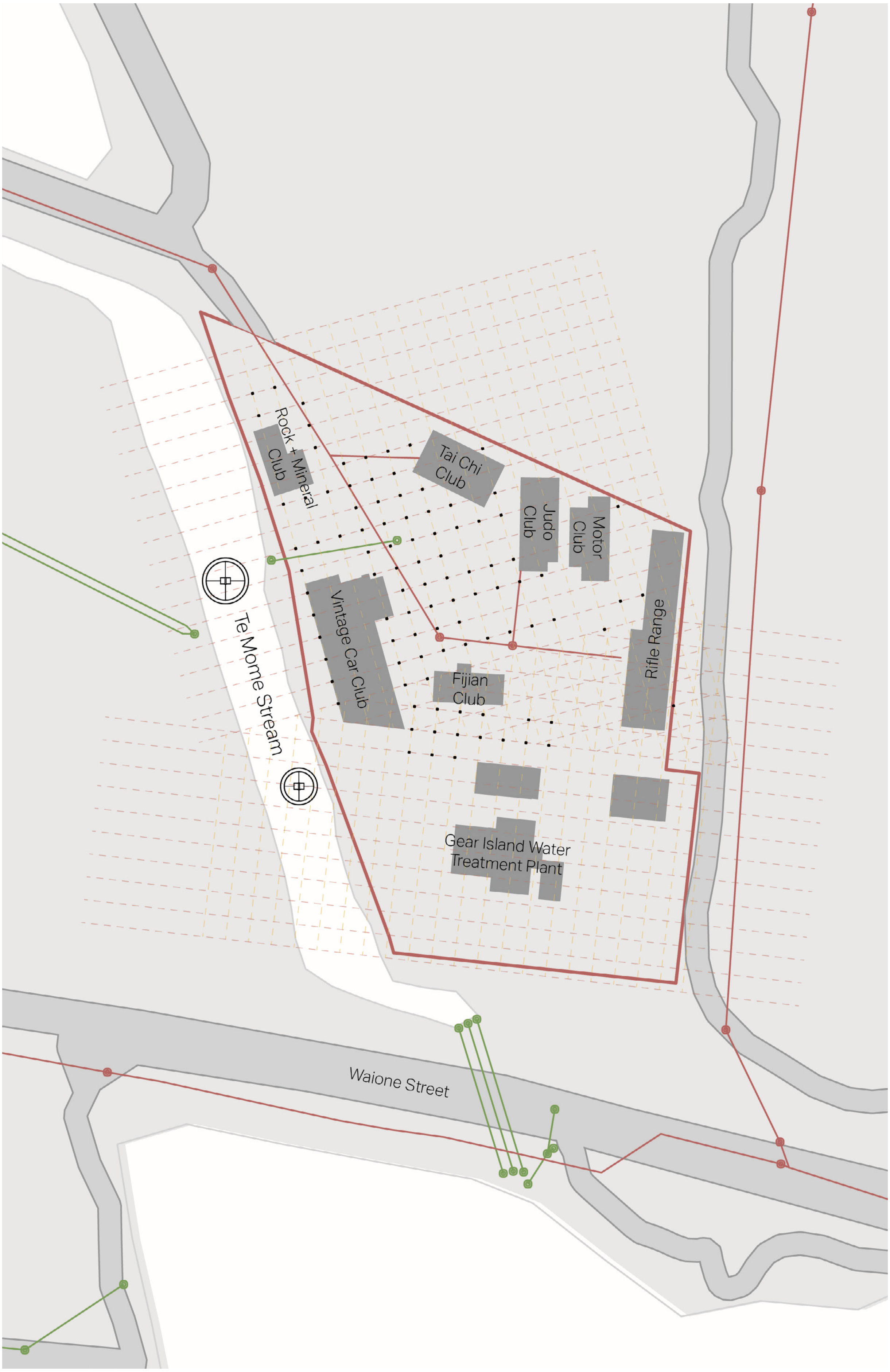


Figure 65.
Phase One Site Plan

Figure 66.
Phase Two Site Plan

9. Discussion

9.1. Key Findings

One of the key findings of this research is that architecture and bioremediation cannot be separated if brownfield site remediation is to contribute to a regenerative built environment. This integration of the two elements is integral to support both biological ecosystem restoration and socio-ecosystem regeneration. Architecture is integral to the remediation process as it allows people to interact with the ecological process at work. By utilising eco-revelatory design and architecture, bioremediation techniques can be explained and revealed to the users of these spaces in a way that allows for a deeper understanding into human nature relationships. As discussed, human nature relationships are important because of the need for a paradigm shift from humanity's domination over nature to an ecological worldview.

Another key finding from this research, which builds upon the previous research in this field, is that education and ecological restoration also cannot be separated if brownfield site remediation is to contribute to a regenerative built environment. Ecological remediation process education for local communities and users of the space is critical because of the need to repair or create the relationship between humans and nature. This psychological shift to an understanding that humans are a part of the wider ecosystem, rather than the more typical (in the industrialised world) attitude of anthropogenic domination over nature, is just as important as actively remediating environmental damage. This is because the causes of the issues (i.e. pollution and unsustainable use of ecosystem services) not just the results of them must be reduced or removed. Therefore, education and restoration need to happen simultaneously. The educational aspects of these projects help to establish stewardship roles and values in individuals and local communities, which is critical to ensure successful remediation and regeneration of brownfield sites.

Bioremediation of brownfield sites need to be an adaptive process. This research found that time is an important factor in brownfield site remediation because of bioremediation's dependence on time to enact remediation. When designing bioremediation projects, it is also critical to consider future site conditions and how climate change may affect this. The full extent of climate change and biodiversity loss effects are largely unknown or are still being realised so this research found that designing projects to be adaptive to future site conditions is important to ensure projects are able to successfully adapt to changing future conditions. This was achieved by designing the new additions and retrofitting the existing buildings to be modular architecture. These modular architectural elements can be moved and adapted as site conditions change or can be deconstructed into modular parts that can be reused in other architectural interventions. This also means that when the site has been determined as "remediated", the bioremediation technologies can be deconstructed and used at other contaminated sites requiring remediation.

While this research focused on one of New Zealand's most contaminated site, the principles and methods could be applied to many other brownfield site remediation projects. This research focused on Te Mome Stream as a site for investigation because of the assumption that if the worst-case scenario is designed for, then the same methods could accommodate other situations.

9.2. Research Constraints and Limitations

The kind of project team that would come together for a regenerative design project would usually include a large team of multi-disciplinary professionals and requires a large base of knowledge and resources. For a project to be truly regenerative it would require input from a wide range of consultants, such as: ecological engineers, hydrological engineers, bioremediation experts, mycologists, ecologists, city planners, as well as including input from holders of Indigenous knowledges and local communities and stakeholders.

Due to time and resource constraints of this research, only a few bioremediation techniques were able to be explored in the field test section of this research. Even though the field tests conducted in this research were rudimentary in nature, they revealed useful results for the application of bioremediation techniques in a New Zealand context. If a wider range of bioremediation techniques were examined through field testing, decisions about the application of bioremediation techniques to the site would have been more evidence-based rather than relying on precedents.

As this research was primarily focused on bioremediation techniques and the remediation of brownfield sites many other aspects for the design interventions at Halford Place could not be fully explored. Due to the time constraints of this research, many aspects of the design at Halford Place that would have moved the architectural interventions closer to a regenerative built environment could not be explored in detail.

9.3. Future Research

There is an opportunity for future research in the same line of investigation by examining different brownfield scenarios. As this project focused solely on Te Mome stream, where contaminants consist of heavy metals, there would be merit in examining spatial arrangements of bioremediation techniques for different types of contaminants as well. Different sites and contaminant types would provide an array of new challenges and opportunities to design for and would help deepen the understanding of architecture's role in brownfield site remediation.

This research focused on an architectural approach for bioremediation techniques but found that there is an opportunity to peruse the same line of investigation for a landscape architecture approach. Some of the spatial arrangement methods in this investigation could be considered landscape architecture, but this research did not capture the full potential of bioremediation techniques that landscape architecture focused research would provide. There is a difference in the way in which a landscape architecture professional would approach bioremediation techniques, and this would lead to a new set of valuable findings. This further reinforces that in practice bioremediation must be a multidisciplinary approach.

There is an opportunity to develop and test new bioremediation technologies that are specifically suited for integration in architecture. This research looked specifically at adapting existing technologies for the use of architectural integration, but this line of investigation would benefit greatly in bioremediation techniques were to be developed with architectural integration in mind. This research found that many existing bioremediation technologies were not suited to exist alongside architecture or human inhabitation in general or did not contribute to a regenerative built environment. Bioremediation is an emerging field in the remediation sector so there is room for innovation when designing technologies to coexist with architecture, and therefore to make human interaction with sites possible and more conducive to a focus on regenerating human nature relationships. Essentially, bioremediation strategies must include architects at the concept and design stages.

