BIKE SHOP

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ABSTRACT

The aim of the research is to develop a new model of bicycling supporting infrastructure that is cost-efficient, easily fabricated and installed, energy-efficient, globally transportable and adaptable to site. Cycling has entered into a new era, with a large population of active cyclists competing with unsustainable fossil fuel transport systems. The increase in cycling is a result of rising fossil fuel costs and a more environmentally aware public. The thesis seeks an architectural way of provoking greater incentives for cycling by increasing its appeal and ease of engagement, while decreasing related infrastructure costs.

The design proposes 'Bike Shop', an architecturally integrated cycling support facility that can be positioned at regular intervals along a cycling route. The design research challenge is to conceive a facility that is self-sustaining, adaptable, economically produced, environmentally sensitive, portable and able to be applied globally. As a vehicle for design, the Great Harbour Way/ Te Aranui o Pōneke will be used. The Great Harbour Way includes plans for a parallel cycling route that stretches over 50 kilometres along the shoreline in the Greater Wellington region from Eastbourne to Owhiro Bay. The Greater Wellington Regional Council has proposed their second highest funding of large projects over \$5 million for walking and cycling development in the region. The funding of \$17.05 million goes towards the development for a walkway/cycleway between Ngaraunga and Petone. This thesis will test how prefabricated methods such as kit-of-parts and mass customisation techniques can reduce costs yet encourage adaptability to address the wide range of conditions that the Great Harbour Way offers. The challenge of the design experiment for this facility will be to become a new model of cycling infrastructure around the world.

The thesis proposes to reinterpret the Bike Shop as a linear sequence of cycling facilities that inhabit the Great Harbour Way. The Bike Shop is to be placed on this stretch of shoreline at fixed intervals. At these locations with the wide range of site conditions the design challenge is for the facility to arrive as a kit-of-parts, be assembled quickly and adapted to unique site conditions.

The thesis proposes a program where each architecturally integrated facility along the linear sequence will function as new cycling infrastructure, where simultaneously a bike can be repaired or a tire can be inflated or a bicyclist can rest and rehydrate with other cyclists off the road. In this way, each facility will promote safe cycling, thereby providing safety, environmentally sustainable energy, and public health benefits to more cyclists. In this way, the thesis argues that the facilities will be recognized as signifiers of the city as well as markers of location and orientation. Overall this thesis invites prefabricated elements to be adaptable in ways that make them responsive and beautifully reflect the site rather than just repetitive.

PREFACE

The following section outlines the scope and argument of the thesis. The objective of the research is to establish a new model of cycling infrastructure that offers cost-effective, easily fabricated and installed, energy-efficient facilities. To develop this facility a set of design objectives have been generated. The aim of the research is to implement the objectives of architectural integration, self-sustainability, adaptability, economic-production, environmental-sensitivity, portability and global applicability. The structure of the thesis is separated between five chapters. Chapters 1-3 consider the theoretical background. Chapters 4-5 of the thesis processes these ideas into design.

-Chapter 1 summarizes the format and objectives of the research. This chapter also provides a general background of cycling as the underlying basis establishing the thesis imperatives. This chapter reflects on cycling infrastructure and how important these facilities are for cycling.

Chapter 2 is the literature review. The chapter examines prefabricated architecture from early misperception such as assumptions about low quality, benefits through sustainability, easy assembly with the kit-of-parts and cost efficient fabrications with techniques used in mass customisation. Finally, the chapter concludes by outlining the essential ideas that contribute to the design.

-Chapter 3 reviews existing case studies that provide for cyclists, provide self-sustaining incentives and use efficient and cost effective methods of construction. This chapter is divided into two sections. The first section is comprised of cycling related case studies such as the Bike Fixtation. This section looks at the strengths and weaknesses of their approaches towards cycling facilities and vandalism. The next section focuses on case studies that involve prefabrication as their main driver for construction. Such prefabrication cases focus on the kit-of-parts, mass customisation techniques and standardised parts. This section looks at the strengths and weaknesses of them in relation to economy, assembly, and adaptability.

-Chapter 4 analyses the selected design research site and program for experimental design. The chapter is divided into two sections. The first section introduces the Great Harbour Way/ Te Aranui o Pōneke as the site vehicle for design exploration, highlighting its inherent capacity to express a prefabricated development with response to its wide site conditions. The following section assesses the programmatic requirements. The program analysis critically considers the facilities and services that the architecture is to house. The objective of the analysis is to uncover potentials and contextual opportunities for developing an architecturally integrated facility.

-Chapter 5 incorporates the experimental designs and conclusion to the thesis. The objective of the chapter is to test the facility against the objectives of architectural integration, self-sustainability, adaptability, economical-production, environmental-sensitivity, portability and global applicability. The chapter develops an overall conceptual design for the selected locations of the Great Harbour Way through multiple experiments. Each experiment will be reviewed and commented upon for further improvements. The design result will be used to illustrate the design initiations. The final section of the chapter serves as a conclusion for both the chapter and the thesis.

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1. INTRODUCTION

1.1 Context of Research

1.1.1 Importance of cycling

Cycling is an activity that provides cycling cities and towns with environmental, energy, reduced congestion and public health benefits. Cycling is a form of outdoor leisure and fitness. Cycling is energy efficient, affordable and improves fitness and well-being. In New Zealand cyclists share the road with cars, rather than having separate cycle routes as in some other countries. Other cycleways such as off the road routes are normally shared with walkers. Any cycling facility which is off the road is the safer way to cycle as you do not have encounters with cars. Lately cycling has been more popular due to the rise of petrol prices. As there are more cyclists on the road better infrastructures are needed to support cyclists.

1.1.2 The new cycleway

The Greater Wellington Regional Council has proposed development of a new cycleway as their second highest funding of large projects. The high priority of the development was published in the final Regional Land Transport Programme (RLTP).

The funding is for the development of the walkway/cycleway from Ngauranga to Petone. The aim of the new cycleway is to lift the safety requirements in line with the Great Harbour Way. The Great Harbour Way is the main cycleway, shared with a high volume of motor vehicle traffic, which spans from Owhiro Bay to Eastbourne.

The Greater Wellington Regional Council Report of Submissions to the Draft Regional Land Transport Programme 2012-2015 was published on 21 May 2012 by the Regional Land Transport Programme Hearing Subcommittee. This

publication reports on the submissions made to the 'draft' Regional Land Transport Programme. This report provided the subcommittee an overview from the submissions received. This draft also provides comments and recommendations on these submissions. These submissions are to be considered in the decision making process for the RLTP. 545 submissions were received. 95% of submissions received were from individual members of the public. Most of these submissions were made through paper feedback form or an online submission through the Greater Wellington website. The remaining 5% received were from local councils, organisations, community groups and advocacy groups. For general funding priorities there was clear support for public transport and walking/ cycling activities. A number of submissions supported road projects while many submitters felt that the money spent for new roads can be spent on public transport, walking and cycling improvements.

The new large projects over \$5 million dollars are classed as 3rd priority. 1st priority activities are those required to maintain the existing level of service of the region's transport network and 2nd priority activities are for relatively low cost studies, walking and cycling activities and minor safety improvement works below \$5 million.

Of the 3rd priority projects, about 20% of submitters commented on Electronic Ticketing and the Ngauranga to Petone walkway/ cycleway'. For the Ngauranga to Petone walkway/cycleway, support for this project was conclusive, with only four submitters opposing. The overall ranking of projects received 436 submissions. Of the 3rd priority projects, the Ngauranga to Petone walkway/cycleway was at 7th. The RLTP had this project at 9th.

In the recommendation notes, there is consideration for elevating the priority ranking of this project. Within the 3rd priority

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group this would signal the region's strong support for this project. The project could be elevated to 2nd. Ranked at 1st is the Mt Victoria Tunnel safety improvements project.

On the 11th June 2012 the Recommendations for Final Region Land Transport Programme 2012-15 were published. This recommends changes to the final RLTP 2012-15. This is also a part of the decision-making process. At section 3.4.1 the recommendations are made to elevate the Ngauranga to Petone walkway/cycleway project to second to reflect its urgency and importance. When the final RLTP 2012-15 was released Table 3 features the activities proposed for the next three years. In the 3rd priority group the Ngauranga to Petone walkway/cycleway was placed at 2nd behind the Mt Victoria Tunnel Upgrade. The funding for the walkway/cycleway is to be sourced nationally at a total of \$17.05 million.

1.1.3 The need for a new cycling facility

According to the literature there are currently no models of cost effective, easily fabricated and installed, energy efficient cycling infrastructures. The Great Harbour Way, if it is to viably incorporate a dedicated new cycling laneway, would need a series of new cycling facilities. The route along the 50 kilometre long Great Harbour Way does not provide a level of safety and practicality for cyclists to stop, rest or allow for repairs made on bikes. Along this route there are no dedicated bike stops. There is lack of public toilets along the cycle way which cyclists can use. Without this form of cycling infrastructure, shelter, water, toilets, and bike repairing facilities cannot be obtained whilst cycling on this road. The Great Harbour Way is in need of a series of safe and practical dedicated bicycle stops. At fixed intervals of five kilometres cyclists should be able to stop and use the facility while being off the road at

a safe location. One of the important challenges is the availability of fresh drinking water and electricity along cycleways, which move from urban into rural areas and back again,

1.1.4 Prefabricated Architecture

Prefabricated design principles can be used to design bicycle stops which allow for simple construction, easy transportation, low cost production and quick assembly. Prefabricated architecture allows for the majority of the building's parts to be built in a warehouse and can be assembled quickly on site. Building in a warehouse will allow for easier construction with the support of tools and shelter. This construction is then able to be repeated accurately multiple times. The negative aspect of prefabrication is the difficulty adapting to a wide range of environmental conditions. Therefore, a prefabrication system must be developed that enables multiple configurations from a limited set of fabricated parts.

1.1.5 Kit-of-parts system

Within prefabrication methodologies, the kit-of-parts system will be explored to allow ease of transportation and quick assembly. The kit-of-parts system can also provide spares, as components of the system may need replacing.

1.2 Problem Statement

A contemporary problem relating to the global advancement of cycling is that there are currently no models for cost-effective, easily fabricated and installed, energy-efficient cycling infrastructures, while cycling grows due to the rise in fuel costs and increased environmental consciousness. The Greater Wellington Regional Council has put forward their second highest budget of large projects over \$5m to encourage cycling in the Wellington region. But 50

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kilometres of dedicated cycling route will need cost effective, easily fabricated and energy-efficient support facilities for cyclists, providing practical aspects such as a place to stop, rest, rehydrate and repair a bike while being in a safe environment. The absence of such facilities will become more of a problem when cycling continues to increase.

1.3 Research Intention

The intention of the research is to use the design objectives of architectural integration, self-sustainability, adaptability, economical-production, environmental-sensitivity, portability and global applicability to create a new model of cycling infrastructure that is cost effective, easily fabricated and energy efficient. This infrastructure will allow for cyclists to stop, rest, rehydrate and repair their bikes whilst being away from traffic. The facilities need to be easily transported to the site and be assembled on site quickly. This will also reflect how kit-of-parts and mass customisation methods are used as a solution for the new model of cycling infrastructure. The prefabricated facilities also need to be able to adapt to a range of environmental conditions.

1.4 Scope of Research

The physical context for the research is the Wellington shoreline spanning from Owhiro Bay to Eastbourne. The cycleway along that shoreline is the Great Harbour Way/ Te Aranui o Pōneke. Conclusions of this research can be applied to other cycling infrastructures around the world. The research focuses on self-sustaining, efficient prefabricated ideas. Kit-of-parts and mass customisation techniques as a part of prefabrication will be focused on. The research will also focus on Wellington's diverse landscape and weather conditions as these provide the critical contexts for design of the facility. The design is set up for possible

global application; therefore adaptability and portability will be design imperatives. Cost estimation will not be included in the scope, the cost effectiveness is considered in relation to the ease of manufacturing, delivery and assembly.

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Background: Cycling infrastructure

This section reviews cycling infrastructures in New Zealand cities, especially Wellington. This focuses on providing incentives to that the architectural facility will provide for. This establishes the infrastructural facilities that are needed and will become essential due to the increase of cyclists on the road. Recently there has been a growth in accidents and casualties regarding cyclists and cars in New Zealand (Ministry of Transport, 2012, p. 2): “Wellington rising in serious injuries in the last two years” (Greater Wellington Regional Council, 2013, p. 16). The inclusion of more cycling infrastructure helps reduce these accidents by increasing the distance between cars and bicycles. Cycling infrastructures are facilities that are cycling related. Facilities such as bike workspaces are currently non-existent in Wellington. These workspaces would allow cyclists to repair a tyre or make adjustments to their bicycles. This facility will be in more of a demand as there are more bicycles on the road. Other facilities such as rest spaces and toilets will also be in demand. In remote locations these resting spaces would be particularly needed. In these spaces shelter from sun, wind and rain will be needed. Making these additions and improvements to cycle ways are methods of making cycling more practical and safe thereby improving cycling numbers.

According to John Pucher and Ralph Buehler of Bloustein School of Planning and Public Policy at Rutgers University in New Jersey, cycling

facilities that increase cycling also improve safety. One concept is “safety in numbers”; when there are more cyclists on the road, other users of the road become more aware of cyclists. The higher number of cyclists means that drivers have higher awareness levels and a greater expectation of encountering cyclists. The cities and countries with higher levels of cycling have lower levels of serious or fatal accidents. (Pucher & Buehler, 2008, p. 15)

Perceived safety is also an important factor. Bad perception can deter cyclists from cycling. Fewer cyclists would want to cycle if they see that there are no facilities supporting cycling. If there are no facilities for cyclists, cyclists would not want to stop on the roadside to make repairs to a bike. Simon Kingham from the University of Canterbury states that perceived safety is more important than actual safety in its effect on an individual’s behaviour (Kingham, Taylor , & Koorey, 2011, p. 28). Søren Underlien Jensen, member of Denmark’s Transportation Research Board Committee on Bicycle Transportation, states that traffic is a major factor; the large volume of vehicles along with the lack of safe space generates a negative perception of safety (Jensen, et al., 2000, p. 66). There must be a balance between infrastructure that is visually safe and physically safe.

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The recommendations below are suggested for New Zealand based on the findings of a report conducted by Kingham for the New Zealand Transport Agency.

1. Investment in cycling facilities of all kinds should be encouraged throughout the country, with the choice of facility subject, where necessary, to practical considerations and best-practice guidance.
2. The uptake of cycling infrastructure that allows cyclists further separation from traffic (including behind parking and kerb lines) should be encouraged, whilst providing adequate safe-design details at intersections and driveways.
3. A wide variety of cycling infrastructure types should be trialled throughout the country (particularly those that were well supported by the participants in this study) and their actual safety records should be monitored, as well as road-user understanding and acceptance of them.
4. Consistent infrastructure for cyclists at junctions, such as hook-turn facilities and dedicated cycle signals, should be implemented.
5. On-site signage and markings should be improved, along with education for all road users on how to interact with and use various cycling facilities.

