Design for Ecosystem Function: three ecologically based design interventions to support New Zealand's indigenous biodiversity

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I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Abstract

This research project explores opportunities for sustainable design in New Zealand. Recently a new framework for sustainable design was proposed by environmental chemist Michael Braungart and architect William McDonough who suggest that the current paradigm of cradle to grave product development is unable to provide a solution to the world's current ecological crisis, and a "cradle to cradle" framework is more appropriate. They suggest that their approach, based on examples from nature, ensures that all human activities have a positive ecological footprint, capable of replenishing and regenerating natural systems, as well as guaranteeing that we are able to develop a world that is culturally and ecologically diverse. A group of New Zealand scientists was asked to evaluate the Cradle to Cradle design framework in an attempt to determine the potential of this, or other sustainable approaches, to design New Zealand products. The key findings from these interviews are described and were utilised to propose a new sustainable design framework – "design for ecosystem function". In design for ecosystem function, biodiversity is placed central to the design decision-making process, alongside human user needs. This framework was then used to help explore the relationship between science and design, while developing three new, innovative and ecologically beneficial products. The three products, or ecological interventions, represent a design response to a range of ecological problems. They include a toy to help children reconnect with nature in urban ecosystems, a trap to assist lizard monitoring and conservation, and a shelter designed to enhance tree survival, and the colonisation of biodiversity in native forest restoration plantings.

ONE. sustainability and biodiversity

"...*design has become the most powerful tool with which man shapes his tools and environments (and, by extension, society and himself). This demands high social and moral responsibility from the designer.*" (Papanek 1985, p ix).

Few could disagree that humans have had a profound influence on the Earth. Our current way of living, especially in developed societies, severely damages natural systems and has endangered their survival and recovery. With resources becoming increasingly limited and substantial environmental impacts resulting from rapid advances in technology, a lack of sustainability is a consequence of the current global situation (Ljungberg 2007). Historically, environmental problems were seen as local issues resulting from single product impacts. It is now clear that these problems are more complex and relate to all phases in a product's life cycle, from the extraction of the raw materials to the disposal at the end of a product's life (Berkhout & Smith 1999). Ljungberg (2007) describes four basic unresolved problems as central to this issue. These include over-consumption, resource utilisation, pollution and over-population. The main problem, however, is that the world is not sustainable by itself, as nature cannot be brought back to an initial condition without drastic external influences that reduce entropy in the Earth's system (Ljungberg 2007).

Sustainability is generally described in the context of future generations (Wood 2000). The World Commission on Environment and Development defined sustainable development as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED 1987). García-Serna et al. (2007) describe a situation where few scientific, social and political areas have been examined in the context of sustainability, and suggest that sustainable development (activities and definition) is in constant evolution. They suggest sustainable development means "*continuously ensuring dignified living conditions with regard to human rights by creating, expanding, enlarging, refining and maintaining the widest possible range of* *options for freely defining life plans. The principle of fairness among and between present and future generations should be taken into account in the use of environmental, economic and social resources. Comprehensive protection of biodiversity is required in terms of ecosystem, species and genetic diversity and all of which the vital foundations of life are*" (García-Serna et al. 2007, p9).

In New Zealand, sustainability is central to the Resource Management Act (1991, section 5) where it is defined as "*managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while:*

a) Sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; and

b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment."

Governments and the private sector in industrialised countries have in many cases successfully implemented improved environmental qualities, but these are often too restricted to resolve the current global issues. A shift from eco friendly production to true sustainable entrepreneurship is required to avoid the future destruction of biodiversity, energy and mineral resources (Keijzers 2002).

In the past it was assumed that advancing ecological sustainability required a trade off against economic profitability. However, a triple bottom line approach that recognises that a long-term solution requires balancing social equity, economic health and the environment is becoming more prevalent (Elkington 1997). This approach, however, has been criticised for being more divisive than unifying and that the division between society, environment and economy is artificial (García-Serna et al. 2007). While these three dimensions must be satisfied, how much each of them is fulfilled will vary depending on the different countries, governments and industries.

The loss of biodiversity, arguably the dominant contributor to environmental sustainability, is considered one of the greatest threats to the continued survival of humans on earth (Wood 2000). Due to the multidimensional character of biodiversity, it is difficult to define (Wood 2000). The term was initially used in the 1980s to capture the essence of research into the variety and richness of life (Jeffries 2006). Many definitions have been proposed and encompass species variety, the genetic variability within these species, and the variety of ecosystems (further analysis may be found in Wood 2000). Wood (2000 p40) describes a general definition for biodiversity as "*differences among biological entities*."

Biodiversity is being lost from earth at an unprecedented rate compared with the background rate of extinctions with human activities being the greatest and almost sole contributor (Sala et al. 2000). Recently, it has been suggested that this rate is 100–1000 times greater than the normal rate of extinction (Haywood 1995). The survival of humanity is dependent on the immediate conservation of biodiversity, which is being lost through alteration, destruction and fragmentation of natural habitat (Wood 2000). The destruction of biodiversity and associated failure of ecological systems resulting from human activities is understood to be a main determinant of the collapse of many societies through history (Diamond 2005). Biodiversity is a non-reproducible resource (Keijzers 2002).

Historically unsustainable practices include deforestation, habitat destruction, soil problems, water management issues, exploitation of animals and fishes, impacts of introduced species on native species, and human population growth. These factors, with the additional "modern" environmental problems of climate change, the concentration of toxic chemicals in environments, energy shortages and the full utilisation of Earth's photosynthetic capability by humans, mean that the potential for major collapses of societies is very real (Diamond 2005). The reliance of people on ecosystems, and the likely failure of these ecosystems to adapt to human impacts, will have serious implications on the health and wellbeing of future populations (Walter-Toews 2004). Biodiversity is central to these environmental problems, as a means to measure human impacts as well as the loss of ecosystem function that results from the loss of species.

Without biodiversity, there is no life on earth (Wood 2000). Biodiversity is housed in ecosystems. Ecosystems consist of living species or organisms and their physical components. Processes that result from the activities of species are called ecosystem services, and include water and gas cycling and purification, soil formation, growth of food and fuel. They are free and essential to the survival of humans (Jeffries 2006). The total sum of an ecosystem's services is called an ecosystem function. Our understanding of biological processes and contributors of ecosystem functioning is reasonably recent and not thoroughly understood. However, we are able to understand the role of biodiversity as a current resource and insurance in our future as an important contributor to sustainability (Jeffries 2006). To this end, O'Riordan and Stoll-Kleemann (2002) describe biodiversity as the key to the connection between ecological and social resilience and "*the currency of co-operative survival of humans and nature. Protecting beyond the protected means saving the souls of the planet and its human tenants*" (O'Riordan and Stoll-Kleemann 2002, p19).

While extinction is a natural process that has occurred since the Earth was formed, the rate at which it is currently occurring means that in many cases there is no opportunity for natural recovery of ecosystems (Wilson 2001, Jeffries 2006). In addition, these impacts reduce the potential for further evolution, as the diversity of genetic material ultimately results in the formation of new species (Gilpin & Soulé 1986, Ward 1995). The current impact on biodiversity by humans has been described as a major mass extinction. Human impacts may be described as proximate or ultimate. Proximate or direct impacts include habitat destruction, introduction of exotic species (and intentional extermination of native species), pollution, ecosystem cascades (indirect disruptions of natural processes) and mismanagement and confusion (Jeffries 2006). These direct impacts result from the underlying causes of human intervention.

These include resource use, cultural attitudes, institutional failure and the failure of economic systems to adequately appreciate the value of biodiversity. Biodiversity impacts have significant effects on ecosystem integrity, or the ability of ecosystems to support and maintain the full range of species, communities and ecosystem processes (Jeffries 2006). The term ecosystem integrity represents an attempt to connect biology with economics, politics and culture. The degradation of any of four elements (structure and organisation of species, natural function resilience to resist damage or recover and the potential for development and adaptation) results in a reduction in integrity (Jeffries 2006). A further cross-disciplinary attempt to protect natural areas resulted in the notion of ecosystem health, which recognises that stresses degrade ecosystems in the way they do for humans (Jeffries 2006).

The failure to recognise the full value of biodiversity is exaggerated when framed in the context of current human activities where an equal right to choose is given to those with a short-term interest ("the democratic trap") who fail to recognise the value to future generations (Wood 2000). When we use the natural environment, anthropocentric values are often the only values prescribed. However, biocentric and ecocentric values reflect the interests of individual non-human organisms and collective entities (species/ecosystems) respectively (Wood 2000). The assumption that only humans have interests (with equal worth between individuals) is a traditional view. However, a departure from this line of thought would require a radical change in the way humanity views the natural environment (Wood 2000). The contemplation of moral considerability, sentience, and environmental ethics introduces a substantial level of complexity into the way in which we view the natural environment, and how it might be valued. Further discussion with respect to the complexity of these issues may be found in Wood (2000).