10. Conclusion

The built environment is known to be a large contributor to climate change and biodiversity loss as well as being a significant contributor to historical and ongoing ecological damage. There is an opportunity for the built environment to reverse these effects and even positively contribute to the ecosystems it is part of. By moving towards a regenerative built environment, not only will buildings contribute to remediating past damage, but they will positively contribute to ecosystem health.

If the built environment is to start reversing these significant historical environmental damages and move towards becoming regenerative, innovative methods that push conventional construction industry practices are necessary. As the world is facing the significant impacts of climatic and ecological change, a conservative approach to built environment design can no longer be the norm. While this research is proposing experimental, cutting-edge technologies for the remediation of historical environmental damage, this type of remediation is necessary if the impacts of climate change and biodiversity loss are to be reduced or mitigated in any way. This research proposed practical methods for the implementation of restorative design, as a way of moving the built environment closer to a regenerative development model. It is acknowledged that if a regenerative built environment is to be achieved, it requires the resource efficiency measures of green design, the remediation methods of restorative design, and the psychological paradigm shift of regenerative design to be used simultaneously.

Brownfield site remediation is an important process for moving the built environment towards a regenerative model. Effective brownfield site remediation requires the restoration of both environmental ecosystems and socio-ecosystems. If the restoration of these spaces was celebrated rather than hidden, the human-nature relationships would benefit greatly. Getting individuals and local communities invested in the restoration of severely degraded sites is critical and requires bioremediation to exist along with architecture and be integrated into it. There is an opportunity to show the ecological value of even the most degraded sites as a means to change the behaviour of people so that conservation, protection, and regeneration of ecosystems, rather than exploitation of them, becomes the norm. Architecture has a crucial role to play in this.

In conclusion, it is clear that brownfield site remediation is critical to moving the built environment towards a regenerative model and architects must therefore apply principles of remediating biological ecosystems alongside the regeneration of socio-ecosystems if we are to make meaningful contributions to climate change and biodiversity loss mitigation. The remediation methods explored in this research can not only be applied to the most contaminated brownfield sites but also to any contaminated site. If brownfield site remediation became a priority within the construction industry, and an accepted and standard aspect of future development, then the future would look significantly more hopeful for generations to come, both of humans and other living species.

11. References

Alcorn, J. A. (2010). *Global Sustainability and the New Zealand House*. http://researcharchive.vuw.ac.nz/handle/10063/1871

Alker, S., Joy, V., Roberts, P., & Smith, N. (2000). The Definition of Brownfield. *Journal of Environmental Planning and Management*, *43*(1), 49–69. https://doi.org/10.1080/09640560010766

Atkinson, B., Bux, F., & Kasan, H. (1998). Considerations for application of biosorption technology to remediate metal-contaminated industrial effluents. *Water S. A*, 24(2), 129–136.

Australian Department for Transport, Energy & Infrastructure. (2009). TravelSmart: Households in the West, Government of South Australia. Department for Transport. *Energy and Infrastructure*.

Behkish, A., Lemoine, R., Sehabiague, L., Oukaci, R., & Morsi, B. I. (2007). Gas holdup and bubble size behavior in a large-scale slurry bubble column reactor operating with an organic liquid under elevated pressures and temperatures. *Chemical Engineering Journal*, *128*(2–3), 69–84.

Bell, R. G., Lawrence, J. H., Allan, S., Blackett, P., Stephens, S., New Zealand, & Ministry for the Environment. (2017). *Coastal hazards and climate change: Guidance for local government*. http://natlib-primo.hosted.exlibrisgroup.com/NLNZ:NLNZ:NLNZ_ALMA11298516500002836

Bisht, S., Pandey, P., Bhargava, B., Sharma, S., Kumar, V., Sharma, K. D., Bisht, S., Pandey, P., Bhargava, B., Sharma, S., Kumar, V., & Sharma, K. D. (2015). Bioremediation of polyaromatic hydrocarbons (PAHs) using rhizosphere technology. *Brazilian Journal of Microbiology*, *46*(1), 7–21. https://doi.org/10.1590/S1517-838246120131354

Brown, B., Harkness, T., & Johnston, D. (1998). Eco-Revelatory Design: Nature Constructed/Nature Revealed: Proposal. *Landscape Journal*, *17*, x–xi. JSTOR.

Busby, P., Richter, M., & Driedger, M. (2011). Towards a new relationship with nature: Research and regenerative design in architecture. *Architectural Design*, *81*(6), 92–99.

Capra, F. (1987). DEEP ECOLOGY: A NEW PARADIGM. *Earth Island Journal*, *2*(4), 27–30.

CCME. (2001). *Canada-wide Standards for Petroleum Hydrocarbons (PHC) in Soil. 8*.

Cole, R. J. (2012). *Regenerative design and development: Current theory and practice*. Taylor & Francis.

Cole, R. J., Busby, P., Guenther, R., Briney, L., Blaviesciunaite, A., & Alencar, T. (2012). A regenerative design framework: Setting new aspirations and initiating new discussions. *Building Research & Information*, *40*(1), 95–111.

Corner, A., & Randall, A. (2011). Selling climate change? The limitations of social marketing as a strategy for climate change public engagement. *Global Environmental Change*, *21*(3), 1005–1014. https://doi.org/10.1016/j.gloenvcha.2011.05.002

Dahmen, J. (2017). Soft futures: Mushrooms and regenerative design. J*ournal of Architectural Education*, *71*(1), 57–64.

Das, S. (2014). *Microbial Biodegradation and Bioremediation*. Elsevier. http://ebookcentral.proquest.com/lib/vuw/detail.action?docID=1741074

Dixit, R., Wasiullah, Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., Shukla, R., Singh, B. P., Rai, J. P., Sharma, P. K., Lade, H., & Paul, D. (2015). Bioremediation of Heavy Metals from Soil and Aquatic Environment: An Overview of Principles and Criteria of Fundamental Processes. *Sustainability*, *7*(2), 2189–2212. https://doi.org/10.3390/su7022189

Du Plessis, C. (2012). Towards a regenerative paradigm for the built environment. *Building Research & Information*, *40*(1), 7–22.

Dubey, B., Upadhyay, R. K., & Hussain, J. (2003). Effects of industrialization and pollution on resource biomass: A mathematical model. *Ecological Modelling*, *167*(1), 83–95. https://doi.org/10.1016/S0304-3800(03)00168-6

Edwards, B., & Hyett, P. (2001). *Rough guide to sustainability*. RIBA.

EPA, U. (2001). *Use of bioremediation at superfund sites*.

Gupta, V. K., & Rastogi, A. (2008). Biosorption of lead(II) from aqueous solutions by non-living algal biomass Oedogonium sp. And Nostoc sp.—A comparative study. *Colloids and Surfaces B: Biointerfaces*, *64*(2), 170–178. https://doi.org/10.1016/j.colsurfb.2008.01.019

GWRC, Markland, H., Strange, T., & Van Erp, S. (2005). *Investigation into Stormwater Contamination from the Exide Technologies Reprocessing Plant, (51-57 Waione Street, Petone)*.

Harris, J., New Zealand, & Ministry for the Environment. (2011). *Cleaning up Mapua: The story of the Fruitgrowers' Chemical Company site*. Ministry for the Environment.

International Living Future. (2019). *Living Building Challenge 4.0—A Visionary Path to a Regenerative Future*.

IPCC (Ed.). (2015). *Climate change 2014: Synthesis report*. Intergovernmental Panel on Climate Change.

Joshi, P. K., Swarup, A., Maheshwari, S., Kumar, R., & Singh, N. (2011). Bioremediation of Heavy Metals in Liquid Media Through Fungi Isolated from Contaminated Sources. *Indian Journal of Microbiology*, *51*(4), 482–487. https://doi.org/10.1007/s12088-011-0110-9

Larson, S. (2006). *Design Document For Passive Bioventing*. ESTCP.

Lyle, J. T. (1994). *Regenerative design for sustainable development*. John Wiley.

Mang, P., & Reed, B. (2012). Designing from place: A regenerative framework and methodology. *Building Research & Information: Regenerative Design and Development*, *40*(1), 23–38. https://doi.org/10.1080/09613218.2012.621341

Mang, P., & Reed, B. (2015). The nature of positive. *Building Research & Information*, *43*(1), 7–10. https://doi.org/10.1080/09613218.2014.911565

MfE. (2017). *Coastal Fact Sheet 5: Storm Surge*. https://www.mfe.govt.nz/sites/default/files/media/MFE_Coastal_Fact%20Sheet%205.pdf

Neese, J. (2002). *Floating trail bridges and docks*. USDA Forest Service, Technology and Development Program.