6. More low-speed (30/40km/h) zones and cycle-friendly traffic management should be implemented throughout the country, so that people become more familiar with the concepts.
7. The continuity and understanding of existing cycling facilities, both in terms of physical road/path features and signage/ marking guidance, should be improved.
8. Further investigation of the effect of access to company vehicles on the uptake of utilitarian cycling should be carried out, both in terms of vehicles provided for travel to/from home, and vehicles available for private use during the day.
9. Those involved in the planning and design of cycling infrastructure should be encouraged to consider the broader health benefits associated with increased cycle use, in addition to the safety implications of infrastructure design. (Kingham, Taylor , & Koorey, 2011, p. 121)

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As the research questions are focused towards designing a unique architectural portable facility not all recommendations will be applicable. For example, the recommendations that address roading developments and vehicle issues such as 4 and 8 are unable to be applied as they are remote from the research questions. Recommendation 3 is also not applicable as it focuses on multiple typologies, whereas this thesis looks at one that becomes adaptable. The research is looking for a solution towards providing an architectural facility that benefits recommendations 1, 2, 7 and 9. The other recommendations 5 and 6 can be implemented by local authorities such as city, regional councils in later stages when the facility is introduced.

2. LITERATURE REVIEW

INTRODUCTION.

The literature review will help inform design solutions for addressing the research problem, which is primarily the lack of models for cost-effective, easily fabricated, energy-efficient cycling infrastructures. All these problems relate to the global advancement of cycling. As there are now more cyclists on the road due to the increased costs in fossil fuels and a more energy conscious public there needs to be a model that facilitates this increase. The research objectives used to help address these problems are to create a new and unique architecturally integrated cycling facility that is self-sustaining, adaptable, economical to produce, environmentally sensitive, portable and can be applied globally. The literature review used to assist with this research is divided into two sections. The first section looks at prefabrication literature, including ideas from the kit-of-parts and mass customisation. This section of the literature review looks specifically at self-sustainability, adaptability, economy in production, portability and environmental sensitivity. The information gained from the first section is then applied through approaches to prefabricated architecture; from here the thesis will seek a new outcome.

This chapter looks at addressing issues of adaptability, economic production and environmental sensitivity. This chapter discusses prefabrication ideas and their issues. As prefabrication was based initially on the ideas of mass production first put into practice with Henry Ford's Model-T (Bergdoll & Christensen, 2008, p. 16), these techniques are explored as they allow for cost effective buildings to be built quickly. This chapter will investigate the techniques used that result in cost effective and quickly built buildings. These two ideas are important towards the new design solution therefore this chapter will also look at issues and benefits of prefabrication. Issues regarding prefabrication occurred when assumptions made by the public were of low quality design and materials. These misperceptions are still known today. Prefabrication and sustainability will be discussed, as they are important economically and environmentally in today's architecture. These ideas are used to assist with the design of an architecturally integrated cycling facility. Prefabrication with sustainability addresses the environmentally, self-sustaining ideas used to arrive at a new design solution.

Within the prefabrication section the idea of kit-of-parts idea will be reviewed. This section explores the kit-of-parts, an approach that uses an array of parts that are pre-manufactured

and brought to site to be assembled. The exploration of a kit-of-parts approaches differ from other prefabrication methods. This method of prefabrication allows for a large amount of adaptability and further portability. Kit-of-parts with standardised parts are known to be cost effective as parts are repetitively made. Standardised parts often result in a standardised result but this thesis investigates using these parts in a variety of ways to produce something that appears to be different. This also allows the building to be assembled easily allowing for portability and adaptability. These ideas will be used towards a new solution for addressing the design problems.

Following on from prefabricated architecture and the kit-of-parts is mass customisation. Mass customisation offers the client many options based from one base mode. The techniques used in mass customisation allow a machine to produce a part that has minor changes made towards it to suit the clients' needs. A series of parts are made but each is different. In comparison the kit-of-parts idea uses standardised parts that are assembled together, where mass customisation is an extension of the kit-of-parts idea. Allowing standardised parts to be customised, this part may be different to the part made before and after it. From mass customisation, this thesis takes on board specifically the techniques used in making varied parts. As a result of mass customisation a series of final products are produced which are each different. The techniques from this result will be used to assist with adaptability and economic production.

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PREFABRICATION: BACKGROUND.

This section discusses prefabrication and how it is closely related to sustainability in today's architecture. In the early twentieth century prefabricated architecture allowed clients to pick their new home from a catalogue. The home is built indoors in a warehouse offsite. This allowed production to be controlled and brought costs down. This method of construction still exists in today's prefabricated architecture.

Human housing is a matter of mass demand. Just as it no longer occurs to 90 percent of the population to have shoes made to measure but rather buy ready-made products that satisfy most individual requirements thanks to refined manufacturing methods, in the future the individual will be able to order from the warehouse that housing that is right for him. It is possible that present-day technology would already be capable of this, but the present-day building industry is still almost completely dependent on traditional, craftsmanly construction methods. Walter Gropius (Wohnhaus-Industrie) 1923 (Bergdoll & Christensen, 2008, p. 12)

This statement from Walter Gropius published in 1923 in *Wohnhaus Industrie* states the opportunities offered by a manufactured house over traditional building. At the same time (1923) Le Corbusier published *Toward an Architecture*; it was here his thoughts about early prefabrication were also discussed. He envisioned a house as a machine or tool for living. He was influenced by the design and manufacturing of vehicles and aeroplanes. Here Le Corbusier experimented with these ideas producing his patented Dom-ino structural system in 1914. It consisted of pilotis elevating the building off the ground, a series of load bearing columns which allowed open plan interiors, horizontal windows and a flat roof plane. This experimentation resulted in a structural system that is standardised allowing everything to fit within this system.

During early history of prefabrication there were issues that deterred the public from building with prefabrication. Even though prefabrication allowed fast construction and cheaper overall costs the issues were mainly misperceptions of prefabrication. In the United Kingdom, prefabrication was regarded as having poor material quality and bad design as exemplified by the temporary prefab programme of the post-World War II era. Even though this programme was temporary and the buildings survived their proposed duration, visible deterioration after the proposed duration provided negative connotations towards prefabrication. During this era negative perceptions of prefabrication regarding quality issues unfortunately became well established (Bell, 2012, p. 41). Prefabrication also suffers from aesthetic misperceptions with standardisation. In the past decade, this misperception about standardisation began to be challenged:

Prefabrication does not necessarily imply either mass production or standardisation. In fact none of the three terms necessarily implies the other two. Standardisation is not essential and mind-numbing monotony is not inevitable. (Colin, 2005, p. 205)

These misperceptions have allowed members of the public to gain a false understanding of what prefabrication really is. These misperceptions provide a background in this research allowing overall strengthening of the prefabrication idea. The design of a successful prefabricated cycling facility must look at designing with the intent that these misperceived ideas are not stimulated.

Misperceptions aside prefabrication today focuses on contemporary design that is sustainable. Prefabricated architecture has a close relationship with sustainability. Reduced building waste, minimalised transportation to site and future reuse are the main sustainable issues that prefabrication can address. Prefabrication generally leads to fewer deliveries to site compared to traditional construction methods, therefore reducing the carbon footprint of

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each building. Sustainable approaches to prefabrication also lead to less building waste. As the building is built indoors, this allows for a far better waste management with more efficient use of materials and ordering of exact amounts. Additionally, any waste can be easily collected and reused or recycled. There is further potential for reducing waste when using prefabrication if the designer is prepared to co-ordinate sizes so that standard materials such as timber and gypsum sheets are used without creating any offcuts (Gorgolewski, 2008, p. 127). Prefabricated architecture in its greenest form is designed for disassembly and potential future reuse of material and components (Bell, 2012, p. 40). These sustainable processes are what benefit prefabrication. These benefits would also draw more interest from the public, and they would further reinforce government initiatives toward sustainability that form the basis for increasing cycling in our communities. For the bicycle pavilion, sustainable approaches should be used. Using sustainable approaches will allow for a better perception towards prefabrication but more importantly reduce criticism for waste from the public. Self-sustaining services will also be adopted. These services are used in conjunction with the bike workspaces and rest spaces.

PREFABRICATION: KIT-OF-PARTS.

A kit-of-parts approach lends itself to cheaper and more efficient manufacturing and is a clean way of constructing a building without having to deal with loose ends associated with the complexities of unorganised raw materials. (Howe, 1999, p. 165)

The kit-of-parts theory involves organising the millions of individual parts of a building into assemblies of standard easy-to-manufacture components, sized for convenient handling. (Howe, 1999, p. 165) It allows buildings to be cheaper and more efficient than traditional construction. This building system consists of several individual parts. The aim for this system is to allow easy manufacturing of parts and installation. This system also allows for the transportation of the parts to be delivered to site easily. Traditional construction methods are built in a real time situation. Where it is built, there it will remain. Traditional construction requires raw materials, tools and buildings to be gathered at the site where the construction will proceed. The processing of raw materials will be the main consumer of labour. The idea of the kit-of-parts is that all parts are prefabricated and then brought to site to be assembled. With kit-of-parts, the prefabricated parts have already been processed and test fitted before they reach the site. The assembly on site is fast and clean with minimum labour and tools and material processing used.

How does the kit-of-parts system differ from prefabrication? The kit-of-parts system is a form of prefabrication where the kit-of-parts components are able to be replaced and dismantled entirely down to the nuts and bolts.

One potential weakness of kit-of-parts is that the construction system involves a higher level of design resolution. The design aesthetics can be compromised due to the need to design the process of assembly. Here co-ordination between designer and manufacturer is imperative. At the human furniture scale the

2. LITERATURE REVIEW

designer and manufacturer must communicate how the furniture piece is constructed, normally through an instruction manual. In architecture, the designers and the manufacturer must communicate even further. Kit-of-part designs need to consider the method of construction. The designer is to create a parts list which he/she has processed from the overall design. Within that list of parts connections between each element are defined. The kit-of-parts philosophy looks towards manufacturing through automation with a systematic approach. The essence of this is to introduce a form of low cost and efficient manufacturing.

The overall design with the kit-of-parts shall attend to:

- *Systems that are composed of separated components that can be connected or integrated together*
- *Systems that allow components to be added or replaced without affecting the rest of the system*
- *Systems that can create spaces of differing scale through repetition of components.*
- *A 'modular architecture' that easily allows the addition or subtraction of components and can enhance the flexibility of usage and maintenance of a built structure. (Luther, 2009, p. 7)*

The kit-of-parts system offers a high design resolution and quick assembly. For this thesis this method can be the gateway to an easy to assemble and easy to transport bicycle facility.

MASS CUSTOMISATION.

You have a choice. Build architecture the way Henry Ford showed you to build automobiles at the turn of the twentieth century.... Or, build architecture the way Michael Dell builds his computers at the beginning of the twenty-first century. Use what is appropriate. Let the customers have it their way. And have it faster, better and cheaper. (Kieran & Timberlake, 2004, p. 133)

Mass customisation evolved from prefabricated architecture; it provides us with more choices and allows clients to express their style and individuality. Commercial companies such as Dell Computer Company, Nike Shoe Company and the automobile industry have already been marketing their mass customisation products. These products meet clients' needs by creating choices, in real time, at lower cost and at higher quality. As these products break down into small parts, companies can allow for more choices for clients (Kieran & Timberlake, 2004, p. 133).

Mass customisation is the rejection of the one size fits all model. The one size fits all model works with all designs, all projects, at all sites with all clients, today this model does not appeal to clients. Mass customisation offers the client many options based from one base mode. Phillip Anzalone of Columbia University states that mass customisation proposes a new process to build using automated products with the ability to differentiate each piece from those fabricated before and after (Anzalone, Vidich, & Draper, 2008, p. 298). This allows the ability to differentiate architecture based on site, use and desire. Mass customisation is an extension of the kit-of-parts idea with the use of developing digital software and CNC machines. Components can be made that have minor changes made towards them. These components can be used towards a kit-of-parts that becomes more adaptable.

As this thesis takes on the idea of the kit-of-parts, mass

2. LITERATURE REVIEW

customisation techniques will also be taken on-board. As a result of mass customisation, a series of components will be produced which are each different. The results will be used to assist with adaptable, economic production.

DISCUSSION.

This chapter considers design approaches that contribute to the design of models for cost-effective, easily fabricated, energy-efficient cycling infrastructures. To provide a new solution to this problem an architecturally integrated bicycle facility will be explored that uses kit-of-parts integrated with mass customisation opportunities for greater site adaptability.

Literature on cycling infrastructure expresses the need for safer and practical facilities to improve cycling experiences. This review with the growing number of cyclists on the road has confirmed that there is an inadequate amount of infrastructure to support cycling. From this review cycling facilities such as bike workspaces and bike rest spaces are needed. Bike workspaces are needed to support cyclists when they need to work on their bike. This also removes the cyclist from the side of the road. Rest spaces and toilets are also needed as more cyclists would lead to higher demand. These self-sustaining facilities are needed especially in remote locations. The goal is to provide safer and practical cycling and promote cycling in a way that expresses a suitable method of transport and exercise.

Literature on prefabrication as a method of building was reviewed because it featured cost effective and sustainable methods of production. Negative perceptions of prefabrication come from many misperceptions that the public have experienced. These misperceptions have allowed the public to gain a false understanding of prefabrication. These issues have been reviewed so that the new designed facility that is to be prefabricated does not stimulate these misperceptions. The ideas from sustainable approaches towards prefabrication have been reviewed as the new design solution looks at environmentally friendly and self-sustaining results in design. Methods used to lowering building waste, reducing off cuts and the pavilion's overall carbon footprint will be explored. As the designed facility will be produced for the public, sustainable approaches are

2. LITERATURE REVIEW

suitable as it reinforces government initiatives, reduces criticism and provides a better perception towards prefabrication.

The kit-of-parts idea examined how this method of building can produce a new bicycle facility that is to be used as additional cycling infrastructure to the Great Harbour Way. The kit-of-parts literature has been looked at because it allows for a cost effective method of building as well as the opportunity to allow for adaptation and portability. These ideas are delivered from parts. These parts can be supplied to suit requirements and would allow for a different appearance and parts configurations. Along with the kit-of-parts findings, the findings from mass customisation are to be integrated.

Mass customisation, a further evolution in prefabrication, reflects the needs of the clients. This model allows for customisation of clients specifications. By using advancing digital software and CNC machines these customisations are made possible. From this literature the technique from mass customisation will be taken on-board. This becomes helpful in situations where accurate cutting is needed to produce less offcuts and parts that may be multipurpose are made accurately. The combination of the findings from the kit-of-parts and mass customisation results in environmentally friendly and economic production that also enables adaptability and portability.

3. CASE STUDIES

INTRODUCTION.