The term cultural biodiversity describes the relationship of people (cultural diversity) with ecosystems that make up their environment (biodiversity) (Happynook 2000). Happynook (2000) argues that many global indigenous peoples are unable to use such belief systems due to oppression. Cultural biodiversity reflects the cultural practices of indigenous people to conserve biodiversity and ecosystem processes, and maintain the balance of nature. Jefferies (2006), extending this theme further, broadly describes three groups to reflect the diversity of attitudes to biodiversity. Ecosystem people combine the use of nature (and its importance to sustain societies) with rules to conserve the natural system, a description akin to that of cultural biodiversity. Biosphere people treat biodiversity as a resource to be exploited, and are generally typical of the developed world. A final group, ecological refugees, represent those people who have been forced to move to new areas, and who without an understanding of their new environment exploit the resource base. Diamond (2005) paints a picture of controversy and complexity, when viewing past indigenous people as different from modern people from developed countries. Every human colonisation of a new land has resulted in extinctions of large indigenous animals, due to the difficulty of sustainably managing environmental resources (Diamond 2005). In order for biodiversity to become more culturally relevant, and therefore valued by communities, it must be visible and accessible by communities (Meurk & Swafford 2000, Louv 2005).

New Zealand, a land shaped by 80 million years of isolation, has earned one of the worst records for biodiversity loss (Park 2000, Preliminary Report of the Ministerial Advisory Committee 2000, Saunders 2000). Since humans arrived in New Zealand, one third of birds, 20% of sea birds, three frogs, 12 invertebrates, a fish, a frog, three bats and 11 plants have become extinct. Around 1000 species are considered threatened. The richest ecological habitats are often those most valued by humans, and consequently marginal ecological areas are those in the conservation estate. Therefore remaining indigenous species are under constant pressure from habitat loss, urbanisation and introduced species.

The New Zealand Biodiversity Strategy (2000) outlines four goals for managing New Zealand's biodiversity. The first, community and individual action, incorporates the need to enhance community understanding of biodiversity issues, and to motivate and promote action to conserve and sustainably use biodiversity. The Treaty of Waitangi is at the core of the second goal, actively protecting iwi and hapu interests in indigenous biodiversity and strengthening partnerships between Government and iwi and hapu. The third goal is to maintain and restore a full range of remaining natural habitats and ecosystems to healthy functional states, enhance scare habitats, sustain modified urban and production ecosystems, and restore viable populations of indigenous species across their natural ranges. The final goal is to maintain genetic resources of those introduced species important to the economy, biology, and culture by conserving their genetic diversity.

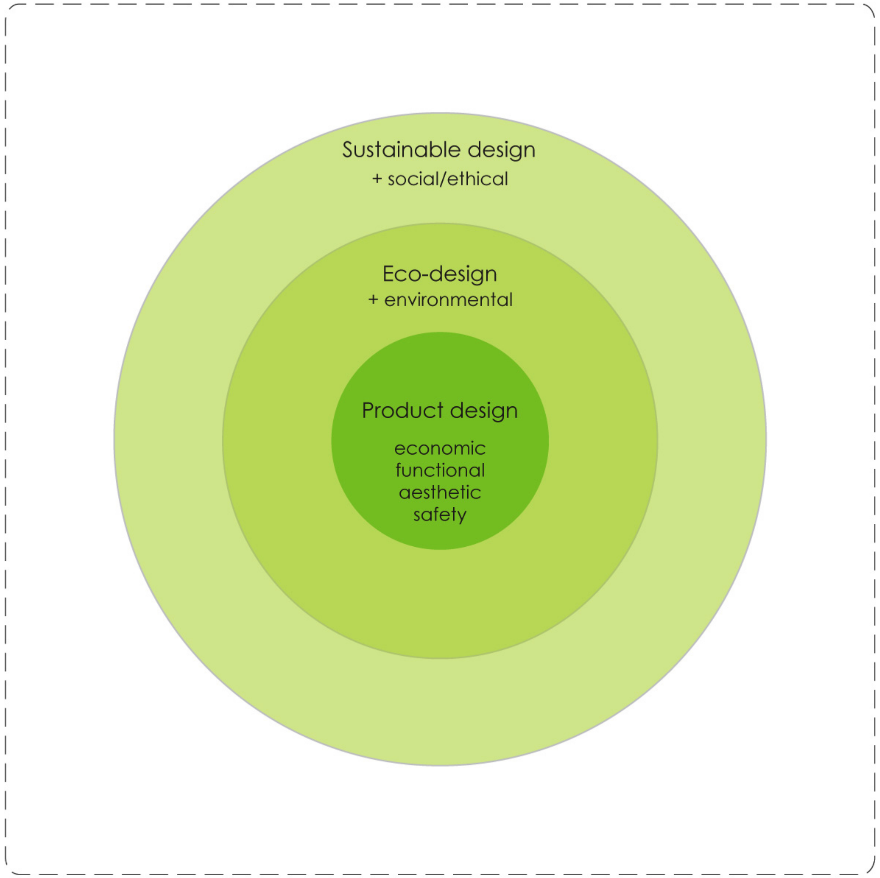
In the context of preserving biodiversity and the environment, design has mostly failed to add value. Until recently, design was viewed as a powerful tool, or solution, to release society from economic evils (Papanek 1985, Whiteley 1993). While the advent of consumer-led design has delivered products of desire, and brought prosperity for many, it has been at the expense of our environment. It should be possible for designers to step outside the current paradigms and use design as a means to add longer-term value, for people and the environment.

TWO. sustainable design

Design practitioners, through their roles in shaping the future, are viewed as being able to promote change in society, especially around unsustainable behaviours (Sosa & Gero 2008). In "Design for society", Whiteley (1993) argues that designers have a moral and ethical obligation to be responsible for their designs, and the social and environmental impacts of their work. Whiteley (1993) follows the writings of others (i.e. Papankek 1984) to reveal a lack of values and ambition, in the marriage between design and consumerism. Consumer-led design is so prevalent that it appears as a "*natural and inevitable aspect of our society*" (Whiteley 1993, p7). For design to change, the role and values of design, as well as the relationship of design with society, needs to change. This may come from a reflection as to whether design is merely a servant of industry, or can inform through intelligent thought and action, while contributing to the global ecological balance (Whiteley 1993).

The design community has responded to the growing concern around social and environmental issues by developing concepts and frameworks such as eco-design and sustainable design, and the numerous related iterations (Sherwin 2004). These concepts are centred on ideals of acknowledging ecological limits and demonstrating responsibility, and increased contribution to society and the environment (Sherwin 2004). Approaches generally fall in between two main areas, eco-design or sustainable design (Figure 2.1) (Tischner & Charter 2001, Sherwin 2004).

Figure 2.1 The relationship of various design strategies with the environment and society (simplified from Tischner & Charter 2001)



Eco-design approaches simply aim to incorporate environmental issues into product design and development, with an overall aim of minimising environmental impacts (Tischner & Charter 2001). Additional motivation for these approaches is usually framed in the form of economic gains resulting from cost reduction associated with the corresponding "efficiency". These strategies reflect a product development process that considers the environment at each design and manufacturing stage to make the smallest environmental impact throughout the product's life (Glavič & Lukman 2007). Often attempts are made to use materials with low environmental impact in its production, but environmental impacts after the product has been sold are not taken into account (Ljungberg 2007). Many techniques are not widely adopted as they are not generic and need to be customised prior to use, rather than being immediately compatible with current product development processes (Knight & Jenkins 2009). Furthermore, to be successful, eco-design approaches should be based on rigorous design and engineering principles (Knight & Jenkins 2009).

The substantial variety of tools and frameworks range from qualitative strategic tools to help designers consider the environmental impacts of a product, through to more rigorous quantitative techniques to measure and compare the environmental impacts of products or services. For further description and a more complete analysis of these (e.g. cleaner production, pollution control, green chemistry, waste minimisation, zero waste and industrial ecology) refer to the works of Wenzel et al. (1997), Bhamra and Lofthouse (2007), Ciambrone (1997), Kobayashi (2006), O'Connor (2006), García-Serna et al. (2007), Glavič & Lukman (2007) and Seager & Theis (2002). While aspects of the differing approaches vary, a common theme throughout is that the greatest benefit to the environment is had when sustainability is considered in the early design stages, rather than during later stages (Waage 2007, Huber 2005). In the absence of a sustainability vision, businesses or industry may be able to introduce measures that provide short-term sustainable gains. However, these are less likely to result in long-term sustainability (Waage 2007).

Life cycle assessment (LCA) is probably the most commonly used method to assess the environmental impacts of a product or service (Ciambrone 1997, Wenzel et al. 1997, Sherwin 2004). This approach is described as the current "best practice" and is used to make small or incremental improvements (Sherwin 2004). LCA attempts to measure all impacts from the initial extraction of materials to the product's disposal (Ayres 1995). This is often an expensive and time-consuming approach, and may include many inherent difficulties, such as comparing products of differing material and profiles (Ayres 1995). Other problems may occur when complete data is not available, or data differs due to inter-country factors. Furthermore, it can be difficult to set the boundaries of systems being assessed (Bhamra & Lofthouse 2007). Consequently, results may be difficult to interpret with any rigour.

With the LCA approach, the environmental impact of a product is evaluated at the later stages of the design process after most design decisions have been made, rather than during the planning and conceptual stages (crucial to the successful design of eco-products) (Sherwin 2004, Kobayashi 2006). Therefore, any improvements that may benefit the environment cannot be introduced until subsequent product iterations are made (Sherwin 2004). Schmincke and Prösler (2000) suggest eco-design may facilitate novel, innovative and new systems, providing an agenda for value adding to the design process. However, Sherwin (2004) describes eco-design as an approach that does not foster "radical innovation", with the LCA approach utilised by many companies focusing on the technicalities of design (i.e. the organisation optimisation of material components). Consequently, designers are often not involved in the design process, which is left to others (i.e. engineers). While being comprehensive, LCA can only accommodate a single assessment chain and thus has limited scope (Abukhader 2008). A number of tools have been developed to address the complexity of LCA or failure of LCA to perform in the initial design stages. These include MET matrix and Eco-Indicator 99 (Bhamra & Lofthouse 2007), Quality Function Deployment (QFD) (Akao 1990), Life Cycle Planning (LCP) (Kobayashi 2006), TRIZ (Altshuller 1988).