Nguyen, V. K., Choi, W., Yu, J., & Lee, T. (2017). Microbial oxidation of antimonite and arsenite by bacteria isolated from antimony-contaminated soils. *International Journal of Hydrogen Energy*, *42*(45), 27832–27842. https://doi.org/10.1016/j.ijhydene.2017.08.056

Odum, E. P. (2005). *Fundamentals of ecology* (5th ed.). Thomson/Brooks/Cole.

Pedersen Zari, M. (2012). Ecosystem services analysis for the design of regenerative built environments. *Building Research & Information*, *40*(1), 54–64.

Pedersen Zari, M. (2018). *Regenerative Urban Design and Ecosystem Biomimicry*. Routledge.

Pedersen Zari, M., & Jenkin, S. (2010). Re-defining cutting edge sustainable design: From eco-efficiency to regenerative development. *Sustainable Building Conference (SB10)*, Wellington, New Zealand.

Pepper, I. L., Brusseau, M. L., & Artiola, J. (2004). *Environmental Monitoring and Characterization*. Elsevier Science & Technology. http://ebookcentral.proquest.com/lib/vuw/detail.action?docID=294595

Phytotech. (1996). News: Sunflowers remove radionuclides from water in ongoing phytoremediation field tests. *Environmental Science & Technology*, *30*(5), 194A-194A. https://doi.org/10.1021/es962219c

Plaut, J. M., Dunbar, B., Wackerman, A., & Hodgin, S. (2012). Regenerative design: The LENSES Framework for buildings and communities. *Building Research & Information*, *40*(1), 112–122.

Pontee, N. (2013). Defining coastal squeeze: A discussion. *Ocean & Coastal Management*, *84*, 204–207.

RAIC. (2015). Centre for Interactive Research on Sustainability. *Canadian Architect*, *60*(5), 32–33.

Reed, B. (2007). Shifting from “sustainability” to regeneration. *Building Research & Information*, *35*(6), 674–680. https://doi.org/10.1080/09613210701475753

Stott, R. (2014, June 27). *Hy-Fi, The Organic Mushroom-Brick Tower Opens At MoMA’s PS1 Courtyard*. ArchDaily. https://www.archdaily.com/521266/hy-fi-the-organic-mushroom-brick-tower-opens-at-moma-s-ps1-courtyard

Svec, P., Berkebile, R., & Todd, J. A. (2012). REGEN: Toward a tool for regenerative thinking. *Building Research & Information*, *40*(1), 81–94. https://doi.org/10.1080/09613218.2012.629112

Todd, J. (1994). Living Machines and Ecological Design: A New Synthesis. *Bulletin of Science, Technology & Society*, *14*(2), 69–74. https://doi.org/10.1177/027046769401400204

Todd, J. (2019). *Healing Earth: An Ecologist's Journey of Innovation and Environmental Stewardship*. North Atlantic Books.

Todd, J., Brown, E. J., & Wells, E. (2003). Ecological design applied. *Ecological Engineering*, *20*(5), 421–440.

Todd, J., & Josephson, B. (1996). The design of living technologies for waste treatment. *Ecological Engineering*, *6*(1–3), 109–136.

UNEP. (2007). *Buildings and climate change: Status, challenges and opportunities*. United Nations Environment Programme. https://wedocs.unep.org/handle/20.500.11822/7783

USDA. (1996, August). *Riparian Areas Environmental Uniqueness, Functions, and Values | NRCS*. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=nrcs143_014199#what

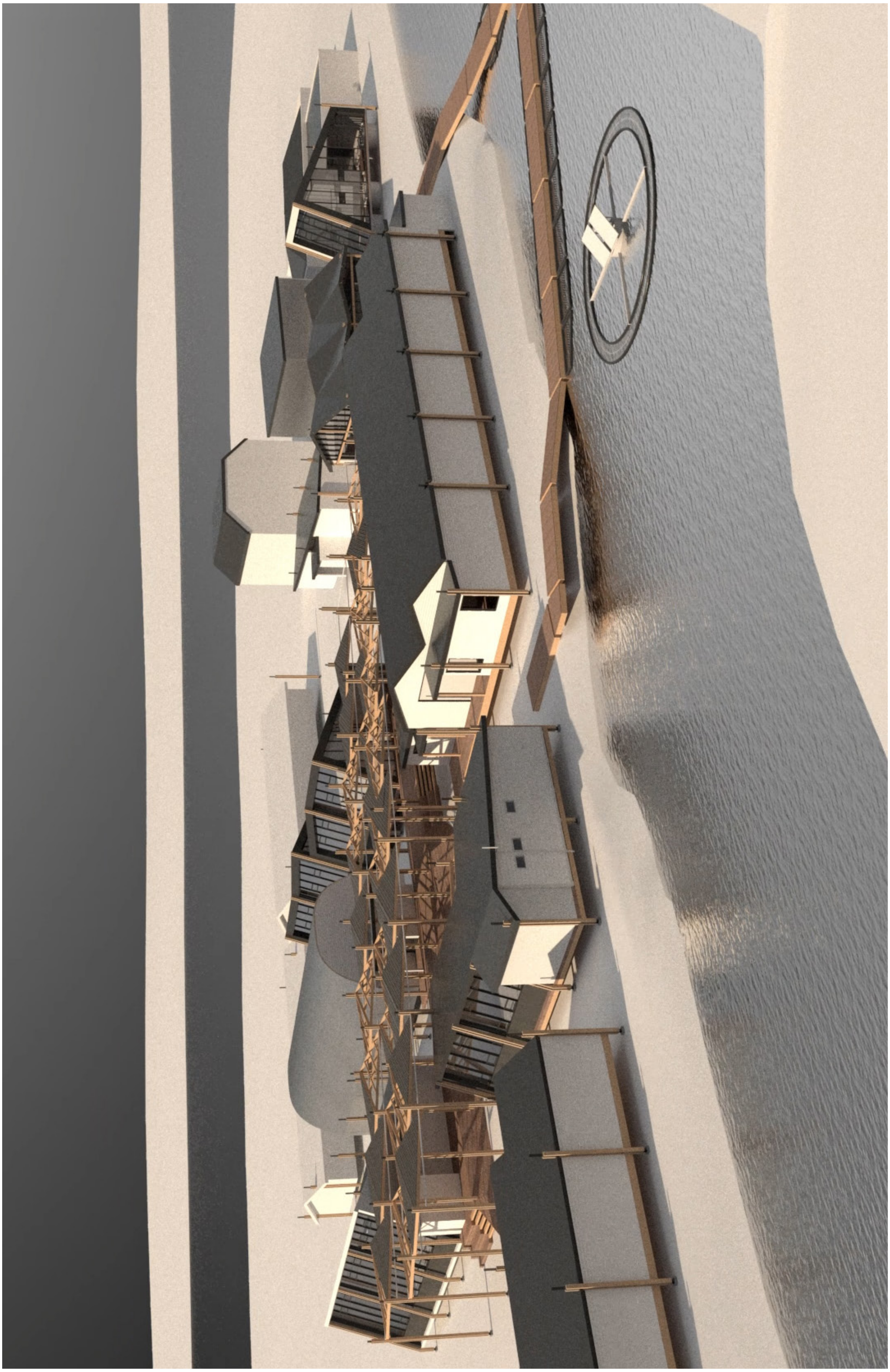
Velásquez, L., & Dussan, J. (2009). Biosorption and bioaccumulation of heavy metals on dead and living biomass of Bacillus sphaericus. *Journal of Hazardous Materials*, *167*(1), 713–716. https://doi.org/10.1016/j.jhazmat.2009.01.044

Wenk, W., & Gregg, B. (1998). Stormwater Gardens (Convey, Capture, and Reuse: Stormwater). *Landscape Journal*, *17*, 24–25.