This chapter reviews existing case studies which can contribute towards a new model of cycling infrastructure. While some case study examples resolve some of the issues facing cycling facilities, there are currently no overall models for cost effective, easily fabricated and assembled, energy efficient cycling infrastructures. This issue is answered through designing a facility that is uniquely architecturally integrated, self-sustaining, adaptable, economically-produced, environmentally-sensitive and portable with global applicability. The first case study is the Bike Fixtation of Minneapolis. This case study has been chosen as it has resolved solutions towards anti-vandalism within public exposure. Although the Bike Fixtation participates as cycling infrastructure in Minneapolis it does not address energy efficiency and would not be suitable in remote situations. The Hydroleaf case study features a self-sustaining unit that provides amenities such as water and lighting for members of the public. This facility addresses issues of environmental sensitivity, portability and global applicability. This case study is deficient in providing adequate shelter and does not support cycling very much in terms of resting and repairing. The case study of the Mount Whitney Trailhead Prototype has been reviewed as the prototype uses prefabrication techniques to address issues regarding difficult site conditions. The prototype features prefabrication techniques that are easily fabricated and easy to install. Although this case study is highly successful in prefabrication, it does not include facilities such as a water fountain or cycling workspaces. The Trusset system, an exhibition at the University of Columbia, has been reviewed because of its techniques used toward producing parts that are easily assembled. This case study does not focus solely on prefabrication or cycling but it does extract ideas from the kit-of-parts. These techniques provide a method of production which will cater towards easy manufacturing

while being environmentally sensitive regarding building waste. The Click-raft by Chris Moller of CMA+U and colleagues is a case study that focuses on the ideas of quick assembly that enabled cost effective, adaptable production that was environmentally sensitive. The Click-raft features standardised parts that allow the overall building shape to be different due to the effects of site and client desire. But the parts are only limited to specific configurations. This information has informed this thesis by acknowledging the effects of standardised parts that lead to limited configurations. The combined findings from each of these case studies contribute towards a solution for cost-effective, fabricated, energy-efficient cycling infrastructural models.

3. CASE STUDIES

BIKE FIXTATION BY BIKE FIXTATION.

Above 1: Figure 03-001 Bike Fixtation with powder coated finish and tools

Above 2: Figure 03-002 Bike Fixtation with electronic vending machine

The Bike Fixtation kiosks in Minneapolis are a bike fix station that is placed within public transport infrastructure. The Bike Fixtation addresses the issues of vandalism in a publicly exposed place. The Bike Fixtation is a bike maintenance kiosk where a cyclist can simply purchase products and make adjustments to his/her bicycle. The kiosks are currently located at two sites in Minneapolis, both at transit stations with goals to expand public modes of transport as well as cycling. They consist of a public bike pump, bike stand and a high security vending machine offering inner tubes, patch kits, locks, snacks, drinks and other cycling necessities. These physical products are all enclosed for extra security (Bike Fixtation, 2012). Although the Bike Fixtation provides a space for working on bikes, the vending machine of this kiosk is not self-sustaining as it requires electricity off a mains supply. Also the kiosks do not provide other facilities that cyclists need. Facilities such as rest spaces, water supply and toilets are not provided at these kiosks, although they are available in the vicinity.

The Bike Fixtation not only focuses on providing a self-service kiosk which only allows bikes to be maintained but also focuses on the security of the system. The bike stations are situated in urban environments open to everyone in the public. As the operating hours are long, security is one of the main priorities in its design. The components that combat against vandalism feature TIG welded steel elements for strength and powder coated surface for durability. A universal bike stand is used. This stand is simple, low maintenance and allows any bike to be hung from the seat. The stand also provides tools. The tools individually are attached to the stand with aircraft cable. These components will be adopted into this thesis as they feature a simple way to reduce the chances of components being stolen or vandalised.

The inventors are pitching this idea to cities, organisations and individuals across the United States as a cyclist's dream vending machine. Along with car sharing and public transport the bicycle kiosk becomes a resolution to current transportation issues. Even though the pragmatics of this idea are resolved there are issues of funding, location and ownership that may affect the expansion of this facility. Currently there are only two of these kiosks available to the public.

3. CASE STUDIES

HYDROLEAF BY MOSTAFA BONAKDAR.

The Hydroleaf looks at a form of public infrastructure to provide shelter and drinking water. This form of public infrastructure is self-sustaining and easy to install. This case study focuses on its structure and its systems used to provide shelter and drinking water.

The Hydroleaf is simply a shelter which also collects water and provides shelter from the sun and rain for 'developing arid regions'. The program of this design is a bus shelter, a street light, rainwater collection system and drinks dispenser all in one. The shelter turns rainwater into drinking water through filtration. The drinking water filtration unit is powered by a solar cell panel, which is also the overhead shelter and the water collection device. The shelter can store up to 60 litres of water and can be obtained warm or cold. Along with these programs the tip of the panel includes a small street lamp for night time illumination. The Hydroleaf placed by a bus stop or in a park is a form of infrastructure that provides several programs for members of the public. (Selleck, 2010)

The triangular solar panel becomes the canopy of the shelter. It is 1900mm long and 1150mm at its widest point. The water streams down at 15 degrees downwards to a point, where the water is collected into the filtration system. The canopy is cantilevered off the central cylinder. Within the central cylinder is the water's filtration system and dispensing unit. Multiple numbers of these shelters can be combined to house more users.

The design of the shelter features programs which are self-sustaining; therefore this unit can be standalone. The shelter is also not site-specific; therefore it can be placed anywhere in the world. The systems are placed in layers hidden within the cylinder. The layers consist of water storage tanks, water filtration systems, water pumping system, solar power

Above 1: Figure 03-003 Hydroleaf facility with configuration of 5

Above 2: Figure 03-004 Hydroleaf with separated systems

components and solar power storage. Each layer of components is then put together to work as a whole.

Even though the design is not site-specific there are missed opportunities for issues of addressing wind shelter and angular rain and sun shelter. These adverse conditions may be present where the shelter is placed. The solar panel canopy is a relatively large cantilever. Supporting the canopy is a 300mm diameter cylinder. This cylinder is securely bolted into the ground to allow the canopy to cantilever.

Opportunities which the shelter should have taken into account would be the variable angle of the solar panel. Solar panels would be most efficient when the panel is directly facing the sun. The 15-degree angle is relative to the earth latitude angle. It would not be as efficient if it were located far north or south greater than 15 degrees.

This standalone system is a form of infrastructure that provides several programs for the users. The standalone system allows interaction with its users, the users being the people walking or waiting for a bus. This system due to the overall size allows the entire unit to be transported and placed anywhere. The parts here are all assembled in the factory. Additions and replacements are able to be made towards this system. This case study addresses issues regarding portability, self-sustainability and environmental sensitivity.

Above 1: Figure 03-005 Hydroleaf facility with night lighting

3. CASE STUDIES

MOUNT WHITNEY TRAILHEAD PROTOTYPE BY ANDERSON ANDERSON ARCHITECTS.

The Mount Whitney Trailhead Prototype by Anderson Anderson Architecture is located in the Inyo National Forest in California, United States of America. The prototype uses the ideas of prefabrication in the form of kit-of-parts with the majority of the manufacturing done in the factory. As the National Forest is remote the delivery of the prototypes in part form offers an easier method of delivery and building. This attends to issues regarding building on extreme site conditions. The prefabricated structures focus on providing an orientation marker and facilities for climbers.

The project was a collaboration between the College of Environmental Design and the National Forest Service. Over the years of use the Forest Service has been making the public aware of maintaining trails and environmentally sensitive hiking. The increasing trail use created the need for infrastructure at the trailheads. Programs such as toilet stops, garbage disposal, warning signs of surrounding dangers and educational signage needed to be housed. The primary objective for the project was to create a prefabricated structure that would be able to screen light and signage along with infrastructure that can blend seamlessly into the landscape. It was to also become a clear marking point especially at night (Whitney Trailhead Prototype, 2005).

Mount Whitney has the highest summit in the United States with an elevation of 4421m above sea level. The Mount Whitney trail is the most popular route to the summit. The trail starts at the Whitney Portal at an elevation of 2550m; the hike along the trail lasts for 35 kilometres round trip with an elevation gain of 1900m. Permits are required to prevent overuse between May to November. The National Forest Service commissioned this design to celebrate their 100-year anniversary.

This design includes a series of prefabricated

Above 1: Figure 03-006 Trailhead prototype in Mount Whitney context

Above 2: Figure 03-007 Trailhead prototype with night lighting

structures to provide support for the users of this park. These structures were to be at points of departure. Due to the nature of the surrounding terrain these structures had to be brought to site and assembled onsite.

The structure was a combination of parts consisting of large CNC pine columns with galvanised steel mounting plates and cross bracing. This combination produced the primary structural frame. The secondary element contained a screen of small pine strips which provided the sun shading and the space for educational and notification signage. The cross bracing is a lattice of stainless steel wire which is fastened together with turnbuckles and karabiners. The karabiners were also used to reference the long mountain climbing history of the site. (Anderson & Anderson, 2007, p. 48)

The sites consist of extreme site conditions such as varying altitude and extremely high and low temperatures. During the summer season the track is open to climbers. During this season the climbers are to apply for a permit to gain access to this park. The climbers normally make their ascent early in the morning to avoid the high temperatures later in the day. The large numbers of users need facilities and information to support their ascent and encourage awareness of environmental sensitivity as well. Programs such as toilets, rubbish disposal and warning signs are needed to do this. The design of the prefabricated structures becomes an aid for the users of the park.

These structures are prefabricated in the form of parts. The structure as a kit-of-parts would be assembled in the factory to test that the system works. After prototyping, multiple kits can be sent to their allocated sites. The kit-of-parts system used a combination of wooden columns, mounting plates and steel tensioning wire. This system became the main structure; minor elements were then attached. In this case the kit-

of-parts system worked in a way which allowed assembly on multiple locations easily, although each installation is identical.

Above 1: Figure 03-008 Trailhead prototype with prefabricated fixings.

3. CASE STUDIES

TRUSSET SYSTEM GSAPP BY PHILLIP ANZALONE AND CORY CLARK.

The Trusset system is a patented structural wall system invented at the DFL by Phillip Anzalone and Cory Clark (Anzalone, Vidich, & Draper, 2008). It was designed for the GSAPP's (Graduate School of Architecture, Planning and Preservation) 125th Anniversary Installation at Columbia University. The Trusset system uses mass customisation techniques along with kit-of-parts assembly methods. In this case study both these ideas overlap; they look at mass customisation through easy manufacturing and as a product, producing a large array of parts that are to be assembled. This case study also looks at the procedures required in computer-generated design of physical elements and how parts are sorted to avoid confusion.

The Trusset system was to function as both a wall partition and furniture. The space-trusses are highly efficient structural systems that allow for spanning long distances. This Trusset system focuses on easy manufacturing with 3-axis CNC laser cutter and easy assembly with unskilled labour. This system contrasts the traditional manufacturing and assembly methods. The joining brackets, were manufactured from aluminium sheet material and shipped flat to site allowing easy transportation. The project featured a node and strut system with each component being different due to its irregular form. To combat the confusion the parts were catalogued digitally before they were fabricated. Once fabricated, each component needed to be labelled digitally. This was their method to allow clarity.

The Trusset was an inventive system which allowed easy assembly with unskilled labour. Although this was seen as easy manufacturing and easy assembly the overall assembly would have been complicated. The system had thousands of little parts which required labelling after they came out of the CNC laser cutter. The majority of these parts were joining brackets

Above 1: Figure 03-009 Trusset system at GSAPP
Above 2: Figure 03-010 Laser cut components of the trusset system

made of thin aluminium. The remainder of the structure was the struts and panels that are each different in length and shape. These struts and panels are to be connected to the aluminium joining brackets. This was seen as the most efficient way to produce this kind of structure. Using a range of techniques to produce an array of parts will make the assembly easier. Small joining parts that connect the larger components are what Trusset structure has done. This is also what this thesis design experiment will do as this can simplify the method of assembly.

Above 1: Figure 03-011 Prepared parts for installation

Above 2: Figure 03-012 Test construction of the Trusset system

3. CASE STUDIES

CLICK-RAFT BY CHRIS MOLLER.

The Click-raft by Chris Moller of CMA+U and colleagues in Wellington began with experiments towards an evolutionary architecture. This case study focuses on the ideas of quick assembly, cost effective production, adaptability and environmental sensitivity. This case study contributes towards the prefabrication side of this research. The Click-raft features a range of CNC cut timber “Click-leafs and Click-beams” that are clicked together to produce a lattice-like structure (Southcombe, 2012, pp. 117-118). These standardised panels can be assembled quickly through DIY or by builder and are cost effective to produce.

This system does not have a fixed shape; this way it can be assembled according to the building’s purpose and builder/client’s desire. The idea behind this is that it is a new and more intelligent way of building. The building is also easily understood, allowing the owners to adapt or tune the building towards suitable environmental and site conditions. The standardised panels allow for the building to become easily adaptable. The standardised parts are the most important regarding the design even though standardised parts only allow for limited variations. The design resolution must consider many variations that each part is going to engage. The limited variations may result in failure to do something that is needed. The building also integrates the cladding, data networks, electrical systems and water systems into the structure.

Above 1: Figure 03-013 Click-raft system

Above 2: Figure 03-014 Standardised parts of “click-leafs and click-beams”

Above 3: Figure 03-015 Minor fixings needed

Currently the Click-Raft offers four variants that change in size and purpose. There is the minimal version which is geared towards emergency relief shelter. The unit footprint is 10m2. The “basic” variant is geared towards a spare room or a garden office. This unit is 30m2 and features insulation and an operable opening façade. A larger variant such as “Type 03” is geared towards retail and business as it features

a 200m² floor area. Lastly the “Extended” unit is prototyped for more advanced needs. This 30m² unit offers energy generation and storage. This variant also adapts to changing conditions and has almost no impact on the environment when disassembled (Dankert, 2011).

This case study does not look at cycling infrastructure but does have solutions that can contribute towards the new cycling infrastructure in this thesis investigation. This case study has focused on using standardised parts to produce an easily adaptable structure. These standardised parts do not result in standardised buildings that all look the same. The standardised parts allow for the overall building shape to be different due to the effects of site and client desire. Although standardised parts allow for this, the parts are only limited to specific configurations. This information has informed this thesis regarding limited configurations caused by standardised kit-of-parts.

Above 1: Figure 03-016 Click-raft prototype made from laser cut ply wood sheets

3. CASE STUDIES

DISCUSSION.