Sustainable (product) design goes well beyond the principles of eco-design as described above. While encompassing elements of eco-design, sustainable design attempts to incorporate greater innovation or new concepts, ethics and socio-economic dimensions of sustainability and utilises ecological principles as methods of designing, thus aiming for 'triple bottom line' solutions (Tischner &

Charter 2001, Sherwin 2004). Ultimately, sustainable design is orientated toward balancing economic, environmental and social aspects, while minimising adverse sustainable impacts and maximising sustainable value, throughout the life of a product (Tischner & Charter 2001).

The design of sustainable products is not simple (Ljunberg 2007). Sustainable product design is a relatively new discipline and sustainability itself is complex and multifaceted (Fiksel 2001). Furthermore, the definition or concept of sustainability is complex, dynamic, and constantly changing (Walker 1998, Walker & Dorsa 2001). Consequently there are few examples of actual products, and those that do exist are often experimental (Zafarmand et al. 2003, Sherwin 2004). The actual role of products and services is central to the sustainability debate, with huge benefits for those who are able to identify opportunities to develop sustainable products and services (Tischner & Charter 2001). More specifically, these opportunities will be realised by designers who develop radical innovative solutions by being involved at the early stages of the design process (Sherwin 2004).

Unlike eco-design, there are few sustainable product design models (Tischner & Charter 2001). Four of these are presented below. A broad overview of a four stage “road-map”, cyclic-solar-safe principles and The Natural Step will be presented, while the Cradle to Cradle design framework will be presented in greater detail, and is the basis of the following chapter. These approaches are largely ecologically focused and do not attempt to address wider social or ethical issues (Tischner & Charter 2001).

“Road-map”

Waage (2007) describes a four stage practical “road-map” to guide product designers and companies through complex sustainability issues. Firstly, it is necessary to understand and establish the sustainability context. Secondly, designers and companies must explore and define sustainability issues. The third stage is a process of defining, refining and assessment to identify the best and most sustainable solution. Finally, the process of product implementation is followed by customer feedback, while product impacts are monitored over time.

Cyclic-solar-safe principles

Five sustainable design requirements developed by Edwin Datschefski mimic plant and animal ecosystems, in order to maximise the use of finite resources while maximising human happiness and potential (Tischner & Charter 2001). The five principles are described by Tischner and Charter (2001) as follows:

Cyclic- The product should be made from organic materials and be recyclable and compostable. If it is mineral based it should be cycled continuously in a closed loop system.

Solar- Solar or renewable energy should be used during manufacture and use.

Safe- The manufacture, use and disposal should be non-toxic and not interfere with, or disrupt, ecosystems.

Efficient- A product's manufacture and use should use 90% less material, energy and water compared with a 1990s equivalent.

Social- The manufacture and use of a product should not impact on basic human rights or natural justice.

The Natural Step

The Natural Step (TNS) is an approach (and international charity) of four conditions for triple bottom line sustainability, underpinned by scientific principles (The Natural Step 2009). The four conditions are:

- The concentration of substances derived from the Earth's crust must not systematically increase in the ecosphere

- Society must not produce substances that increase in concentration in the biosphere
- The physical basis for the productivity and diversity of nature must not be degraded
- People must not be subject to conditions that systematically undermine their capacity to meet their needs

The scientific principles underlying TNS are:

- Total energy in a system remains constant (first law of thermodynamics)
- Matter and energy tend to disperse (law of entropy)
- Society consumes quality, structure or purity of matter, not molecules
- Increases in material quality on Earth are almost entirely the result of photosynthesis

Cradle to Cradle design framework

Cradle to Cradle design is a new design framework, and a new paradigm for designing products (McDonough & Braungart 2002, MBDC 2002, McDonough et al. 2003, Braungart et al. 2007). Like Biomimicry and The Natural Step (and others), Cradle to Cradle is a framework inspired by looking to natural systems. Central to Cradle to Cradle is the critique of the use of "eco-efficiency" as a driver for developing environmentally benign products and systems (McDonough & Braungart 2002, Braungart et al. 2007). The authors argue that such strategies (doing more with less) focus on maintaining or increasing economic outputs while decreasing impacts on ecological systems. Zero emission, which aims for maximum economic output with zero environmental impacts, is the ultimate endpoint of such an approach and represents a breakdown of the economic and ecological relationship (McDonough & Braungart 2002, Braungart et al. 2007). Braungart et al. (2007) describe eco-efficiency as:

- a reactionary approach that does not address the need for fundamental redesign of industrial material flows

- being inherently at odds with long-term economic growth and innovation
- not effectively addressing issues of toxicity

Braungart et al. (2007) argue that eco-efficiency is based on the assumption of cradle to grave material flows that transform resources into waste, which is buried into the Earth as a graveyard. Ultimately Braungart et al. (2007, p1338) regard eco-efficiency as "*less bad is no good*".

In place of an eco-efficient approach an alternative approach of "eco-effectiveness" is described (McDonough & Braungart 2002, Braungart et al. 2007). Eco-effectiveness "*proposes the transformation of products and their associated material flows such that they form a supportive relationship with ecological systems and future economic growth*" (Braungart et al. 2007, p1338). Rather than minimising, this approach aims to generate cyclical Cradle to Cradle metabolisms to maintain the status of resources. They claim this approach generates a synergy between economic and ecological systems. Ultimately eco-effectiveness starts with a vision that industry is 100% good. The concept of waste does not exist, as all outputs from one process become inputs for other processes. Therefore eco-effectiveness supports and regenerates ecological systems and enables long-term prosperity, and is the basis for "triple top line" objectives (Braungart et al. 2007). Basically, eco-effective design results in products that are absorbed into the environment. In eco-effective industrial systems wastes may become nutrients for ecological systems and are therefore ecologically irrelevant when included in a saleable product (Braungart et al. 2007). The authors suggest that even if an enormous amount of waste is generated during production, the system will be eco-effective as waste and other by-products (i.e. trimmings) are productive resources for natural systems.

The failure of the eco-efficiency concept is recognised by Huber (2005) who suggests that innovations aimed at eco-efficiency mostly do not make significant contributions to improving industrial metabolisms, and improvements are better realised using an eco-effective approach. This is because eco-efficiency is fundamentally disruptive as a universal prescription for environmental policy (Hukkinen 2001). At the cognitive level, eco-efficiency assumes that an individual's concern for the environment can be decoupled from their material dependency on ecosystem services. This approach will fail as an environmental management tool in the absence of an individual's understanding of local ecosystems (Hukkinen 2001). At the collective level, eco-efficiency requires decoupling environmental governance from local economic and social contexts, creating the illusion that environmental impacts are equal regardless of where an impact occurs, and therefore may be governed at the global level (Hukkinen 2001). In reviewing 500 examples of new technologies, Huber (2005) concluded that a paradigm shift was required, one that focused on upstream processes in vertical product chains and technology life cycles. Such a paradigm shift requires a reprioritisation of those industrial operations where large environmental impacts occur (i.e. energy, raw materials, agriculture, etc.).

Eco-effectiveness is an "emerging concept" which is viewed as a metaphor (Abukhaner 2008). Abukhaner (2008) describes efficiency as doing things the right way, while effectiveness is described as doing the right things. However, the concept of eco-effectiveness needs to be expanded to incorporate the human consumptive condition, and to complement, but not replace, eco-efficiency (Abukhaner 2008).

Cradle to Cradle design is described as the practical strategic framework that is required to create eco-effective products and systems (McDonough & Braungart 2002, MBDC 2002, McDonough et al. 2003, Braungart et al. 2007). Cradle to Cradle identifies three tenets in nature that can inform the design process:

- waste equals food
- use current solar income

- celebrate diversity

The Cradle to Cradle framework attempts to turn materials into nutrients by enabling their perpetual flow within either biological or technical metabolisms (Braungart et al. 2007). Biological nutrients are biodegradable materials that are products of consumption (e.g. textiles, brake pads, shoe soles – things that wear out) and do not harm living systems. These may be returned to the environment to feed future biological processes. They include natural materials, biopolymers and synthetics that are safe for humans and natural systems (Braungart et al. 2007). Technical nutrients are described as synthetic or mineral materials that remain safely in a closed loop system of manufacture, recovery and reuse to maintain their material value through many cycles (Braungart et al. 2007). These products of service are used by consumers, but owned by the manufacturer, who recognises the value of the materials as assets for continual reuse. McDonough and Braungart (2002) suggest that their approach, based on examples from nature, ensures that human activities have a positive ecological footprint, and are capable of replenishing and regenerating natural systems as well as guaranteeing that we can develop a world that is culturally and ecologically diverse.

Braungart et al. (2007) describe a stepwise transition to move from the production of eco-efficient to eco-effective products as follows:

1. Design products free from toxic materials.
2. Make decisions (in the absence of adequate data) based on personal preferences, which will result in products that are generally less bad than their predecessors.
3. Develop a positive passive list for each substance in a product by systematically classifying it by its toxicological characteristics to determine whether a product may be assigned to a biological or technical metabolism.
4. Develop an active positive list to optimise the step above, so that each ingredient is positively defined as fitting into a biological or technical metabolism.
5. Reinvent the product/customer relationship to address interconnected ecological, social and economic systems by extending

biological and technical metabolisms beyond existing products and services.