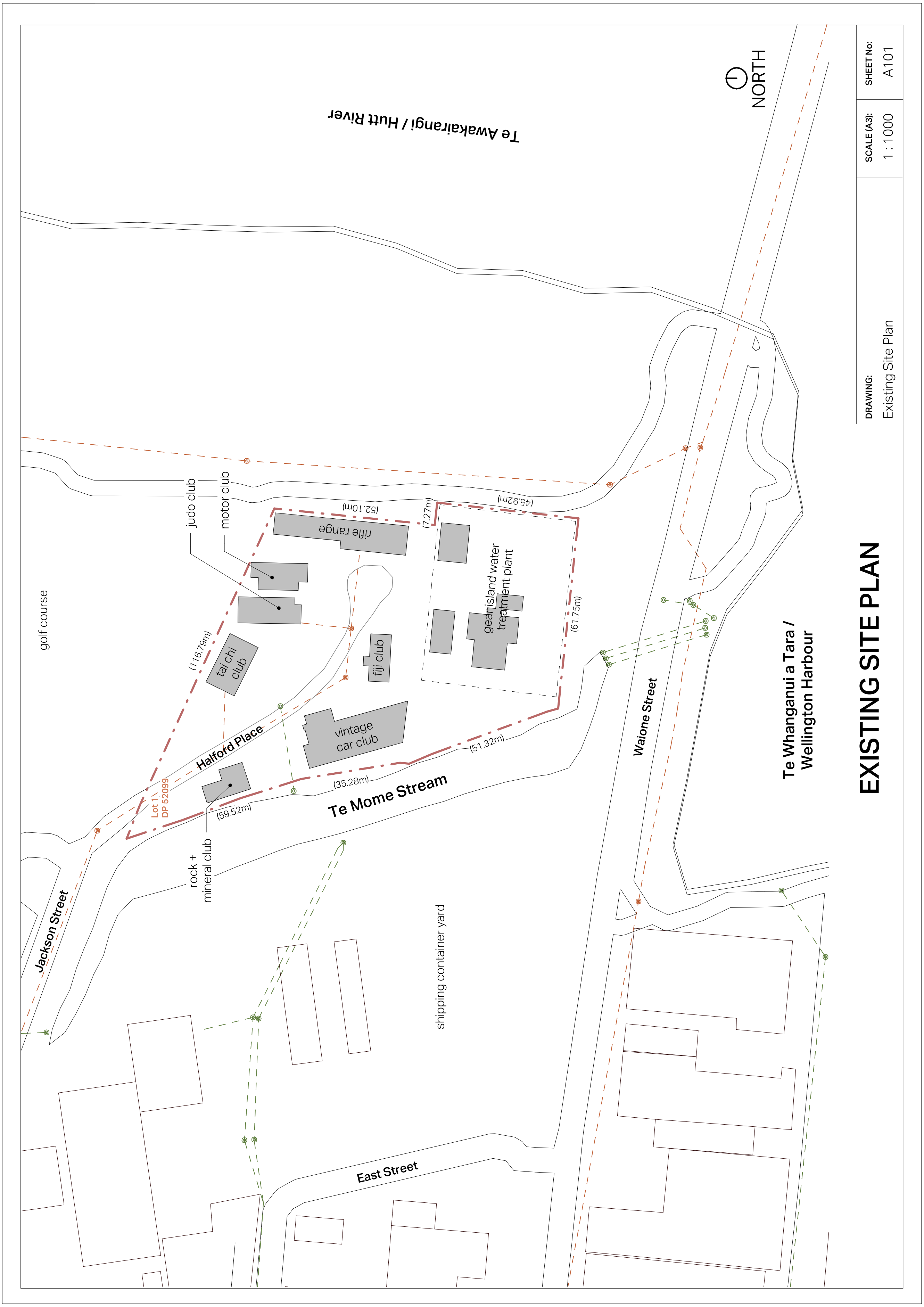
12. Figures List

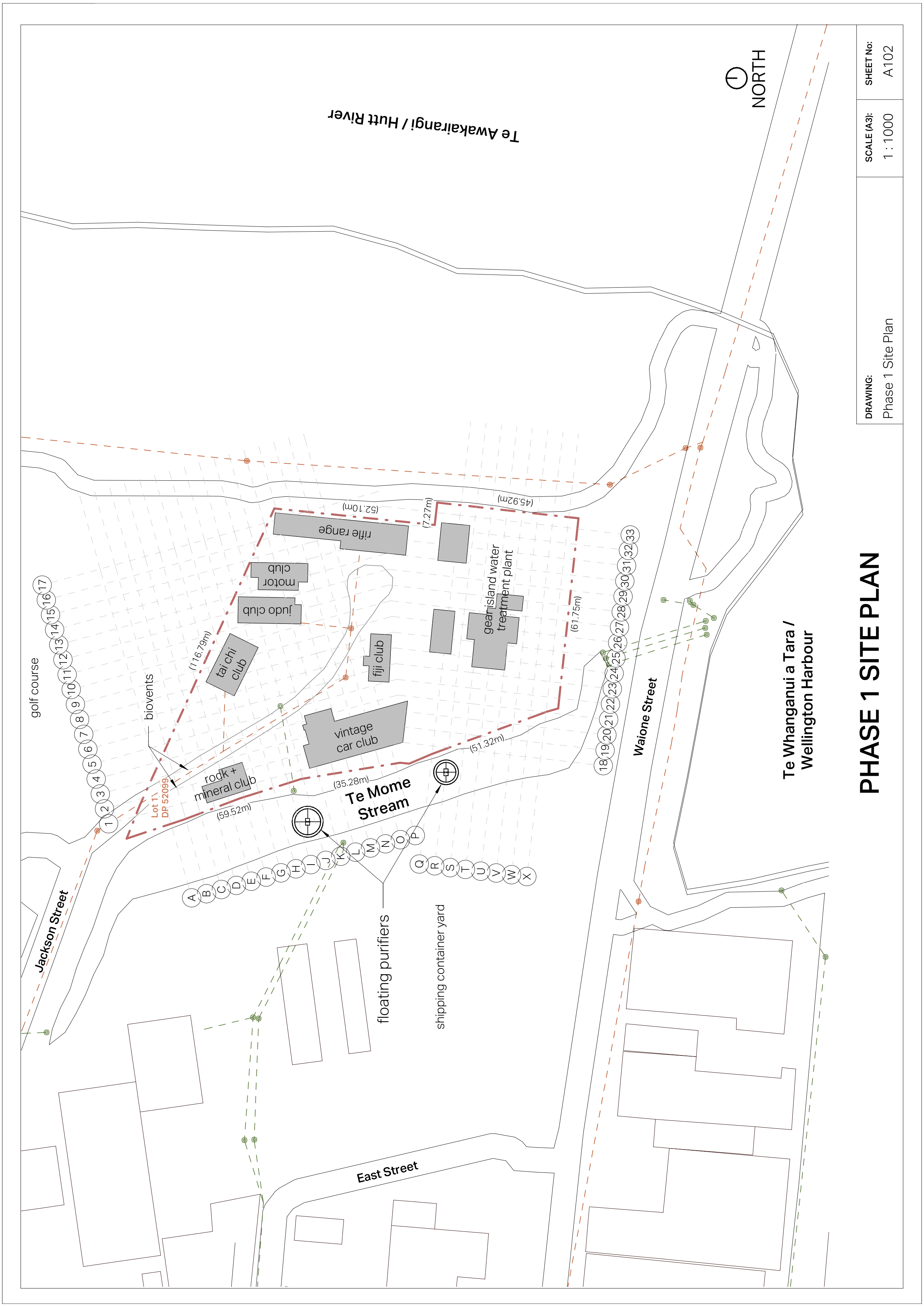
All figures are author's own work unless specified