This chapter has looked specifically at five case studies that can help address the issue of a lack of cycling infrastructural models that focus on cost effective, easily fabricated, easily assembled and energy efficient prefabricated architecture. Bike Fixtation was integrated with existing public infrastructure. Located at transit stations, exposed to the public, the Bike Fixtation addressed issues of security along with a space for working on bikes. The Bike Fixtation addressed issues of security with the use of TIG welded, powder coated components such as the bike work stand. This stand is also low maintenances and free from wearing parts. Aircraft grade cable was also used for securing bike tools. The Hydroleaf was a case study which was highly successful as a self-sustaining unit. The unit provided a shelter which collected rain water and solar power. The collection of water became filtered drinking water. The solar power was stored to become night lighting. These facilities are small and effective. Collection of potable water that comes down to one point is a very efficient method of water collection and would be important for the thesis. Even though the solar panels were architecturally integrated into the design, the solar panels will need to be modified to take full advantage of solar gain. The shelter was too small and did not take into account wind or angled rain. These two aspects of the weather will need to be thought about in this thesis.

The Mount Whitney Trailhead Prototype was a form of infrastructure that was developed for climbers. This case study created solutions towards extreme site conditions. Through the idea of a kit-of-parts, the prototypes were first tested in the warehouse before transporting them onto site. In the next case the Trusset system produced a large array of parts that were produced through computer-generated design with CNC machines. This method of production allowed for easy production of

parts that are easily assembled. This case study also separated out parts from large and small. Small parts became joining components between the large components. The small joining parts become the most important parts of this system. This method of parts assembly is efficient and reduces confusion. This method will also be applied into this thesis to support the assembly of new cycling infrastructure. The Click-raft looked into standardised parts. These parts have been designed to allow for the overall building shape to be different due to the effects of site and client desire, making it adaptable. Although standardised parts allow for this, the parts are only limited to specific configurations. This review has informed this thesis regarding limited configurations that standardised parts may cause.

3. CASE STUDIES

4.1 SITE ANALYSIS

INTRODUCTION

This chapter introduces the site, which is the coastal edge stretching from Owhiro Bay to Eastbourne. The coast edge will be critically analysed to find ways to test the design experiments. The analysed site locations will provide supporting information which will be used to produce a designed outcome.

Firstly this chapter discusses the Great Harbour Way/ Te Aranui o Pōneke, the limits of this site and then critically analyses the topographical changes, the main highways and the edge conditioning of the site. This thesis is focused on developing an architecturally integrated facility that is self-sustaining, adaptable, economically-produced, environmentally-sensitive, and portable and is able to be applied globally. This chapter will analyse how the site will allow this thesis to meet these objectives. The chapter will analyse five sites representing different conditions along the Great Harbour Way. This analysis will be more indepth as it looks at these selected sites individually. Here the analysis will take account of the differences and similarities between the selected sites.

Located in the lower North Island of New Zealand the Greater Wellington Region showcases the area's diverse landscape and weather conditions. The Great Harbour Way developed by the Greater Wellington Regional Council will be the vehicle for the proposed design experiments. The site is significant in its numbers of daily commuters who head in and out of the city along the Great Harbour Way. The creation of the Great Harbour Way allows walking and cycling around the Wellington Harbour. The entire route spans from Owhiro Bay in the southernmost corner of the region to the small suburb of Eastbourne at the north-western section of Wellington Harbour. The route offers a rare opportunity for walkers and cyclists to experience the entire shoreline of the region. On one side is the always-present Wellington Harbour with the Harbour entry or

Cook Strait in the distance. On the other side is the ever-changing Wellington terrain.

— Great Harbour Way
State Highways

4.1 SITE ANALYSIS

CONTEXTUAL STUDY

The primary incentive for this thesis was generated when the Greater Wellington Regional Council gave the go ahead for a new bicycle track development along the harbour. The significance to the Council and the public gave the Harbour Way the number two funding priority. My research will contribute to the development of the Great Harbour Way. The thesis examines how the council can best provide for cyclists with rest, rehydration and repairing of bikes.

On either side of the Great Harbour Way are diverse landscape conditions. On one side the landscape conditions are steep and on the other side they are rocky. The cycle way which is in the middle of these diverse conditions is the zone where cyclists are able to ride. The diverse landscape conditions will be implicated in the design of the pavilions as they are to be placed at regular intervals.

The Great Harbour Way meets the state highways at a few points. These sections are where safety is most important to be considered. The traffic speeds are high and the space for cyclists is limited. Firstly the two routes meet on their way towards the airport situated across from the Miramar Peninsula. The next point they meet is at the off ramp of State Highway One at the base of Ngaraunga Gorge. The State Highway One leads directly north. At this point of the Great Harbour Way the cyclists have the option to ride in conjunction with State Highway Two for a more direct ride or take the shared path with the walkers on the seaside of the State Highway. This section of the Great Harbour Way is to undergo a redevelopment through the Greater Wellington Regional Council and Land Transport New Zealand.

Opposite: Figure 04-001 *The Great Harbour Way in the context of Wellington Harbour*

4.1 SITE ANALYSIS

SITING EXPERIMENTS

An essential part of the site analysis is to determine where the facilities are to be placed. This section will look at the most appropriate regular interval where the facilities will be placed. This will consider how often cyclists need a rest stop. A cyclist would not need to stop and rest at every kilometre but cyclists would eventually need to stop for drinks breaks, the toilet and bike repairs. The diagram shows stops at every five kilometres, which would ensure that no cyclist would have to walk more than 2.5 kilometres to a repair facility. This would allow cyclists to have water, toilets, shelter and puncture repair facilities and also allow cyclists to know how far they have travelled.

As an early experiment the five kilometre intervals were placed long the Great Harbour Way starting at the pier at Eastbourne. This allowed me to see where each of the facilities is located along the route. Next, keeping with the five kilometre intervals all of the locations were shifted along the route to see what other locations were most suitable.

Opposite: Figure 04-002 *The Great Harbour Way with location experiments, surrounding cycleways and state highways*

4.1 SITE ANALYSIS

SITE LOCATIONS

At this point the distances between each facility have been set at five kilometre intervals allowing cyclists to consider their travelling distance with the support of cycling amenities. With the locations set along the Great Harbour Way I can now analyse the locations. This indepth analysis will further help with my research objectives.

An analysis of the altitude shows the altitude profile over the entire cycle route. This course map can allow me to determine the route's terrain condition surrounding the stops. From one direction a high altitude reading would determine that there is a large climb. The analysis of the altitude profile shows the graph at sea level. The maximum height above sea level is 20 metres. This is considered mild compared to other larger cycle circuits around New Zealand.

Opposite: Figure 04-003 *The Great Harbour Way with pavilion locations and altitude diagram, surrounding cycleways and recreational spaces.*

4.1 SITE ANALYSIS

WEATHER CONDITIONS

The site's diverse weather conditions are analysed and provided as a tool to establish requirements for different facility configurations. The weather patterns determine how the facilities can shelter the cyclists when they have stopped. As analysed Wellington has a great amount of wind. This reading was provided by NIWA from the Wellington Airport. The wind predominantly blows in the north south direction. The north to south wind is high and more frequent. The wind from south to north is the cooler breeze but it is less frequent and less intense. These winds along with the surrounding terrain will determine the configuration of wind shelter needed at these site locations. The terrain plays a part as it may funnel or shelter the wind along these specific locations.

Opposite: Figure 04-004 Sunpath and wind diagram within the context of Wellington Harbour

4.1 SITE ANALYSIS

SOLAR ENERGY

Wellington's sun direction relative to the Great Harbour Way shows that the majority of the route is covered with sunlight at certain times of the day with some locations limited due to the surrounding terrain.

The southernmost section of the route will have limited direct sunlight at certain times. **Figure 04-005** Shows the sun's energy output to one metre of surface area. These measurements have been taken at the most northern (Hutt Road), southern (Wahine Memorial Park), western (Owhiro Bay) and eastern (Eastbourne) proposed site locations. These diagrams allow us to determine the energy output during all seasons. The facilities will act as satellites around the Great Harbour Way which collect energy. This energy will allow the facility to power itself. The facility will provide night lighting indoor and outdoor and recharge a cellular phone in emergency situations.

Opposite: Figure 04-005 Solar energy diagrams per metre of surface area.

Site Condition: Type A
Location: Kaiwharawhara
Context: Highway
Terrain: Flat

4.1 SITE ANALYSIS

SITE TYPE A

Site A is located in Kaiwharawhara. This location is flat with hills towards the northwestern side. This site is located on a fast stretch of road. The hill shelters the strong northerly but the cool southerly wind is funnelled through. The site gets sun most of the day with the landscape blocking off the sun in the late afternoon. The design objectives for this site condition require a facility on a flat terrain capable of sheltering from the tunnelling southerly wind and from the road.

Opposite: Figure 04-006 Site Condition type A
Above 1: Figure 04-007 Site location from north
Above 2: Figure 04-008 The road looking north highlighting fast traffic.

Site Condition: Type B
Location: Chaffers Marina
Context: Urban
Terrain: Flat

4.1 SITE ANALYSIS

SITE TYPE B

Site B is located in central Wellington near Chaffers Marina. This site is surrounded by recreational activities. This causes a large amount of foot and cycle traffic as there are more active people. This site is exposed to strong northerly winds. This is caused by the harbour being very open. On this site there has been a large amount of landscaping done so the shade from this landscaping shelters the southerly which comes through Waitangi Park. The site is exposed to sun over most of the day with limited direct sunlight during the early hours of the morning. The facility on this site requires shelter from the north with the best views also towards the north.

Opposite: Figure 04-009 Site Condition type B
Above 1: Figure 04-010 Site location from Chaffers Marina
Above: 2 Figure 04-011 Site location from Te papa

Site Condition: Type C
Location: Hataitai
Context: Recreational
Terrain: Flat

4.1 SITE ANALYSIS

SITE TYPE C

Site C is located in Hataitai. It is located at the boatsheds of the centre point of the bay. This flat site also is surrounded by recreational activities but has not much foot traffic. The area is exposed to the southerly wind. The hills to the northwest provide shelter from the northerly. The sun is also exposed during most of the day with limited sun in the late afternoon. This site offers 180 degrees of view with most of the water view looking towards the southeast. The facility on this site would require shelter from the southerly and provide views out over the harbour towards Shelly Bay and the airport.

Opposite: Figure 04-012 Site Condition type C
Above 1: Figure 04-013 Site location from south
Above 2: Figure 04-014 Site location from apex of the road.

Site Condition: Type D
Location: Seatoun
Context: Residential
Terrain: Rugged

4.1 SITE ANALYSIS

SITE TYPE D

Site D is located in Seatoun. It is located on a corner very close to the road. The terrain for the facility is rugged and sits half on the run-off and half on the rocks. This site is surrounded by residential houses and is exposed to the sea. There is a hill on the western side of this location and towards the south are the hills entering into Seatoun. This landscape funnels northerlies with the southerly sheltered. Views are provided east towards Eastbourne. The facility would need to be located over uneven land and provide shelter from the strong northerly.

Opposite: Figure 04-015 Site Condition type D
Above 1: Figure 04-016 View of location from south highlighting rough terrain
Above 2: Figure 04-017 The curving road north of location

Site Condition: Type E
Location: Wahine Memorial Park
Context: Park
Terrain: Uneven

4.1 SITE ANALYSIS

SITE TYPE E

Site E is located at the Wahine Memorial Park on the southernmost point of the Miramar the peninsula. This site sits within a large park with uneven terrain. This location is also at the centre point of a bulge caused by the landscape. This location is largely exposed to the southerly as this is the southernmost point of this area. The hills surround the northern side of this location therefore sheltering all of the northerly wind. The hills which surround the site also limit the amount of direct sunlight. The facility will require construction on uneven land and shelter from the cool southerly wind while providing views south over the Cook Strait.

Opposite: Figure 04-018 Site Condition type E
Above 1: Figure 04-019 Site location from north
Above 2: Figure 04-020 Site location from south
highlighting rough terrain

20 Foot	L	W	H
External	20'0"	8'0"	8'6"
	6.1m	2.4m	2.6m
Internal	19'4"	7'8"	7'9"
	5.9m	2.3m	2.4m
Door Opening	19'4"	7'8"	7'6"
	5.9m	2.3m	2.3m
Capacity	1195(cu ft)		
	32.5m3		

40 Foot	L	W	H
External	40'0"	8'0"	8'6"
	12.2m	2.4m	2.6m
Internal	39'6"	7'8"	7'9"
	12.0m	2.3m	2.4m
Door Opening	39'6"	7'8"	7'6"
	12.0 m	2.3m	2.3m
Capacity	2440(cu ft)		
	63.5m3

4.1 SITE ANALYSIS

SITE: CONTAINER

As an additional opportunity for exploring successful design solutions, a shipping container will be included in this site analysis. The shipping container is a site where the facility would be disassembled, packaged and shipped to other locations allowing portability. This relates to the design objectives of portability and global application, so it is important that the dimensions of a standard container are taken into account. The disassembled facility will initially be located inside the container from its manufacturing warehouse. Once the facility has arrived on site the facility will be assembled.

Standard shipping containers are 20 and 40 foot sizes. The 20 foot container externally is 6 metres long by 2.6m high and 2.4m wide. The shipping containers are based purely on the volumetric space therefore the internal dimensions will be important, set at 5.9 meters long x 2.4m high and 2.3m wide. These are therefore the maximum length and width parameters for the facilities' parts. The height will be limited when the parts are stacked.

Opposite: Figure 04-011 Container Site Condition
Dimensions

4.2 PROGRAM ANALYSIS

INTRODUCTION.

This program analysis chapter addresses specific parameters that this thesis investigation faces. A successful cycling pavilion should house all necessary programmatic requirements. The pavilion offers a freestanding structure that allows the multiple program elements to be housed within. The pavilion, through the kit-of-parts and new fabrication techniques, offers the opportunity for easier adaptability to site conditions and easier assembly and disassembly.

Bicycle Facilities

Bike Parking
Bike Workstands
Tyre Pump
Workbenches
Minor Tools

Cyclists Facilities

Drinking Water
Cleaning Water
Toilets
Changeroom
Rain Shelter
Wind Shelter
Sun Shelter
Seating

4.2 PROGRAM ANALYSIS

SPACE REQUIREMENTS.

This program analysis uses the dimensions analysed in **figure 04-012**, which are based on standard bicycle dimensions, minimum access requirements, and handicapped toilet requirements. The design will begin as a shell with these dimensions. The development of the shell begins with converting the shell into parts that are architecturally integrated, adaptable, economical to produce, portable and can be transported easily. Within the dimensional requirements the overall spaces are divided into three program zones: bike repair, cyclists' resting area and a toilet.

Left: Figure 04-012 Program dimension requirements

Mountain Style Bicycle
Wheel size: Ø26-29"
Wheelbase: 1100m

Tyre sizes 1.75-2.5"

Hybrid Style Bicycle
Wheel size: Ø26-29"
Wheelbase: 1150m

Tyre sizes 23-40c

Road Bicycle
Wheel size: Ø700c
Wheelbase: 1050m

Tyre sizes 19-23c

SPACE REQUIREMENTS.