MBDC offer a certification service and a number of products have received Cradle to Cradle[SM] certification (MBDC 2009). "Gold" status products include shampoo, fabrics, a chimney pot, flushable diaper refills, chairs, and a durable surface. Numerous products have attained "Silver" status including boxes, envelopes, tiles, visual communication boards, compostable packaging, chairs, and…

"*WET WOMEN® SURF WAX is a revolutionary, eco intelligent surf wax MAKING SURE WOMEN STAY ON TOP! Our surf wax is truly beneficial to the oceans, air, water, land, and the creatures of the sea and is completely nontoxic*" (MBDC 2009).

The remainder of this thesis explores ways in which sustainable design may be utilised to develop and design new innovative products that have a positive impact on New Zealand's indigenous environment. This begins with an exploration of the Cradle to Cradle framework, and its suitability to guide design according to eight New Zealand scientists.

THREE. objectives and limitations

I am a recent student of design, and come to the discipline with an interest in biology. While I acknowledge the important role of the economy and society, I believe sustainable design issues ultimately fall back on the dependence of natural environments to maintain human systems. Inherent in this is the necessity to minimise human impacts on biodiversity.

The majority of design decisions appear to be based within an economical context, despite the triple bottom line approach. If a product is not economical then it will not be produced. While I recognise that this is a current social reality, “stepping back” allows an opportunity to explore sustainable design from an ecologically ethical perspective. One of the many issues around designing for environmental systems is that they are very complex, and often not well understood. Therefore, it can be difficult to truly quantify ecological impacts by products, especially over longer time periods.

This body of work provides a unique opportunity to use a multidisciplinary approach to explore a range of potential design solutions by bringing science (in particular the fields of biology and ecology) to design. It allows the chance to explore the interaction between science and design. I believe that better exchanges between disciplines are necessary to meet the sustainability challenges facing our societies. I will use the processes of design to explore opportunities associated with designing for natural environments, without the economic (and marketing) constraints of many design projects. Human-centred factors will be dominant, but not as sole main drivers of the design process, as is usual in design practice. This thesis will attempt to develop products that are useful or have value to people (individuals and society), but which also aim to be beneficial to the environment. I see this work as an opportunity for design to help address and increase the understanding of issues centred on sustainability, framed in the context of understanding ecological systems.

The objectives of this study were to:

- Utilise a group of scientists as key informants to evaluate critically the potential of the Cradle to Cradle design framework, and explore the potential for science to inform sustainable design processes in New Zealand.
- Develop a design framework to design a range of products that may be used to enhance New Zealand's biodiversity.
- Explore whether this framework may be used to contribute usefully to the future design of sustainable products.

FOUR. methodology

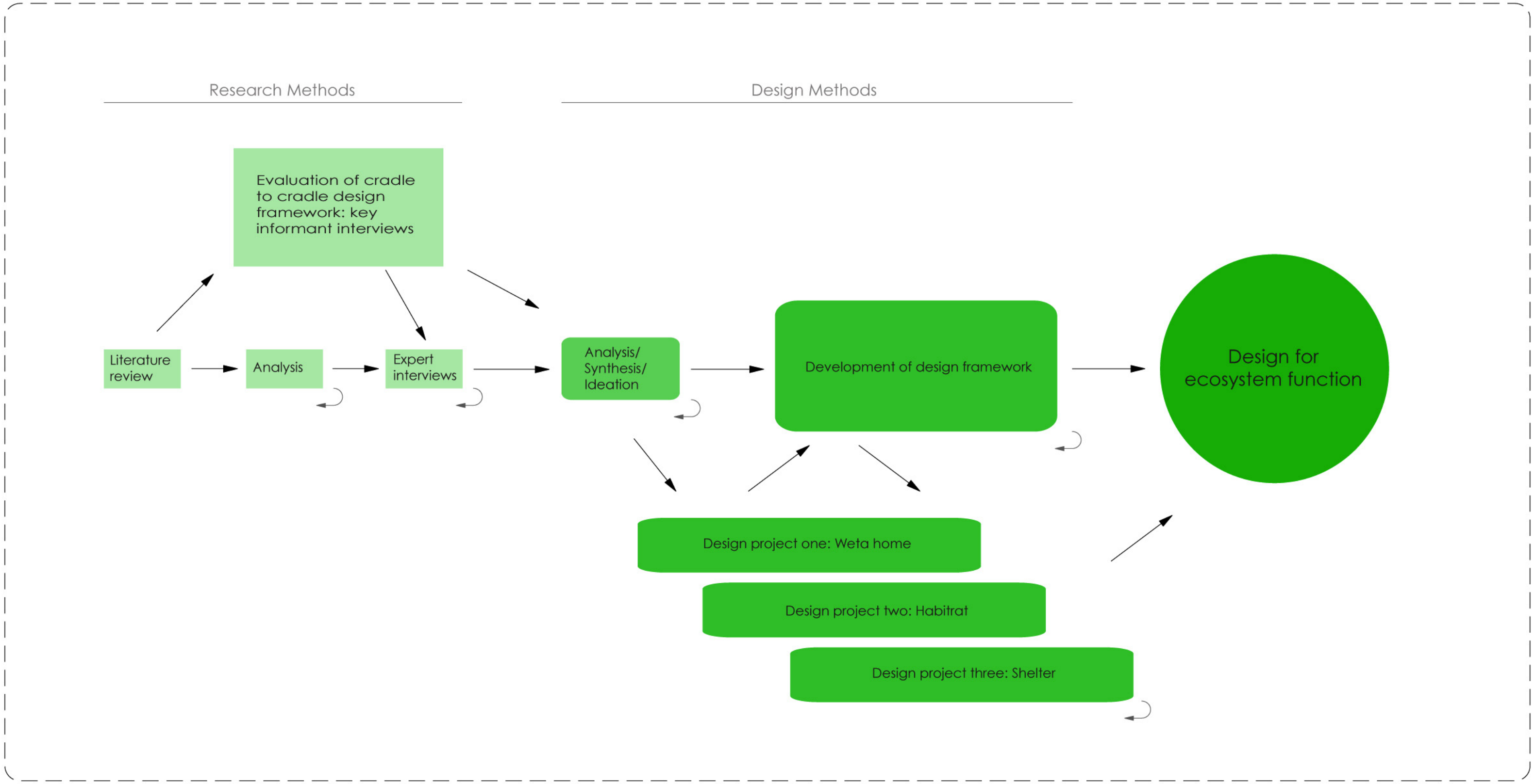
This chapter describes the methodology used in this practice-based research project that explores how design may enhance biodiversity and the conservation of indigenous organisms. Firstly, the overall design process is presented, from outlining the development of the design framework, to evaluating this framework and exploring the interaction between science and design. Secondly, the specific methods used to develop three products that conserve indigenous biodiversity are described.

Design research can be a difficult undertaking (King Roth 1998). This is in part due to the evolving nature of design research methods where no single method or approach is dominant (King Roth 1998, Bürdek 2005, Lawson 2006). A mixed-methods research methodology (Bryman & Bell 2003, Creswell & Plano-Clark 2006) was used to analyse the area of sustainable design and to explore product solutions to ecological problems. A generalised map, as described by Lawson (2006), was used to organise the design process. The design process was initiated in an analysis phase before moving to a stage of synthesis. Following this the design was evaluated. At each step it was possible to return to either of the previous steps. However, in reality this process was not ordered and separated by distinct events. Lawson (2006, p48) suggests that the design process is a "*negotiation between problem and solution with each seen as a reflection of the other*", where the direction of flow is not apparent, nor are the start and end points. A similar framework describing a structured approach is the basic learning cycle described by Kolb (1984). The process is started on the basis of real experiences. Reflection and observations are made of further knowledge obtained. This then leads to the formation of new (improved) concepts and generalisations. These in turn lead to ideas for a new approach, which is formulated and tested in new situations – thus resulting in the initiation of a new learning cycle.

Action research is a reflective-action research method where active intervention by the researcher (or designer) affects process and phenomenon (Schön 1983). While action research is usually employed when researching social and behavioural systems, action research was the dominant methodology used in this study. An important aspect of action research is that it is concerned with processes in action, rather than research being undertaken and the research results applied. Instead, research is undertaken as a process of application, including the collection of data and the evaluation of results. Schön (1983) describes "reflection-in-action" and "reflection-on-action" as central to the reflective practitioner. Reflection-in-action represents the practitioner experiencing a unique situation, while simultaneously reflecting on this new experience as well as previous experiences and understanding. In essence, this is a process of developing new understanding to inform action in an unfolding situation. The process of reflection-on-action is usually undertaken after the reflection-in-action "experience", where a period of contemplation is undertaken and the practitioner explores why they acted the way they did. Action research is a process of learning, where new experiences and knowledge are an important part of the research process; by engaging with a "situation" the practitioner may avoid significant problems while making preliminary assessments. One of the problems associated with action research is that it may be difficult to differentiate between the research and action (Usher et al. 1997). In the context of this study, action research is primarily a background structure where the development of the proposed design framework and product concepts are of primary importance, rather than the process from which they were conceived.

The first phase (research methods) (Figure 4.1) was used to gather and review information, which was then analysed to derive key insights that drove the design process. The second phase (design methods) (Figure 4.1) was an iterative, practice-led process to synthesise some aspects of sustainable design and to develop concepts and prototypes that enhance biodiversity through the design of products. The interface between each step in the process was linked, rather than being discrete.