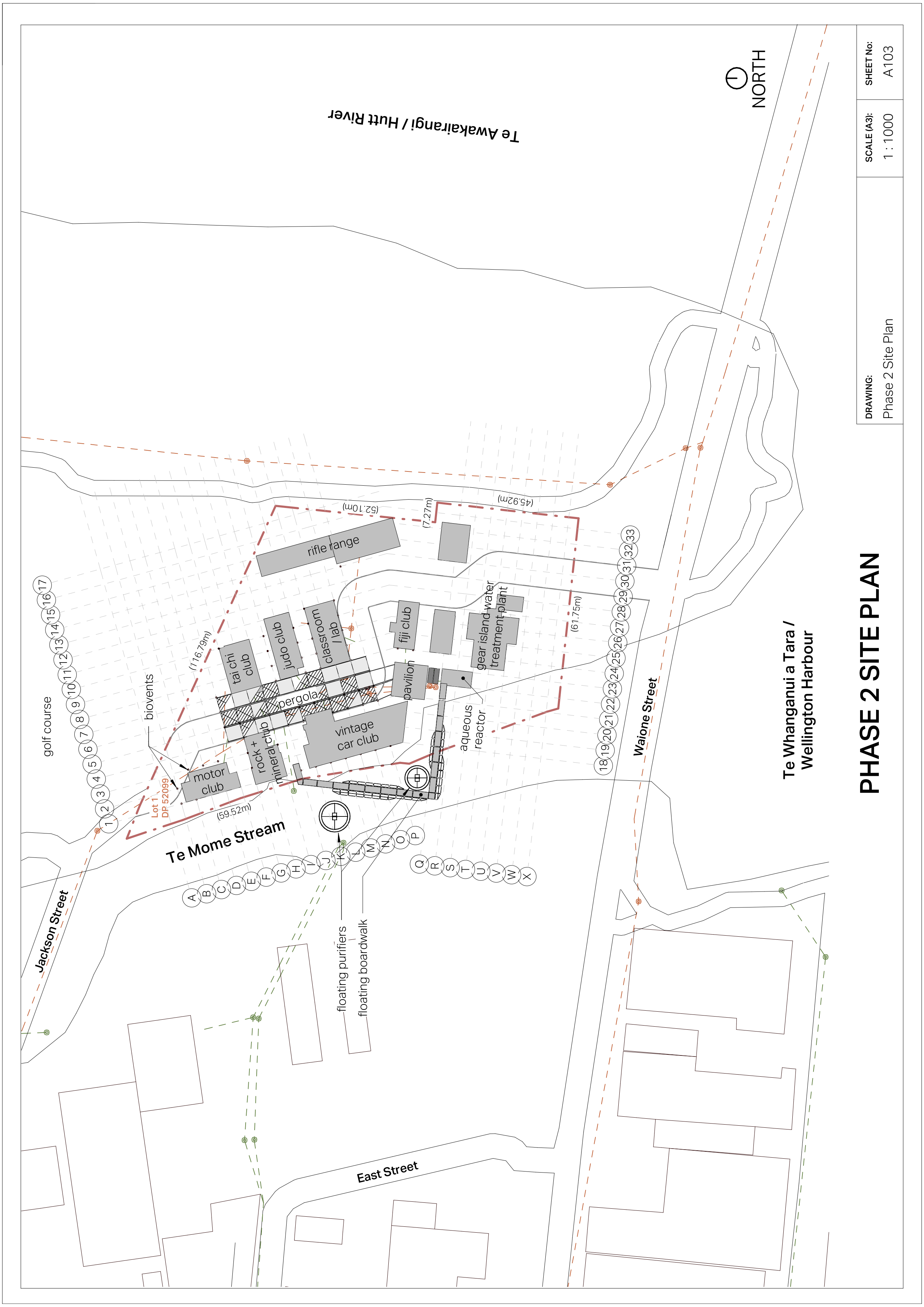
13. Appendices

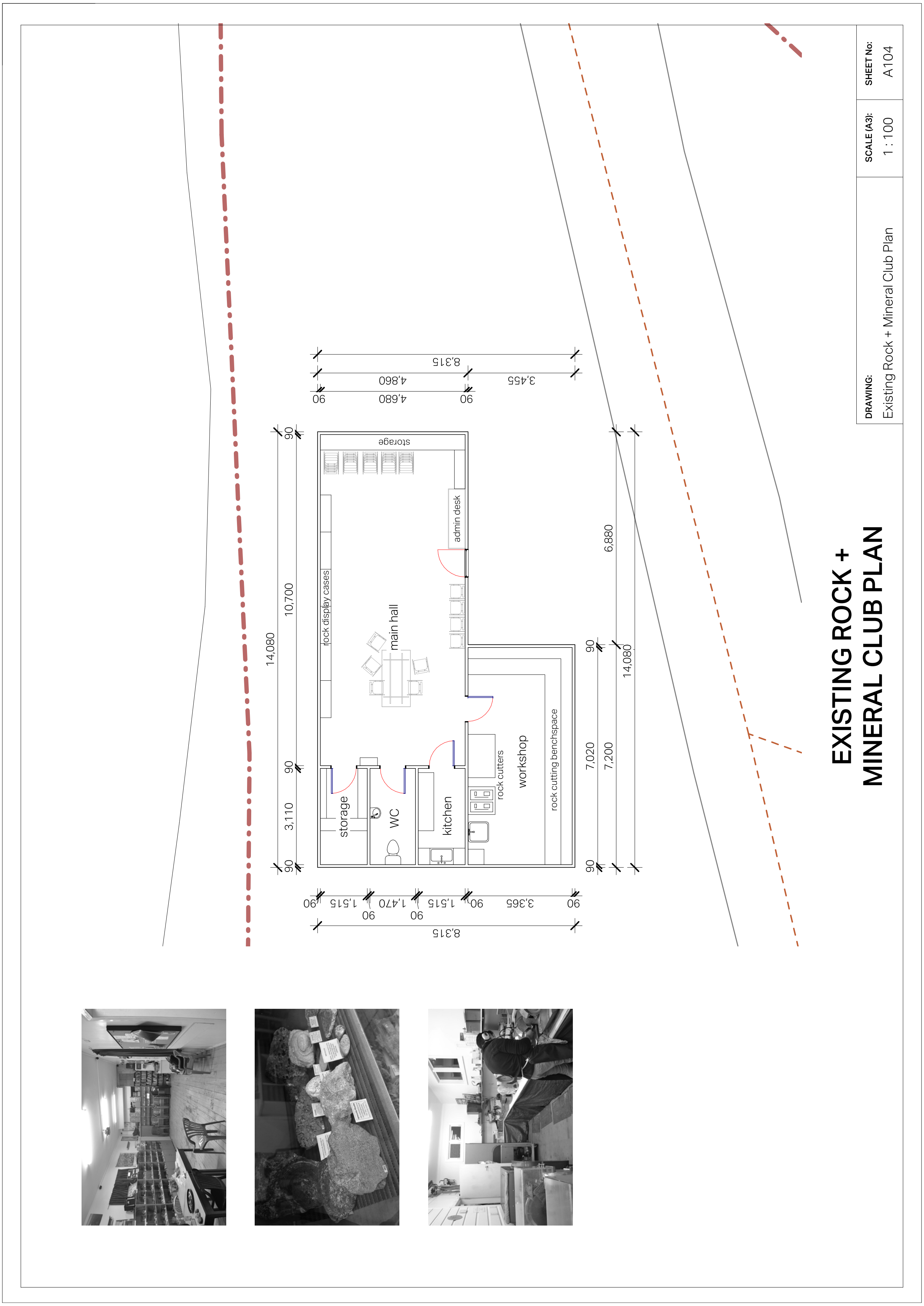


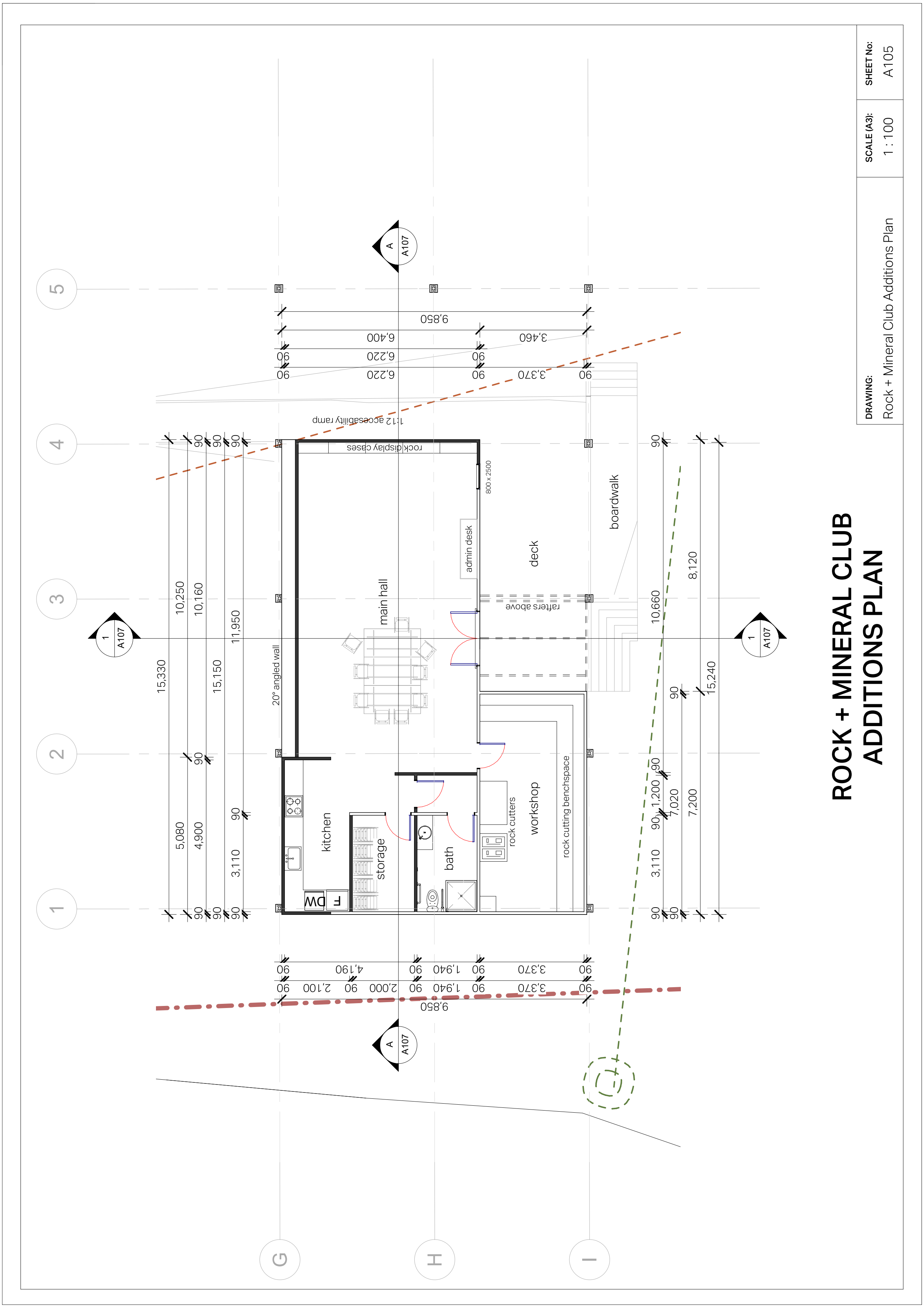
Video Walkthrough of Final Design
available @ http://tiny.cc/jab2tz