Here the analysis looks at the different types of bicycles which would be using the pavilion. These program requirements will become architecturally integrated into the pavilion. There are three main styles of bikes which are mainly used along the Great Harbour Way. A mountain style, a hybrid style and a road style bicycle will be analysed. Each has a different purpose but all have the capability of being ridden on the cycle route. The mountain style would normally be seen on trails but they are often also ridden on the road. Although they are capable of riding on the road, they are normally heavier than the other styles and harder to pedal due to the wide tyres. Within the commuting group of cyclists the hybrid style of bikes is most often used. They provide the comfort of a mountain style bike, but their large diameter wheels and narrower tyres allow them to be as multi-purpose as they are. These bikes are designed with the geometry for comfort and efficiency. Finally a road style bicycle is looked at. This style is the most used bicycle along the cycle route. Because of their efficiency they allow the riders to make the most out of their energy input. Road style bikes are normally not as comfortable for the riders as a hybrid bike. The large size for the integrated bike parking facilities is 1150mm wheelbase with wheel size of 29" and a 2.5" tyre. The overall dimension of the bike is 2014mm. This dimension is based on a hybrid style frame with the largest wheels and tyres fitted.

From this information a universal sized bike parking space will be used. This is to be integrated into the pavilion. The importance of the docking is that the bicycles are secured from thieves and will allow the bicycles to stand without being damaged by another bicycle or vehicle. The pavilion will look at challenging standard bicycle mounting methods by having the mounting system integrated into the pavilion. The mounting system is part of the overall pavilion facility. The bicycle will be the bridge between rider and the pavilion.

Left: Figure 04-013 *Dimension analysis of mountain, hybrid and road style bikes*

Solartech 190W Panels

Opt Operating Voltage (V)	36.5
Opt Operating Current (A)	5.2
Module Efficiency (%)	14.9
Max System Voltage (V DC)	1000
Size of Cells (m2)	0.015
No. of Cells	72
Area of Cells overall (m2)	1.08
Weight (kg)	15.5
Dim L (mm)	1580
Dim W (mm)	808
Dim H (mm)	35

Table 1 Solartech solar panel
<http://www.neolec.com.au/pdf/datasheet/SUN-TECH%20190W.pdf>

TriStar MPPT Solar Controller

Maximum Battery Current (A)	45
Maximum Solar Input (W)	600
Peak Efficiency (%)	99
System Voltage (V)	24
Weight (kg)	4.2
Dim L (mm)	291
Dim W (mm)	130
Dim H (mm)	142

Table 3 TriStar solar controller
www.morningstarcorp.com/en/tristar%20mpp

Solar Output of Wellington

Time Frame	Power Locations along path (kW/m2)			
	North	South	East	West
21 March	4.09	4.18	4.13	4.11
21 June	1.74	1.96	1.94	1.90
21 August	2.59	2.72	2.71	2.26
21 October	4.40	4.43	4.41	4.38
21 December	5.18	5.19	5.19	5.17
Yearly Average	3.6	3.696	3.676	3.564
Avg x 190w Panel @ 15% Efficiency (kW)	0.58	0.59	0.59	0.57

Table 2 Solar output of Wellington

Energy Audit

Loads (Winter)				
Item	Qty	Wattage	Hrs/Day	Total Consump (Wh)
Indoor Lights	4	9	4	144
Outdoor Street Light	1	50	12	600
Outdoor Illumination	4	22	12	960
Cell phone Charger	1	15	0.25	3.75
Toilet Fan	1	0.0025	24	0.06
Total (W)		189	Total	1707.8 =1.7kW

Table 4 Energy audit by www.powersmart.co.nz

Trojan Deep Cycle Battery

Battery Voltage (V)	6
Battery Capacity (mah)	433
Weight (kg)	52
Dim L (mm)	295
Dim W (mm)	178
Dim H (mm)	424

Table 5 Trojan deep cycle battery
http://www.trojanbatteryre.com/PDF/datasheets/L16P_TrojanRE_Data_Sheets.pdf

Energy Output

Item	Wattage	Output	Output/Wattage (lm/w)
Indoor Lights	9	720lm	80
Outdoor Street Light	50	4200lm	84
Outdoor Illumination	22	1800lm	81
Cell phone Charger	15	6v	
Total (W)	189		

Table 6 Energy output
http://www.dmxledlights.com/docs/Solar_LED_Street-lights_Manual.pdf

Studer AJ 1000w Inverter

Battery Voltage (V)	24
Input Voltage (V)	21-32
Max Efficiency (%)	93
Weight (kg)	8.5
Dim L (mm)	428
Dim W (mm)	142
Dim H (mm)	84

Table 7 Studer Inverter
http://www.studer-inno.com/?cat=sine_wave_inverters&id=430

4.2 PROGRAM ANALYSIS

SOLAR ENERGY ANALYSIS.

A solar power system is proposed in conjunction with other systems to make this pavilion self-sustainable. Solar collection is an intelligent system which absorbs the sun's energy and transfers it into electricity. The solar power system provides off-the-grid electricity. This off-the-grid system requires no connection to the mains and all the electricity collected is stored in batteries, which enables the pavilion to function in remote locations. This specific off-grid system has been determined through an energy audit from www.powersmart.co.nz. See **Figure 04-014 Table 4**. This system involves 125 x 125mm photovoltaic cells which are to be fixed where there is exposure to the sun. Often buildings only have a discrete area where solar panels can be placed. The approach to this pavilion allows the solar panels to be integrated. The orientation of the pavilion will be north facing. The north facing orientation allows the solar gain to be maximised; it also enables the overall pavilion to be understood as a directional marker. From these photovoltaic panels the energy is transferred into an electric current which is directed into a charge controller and then into an inverter. Here the charge controller controls and regulates the voltage that comes off the solar panels. Connected in parallel are the inverter and the battery in which surplus energy is stored. The inverter here converts the voltage from 24 volts DC to 230 volts AC. From this point energy is readily available for night and day lighting. The batteries are different from a standard car battery. Deep cycle batteries are used because they hold charge for longer and allow many cycles through before they need to be replaced. Expected usage for these batteries would be 10 years. Each battery weighs 50 kilograms. **Figure 04-014 Table 5** outlines the technical specifications.

Left: Figure 04-014 Solar energy components and diagrams of solar output of Wellington, energy audit and energy output

Left: Figure 04-015 GNS diagram latitude angle and with north correction
Below: Figure 04-016 Wellington sun path diagram

The solar power system with regards to the bicycle pavilion will play a vital part in lighting and mobile phone charging in cases of accidents. The bicycle pavilion will need to address such issues when located at different locations. When in different locations sunray angles are different so the solar panels will need to attend to this. Within the Great Harbour Way the latitude does not vary very much. When the pavilion is placed overseas solar panels will need different altitude angles and either be oriented north or south depending on southern or northern hemisphere. For the solar power system to be most efficient the panels need to be angled perpendicular to the sun's direction. But the maximum angle is only reached in Wellington at 12.30 each day (depending on daylight savings adjustments) and every day the maximum sun angle changes. According to the Wellington Sun path diagram the maximum sun angle in December is about 72 degrees. In June the maximum sun angle is 26 degrees. For the solar cells to be perpendicular to these sun angles a concave panel perpendicular to 72 to 26 degrees is to be used. One of the objectives in this thesis is to allow for global applicability. A concave solar panel will allow for a variety of maximum perpendicular sun angles. The concave panel will use 72 125 x 125mm cells producing 190w. This thesis currently focuses on Wellington in the Southern Hemisphere; Northern Hemispheric buildings would be facing the other way towards true south.

SolarView estimates the available solar energy in particular locations for people considering installing a solar energy system. The solar irradiance values calculated represent the average amount of solar irradiance both direct and indirect with account for clouds (NIWA). Firstly the amount of power gained on an area of surface is determined. This information along with the energy audit allows this research to determine the amount of solar panel surface needed. The amount of efficiency from the sun's energy to electric energy on a 190w panel would be 15.3%. **Figure 04-014 Table 2** shows the power at locations of the Great Harbour Way with time frames of the year. The June reading is the lowest with 1.74 kilowatts per m² of exposed area. The average power in the winter months is 1.88 Kw

per m² of cell area, since each solar panel has an area of 1.08 m² with the efficiency of 15%. Multiply the average power in winter months by the area of solar panel to determine how much energy is gained from one 190w solar panel. This analysis determines that around 0.30 of a kilowatt is gained in the average winter from a 190w solar panel.

From the calculations from the energy audit this analysis determines how many 190w solar panels are needed to accommodate the needs of each pavilion. Here the audit considers the base components needed for the pavilion. Primary components such as indoor and outdoor lighting and toilet fan are in operation all year long. The secondary components such as a phone charger may only be in emergency situations. This energy audit has been taken from the use over a winter season; this will allow some surplus over the summer. The energy audit totals at 1.7 kilowatts per 24 hour day. The solar gain from the winter averages 0.30 kilowatts per 190w panel.

Below: Figure 04-017 Water collection diagrams and tables

Rainfall of Wellington

Time Frame	Locations along path (mm)			
	North	South	East	West
2011	1053	1179	1072	1128
2010	1220	1204	1180	1275
2009	1104	654	859	1046
2008	1307	982	1123	1332
2007	668	1083	788	
5yr Average	1070	1020	1004	1195*
Avg Rainfall/Day	2.93	2.79	2.75	3.27*
Water Collected/Day @ 1m2 x Run-off Co (L)	2.78	2.65	2.61	3.10*

*Based on 4yr Average
-Run-off Coefficient @ 0.95

Table 1 Rainfall of Wellington from www.niwa.co.nz

Diagram 1 Conventional water collection system

Diagram 2 Proposed water collection system

4.2 PROGRAM ANALYSIS

RAINWATER COLLECTION.

-Rainwater Collection

Using rainwater is another solution towards a self-sustaining facility. The rainwater collection can be filtrated to be drinking water and also used for washing hands. Due to using a waterless decomposing toilet a large amount of water is not needed. Displayed in **figure 04-017 Diagram 1** is the generic water collection system. It is compiled initially with a surface which collects the water. This illustration has shown that the solar panel can also act as a water collector. The water comes down to one point where the water is directed through into a water tank. Also the water tank does not need to be below ground. The use of a water tank placed above can provide a gravity fed system without having to need powered pumps; an above ground location also enables easier installation. Along with gravity feed, an internal air bladder is used to create more pressure inside the tank. Traditional water bladder tanks use compressed air to fill the bladder. A more efficient way would be to use a manual air pump. Bicycle pumps can pump up to over 100psi in pressure. This system only requires a maximum of 30psi; therefore a regulator is needed. The assisted pressure can pump water into the separate basin in the toilet and pump water up for a water fountain.

The water collection facilities are used for washing hands after the toilet, filling up a drink bottle during a ride, for new cyclists who come unprepared (without drink bottle) and in emergency situations. Cyclists will not need to refill their water bottles every 5 km. Most will only need to do so at the start and finish of their journey. As this design should be as useful in Fiji or San Francisco as it is in Wellington, the goal is to ensure water is available in special circumstances such as lots of kids on a ride, or for

those on amateur outings.

To determine how much water can be provided the tank's capacity needs to be determined. The capacity of the water tank is also limited to how much space the pavilion has for the tank. From the dimensioning of the pavilion, the dimensions for the cyclists' facilities are ideally 2000 x 1600mm. Apart from the water consumption station the other cyclist facilities included in this area are seating, rain, wind and sun shelter. As the tank is placed above this area, the cylindrical tank can be 1600mm in diameter but the depth will affect the height of the pavilion. To allow this space to be more efficient the area of the tank size should be smaller to allow circulation with adequate head height while the depth will be larger to allow more water storage. This is done by taking 600mm off each wall. According to New Metric Handbook diagram 600mm is needed for standing behind a basin. The water collection space is allocated 1m². This provides plenty of circulation and sitting space. The area of the tank will also be 1m² as it will be placed directly above the basin area without interfering with the circulation and head space. An area of 1m² with the depth of 100mm provides a volume of 0.1 cubic meters. That is 100 litres of maximum water storage. Formula $x \times h$ has been used.

Figure 04-017 Table 1 illustrates the average rainfall at all zones of the Wellington Region. This is an average over an entire year. This information can help determine the amount of water able to be collected. The design of the water collection panels will confirm how much water is collected depending on their size.

-Water filtration analysis

This section of the program analysis looks at the water filtration system that this facility will use. As the facility is to collect clean drinkable water while being self-sustaining a smart filtration system is needed. From the water collectors,

the water is funnelled through a mesh into a primary tank. The mesh is to remove the larger specs such as debris. As illustrated in **figure 04-017 Diagram 2** the primary tank is split into two sections. One section is for water straight from the collections. Between the first and second section are four ceramic filter candles. These filters use a gravity fed system and require no electricity. The filtered water will be stored in this section of the tank before flowing through into the major storage tank that features the pressure bladder. From the faucet this facility provides water for cyclists as a drinking fountain and for the cyclist's drink bottles.

The system will allow the filling of a water bottle. A normal bottle of a cyclist is at 750ml capacity. This capacity is primarily determined by the drink bottle holders on the bicycles and the space provided to be mounted. Other hydration backpacks are also used; their capacity ranges from 1.25 litres to 4 litres. The faucet will face certain requirements to allow bottles to fit. Bottles are generally 70mm in diameter and 200mm high. These are minimum dimensions for clearance. The faucet mouth is to be at the maximum of 20mm in diameter to address issues of bottle openings being too small. A generic cycling drink bottle's opening is 50mm in diameter while some other drink bottles are of 25mm in diameter

4.2 PROGRAM ANALYSIS

FACILITIES: TOILETS.

Facilities such as toilets and changing rooms will be designed for environmental sensitivity. The program of the toilet will be open to not just the riders but other members of the public. The pavilion will have to take into consideration who will be using these toilets. A majority of public toilets have both standard cubical toilets and disabled toilets. In this case a disabled toilet would be most effective, as it meets all needs and there will not typically be large numbers needing access at any one time. The minimum size for a disabled toilet is 1500 x 1750mm See **Figure 04-018**. This large floor area accommodates wheelchair turning circles.

A water-less composting toilet will be used. This system will allow the conservation of water and will be emptied out periodically. Without the need for water, the water will be used solely for washing and drinking. Generic toilets flush up to 10 litres per flush. The decomposable toilet separates urine from faecal material. The faecal matter is to be emptied out while the urine is diluted down with the wastewater tank for watering plants near the pavilion. When dilution proportions are needed to be corrected water from the main tank will be used. Solar electricity will be used to power a fan which ventilates the toilet through an exhaust pipe. The fan is to be on continuously when faecal excretes are identified. A weight activated relay will turn on when there are faecal excretes. The fan only draws 0.06kWH over 24 hours. This fan remains on as the smell of faecal excretes needs to be ventilated consistently. The smell of excretes will be present when the fan is on. This electricity use has been included into the energy audit in the previous section.