Figure 4.1 Map of the design process to develop “design for ecosystem function”



Literature review

A literature review is a body of text that attempts to review and critically analyse the current body of literature surrounding a particular topic of interest. For this study, four literature reviews were undertaken. Firstly, during the initial stages of the project the literature was scoped, reviewed and analysed to gain insight into the area of sustainable design and to determine the current knowledge around sustainability, biodiversity and sustainable design. A comprehensive search of scientific, design, and social science databases provides the basis for the literature review. An advanced search strategy was utilised on these databases with the following search terms: "sustainability", "sustainable design", "eco-design", "Cradle to Cradle", "eco-effectiveness", etc. Searches were limited to research articles, review articles, and qualitative and quantitative research published in English between 2000 and 2008. In addition, the reference list of relevant research articles was searched for additional articles. All studies reporting on the development of relevant products, systems and research and design were selected and appraised. For each of the design projects a literature review was undertaken using the methods described above, and using search terms relevant to each project.

Expert interviews

Expert interviews are often conducted during the infancy of a research project to help ensure that the research problem is fully understood, but they may also be used to collect data in collaboration with other methods (Kolb 2008). Experts are those who have specific knowledge of a particular product, situation or area, and are able to provide factual information pertaining to this. Experts are often professional, and the time for an interview is kept to a minimum. Interviews generally consist of two phases, opening and questioning (Kolb 2008). In this study, a variety of experts were consulted at each stage of the design process, and to explore specific areas relating to the case studies. Individuals included: scientists, farmers, horticultural experts, conservationists, ecologists, educators, etc. In addition to the expert interviews, a number of semi-structured and in-depth key informant interviews with senior New Zealand scientists from a range of fields were undertaken to scope knowledge, expertise, critical viewpoints and "support" for sustainable design in New Zealand. The purpose of conducting key informant interviews is to generate a broad understanding of the key issues from those who have specific expertise. A semi-structured interview format was utilised to guide the interview and allow differing ideas to surface, and to allow for reflective discussion. The full method, and the results of these anonymous interviews, are presented in chapter five.

Analysis/Synthesis

A variety of techniques, described below, were utilised to analyse data collected during the research process.

Mapping

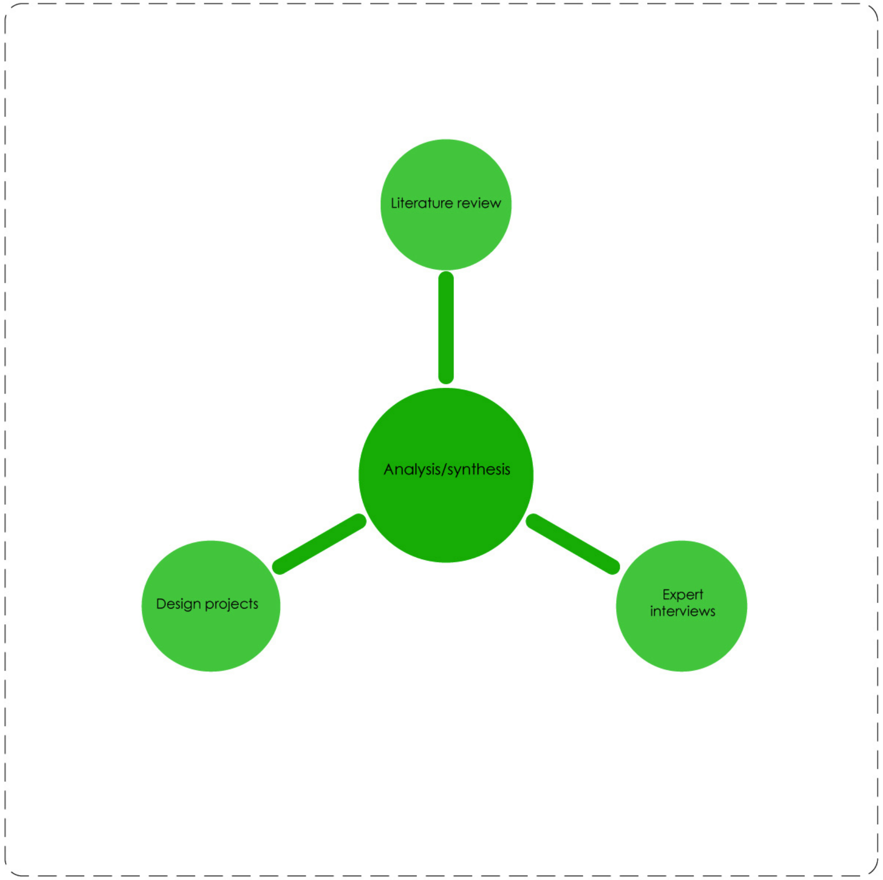
Mind maps are a graphical representation of words and ideas, linked to a central theme, to generate, visualise, structure and classify ideas. Buzan and Buzan (1993) describe mapping as being able to aid intellectual exploration through reflection. In this study, mapping aided the visualisation of the projects and themes by helping to group ideas, define relevant areas and provide a structure to help synthesis. Ideas and themes were crossed and linked across a map in a way that encouraged a brainstorming approach to organisation. The linking or combining of opposite or unusual elements often helped create unique insights and ideas.

Triangulation

Triangulation Design is a common design method used to obtain complementary information on a topic to help fully understand the research problem by converging different methods (Creswell & Plano-Clark 2006). Triangulation is a single-phase process where both quantitative and qualitative methods are concurrently implemented with equal weight. While this design process makes intuitive sense, is efficient and allows separate collection and analysis of data sets, there are factors that may make this method less suitable

(Creswell & Plato-Clark 2006). These include the substantial effort required, the use of many complex research methods (both quantitative and qualitative) and the potential problem of interpretation when the different methods give inconsistent results. Triangulation was used in this study to aid the analysis and synthesis of data collected using a variety of methods, as described above (Figure 4.2).

Figure 4.2 Example of triangulation as used in this study



Exploring the relationship between science and design

Due to the nature of this project, an engagement with science (and scientists) was required to inform and critique the design process. More specifically, scientists from the disciplines of biology and conservation were closely collaborated with during the research and design research phases. One of the outcomes of these collaborations was that the relationship between the disciplines of science and design could be explored, especially with regard to their roles in sustainable design.

Three design projects

In this study three generative design projects were simultaneously undertaken. These provided an opportunity to gain a greater understanding of a complex issue (i.e. sustainable design). This is a similar approach to that of the case study, which is often utilised when examining real life situations. However, in case studies the researcher is not actively intervening in the research, although reflection by those individuals involved in the research may result in change (Yin 1984). These design projects (as with case studies) were complex and involved many data sources. In these design projects multiple research methods were used (or embedded) and an action research methodology was used, as described above, to explore the relationship between theory and practice. The primary aim of each of these projects was to design a product that supported and enhanced New Zealand's biodiversity. However, undertaking these projects played a greater role in the overall development of the project as described below.

Evaluating design framework

The three design projects were used to test and evaluate the design for ecosystem function framework that was being simultaneously developed. The framework was utilised as an integral part of the design process for the three projects, and was used to generate ideas, inform decision-making and evaluate prototypes. The framework was incorporated in a cyclical generative manner, whereby the framework informed the design process, and the design process thus informed the development on the framework. Thus the relationship between the framework and the three design projects was a process of two-way interaction. Ultimately, the design for ecosystem function framework was used as an overarching anchor, to guide, inform and affirm the projects' ethical and moral integrity, with regard to sustainable design.

Ideation tool

The research and design process utilised during the three design projects informed and aided the development of new ideas, or concepts that could be incorporated into the design framework. These new insights could then be cycled back into the design process using the amended framework, thus providing the basis for further development of ideas and design iterations. The design projects were used to generate new, innovative designs to support biodiversity and the conservation of New Zealand's indigenous species.

Process

The design framework was used to provide a starting point and structure for the design process. The framework helped inform the processes that guided the research, generated key insights, and provided a basis from which prototypes were evaluated. The design decision-making process was linked back to the framework through the design process. In addition, the three design projects were used as a mechanism to reflect on development of the design framework.

Reflection

The three design projects were used as a mechanism to reflect on the design process and the suitability of the design framework as a tool to generate new ideas and concepts for biodiversity. As well as a tool for decision-making, the framework was utilised as an ethical foundation for decision-making with regard to design. This included helping to make decisions around material use, appropriateness of design direction, and suitability and appropriateness of the design approach. These design projects were used to reflect on the role and value of having an underlying ecological ethic.

Evaluating the design process

The three design projects, and their success, were used to evaluate the design framework as a tool to develop sustainable solutions to benefit biodiversity.

Communication

The three projects were used to communicate the design process and the effectiveness of the design framework. In addition, the projects were used as a means to communicate the exploration of the relationship between science and design.