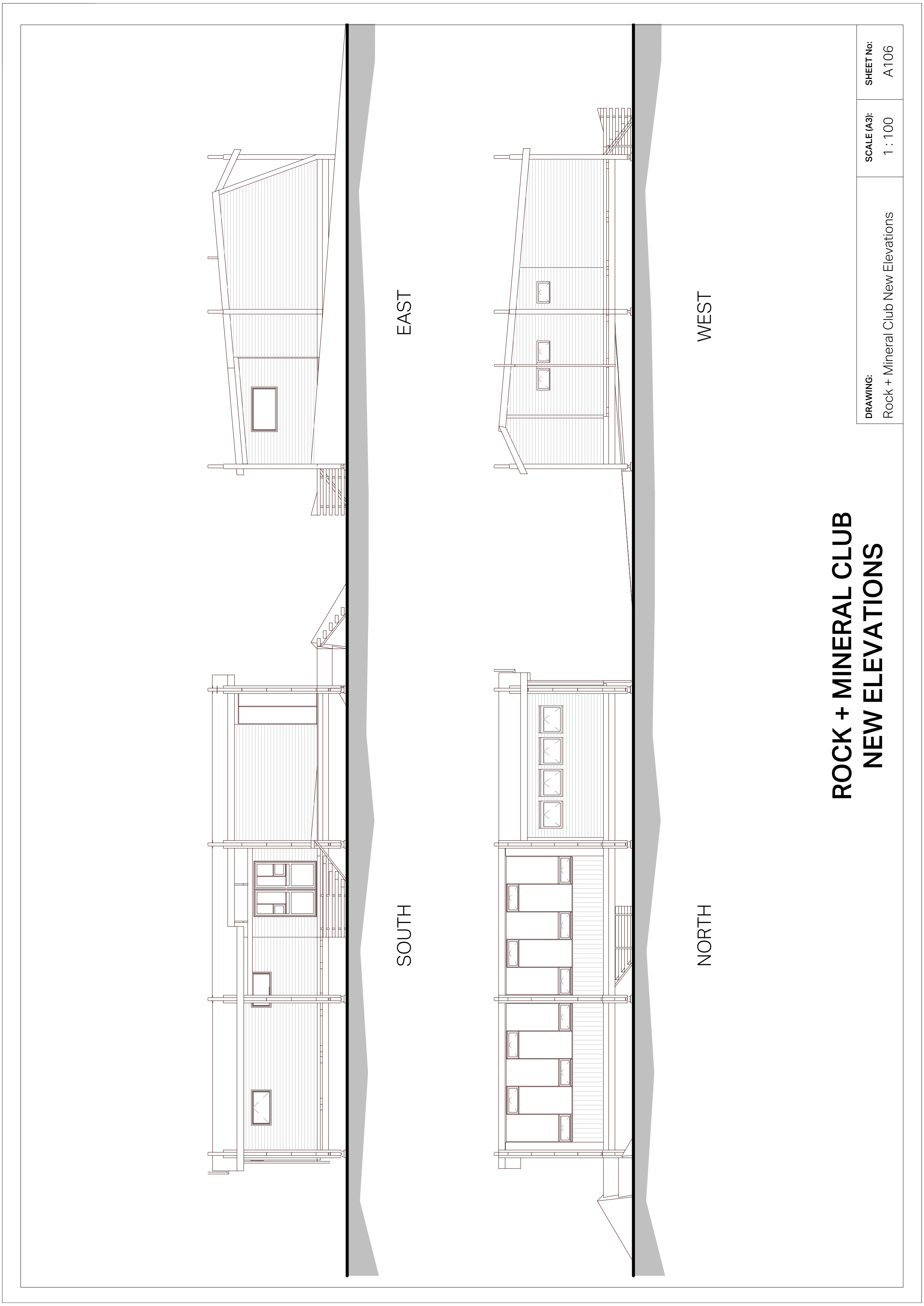

Te Awakairangi / Hutt River
NORTH
SCALE (A3):
1 : 1000
SHEET No:
A101
DRAWING:
Existing Site Plan
EXISTING SITE PLAN
Te Whanganui a Tara / Wellington Harbour
Waione Street
golf course
judo club
motor club
rifle range
(52.10m)
(7.27m)
(45.92m)
gear island water treatment plant
(61.75m)
(116.79m)
tai chi club
fiji club
vintage car club
Halford Place
(51.32m)
(35.28m)
Te Mome Stream
(59.52m)
Lot 1 DP 52099
rock + mineral club
Jackson Street
shipping container yard
East Street

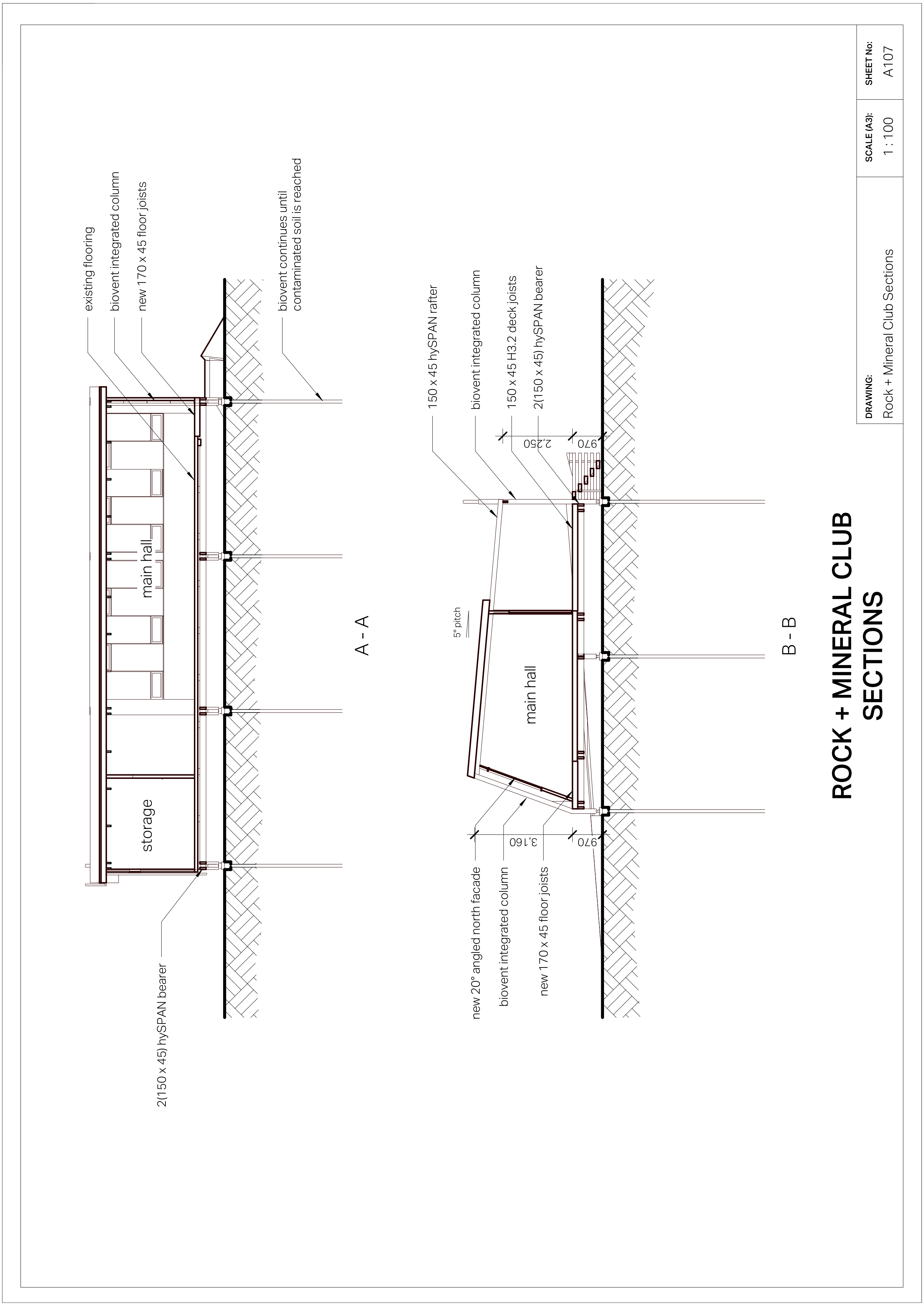

Te Awakairangi / Hutt River
NORTH
SHEET No:
A102
SCALE (A3):
1 : 1000
DRAWING:
Phase 1 Site Plan
PHASE 1 SITE PLAN
Te Whanganui a Tara / Wellington Harbour
Waione Street
Jackson Street
East Street
golf course
biovents
rifle range
motor club
judo club
tai chi club
fiji club
gear island water treatment plant
vintage car club
rock + mineral club
Te Mome Stream
floating purifiers
shipping container yard
Lot 1 DP 52099
(52.10m)
(7.27m)
(45.92m)
(61.75m)
(116.79m)
(51.32m)
(35.28m)
(59.52m)