Technical Specifications

Inner Volume (L)	23
Supply Voltage (V)	12
Current (A)	.21
Wattage (W)	2.5
Power Conusmp.(kWh)	0.06/24h
Fan Noise (dB)	<30

Table 1 Waterless toilet specifications

Diagram 1 Waterless toilet dimensions
<http://www.separett.com/villa-9010-eu>

Diagram 3 Dimensions for disabled toilet

Diagram 4 Dimensions for disabled toilet

Left: Figure 04-018 Waterless toilet specifications, dimensions. Disabled toilet dimensions

5. DESIGN CASE STUDY

INTRODUCTION.

This chapter uses design as a research tool to investigate solutions to contemporary problems relating to the global advancement of cycling. More energy conscious people and rising peak oil costs contribute to the global advancement of cycling. Currently there are no models for cost-effective, easily fabricated and installed, energy-efficient cycling infrastructures that are adaptable to varying conditions. This thesis argues that design can be an effective tool to address these problems. The objectives of this thesis investigation are to explore ideas leading to development of a uniquely architecturally integrated, self-sustaining, adaptable, economically-produced, environmentally-sensitive, portable facility with global applicability. Such facilities are not currently available on the market. This thesis argues that they could provide significant benefits for advancing cycling within the current energy-conscious, struggling world economy.

The final design is developed through iterative experiments using selected diverse sites, methods integrated from diverse case studies, and contemporary prefabrication ideas leading to greater adaptability. There are three review stages from these experiments; each review stage discusses the results from the experiments. These experiments led to the final design outcome. From the site analysis five diverse sites were selected and examined. The sites chosen featured a wide range of various site conditions from flat land to rugged coast and from urban to remote contexts. This design chapter begins with testing the design experiments on the most rugged condition that the Great Harbour Way offers, which provides the basis for the remainder of the design experiments to build from. The design process begins with the placement of structural footings on the site is experimented. The footings allow the base structure to be placed. This structure is comprised of an assembly of steel beams that

allow the entire pavilion to cantilever from the footings. The assembly can come apart and be made portable. The design experiments explored modules of spaces within a long rectangular form with side wings attached. The roof faced north for optimal solar energy gain. The next iteration of this featured panelised wall and floor parts that are repetitive and easy to connect. These advancements participated in forming a base pavilion form before designing the entire pavilion into a kit of parts. These experiments contribute to review 1.

In review 2, experiments towards rainwater collection, wind shade, solar panels and bike parking were conducted. The first experiment involved the rainwater collection panels. Information from the site analysis can help determine how much average rainfall each panel from the pavilion can collect. This information the size and shape of the panels are tested. In this review the wind shade panels were tested. This experiment tests how the panels are to be fitted and how they can allow for repetitive production while being cost effective. The bike parking facilities in this review tests how the slits in the wall panels can provide parking for bikes. The information from the bike dimensions from the program analysis contributes to this experiment. Lastly in this review the roof and solar panels were tested. This experiments how the roofing system becomes repetitive throughout the pavilion. This also tests how the solar panels can collect and distribute water for drinking and washing. Review 3 begins with the review of each of the parts; this section also reviews the entire pavilion with the five selected sites from the site analysis. The review of the parts comments on materiality, production and usability. This reviews how each of the pavilion changed according to the location of the site and surrounding conditions.

Finally in review 4, the whole pavilion in parts is tested against the shipping container. Discussing how each part is packaged and placed into the container. This review is important towards global applicability and portability.

The majority of the design is devoted to creating parts that are assembled and disassembled with bicycle tools. In the early design experiment stages of this the design services such as toilets, water collection, bike workspaces and solar power were placed as markers before the outer shell was completed. Once the main parts such as the floor, walls and roof were at a high level of resolution the services were then fully incorporated. Including the services then requires reworking of the parts to allow each component to fit together, so it was an iterative process back and forth. These steps were repeated as each change was related to one another. While the parts have been designed to allow for easy fabrication and installs, there are probably too many part groups making production less cost effective. The end of the chapter will discuss this weakness and review the resulting findings and conclude the thesis.

5. DESIGN CASE STUDY

SUMMARY FROM PREVIOUS CHAPTERS

The previous chapters contributed to the designing of the new cycling infrastructure. The literature review explored the current situation relating to cycling infrastructures. This provided incentives for what infrastructural facilities are needed to making cycling more practical and safe. The facilities needed to support cycling are bike workspaces off the road away from traffic, and other facilities such as rest spaces and toilets to provide for and encourage the growth in cycling. These services are incorporated into the design of the facility. This makes cycling more attractive as a cyclist would be more willing to ride if there are support facilities for them. This then contributes to having more cyclists on the road, stimulating the concept of safety in numbers.

In the review of prefabrication literature, information about early issues for prefabrication was reviewed. Common misperceptions about prefabrication such as poor material quality and bad design which lead to visible deterioration was the main misperception that the public had. To contribute to the design, these issues were taken into consideration to avoid encouraging this misperception. The review of sustainability through prefabrication offered opportunities to reduce building waste, minimize transportation to site, and enable future reuse. Prefabrication built indoors reduces the carbon footprint through fewer deliveries to site (final location of building) compared to traditional methods. Prefabrication inside also leads to better waste management allowing more chances of collection and reuse of building material. To reduce offcuts co-ordinated sizes are to be taken into consideration. Furthermore the design for disassembly and future reuse of materials makes the facility more sustainable. These sustainable approaches are incorporated in this design as the kit-of-parts.

Reviews of the kit-of-parts and mass customisation

led to construction methods that allow for a cost effective facility which is easily fabricated and easily installed. This literature about prefabrication looks at using multiple individual parts that is assembled on site. This method of construction reduces build times and provides a high level of accuracy. The parts are produced economically through mass customisation methods. These methods use new computer programming and machinery to create multiple standardised parts. Designing in the kit-of-parts – incorporating elements of mass customisation – is the main method of design for this thesis.

The thesis design research experiment will incorporate successful features taken from each of the five case studies:

From the case studies Bike Fixtation featured a bicycle kiosk which was orientated towards anti-vandalism. The kiosk used a simple bike stand that had tools attached to it with aircraft wire. The bike stand featured a steel TIG welded frame that is powder coated. It is easy to install and low maintenance. The bike stand with attached tools is adapted and used in this design. This material and finish is used. The remainder of the kiosk is a parts vending machine that requires a mains supply to power; this would not be used.

The Hydraleaf case study was a self-sustaining portable unit that provides amenities such as water and lighting for the public. This unit collected rain water and solar power. The water is filtered for drinking and the solar power was used in lighting. These methods of self-sustainability are used in the thesis design research experiment.

The Mount Whitney Trailhead Prototype reviewed prefabrication techniques which address difficult and remote site conditions. The prototype featured CNC cut materials that are made in a factory and delivered to site to be assembled. As the design is tested in the factory, assembly is

easy when on site. These techniques are featured in the thesis design research experiment.

The Trusset system reviewed techniques towards producing parts that are easily assembled. The Trusset system used multiple little parts which were cut through a CNC laser cutter. These were the joining parts of the structure. These parts are the most important as they join the larger parts together. These techniques have been adopted to contribute to easy manufacturing while also being environmentally sensitive regarding reduced building waste.

The Click-raft case study features standardised parts which offer economically produced adaptable housing. As all parts are the same it is limited to specific configurations. These positive and negative effects from standardised parts have informed this design.

The program analysis examined the systems needed in this design. The water collection system provides the design with a self-sustaining facility. This water collection system uses ceramic filters and an air bladder pump to provide extra pressure. This system does not require any electricity. The water tank's volume is calculated at 100 litres depending on the size of the water consumption station. 1m² area water consumption station has been used.

Solar power collection has also been analysed. This also provides the design with a self-sustaining facility. This solar power collection system is an off-the-grid system which uses batteries to store the majority of the energy collected. From the review of Wellington's solar output along with power needed, 4x 190w solar panels are to be used.

A Waterless Toilet was also analysed. This toilet offers portability as the main sewer pipes do not need to be connected. The waterless toilet is also environmentally sensitive as it requires no water to flush and uses urine in diluted form to water surrounding vegetation. This waterless toilet is to be used in a disabled toilet cubicle. The toilet is open to cyclists and also other members of the public.

Dimensions of many bikes were analysed towards producing an architecturally integrated bike

stand. The bike length of 2013mm is the largest bike size based on a hybrid bicycle with mountain bike tyres. This is used to create the bike stand, with bikes smaller fitting inside it. The design of the rack is to provide a secure parking spot for the bikes without damaging any other bicycle or vehicle.

5. DESIGN CASE STUDY

OUTCOME

Above 1: Figure 05-001 Overall outcome

INVENTORY

Panels:

14-Floor panels
5-Floor joining panels
16-Wall panels
8-Wind shelter panels
16-Water collection panels
16-Rain shelter panels A
16-Rain shelter panels B

Structure:

2-Under structure A
4-Under structure B
4-Under structure C
8-Footings
8-Water collection ring parts
8-Water collection gutters
6-Bike parking bracket
36-Poles
6-Seating brackets

Assemblies:

4-Solar/roof panel
1-Bike workstand
1-Bike pump
1-Main wash basin
1-Toilet was basin
1-Water collection tank/
filter
1-Waterless toilet

Mounting brackets
26-Floor mounting
40-Pole mounting
80-Panel mounting
32-Rain panel mounting

5. DESIGN CASE STUDY

A 3D rendering of a flat parts layout for a mechanical assembly. The layout includes a large rectangular panel with vertical ridges, a stack of curved panels, a stack of flat panels with holes, a stack of L-shaped brackets, a stack of cylindrical rods, a stack of small cylindrical pins, a stack of small U-shaped brackets, a stack of small rectangular plates, and a stack of small rectangular plates with holes. The parts are arranged on a light gray surface, and the background is a solid light gray.

ets:
brackets
brackets
t clamps
brackets

Spread 1: Figure 05-002 Flat parts layout with inventory list

87

5. DESIGN CASE STUDY

ets:
brackets
brackets
t clamps
brackets

Spread 1: Figure 05-002 Flat parts layout with inventory list

87

[illegible]

MATERIALITY

The overall design is comprised of many specific material finishes were selected avoid vandalism, are lightweight and economical. Materials used are structurally resilient and are used with mass customisation techniques. Floor panels used are made of mild steel and have the longitudinal sides folded at right angles. The right angles allow for further strengthening. Just these flooring panels require folded sides. These panels are powder coated all around. Further, an abrasive finish is applied on the walking surface for more grip. Also powder coated and made of mild steel are the bike work stands. This material and finish used can reduce vandalism and maintenance. The wall and wind shelter panels are the same material with the same thickness and finish but are different in size. Although these panels are very similar they adopt mass customisation techniques to allow the panels to be made efficiently and more cost effective. Fibreglass has also been used as the water collection panels. This material has been used as it is lightweight and durable. The production of these panels will use a mould which can be used multiple times. As there is such a diverse range of materials the parts are not able to be made in one room. The parts may be made at different locations but can still be cost effective as the parts transported are for multiple pavilions rather than just one.

5. DESIGN CASE STUDY

TOWARDS REVIEW 1

Above 1: Figure 05-003 Adjustable piles and standardised panels

Above 2: Figure 05-004 Wellington sun path diagram

The overall form is generated by the need for a north-facing surface to collect solar power in the southern hemisphere. The entire form is broken down into repetitive panelised parts. This allows for one panel to be duplicated and used multiple times. It allows for easy assembly, transportation, as well as manufacturing. This panelising allows the whole roof structure to be made of solar panels. These panels are mounted onto an inner frame. The tilt in the roof becomes the water collection system of this facility. The wall panels provide slits in the wall that allow more light to flow in. All panelised parts allow for efficient stacking before being packaged into a container for shipping. Footings are also included. These are included to allow for uneven site conditions. As the site conditions around the Great Harbour Way vary from a rocky edge to smooth edge special attention to this is needed. This footing configuration cantilevers the structure under the bike workspace and toilet. The cantilevering structure allows for one flat floor plane. The flat floor panel reduces the need for further parts that accommodate the change in floor plane heights.

In Wellington the latitude is 41.2889° S. The design approach to selecting the optimal angle for the solar panels is orientated towards the average sun angle during the whole year. The maximum sun angle varies considerably throughout the year and throughout the day. Whatever angle selected would only provide maximum gain at 12.30pm Standard Time twice a year therefore the solar panels fixed at the maximum sun angle would not be very efficient. Maximum solar gain will need to be compromised by using average solar angles. This will make it more efficient as solar energy can be gained throughout the year. Even though the readings may not be as high the average distribution would be more consistent. According to the Wellington Sun Path Diagram the maximum sun angle in December is about 72 degrees. In June the maximum sun angle is 26 degrees. These are the highest and lowest maximum sun angles during the whole year. For the solar panel to be perpendicular to these sun angles a concave panel perpendicular to 72 to 26 degrees is used.

REVIEW 1

This test examines specifically how the footings fit on the selected sites. The tests are based on three site conditions; B, D and E have been chosen as they represent the most diverse site conditions. These site locations are chosen from the linear sequence of 12 sites along the Great Harbour Way. The linear sequence was determined from the site analysis chapter. Each pavilion is orientated north to allow for the solar panels on the roof to reach average maximum solar gain over the whole year.

Above 1: Figure 05-005 Site Condition B

Above 2: Figure 05-006 Site Condition D

Above 3: Figure 05-007 Site Condition E

5. DESIGN CASE STUDY

TOWARDS REVIEW 2.

This separate water collection unit is based on the most efficient form for water collection. This form allows for a large surface area with the water coming down to one point.

This efficient water collection form is then converted to panels. These panels will capture the water and bring it down to one point. These panels are added on top of the pavilion. These panels contribute to 70% of the water collection of the pavilion the other 30% from the water collected from the solar panels. Each panel is 0.70m^2 in surface area. When fully deployed there are 14 collection panels. When one side is deployed there are seven collection panels. These panels in conjunction with the roof of the pavilion collect the rainwater and bring it down to the filtration system. From the average rainfall and run-off coefficient 2.68mm is received per day. This multiply by $.7\text{m}^2$ of surface area equates to an average of 1.876 litres of water per day in Wellington. 14 panels at 1.876 equal 26.3 Litres per day.

Above 1: *Figure 05-008 3D bowl shape*

Above 2: *Figure 05-009 Water collection panels from 3D bowl shape*

Above 3: *Figure 05-010 Water collection panels from plan view*

WATER SERVICES

The water collection panels' angle down and the water is routed through into the middle where the water will meet the water filtration system. The filtration system will remain suspended to save space. This water filtration unit is located in the central point of the pavilion. These water collection panels are cantilevered and tied along an inner ring. This ring is fixed onto the roof structure of the pavilion with numerous bicycle brake cables. The cables are fixed between the ring and the water collection panels.