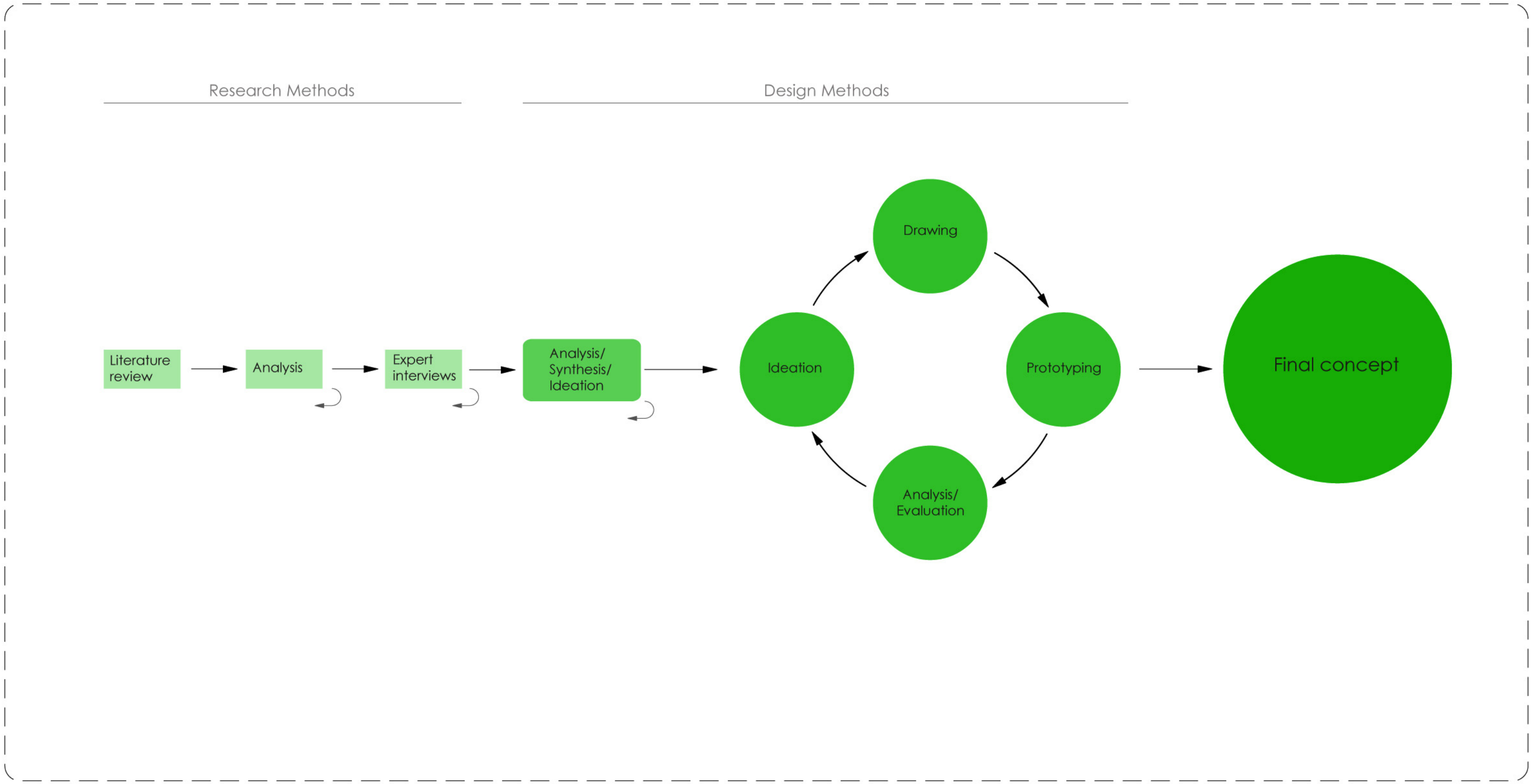
Research process of the three generative design projects

The research process of each of the three design projects was similar to the research process for the overall study, described earlier (Figure 4.1). More specifically, the process and methodology for the three design projects is summarised in Figure 4.3 and described below.

The first phase (research) of each design project was used to gather and review information specific to each of the design projects. The research in this phase was undertaken using the methods described above for the overall design process. This was then analysed to derive the key insights that drove the design process. The design phase involved an iterative, practice-led process to synthesise the research as it related to each concept, and to develop opportunities to generate concepts and prototypes that enhanced biodiversity through product use. The interface between each step in the process was linked, rather than being discrete, and broadly followed the four phases of new product development described by Cagan and Vogel (2002): identifying the opportunity, understanding the opportunity, conceptualising the opportunity, and realising the opportunity.

The specific design methods used in the three design projects are described below.

Figure 4.3 Map of the design process for the three generative design projects



Ideation

Ideation is the generating, communication or development of ideas and is traditionally an essential conceptual tool in the early part of the design process (Johnson 2005, Eissen & Roselien 2007). In this context an idea is a basic element of thought. In these projects, the ideation process used a combination of visual and non-visual methods as described by Schon (1983), although sketching was commonly used. Ulrich and Eppinger (2000) describe concept generation as a five-step process where the problem is clarified, information is gathered externally (including literature searches), a search is conducted internally (to retrieve and adapt the knowledge of the team), exploration takes place systematically using classification techniques to organise thinking and synthesise solution fragments, and there is reflection on the solutions and process.

Drawing

Drawing was used as a method to develop and advance those concepts or ideas realised during the ideation phase (Jones 1992, Eissen & Roselien 2007), and is an important technique in the thinking process (Pipes 2007). Drawing generally has three main functions: externalisation of ideas, provision of a persuasive medium (to sell ideas), and communication of complete and unambiguous information (manufacturing) (Pipes 2007). The first is most important in the context of this study. Drawing was used to externalise and analyse ideas, and simplify multidimensional problems (Pipes 2007). Concept sketches were undertaken to develop collections of visual cues, crystallise thoughts, and aid in the evaluation of ideas. Drawing is an important design practice that allows the designer to visually present information quickly and accurately. The process of drawing allowed the rapid evolution of concepts and provided opportunities to easily incorporate new ideas (Eissen & Roselien 2007, Pipes 2007). Drawing was also used as a creative tool to help the process of divergent thinking (Eissen & Roselien 2007).

Prototyping

Urlich and Eppinger (2000) describe prototyping as the process of developing an approximation of a product along one or more dimensions of interest. The prototypes developed in this study were initially proof of concept prototypes, initially used to test an idea. These included sketch models as well as Computer Aided Design (CAD) models. As the concepts were developed and refined, prototypes resembled more comprehensive prototypes, or full-scale working objects (Urlich & Eppinger 2000). Prototypes were used in this study to learn, communicate and integrate (Urlich & Eppinger 2000). As a learning tool, prototypes were undertaken to determine whether a concept would work and to test what materials and process may be employed in manufacture. In this study, prototypes were used to communicate the ideas, visual form and "feel" of a concept. Finally, prototypes were developed to ensure that the different components of an object fitted together, or that the object could be transformed (i.e. from flat-pack to 3D object) as intended.

For the three design projects in this study, prototypes were developed along a continuum from sketch models, to CAD models, to final fabrication as closely resembling a manufactured object as possible (within the time constraints of a thesis). In particular, CAD models were used to represent designs constructed from a collection of 3D objects (i.e. cylinders, blocks, etc.) and they have a number of benefits (Urlich & Eppinger 2000). The most significant benefit for this study was the ease of representation of an object's 3D form, and the subsequent development of free-form fabrication (rapid prototyping), as well as the development of moulds.

Analysis/evaluation

Concept selection is an integral aspect of the product development process (Urlich & Eppinger 2000). This is a vital phase in the design process where convergence on a single concept (or small number) is the primary goal. However, this phase may also be used to combine a number of concepts, as well to refine and therefore enlarge the number of concepts for a short period (Urlich &

Eppinger 2000). A range of methods was undertaken to determine which ideas or concepts would be advanced for further development and improvement. Furthermore, a structured approach was undertaken to help maintain objectivity, as well as to guide the process through a potential period of difficulty.

Urlich and Eppinger (2000) present a two-stage process of concept selection methodology (concept screening and concept scoring) and this was the approach followed in this study. Three methods were used: selection matrices, expert interviews and concept tests. Selection matrices involve ranking, or scoring, concepts according to a list of important criteria. Expert interviews were undertaken (as described above) and were important to evaluate concepts and prototypes when specific knowledge regarding a concept or prototype was required; for example, when making predictions regarding the behaviour of a user to a particular object or form. Finally, prototypes were tested and evaluated in situ where possible to identify potential design and performance issues. Throughout the design process no single method was utilised in isolation. Furthermore, the weighting or importance ascribed to individual methods varied depending on the stage in the evaluation process.

The concept and prototype selection process resembled the six-stage process described by Urlich and Eppinger (2000). Firstly, selection criteria were identified. Concepts were then rated, and ranked. Following this was a process of evaluation, and concepts were combined and improved where possible. The fifth step was the selection of a number of final concepts/prototypes. Finally, a period of reflection was undertaken to ensure that any issues or problems with the process or the selection criteria were identified, and could therefore be incorporated in any subsequent selection iterations. This concept screening process was undertaken throughout each stage of the design process.

FIVE. what are the issues, barriers and opportunities for implementing "Cradle to Cradle" sustainable design in New Zealand?

Introduction

McDonough and Braungart (2002) describe the "Cradle to Cradle" approach to sustainable solutions as "the next industrial revolution" and suggest that industry needs a new paradigm. Within this new paradigm, design is viewed as the first signal of human intention, where a deliberate and strategic approach should be taken (McDonough & Braungart 2001). They suggest that the current environmental tragedies were not due to deliberate action by early engineers and industrialists. Consequently, eco-efficient changes to current systems will not be able to provide the solutions necessary for sustainability (McDonough & Braungart 2001). Their solution to sustainability, eco-effectiveness, aims to generate cyclical Cradle to Cradle metabolisms to maintain the status of resources (Braungart et al. 2007). As described earlier (chapter two), they claim this approach generates a synergy between economic and ecological systems, where eco-effectiveness supports and regenerates ecological systems. Even if vast quantities of waste are generated during the (inefficient) production of products, an eco-effective approach will ensure that the waste will be good for natural systems.