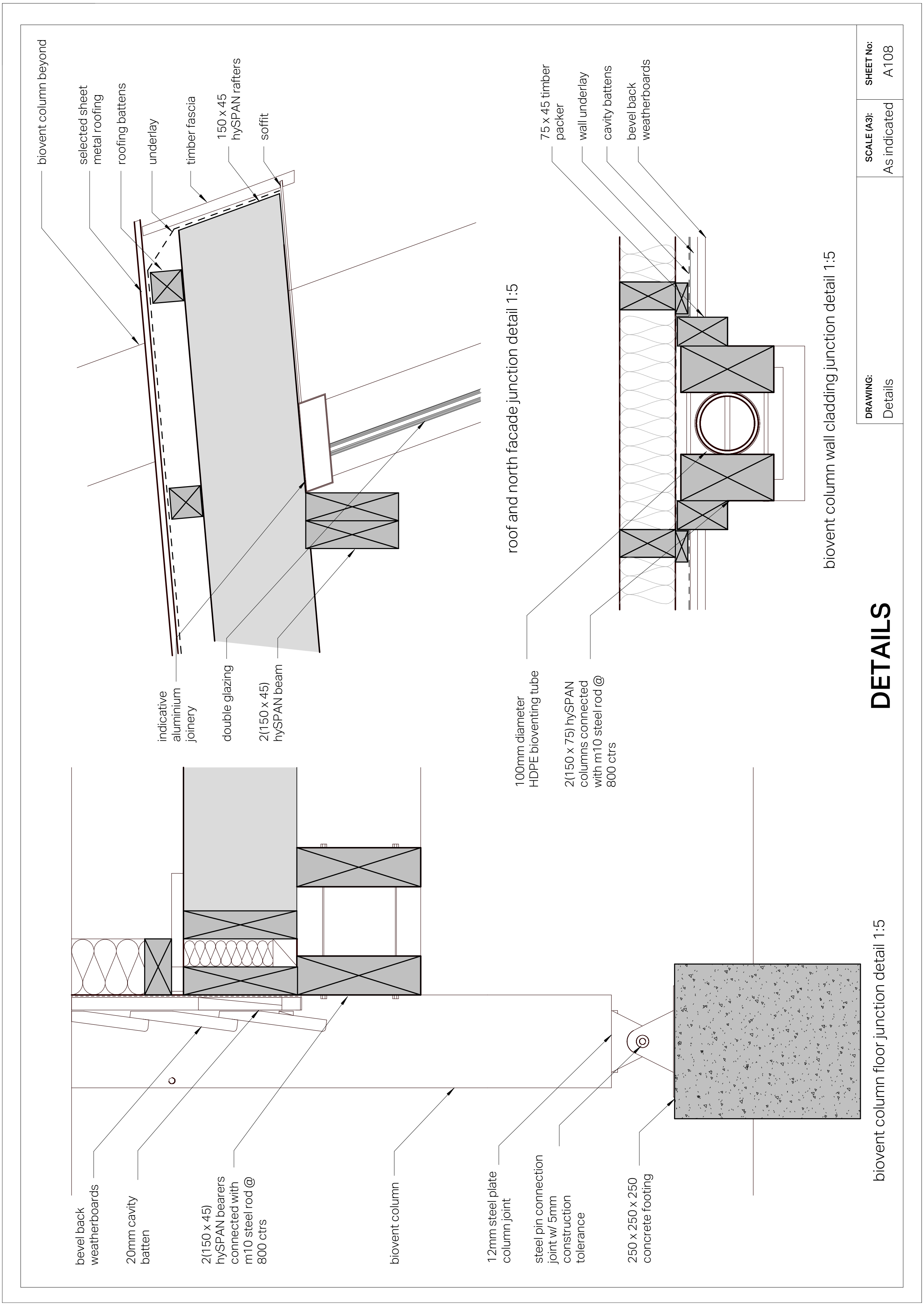

PHASE 2 SITE PLAN
DRAWING:
Phase 2 Site Plan
SCALE (A3):
1:1000
SHEET No:
A103
NORTH
Te Awakairangi / Hutt River
Te Whanganui a Tara / Wellington Harbour
Waione Street
Jackson Street
East Street
Te Mome Stream
golf course
biovents
motor club
Lot 1 DP 52099
rifle range
tai chi club
judo club
classroom / lab
fiji club
gear island water treatment plant
pavilion
pergola
vintage car club
rock + mineral club
aqueous reactor
floating purifiers
floating boardwalk
(52.10m)
(7.27m)
(45.92m)
(61.75m)
(116.79m)
(59.52m)

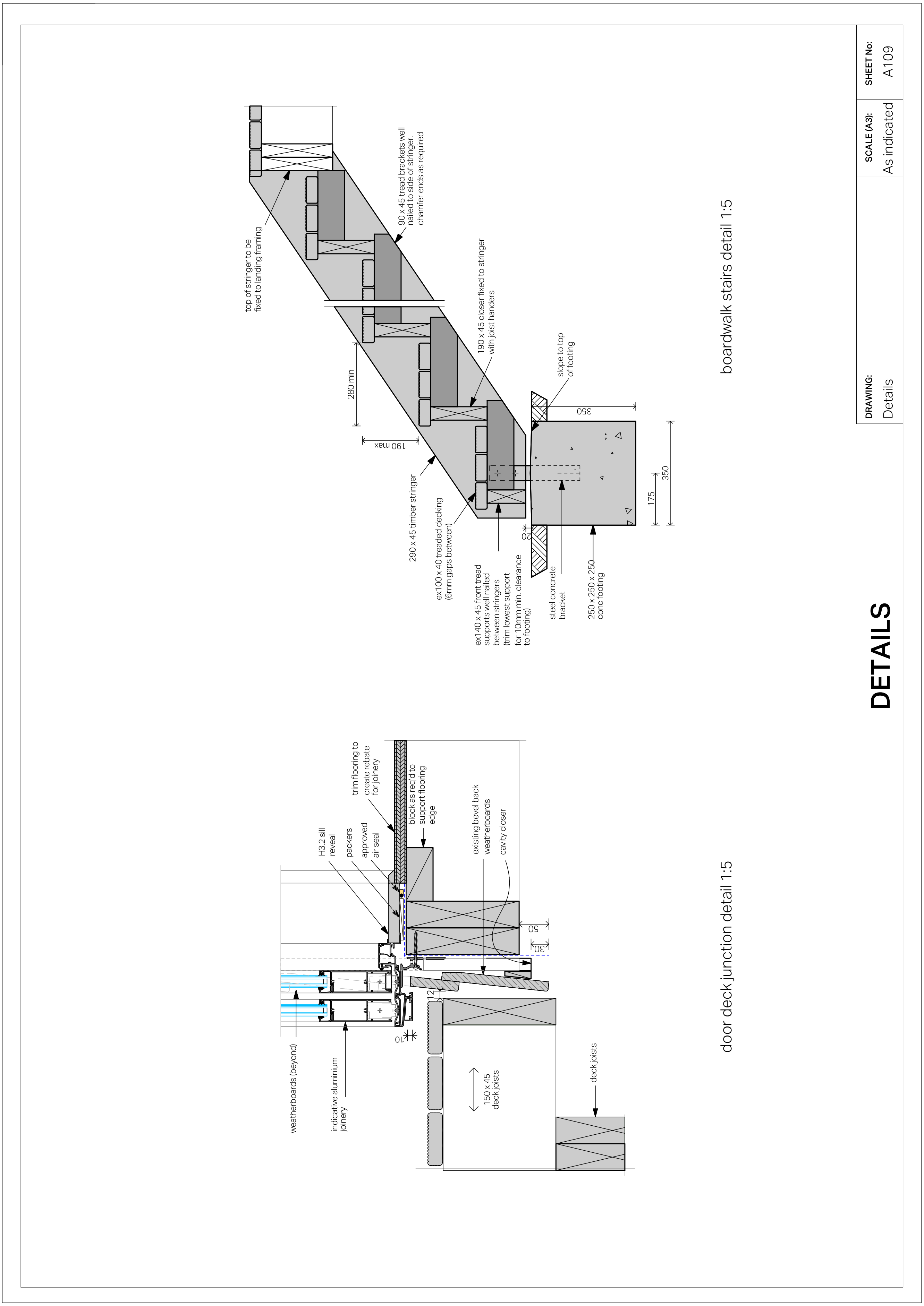

EXISTING ROCK + MINERAL CLUB PLAN
DRAWING:
Existing Rock + Mineral Club Plan
SCALE (A3):
1 : 100
SHEET No:
A104
storage
admin desk
rock display cases
main hall
storage
WC
kitchen
workshop
rock cutters
rock cutting benchspace
8,315
4,860
3,455
4,680
90
14,080
10,700
3,110
6,880
7,020
7,200
1,515
1,470
3,365