Below 1: Figure 05-011 Pavilion with wing attachments

Below 2: Figure 05-012 Section of pavilion. Exposing water collection services and water collection structure

5. DESIGN CASE STUDY

WIND SHADE PANELS

The side wings that are attached to the main rectangle are to be the wind shelter space. The wind shade panels are used to shelter from the wind and also provide shade from the sun. To accommodate them, the wall panels from the main body have been used.

In the substructure, to accommodate for the wing attachment, beams are attached. The beams are individual option parts that come together and then attach to the frame. The use of a CNC machine provides the structure with accurate assembly. The floor panels from the main section of the pavilion have also been used here as floor panels.

The wall panels used for the wind shelter space have been modified as the original wall panels were too wide. Here a new group of panels have been created. During manufacturing the panels would be run through the same machine that is used in cutting the original wall panels. To create these panels another cutting file is needed. As sizes have changed, the size of offcuts will be different. This file will rearrange the panels so that offcuts are minimized see **figure##**. A new group of parts also creates more opportunities for configuration. These panels are used elsewhere in this design through different placement, orientation and use. See **section ##**. The delivery of the narrower panels uses the same method as the main panels through stacking and wrapping before moving into the shipping container.

Above 1: Figure 05-013 Cutting layout for the composite panels. Alucobond provides two widths of sheets at multiple lengths. Top sheet is 1250 x 5500mm used for the wall panels. The bottom sheet is 1500 x 6000mm used for the wind shelter panels.

BIKE PARKING

The bike parking facilities take advantage of the slits produced from the vertical wall panels. The slits in the wall panels and the bike wheel support allow for an architecturally integrated bike stand. Each section of vertical wall can provide three parking spots.

The height from the ground and circulation around these bike parks is important. A bike cannot be parked if it is in the way of circulation or if the bikes are too high and need to be lifted. The parking slots allow the bike's front wheel to be placed inside the slit with a guide holding the wheel up. This bike parking facility is architecturally integrated into the pavilion.

-Roof and Solar panel systems

The main pavilion is divided into three zones. The centre zone houses the water collection unit and resting space around. The other two zones are identical in structure and house the bike workspace and toilets. This will allow the same set of parts for the two identical modules.

Above 1: Figure 05-014 Bike parking slots for flat terrain

Above 2: Figure 05-015 Bike parking slots on piles for uneven terrain

5. DESIGN CASE STUDY

SOLAR ROOF PANELS

The two sections that connect to the central core use four panels each. At the bottom of each panel is a modular channel which will redirect the water back into the water collection point. This channel is manufactured from a long extrusion of plastic and is then cut to a standardised size. As there are several pavilions a bulk amount of plastic extrusion is processed to minimize overall costs. This channel is hugely beneficial as it redirects the water back to the water collection point.

The water collected from the central part of the pavilion is on average is 33 litres per day in the Wellington region. This is calculated by the large surface area of collection 12.4m^2 and the average rainfall readings of the Wellington region is 2.68 litres per m^2 of area.

Above 1: Figure 05-016 Section of pavilion with exposing the three sections

REVIEW 2

As the design progressed potential problems started arising. The main issue regarding tools, bikes and a bike pavilion is that vandals may be able to use the tools provided to take the pavilion apart. As the pavilion uses cycle parts and fixtures, the pavilion may be taken apart using the tools provided. The solution to this would be to use a less common toolset to assemble/disassemble the pavilion. Unlike cyclists' tools, mechanics' tools are specialised tools. They are used to take parts off the bike that do not often come off. A cyclist's tool in his/her toolkit is used to make simple adjustments, so the pavilion can supply common cyclists' tools while being assembled using mechanics' tools. **Figure 05-017, 05-018** illustrates the tools that can be used to assemble the pavilion compared to a standard cyclist's toolkit.

Above 1: Figure 05-017 Park Tools bottom bracket extractor tool

Above 2: Figure 05-018 Park Tools freewheel extractor tool

5. DESIGN CASE STUDY

TOWARDS REVIEW 3

As the major spaces are resolved to a certain level this section focuses on detailing the panels to make them more multipurpose and repetitive. Also further detailing the panels should allow for further ease of manufacturing and assembly.

During this section, keeping the balance between the programs requirements, encouraging modularity and making panels fit is the greatest design challenge. The panels need to be easy to manufacture and assemble.

-Major Flooring Panels

There are two flooring panel that is used throughout the pavilion. One panel is the major panel which is used as the standard flooring panel. The other panel is a secondary panel which is used as a fixture bracket. For a long duration of use with minor wear both these panels are mild steel and are powder coated. The powder coating will have a slightly abrasive finish on the walking surface for extra grip. The sides of the panel are bent at a right angle. The right angle of each panel allows the panels to be stronger thus being less likely to deform. The right angle also allows the panels to attach to each other easily. These panels are placed directly above the under-structure of the whole pavilion. These panels use a water jet cutting machine to make several holes to allow for supporting components to be fixed on such as rollers for the sliding wall panels, brackets for partition walls and some larger cut outs are made for the vertical poles. These holes are cut before edges are bent. These steel panels will be at a thickness of 8mm.

Above 1: Figure 05-019 Main flooring panel with secondary smaller panel

Above 2: Figure 05-020 Flooring panel configuration

Above 3: Figure 05-021 Flooring panel as seating panel

The secondary flooring panel is thinner and is used mainly for the central core where holes are needed for the plumbing. The use of mass customisation methods enables the creation of similar panels with different holes quite easily. This panel is also used as the main seating bench after altering the design of the previous

seating design. This newer system provides a stronger alternative to the previous design. This time the steel panels will withstand the weight without having to double in thickness. This panel also meets the dimensional requirements of a sitting bench.

-Major wall panels

These wall panels are simple and are repetitive all around. These panels are made from a 6mm aluminium/acrylic composite panel. These panels are not used structurally but are used to provide shelter; therefore they are lightweight. These panels have pre-drilled holes which are countersunk for a flush finish. There are 16 of these panels and they are solely used for the main outer walls of the pavilion.

-Wind shade Panels

These panels are similar to the wall panels. These 6mm thick composite panels are placed horizontally as wind shade panels. These panels are identical to the wall panels but they are not as wide. These panels are also used as the sliding door panels and the wall dividers between the toilet and resting space.

Above 1: Figure 05-022 Main wall panel
Above 2: Figure 05-023 Wall panel configuration-
Above 3: Figure 05-024 Wall panels in context of
 pavilion
Left 1: Figure 05-025 Freewheel splined fixing for all
 wall panels

5. DESIGN CASE STUDY

PARTS DESCRIPTION

-Solar panels

The curved solar panel is comprised of multiple flat 125x125 solar collection cells which are connected together. These cells are placed on a curve at perpendicular angles of 28-74 degrees. These angles are perpendicular to the sun's altitude angle 72-26 degrees. These panels are 35mm thick including the thickness of the mounting brackets. On the underside of the panel is a 2mm aluminium sheet which has folded ends to allow the rainwater to catch and flow towards the water filtration system. These individual cells and the aluminium sheet are mounted onto the bracket that curves from 28-74 degrees. The flat individual solar collection cells placed on a curve are an easier method than a purpose made curved solar panel.

Above 1: Figure 05-026 Individual solar + roofing panel

Above 2: Figure 05-027 Solar roofing panel configuration

-Water Collection Panel

The water collection panels, different to the solar panels, capture the rainwater and bring the water down onto gutters which are then directed towards the main water collection point. These panels are made of fibreglass. The final layer of the fibreglass will be lined with a carbon cloth material. The idea of carbon fibre is that it reflects the lightness and also the strength of this material. The carbon look will be a lower cost option than a full carbon fibre panel. Even though the carbon fibre will be much stronger it is not needed for this application. The creation of a fibreglass panel uses a large one-off mould which is produced. The mould would be used to make seven panels at a time. This requires a resin mix with cloth material. Once cured, the panels will be cleaned and sanded. These panels are lightweight and easy to handle especially in high situations. The fibreglass will be layered towards a thickness of 2mm. With the use of a mould repetitive shapes will remain consistent.

Above 1: Figure 05-028 Individual collection water panel

Above 2: Figure 05-029 Water collection panel configuration

Above 3: Figure 05-030 Water collection panels with aircraft cable structure

5. DESIGN CASE STUDY

PARTS DESCRIPTION

-Poles

These aluminium poles are used as the main structure of the entire pavilion. The poles will come in 600mm and 300mm lengths. They are stacked and slotted in together and then locked into place through an internal spring loaded push pin. Mounting brackets would also be needed to be used for certain joins. These aluminium poles are 50mm in diameter.

These aluminium poles are to be fixed into the footing bracket. These footing brackets are fixed onto the main structure.

The wall and wind shade panels are attached via a clamp. Clamps are used as they can accept tolerance.

Above 1: Figure 05-031 Main poles with base fixture

Above 2: Figure 05-032 Pole configuration

Above 3: Figure 05-033 Pole connector clamps with bottom bracket fixture

Right 1: Figure 05-034 Pole connector clamps in context

-Rain shelter Panels

These fibreglass panels are used at the top of the main wall panels and to reduce rain exposure at the top of the pavilion. These are 3mm fibreglass panels with multiple holes made. These fibreglass panels are lightweight and easy to handle in high situations. These fibreglass panels are created as large flat panels which are then cut to size on a machine. The outcome of these panels is translucent, allowing filtered light to come through the panels. The holes made in the panels allow for overlapping and re-orientation to fit certain openings.

The multiple holes allow the fibreglass panels to be fitted at different heights and at different configurations. The introduction of the fibreglass panels allows the main wall panels to be the same. As each panel needs to rise a certain distance the bottom of the pavilion will then be exposed. The fibreglass panels shelter the openings made by the angled roof panels whilst letting light come in. These panels are not sealed in; they are panels that reduce water coming in due to wind and rain.

At this section of the design the detail of the main parts of the pavilion allow the main services to be placed. While designing the services needed, the idea of repetition and ease of assembly and manufacturing will be applied.

Above 1: Figure 05-035 Fibreglass rain shelter panels

Above 2: Figure 05-036 Rain shelter panels mounted on side

Above 3: Figure 05-037 Rain shelter panels mounted at ends

5. DESIGN CASE STUDY

SYSTEM DESCRIPTION

-Water Consumption:

The water station is located in the middle of the central core. This is also where the water collection point is located. Directly above is the gravity feed filtration system assisted with a pressure bladder system. The water consumption station features two different methods of obtaining water. On one side is the fountain tap. This is for drinking straight from the tap. The other side is the water bottle refilling side. A different style of tap is used. The water bottle refilling side also allows for washing hands. Within this section of the pavilion seating is also provided. This seating is of a steel flooring panel. This section of the pavilion is the most sheltered. The seating panel comes from the floor panels used below the water collection station. This panel is placed on top of two aluminium pipes running in the horizontal direction.

Above 1: Figure 05-038 Water consumption station in context of pavilion

Above 2: Figure 05-039 Water consumption station detail

In the water collection station the use of an air assisted water pressure system is used to provide pressure for the drinking fountain. This system uses a bladder in a closed container where the water is stored. The air input would be an external manual pump; in this design a bicycle tyre pump is used. The pump becomes multipurpose as it is also used for the bikes. The outlet of the pump is removable. When needed, the pump is connected to the bladder. A regulator is also used to avoid over pressurizing. The use of the pump is a more energy efficient method as it is handled manually when needed. This does not use any electricity.

-Bike workspaces

Left 1: Figure 05-040 Detail section of water collection station

5. DESIGN CASE STUDY

SYSTEM DESCRIPTION

The bike workspace features a hang style stand adapted from the Bike Fixtation case study. This stand can hold two bicycles. The bike stands are TIG welded and powder coated. The stand is designed to prevent vandalism. This becomes a cost effective investment towards the pavilion. The stand is then fitted onto the powder coated steel flooring panels using the two holes in the panel to fit the stand mounts. The bike workspace allows for cyclists to make adjustments to their bikes. The essential tools will be included but will be attached to the stand with bicycle brake cables.

These limited tools are provided as most cyclists carry their own tool pouch. These tools are the most general tools used for minor adjustment, such as a Phillips screwdriver, 4-6mm Allen wrenches and a 10,13mm and 15mm spanner. A secure bicycle pump will also be provided.

Above 1: Figure 05-041 Bike stand configuration

Above 2: Figure 05-042 Bike workspace from indoors

Above 3: Figure 05-043 Bike workspace from out-doors

Above 4: Figure 05-044 Bike Parking support bracket

-Toilets

A disabled toilet is provided at all bike pavilions. As these facilities are open to the wider public, the disabled toilet is to be used by everyone. The toilet is located within an enclosed area. This area has its own separate entry point. For the toilet, gap covers are made to cover up the slits, to provide extra privacy whilst allowing a bike to be parked in the slits. The gap covers are deep enough for a wheel to be placed in. These gap covers allow the architecturally integrated bike racks to function while allowing privacy. These covers are also used to support the sliding door bracket. Due to code requirements handrails have been placed as well as a mirror and the basin placed at a certain height. The water system runs the same hardware from the main water collection station.

This will be a waterless toilet. The urine and wastewater are stored together beneath the pavilion. The wastewater is used to dilute the urine. If urine is not dilute enough, the filtered water will be used. Regular maintenance will empty the toilet out as well as rubbish from the public bins. Regular maintenance will also release the diluted urine onto nearby vegetation.

Above 1: Figure 05-045 Toilet area
Above 2: Figure 05-046 Gap covers for toilet
Above 3: Figure 05-047 Toilet services configuration
Left 1: Figure 05-048 Toilet water services

5. DESIGN CASE STUDY

SYSTEM DESCRIPTION

Below 1: Figure 05-049 Section outlining solar power services

-Other services

System components such as the batteries and controllers for the solar power system have been placed under the central seating area. The services are all the components needed to store and use the solar energy. The solar energy is mainly used to provide night lighting and in the case of emergency, telephone charging facilities.

REVIEW 3

In review 3, the main focus was to see if the detailing of these parts will allow the pavilion to be assembled easily and manufacturing of each part is easy. Many of the panels are repetitive and will use well-established and new machinery to manufacture. The non-panelised parts such as joining, water and service parts can be manufactured easily with established jigs for repetitive production. The production of a jig is a one-off cost. Creating the cutting file for the CNC machine also requires one-off file creation. From here the production of the parts can be made by machine using a cutting file or moulded from a pre-made jig. As there are 12 pavilions to be made along the Great Harbour Way these one-off parts will still be made repetitively. As all electrical services are located, lighting is to be included, externally and internally. The external lighting will be on during the dark hours of night. The internal lights will be sensor operated. Operation using a sensor will allow the lights to turn on only when someone is using the facility thus allowing power saving.