While many have embraced the Cradle to Cradle concept (e.g. *Time* magazine's "Heroes for the Planet"; Esquire's "Big Thinker of the Year" Bill McDonough crowned "a prophet of sustainability and clean-technology movements" by *Vanity Fair*), there is a paucity of material relating to Cradle to Cradle design in the scientific literature.

This study aims to evaluate the Cradle to Cradle design framework from an ecological perspective, framed within a New Zealand context, in an attempt to determine the potential of this approach for the design of New Zealand products. The Cradle to Cradle framework was chosen for evaluation, as it is recent and has received considerable public approval (in the design community). It is a relevant reference point to reflect where design thinking might currently be, and is a sound basis for initiating a sustainability discussion.

The Cradle to Cradle framework relies primarily on a fundamental understanding of materials, science, systems and processes. Eight key informant interviews with senior New Zealand scientists from a range of disciplines were undertaken to scope knowledge, expertise, critical viewpoints and "support" for the Cradle to Cradle framework from a New Zealand perspective. While the key informants selected for this study (scientists) may have been unfamiliar with Cradle to Cradle design, they were chosen for their expertise in the areas that will ultimately be involved in developing Cradle to Cradle design processes. From this it was anticipated that there might be opportunities to determine what aspects of the framework could be applied to the New Zealand situation.

Methods

A series of key informant interviews were undertaken to explore opportunities for sustainable design in New Zealand. The purpose of conducting key informant interviews is to generate a broad understanding of the key issues, barriers and opportunities from those who have specific scientific expertise. A semi-structured interview format was utilised to guide the interview, to allow differing ideas to surface and for reflective discussion. A thematic analysis of the data was conducted and an explanatory theory based on the emerging themes was subsequently developed.

Design

Each interview (ethnographic interview) was a face-to-face discussion that followed a semi-structured interview schedule based around a number of key research questions enabling an in-depth exploration of relevant issues. The purpose of conducting key informant interviews is to generate an understanding about an issue from people who have expertise in relation to a particular area (e.g. the role of science in developing sustainable futures). Key informants (participants) are usually selected on the basis of their unique expertise or because they represent a particular group. In the context of this study, expertise may include the application of scientific research, an understanding of the biological processes that underpin sustainability, or research into the development of materials and processes that may be required for the development of sustainable systems. Key informant interviews are an important qualitative research method in terms of providing insight into issues that cannot often be identified through other research methods (e.g. focus group interviews or questionnaires).

Participants

Key informant participants were chosen using a non-probability purposive sampling technique. Participants were selected based on their unique experience in a particular scientific field. The scientists selected were chosen from a range of scientific disciplines related to the primary industries in New Zealand. This group were chosen as they have a broad understanding around ecological and material principles and processes as they may be applied to sustainability. Each scientist selected was employed in a senior position in either a Crown Research Institute or New Zealand University.

Potential participants were contacted by a single email inviting their participation. Contact details were obtained from information in the public domain. If no response was received following the email invitation to participate, this was taken to mean the individual declined to take part in the study, and no further contact was initiated.

Participants that took part in the study were from the following areas of expertise: biology, material science/engineering, biotechnology, science strategy, chemical and process science/engineering, pharmacology and active agent science, microbiology, and textiles science.

Procedure

Prior to the commencing of the interview process, approval to carry out the study was sought and obtained from the Auckland University of Technology Ethics Committee (AUTEC Reference Number 09/54).

Participants were invited to take part in a key informant interview to discuss a range of topics centred on sustainability and Cradle to Cradle design. On acceptance to participate in the study, each participant was given a copy of Braungart et al. (2007), as a discussion point for the interview. Prior to the actual initiation of each interview, the purpose of the interview was reiterated. The interviews were based around a series of open-ended questions (see below) and enabled the participants to explore the questions in-depth. New questions were included to reflect emerging issues as interviews progressed. With prior participant consent, interviews were audio recorded to enable transcripts to be used for analysis. Detailed field notes were also taken during the interviews, where possible, to complement the transcripts. These added greater depth to the interview transcripts, provided reminders for the analysis and documented particular emphasis. Interviews took no longer than one hour and were conducted in the participants' workplace at a time that was convenient for them. The author conducted the interviews. Audio-recorded interviews were taken to a transcriber following the interview for verbatim transcription. The interviews were analysed using a qualitative thematic analysis method whereby the textual data was read and coded to identify common and divergent viewpoints, for the purpose of generating a clear understanding of the issues and range of perspectives and possible strategies for working with sustainability and Cradle to Cradle design in New Zealand. The key perspectives were then developed into a conceptual model for consideration for future development and initiatives. All possible attempts were made to obscure the contribution of participants to protect their identities, including their place of employment, age and gender.

Key informant interview themes/questions

1. What is the role of sustainability in the context of your science field?

2. What materials are important/critical to achieve sustainable products?

3. What do you understand about the concept of Cradle to Cradle as a proposition for sustainability with respect to science/design?

    a) What were your first impressions with respect to the principles that underpin the concept?

    b) What is the potential of this concept for New Zealand science/technology?

    c) What is the role of science to help facilitate a Cradle to Cradle or other sustainable design framework?

    d) Can New Zealand embrace this concept, and what do you see as potential barriers/opportunities?

4. How do you view the role of scientists/science in adopting a concept such as Cradle to Cradle design?

Data analysis

All transcripts and field notes were read repeatedly to gain an overall impression of the material being analysed. The transcripts (data) were entered into TAMS analyzer (ver. 3.53, GPL), coded and analysed using a thematic analysis procedure to identify recurrent topics embedded in the texts (Berg 1998). Data were then arranged according to themes. Each theme was analysed until emerging themes were identified.

Results

Results from the textual analysis of the interview data are presented according to the key (dominant) themes and divergent viewpoints. Direct quotations are presented to illustrate a salient perspective, as appropriate. Firstly, the informants' general impressions of the Cradle to Cradle design framework are presented. From here I present a critique of specific aspects, fundamental to the Cradle to Cradle design framework, which were identified by the informants as being vital to the success of Cradle to Cradle design, or were identified as being unrealistic or misleading. This section leads to the participants' perspectives on barriers they identified that may prevent sustainable design frameworks from being broadly implemented, as well as participants identifying opportunities for sustainable design. Finally, this section concludes with the emergent themes around the future of sustainable design in the context of New Zealand, and the potential role of science and technology.

General impressions of the Cradle to Cradle design framework

Participants were provided with an abbreviated version of the Cradle to Cradle framework (Braungart et al. 2007), published in the *Journal of Cleaner Production*, and it was from this basis that the interviews were conducted. Most participants had not heard of the Braungart et al. (2007) Cradle to Cradle design framework prior to this study. All participants were swift to express a diverse range of perspectives on the general concepts and rationale behind the Cradle to Cradle framework.

The overwhelming opinion was in favour of the rationale for the framework.

> "*It's an interesting concept… You know so it sounds like the sensible way to go to me…*" (Materials Engineer/Scientist)

In general, participants agreed that the general principles that underpin Cradle to Cradle are important factors when attempting to address sustainability. Participants supported Braungart et al. (2007)'s description of the tension between economic growth and environmental objectives. The description of the problems with using "eco-efficiency" (as described by Braungart et al. (2007)) as a strategy to resolve issues around resource use and provide a sustainable future was viewed as accurate. Participants were generally favourable toward the rationale for Cradle to Cradle. The majority of participants considered it to be an ideal: a good idea in principle, but not in practice. It was not widely accepted as a mechanism that would reflect the realities of complex social and environmental ecosystems.

> "*… but as I said its aspirational*" (Biologist)

> "*I felt the general scope was idealistic. Not to say that it's bad. Just that I wouldn't want to totally adhere to it*" (Biotechnologist)

"*I think the model's been well thought through but I worry that they tried to apply it in ways that perhaps it doesn't comfortably fit*" (Chemical and Process Engineer/Scientist)

There was not a clear consensus as to whether Cradle to Cradle was an appropriate approach to use for the design of products. One participant felt that it had merit on a product-to-product basis, but that moving from this to society level sustainability was an entirely different proposition. Another suggested that it was an appropriate approach, but questioned whether "*it was the only approach*". Another suggested that the Cradle to Cradle framework was fine, but believed it was not something that had been missing (i.e. it did not add anything new).

The following sections will focus further on the areas where the participants felt Cradle to Cradle was potentially undeveloped, and will provide a commentary on the barriers that they viewed as hindering its implementation. Throughout the interviews, the participants agreed that the current situation we live in is not sustainable, and that greater effort is required to provide for current and future generations.

Critique of the Cradle to Cradle framework

Throughout the interviews, a dominant theme was that participants were critical of aspects of the Cradle to Cradle framework, as well as some of the "arguments" put forward by the authors in order to support their framework. Often the participants' views diverged from each other and not in all cases was there consensus for criticism. Furthermore, participants were supportive of many of the views raised by the authors. This section will describe the key themes that emerged when discussing Cradle to Cradle and the concepts put forward to support the framework.

Can we have a positive impact?

The majority of participants viewed human impacts being minimised or reduced to zero as a more realistic goal, and found it difficult to interpret human activity as being positive to the environment.