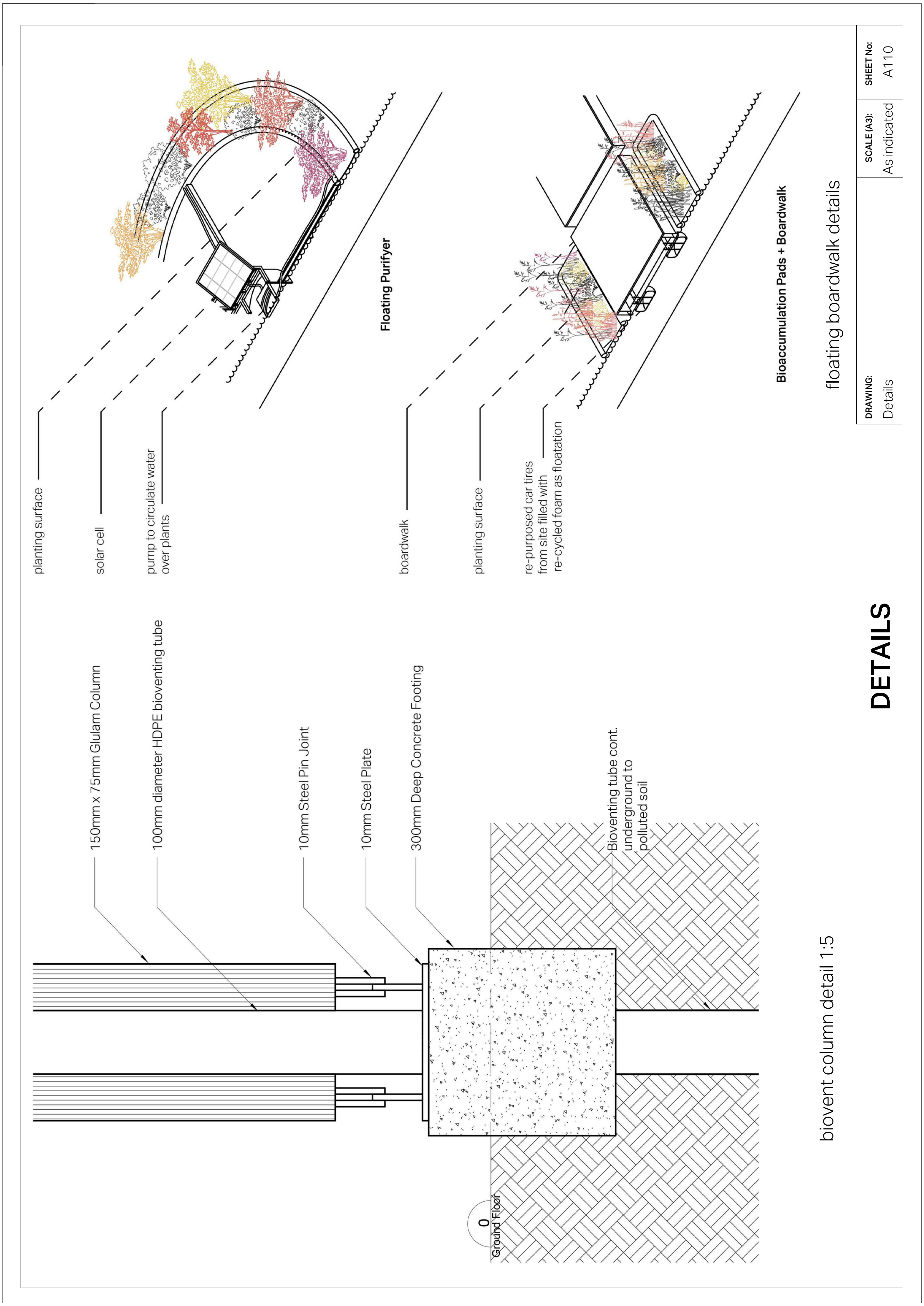

ROCK + MINERAL CLUB ADDITIONS PLAN
DRAWING: Rock + Mineral Club Additions Plan
SCALE (A3): 1 : 100
SHEET No: A105
main hall
kitchen
storage
bath
workshop
deck
boardwalk
admin desk
rock display cases
rock cutters
rock cutting benchspace
rafters above
20° angled wall
1:12 accessibility ramp
800 x 2500


EAST
WEST
SOUTH
NORTH
ROCK + MINERAL CLUB
NEW ELEVATIONS
DRAWING:
Rock + Mineral Club New Elevations
SCALE (A3):
1 : 100
SHEET No:
A106


existing flooring
biovent integrated column
new 170 x 45 floor joists
biovent continues until contaminated soil is reached
main hall
storage
2(150 x 45) hySPAN bearer
A - A
150 x 45 hySPAN rafter
biovent integrated column
150 x 45 H3.2 deck joists
2(150 x 45) hySPAN bearer
2,250
970
5° pitch
main hall
3,160
970
new 20° angled north facade
biovent integrated column
new 170 x 45 floor joists
B - B
ROCK + MINERAL CLUB SECTIONS
DRAWING:
Rock + Mineral Club Sections
SCALE (A3):
1 : 100
SHEET No:
A107


biovent column beyond
selected sheet metal roofing
roofing battens
underlay
timber fascia
150 x 45 hySPAN rafters
soffit
indicative aluminium joinery
double glazing
2(150 x 45) hySPAN beam
roof and north facade junction detail 1:5
75 x 45 timber packer
wall underlay
cavity battens
bevel back weatherboards
100mm diameter HDPE bioventing tube
2(150 x 75) hySPAN columns connected with m10 steel rod @ 800 ctrs
biovent column wall cladding junction detail 1:5
bevel back weatherboards
20mm cavity batten
2(150 x 45) hySPAN bearers connected with m10 steel rod @ 800 ctrs
biovent column
12mm steel plate column joint
steel pin connection joint w/ 5mm construction tolerance
250 x 250 x 250 concrete footing
biovent column floor junction detail 1:5
DETAILS
DRAWING:
Details
SCALE (A3):
As indicated
SHEET No:
A108


SHEET No:
A109
SCALE (A3):
As indicated
DRAWING:
Details
DETAILS
boardwalk stairs detail 1:5
top of stringer to be fixed to landing framing
90 x 45 tread brackets well nailed to side of stringer, chamfer ends as required
190 x 45 closer fixed to stringer with joist handers
slope to top of footing
280 min
190 max
350
175
350
20
290 x 45 timber stringer
ex100 x 40 treaded decking (6mm gaps between)
ex140 x 45 front tread supports well nailed between stringers (trim lowest support for 10mm min. clearance to footing)
steel concrete bracket
250 x 250 x 250 conc footing
door deck junction detail 1:5
trim flooring to create rebate for joinery
block as req'd to support flooring edge
H3.2 sill reveal
packers
approved air seal
existing bevel back weatherboards
cavity closer
50
30
12
10
weatherboards (beyond)
indicative aluminium joinery
150 x 45 deck joists
deck joists


150mm x 75mm Glulam Column
100mm diameter HDPE bioventing tube
10mm Steel Pin Joint
10mm Steel Plate
300mm Deep Concrete Footing
Bioventing tube cont. underground to polluted soil
0
Ground Floor
biovent column detail 1:5
planting surface
solar cell
pump to circulate water over plants
Floating Purifyer
boardwalk
planting surface
re-purposed car tires from site filled with re-cycled foam as floatation
Bioaccumulation Pads + Boardwalk
floating boardwalk details
DETAILS
DRAWING:
Details
SCALE (A3):
As indicated
SHEET No:
A110