Site A: Hutt Road

At this location the pavilion is located on a grass section on the southern side of the road. With this site condition the entire pavilion is placed on the grass section. As this site is flat the adjustable footings have been removed and concrete blocks have been used to support the pavilion. The pavilion would have the toilet located closest to the road and a ramp would be used for wheelchair access. Towards the back of the pavilion would be the bike workspace. As the wind is funnelled down from the terrain the southerly wind is sheltered by deploying the wind shelter panels on the southern side and western side of the pavilion. Also on the southern side the sliding door panels will be used to reduce wind circulating through the pavilion. The seating will be placed on the eastern side of the pavilion away from the tunnelling wind. The seating panel is located on the northern side of the wing facing south facing away from the traffic.

Opposite 1: Figure 05-051 Overall rendering of pavilion

Above 1: Figure 05-052 Pavilion at site A

Site B: Waterfront

This site is located along the waterfront beside Chaffers Marina. This location has the most exposure to the sun as this location has nothing obscuring the sun. As the pavilion is facing north and the sun is not obscured by any buildings, maximum solar energy can be gained. In cases of shelter the highest wind shelter panel and water collection panels provide shelter. The highest wind shelter panel can provide shelter from the

sun at maximum altitude while allow for the best views out over the harbour. The seating is placed on the southern side facing north. Similar to the previous site the pavilion sits on a flat surface. Being an urban site, this time the pavilion would be sitting on a concrete surface, but concrete blocks would still need to be used to allow ventilation beneath.

5 DESIGN CASE STUDY

Site C: Hataitai

Opposite 1: Figure 05-053 Pavilion at site B
Above 1: Figure 05-054 Pavilion at site C

The conditions of this site are also flat but curvature of the road has located the pavilion at the centre point of this curve. The pavilion is placed on a flat surface adjacent to the boat buildings. Here on this site the pavilion sits on a flat surface with both shelter wings used. The wind shelter panels will be installed on the southern side of the pavilion with the seating on the same side. This enables views out to Shelly Bay. The toilet will be located on the southern side of the pavilion with the bike workspaces on the north.

Site D: Seatoun

This site was used in the initial tests for unlevelled and rugged ground surfaces. Here on this site the pavilion sits with both wind shelter wings used. The adjustable footings have allowed the pavilion to remain level. The wing at floor level allows entry into the pavilion. The toilet will also be facing the road for easy wheelchair access. The wind shelter panels will be fixed on the northern side of the pavilion at both sides. This is to shelter from the northerly wind. The seating will also be on the same side as the shelter panels. The seating provides views out to Eastbourne.

Site E: Wahine Memorial Park

This site was also used in the initial tests because of its unlevelled surface. This pavilion sits similar to the previous site. It has two wind shelter wings, one facing north and one facing south. The footings have set the pavilion flat with the peak of the ridge. This allows access into the pavilion and minimal ramp length for wheelchair access. Both wings will use all wind shelter panels on the southern side as this location is exposed to the southerly wind. The seating will be placed on the northern side. This can provide shelter from the wind and views out to the sides of the pavilion. The bike work space is located in the southern end. Here the sliding panels will be used to provide more shelter.

Opposite 1: Figure 05-055 Pavilion at site D
Above 1: Figure 05-056 Pavilion at site E

-site reviews

The prefabricated structures are able to be placed anywhere on the selected sites. As they are placed some components such as the footings are not needed as the site does not feature large changes in height. Here concrete blocks may be used to separate the steel structure from the ground. From the lowest floor plane a ramp will need to be included to allow safer means of approaching

the pavilion. In other instances the pavilion may be against another building. In this case only half of the water collection panels may be used. Also one side of the wind shade spaces will not be included. In more remote places the pavilion is isolated. Here all collection panels may be used. After these refinements the pavilion would be ready to use.

5. DESIGN CASE STUDY

Above 1: Figure 05-057 Overall pavilion final render

5. DESIGN CASE STUDY

Above 1: Figure 05-058 Overall pavilion in collapsed parts

[illegible]

Finally review 4, looks at how the parts are arranged for the shipping container. In **figure 05-058** the parts have been laid flat illustrating all components of a complete pavilion. **Figure 05-059** shows all the parts packaged against the 20 feet shipping container. This arrangement uses two large 2400 x 1200mm pallets, 1 smaller 800

x 800mm pallet and various boxes. The two large pallets hold the large parts, the under structure, floor panels, water collection panels and wall panels. The single smaller pallet holds smaller panels such as the waterless toilet, fibreglass panels and the footings. The boxes hold the wash basins and mounting brackets. The pipes for the

REVIEW 4

structure have already been connected at suitable lengths. The long pipes are strapped to a board allowing the pipes to be stored vertically.

Above 1: Figure 05-059 Overall pavilion in collapsed parts

5. DESIGN CASE STUDY

CONCLUSION

The main intention of the research was to develop a new model for cost effective, easily fabricated and installed, energy efficient cycling infrastructure. The underlying demand for a new model of cycling infrastructure was identified as there are currently no models that achieve this. As a result of global cycling advancement due to the rise in fossil fuels and more environment conscious people the new model of cycling infrastructure is needed. The research established thesis objectives to provide solutions for a new model. These objectives are to develop a uniquely architecturally integrated, self-sustaining, adaptable, economically-produced, environmentally-sensitive, portable facility with global applicability. Such facilities are not currently available on the market, and this thesis argues that they could provide significant benefits for advancing cycling within the current energy-conscious, struggling world economy.

The new model to facilitate the global advancement of cycling is used to provide a facility that can be applied globally and locally. Locally, there are sizing and cost constraints as there is an involvement with government and council. These constraints are considered as the facility may be placed on council land with a government-funded background. The treatment of the land available must be used efficiently and become environmentally sensitive. Global constraints such as shipping, costs and adaptability are considered. These constraints are considered, as shipping overseas is a task that involves using many handlers from air, sea and ground. These may contribute to high transportation costs. To keep transportation costs to a minimum while being practical, limits are to be set on the size of the facility. To make shipping more cost efficient the facility should be able to be disassembled and placed in a shipping container where volumetric size is important. Once arrived at its new location terrain and surrounding contexts are different. To allow for this change adaptability is considered.

Cases of self-sustaining, environmentally sensitive, cost effective and adaptable production have been discussed. As each case study developed different

solutions for these constraints, each solution has been considered in the thesis. One solution towards these issues was to produce a facility with standardised parts that uses no fossil fuel energy, is off the grid and has efficient use of floor space. From the case studies, the use of standardised parts allows for adaptability depending on what the part is designed for and how well it has been designed. These parts may become problematic when certain configurations are needed.

Locations of a cycling facility need to be considered in relation to the amount of use they will get and how the facility will participate in safety and practicality towards cycling. In the design case study a series of bike facilities, five kilometres apart, were located along the Great Harbour Way; this site is a route that many cyclists use, whether it is commuting, recreational cycling or racing. A series of 5 kilometre apart facilities might not always be the most efficient method in other locations. Other locations that use a grid layout or larger density of cycling may use a different site locating method.

The sites chosen for the design were limited to 5km intervals along the Great Harbour Way as a means of enabling cyclists to know the distance travelled, as well as providing regular facilities. The selection of fixed 5km intervals limited the placement of the facilities. As these locations were fixed at 5km intervals, some facilities were located in urban to remote areas, some facilities encountered uneven rugged terrain where others encountered flat grass terrain. The facility needs to accommodate these diverse conditions. This issue is addressed by designing for adaptability and portability. In the design case study, the facility used adjustable footings that were connected to the substructure of the facilities. This was tested with the most rugged conditions that the facilities encountered. The easier flat conditions were also tested to see if the facility can accommodate for both. The practicality of using these footings means that the facility can be levelled out before the substructure is placed on to it. These footings are limited to a certain amount of travel upwards and downwards. If the site causes the

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footings to fall outside these travel limits the site itself would need to be worked on or reconsidered.

This thesis argues that design can be used to provide a solution by using specific design objectives. The idea of kit-of-parts and mass customisation methods are used to illustrate the ease of fabrication, assembly and portability. This leads to the sustainable and economic production of parts in large warehouses, the parts to be packaged and shipped to site. The parts are then assembled and adapted according to site. For the facility to be energy efficient, solar power solutions are used. The solar power system is to be off the grid with the use of batteries as energy storage. Water collection and a waterless toilet provide further off the grid, self-sufficient facility. The design demonstrates parts that are repetitively produced and are widely used around the facility. The design demonstrated that it is possible to create a cost effective, easily fabricated and installed energy efficient facility.

One of the difficulties in designing the cycling facility for economical production was to create a minimal amount of part groups while allowing for easy adaptability and the inclusion of self-sustaining systems. More part groups means that there are more different parts used. This would result in more repetitive parts rather than more unique parts. Production for more unique parts may mean that it would cost more. Future experiments should include a hands-on experimental approach. This method can allow production of experimental parts that are then experimented together physically to find outcomes that require the least amount of part groups. The results from this experiment may be used to gain a more accurate number on costs. This method will also experiment with how parts can physically be repeatedly used around the facility while keeping the part groups low. This method can be used as information for council applications and funding.

The research has explored drawing together the ideas of prefabrication with the kit of parts, mass customisation methods and self-sustaining systems to create this new model. A model has been created using a variety of panels, poles, fixings and sustainable systems.

While parts have been created to allow for easy fabrication and installation, there are probably too many part groups making production less cost effective. Despite these limitations the advantages of having ways to adapting a portable facility that is self-sufficient and architecturally integrated makes this new model a viable explorative option for supplying the global advancement of cycling.

In conclusion, this thesis has explored ways of developing a new model of cycling infrastructure. The adoption of this new model of cycling infrastructure globally may further facilitate the advancement of cycling.

REFERENCE LIST

TEXT

Anzalone, P., Vidich, J., & Draper, J. (2008, September 27). Non-Uniform Assemblage: Mass Customisation in Digital Fabrication. *Without a Hitch: New Directions in Prefabricated Architecture*, pp. 298-306.

Bell, P. (2012). Primer: About Prefab Housing. In P. Bell, & M. Southcombe, *Kiwi Prefab: Cottage to Cutting Edge* (pp. 34-43). Auckland: Balasoglou Books.

Bergdoll, B., & Christensen, P. (2008). *Home Delivery: Fabricating the modern dwelling*. New York: The Museum of Modern Art.

British Library. (n.d.). *Provo*. Retrieved November 2012, from British Library: <http://www.bl.uk/learning/histcitizen/21cc/counterculture/assaultonculture/provo/provo.html>

Critical Mass. (n.d.). Retrieved November 2012, from Critical Mass Past and Present: <http://www.criticalmass.org.nz/>

Dankert, J. (2011, June 13). Frontpage. Retrieved January 24, 2013, from Click-raft.com | *evolving a persona fabrication architecture*: <http://click-raft.com/>

Davies, C. (2005). *The Prefabricated Home*. London: Reaktion Books.

Gorgolewski, M. T. (2008). The Potential for Prefabrication in UK Housing to Improve Sustainability. In J. Yang, P. S. Brandon, & A. C. Sidwell, *Smart & Sustainable Built Environments* (pp. 121-128). Oxford: Blackwell.

Greater Wellington Regional Council. (2013). *State of Cycling Report: Wellington region 2001-2012*. Wellington: Greater Wellington Regional Council.

Hayes, N., & Lawrence, A. (2012). *Recommended Final Regional Land Transport Programme 2012-15*. Wellington: Greater Wellington Regional Council.

Hjelm, S. L. (2002, September). *Semiotics in product design*. Stockholm, Sweden.

Howe, A. S. (1999). Kit-of-Parts: A review of object-oriented construction techniques. *Automation and Robotics in Constrction XVI* (pp. 165-171). UC3M.

Jensen, S. U., Anderson, T., Hanse, W., Kjaergaard, E., Krag, T., Larsen, J. E., et al. (2000). *Collection of Cycle concepts*. Copenhagen: Road Directorate.

Kieran, S., & Timberlake, J. (2004). *Refabricating Architecture*. New York: McGraw-Hill.

Kingham, S., Taylor, K., & Koorey, G. (2011). *Assessment of the type of cycling infrastructure required to attract new cyclists*. NZ Transport Agency.

Krippendorff, K., & Butter, R. (1984). *Product Semantics: Exploring the Symbolic Qualities of Form*. Pennsylvania, United States of America.

Luther, M. (2009). *Towards prefabricated sustainable housing*. BEDP environmental design guide, pp. 1-11.

McClintock, H. (2002). *Planning for Cycling: Principles, Practice and Solutions for Urban Planners*. Cambridge: Woodhead Publishing Limited.

Ministry of Transport. (2012). *Cyclists crash factsheet 2012*. Wellington: Ministry of Transport.

NVA. (2010, April). *Witte Feitsenplan (White Bike Plan) Past Projects*. Retrieved November 2012, from NVA: <http://www.nva.org.uk/past-projects/witte+feitsenplan+white+bike+plan-24/>

Pawley, M. (1992). *Design Heroes: Buckminster Fuller*. London: Grafton.

Pucher, J., & Buehler, R. (2008). Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. *Transport Reviews: A Transnational Transdisciplinary Journal*, 495-528.

Selleck, E. (2010, December 28). Hydroleaf Shelter Collects and Purifies Water, Acts as Bus Stop. Retrieved August 21, 2012, from Slashgear: <http://www.slashgear.com/hydroleaf-shelter-collects-and-purifies-water-acts-as-bus-stop-28121661/>

Southcombe, M. (2012). Digitally Fabricated Futures. In P. Bell, & M. Southcombe, *Kiwi Prefab: Cottage to Cutting Edge* (pp. 108-125). Auckland: Balasoglou Books.

Urban 75. (n.d.). *Urban 75*. Retrieved November 2012, from About Critical Mass: <http://www.urban75.org/photos/critical/>

Van der Vilst, B., Niezen, G., Hu, J., & Feijs, L. (2012). Semantic connections: A new interaction paradigm for smart environments. *Design and semantics of form and movement* (pp. 16-27). Lucerne: DeSForM.

IMAGES

Architecture, A. A. (2005). Retrieved from <http://andersonanderson.com/?p=1164>

Bike Fixtation. (2013). Retrieved from http://www.bikefixtation.com/locations/uptown_transit_station

Collins, M. (2006-2007). Trusset Wall. Retrieved from <https://plus.google.com/photos/115782206863097279612/albums/499698396834955265>

GNS. (2010). Retrieved from <http://www.gns.cri.nz/Home/Our-Science/Earth-Science/Earth-s-Magnetic-Field/Declination-around-New-Zealand/Declination-across-NZ-2010>

Moller, C. (2012). Retrieved from <http://click-raft.blogspot.com/2012/03/cnc-click-raft-puzzlekit-assembly.html>

NIWA. (2012). Retrieved from <http://solarview.niwa.co.nz/>

Raft, C. (2012). Click-Raft. Retrieved from <http://click-raft.com>

Selleck, E. (2010). Retrieved from <http://www.slashgear.com/hydroleaf-shelter-collects-and-purifies-water-acts-as-bus-stop-28121661/>

Wellington, V. U. (2007). Retrieved from <http://www.victoria.ac.nz/cbpr/resources/nz-sun-chart.aspx>