> "*Your impact on the environment, you can't absolutely reduce it to zero… everything we do [has] an environmental impact … and I think what, the aim of this paper I mean, might be zero waste but I think, but there's always going to be this inefficiency somewhere in the system that requires some leakage, you can't have… I don't think you can have a perfect system*" (Biologist)

Participants were generally in consensus around the issue that to have a positive impact we must know what that positive might be. They argued that this may not always be the case, and some added that even if it was, we might not have the capability to measure such impacts.

> "*Because suggesting you actually know what's positive for the environment… we don't seem to have a handle on the complexities of how things interrelate to know precisely what the outcomes will be, so I think it sounds a very strange thing to think that we can do things for the positive to be honest… So I think I'm still a fan of doing as little damage as possible*" (Materials Engineer/Scientist)

> "*… some of these things you can probably never measure… Do we have to measure anything just to get a sense that we*

would be better off doing it one way rather than another way… I don't think we do" (Microbiologist)

Four participants discussed the complexity around deciding what is natural (and therefore what is "good" for the environment), and observed looking to nature for inspiration may not always be appropriate. Reasons included a description of nature as being very complex, and a failure to recognise this when "fixing" one thing may cause a problem elsewhere. The overwhelming consensus was that regardless of whether a positive impact on the environment was possible or not, it was important to minimise impacts as much as possible in the short to medium term.

Is waste always good?

While the ideas of biological and technical nutrient cycles were generally viewed as being interesting, some participants argued that these approaches may not always be possible, or practical. With regard to the idea of biological nutrient cycles participants agreed in principle with the concept. However the majority cautioned against extrapolating a theoretical principle to real world situations. In particular, participants question the potentially enormous quantities of biological nutrients that might be produced, and question what to do with these, especially as high levels of nutrient inputs can have detrimental impacts on biological systems. One participant described that the transition from a largely inorganic system to an organic system would be required to fulfil Cradle to Cradle requirements. While this in itself was viewed positively, most products currently produced are not made from organic-based materials. The result of this could be large quantities of organic "waste" material. One participant observed this was "*fine when things are in village amounts, but with city amounts you get problems*".

Three participants suggested that knowing where to put the biological nutrients and knowing what influence they may have on a system was an issue.

> "*… put it in an environment where its waste can be utilised, not just thrown in an inappropriate place… is all waste good?, it depends upon how it is going to be utilised*" (Biotechnologist)

One participant suggested that the controlled composting of biological waste material was important, as "*uncontrolled composting is not efficient, and doesn't always produce a usable bio-product*".

While many of the participants found the idea of a technical nutrient cycle appealing, six of the eight participants thought the degradation of materials in this cycle wasn't fully addressed. Comments ranged from not illustrating that the material integrity of synthetic materials degrades with use, and repeated reuse, to suggestions that all materials wear out during use.

> "*…so I don't think it's appropriate to just think in an idealistic fashion that materials can be recycled ad infinitum.*" (Biotechnologist)

> "*… it's not perhaps a loop, more of a very slow downward spiral*" (Textiles Scientist)

Furthermore metals (as potential technical nutrients) were described as oxidising and wearing out. While it was suggested that processes such as oxidisation might be reversed, this takes considerable energy inputs.

What do we need to consider when using a new design framework?

One of the common themes that emerged during the analysis was the complexity involved with issues around sustainability.

> "*…they're not simple issues. It's a complex system. And that's what you're talking about here. Sustainability is a complex system…*" (Science Strategist)

Access to clean renewable energy sources was described as being an important aspect of the future of sustainability. Energy, as we currently use it, was described by one of the participants as being the only part of a closed system that disappears due to entropy. They suggested that unlike nature, which has endless energy from the sun, we need energy to create energy.

The methods used to accurately measure impacts were described as being complicated, and a thorough understanding of what to measure was problematic. A key component of sustainability, it was suggested, was looking to understand the complexity of systems (and how small changes have unknown effects) so that not as much is at risk. It was also suggested that a change toward valuing the environment was unlikely until we put a price on the environment.

The majority of participants described the development of better eco-effective or eco friendly materials as being influenced by a variety of factors.

"… *what's the rate limiting step, and it's typically creative people and funding and the identifying need. Creative people on their own without an identified need, aren't going to create what's useful. Needs can be stated, but you need people to make it.*" (Biotechnologist)

It was suggested by one participant that the manufacture of biological-based materials depended on very large quantities of plant materials. Research into base materials and technological challenges associated with using new materials (during manufacture) were examples given by another participant of some of the research challenges. For some base materials, these were not considered to be significant hurdles, but for others it was described as very difficult. The lack of performance by some organic-based materials in comparison with their synthetic counterparts was considered a hurdle in terms of the wider acceptance of organic materials.

How is sustainability perceived by science?

"*Well I think it's been recognised that sustainability will play a role in the future because we need to produce things sustainably in order to continue doing it, it's almost an oxymoron, you have to be sustainable*" (Biologist)

Participants had a range of views with regard to how to define sustainability. Broadly speaking, definitions were similar and were orientated around themes: not taking out of the environment more than is put back, maintaining material quality, maintaining the health of systems, and not depleting the environment.

“*The idea of sustainability to my mind is doing something in such a way the system or our environment, depending on [whether] you want to define it broadly or narrowly in human terms, will continue with the same quality of life*” (Biologist)

“*It’s pretty simple. It’s when you haven’t made anything more unusable when you’ve finished than when you started*” (Science Strategist)

“*It’s coming out with a net cost of zero, and if you start your life and you finish it, coming out with a net cost of zero…*” (Chemical and Process Engineer)

One participant suggested economic sustainability should flow out of environmental and social sustainability and that the two cannot be separated. The majority of participants thought that New Zealanders did not have a unique or different view of sustainability compared with other countries. They did suggest however that New Zealanders have a greater awareness of the environment, and some suggested a greater bond to it. This was described as being because New Zealand is largely an agricultural nation. New Zealand’s global isolation was suggested as a driver for New Zealanders’ thinking around sustainability and why New Zealanders are less likely to embrace high-tech and often less sustainable technologies. Therefore New Zealand “*often has just accidentally ended up with more sustainable solutions than other countries*”. New Zealand was described as being in a good position in terms of sustainability, but that a dramatic change in lifestyle would be necessary.

How might science play a role in the design of sustainable products and services?

Participants were generally in agreement with regard to the role that science might play around issues of sustainability, and developing a more sustainable future. Some participants favoured looking to natural systems for ways of living more sustainably, or for developing and utilising sustainable materials. One participant suggested that sustainability "…*will come from mimicking nature or fitting into nature's cycles*." Another participant suggested we look more to organic materials, and continue research into new ways in which they might be used. It was also suggested we need to look at "old" (organic) materials and to develop new manufacturing processes so we can use them more effectively and efficiently.

Other participants described the role of scientists as helping to negotiate the complexity of systems. Understanding what aspects of systems and processes we need to measure, and how to measure them, were described as being fundamental, for now and into the future. One aspect of this is that scientists will be required to help come up with solutions, as well as identifying the risks associated with a potential solution. This was described as a key role of science. Science was described as a vital process for learning and understanding sustainability problems and solutions. One participant saw the role of science as "*doing the thinking*", and described this as a process of defining what we want to achieve and how might we do it. The process of science was described as "*fast moving*". It was suggested that lack of knowledge therefore should not be the barrier that historically it might have been. This was also described as being true for issues centred on sustainability.

Overall, participants described New Zealand as a largely agriculturally based exporting nation with ready access to bio-based alternatives. This was seen to put New Zealand in a strong position to develop sustainable innovations, and by capitalising on our "*green image*" to make an important contribution to the sustainability of future societies.

Discussion

In general, the majority of participants were involved in research where issues of sustainability, if not central to it, represented a considerable aspect of their research, or they had a great interest in general issues surrounding sustainable futures. Overall participants responded positively to the intent of the Cradle to Cradle framework.

A dominant theme that emerged from the interviews was the complexity associated with understanding the interactions of humans, societies and their environments. To address issues of sustainability with rigour requires an ability to explore complex situations (Bradbury 2002, van Roon & Knight 2004). The domain of a scientist is to understand interactions between multiple factors (see Bradbury 2002). This requires the capacity to ask questions framed in an appropriate context and the aptitude to interpret and discuss complex results. The key informant interviews illustrate that consideration of human impacts on the environment is critical, and was the most discussed factor when referring to sustainability. While issues of social sustainability and economic sustainability were mentioned they were not regarded with the same level of consideration. From the participants' perspective, the environment was considered the foundation of sustainability. Therefore the protection of biodiversity and the natural systems in which it persists is fundamental to human sustainability.

A few barriers to implementing some principles of the Cradle to Cradle framework were raised by the participants. These were around the concepts of technical and biological nutrients, the interpretation of nature (or what is natural), and energy use and generation. The participants agreed with the concepts themselves, but questioned how such concepts may be implemented. Some participants questioned whether technical nutrients were suitable for closed loop systems. They suggested that the material integrity of synthetics and metals is not always easily maintained. These will not be discussed further and are beyond the scope of this study. Instead, I will focus on some aspects of the concept of biological nutrients, to provide examples of the role science might play in understanding the impacts of products on the environment. Participants also acknowledged the role of consumerism in helping to create or encourage unsustainable practices, as well as the failure of consumers to pay the "true environmental cost" of this behaviour. Neither of these was fully acknowledged and addressed by Braungart et al. (2007).

The participants in this study described the need for caution when approaching the concept of biological nutrients as a simple solution to sustainability problems. Reinders (2008, p1140) reached a similar conclusion suggesting it is "*impossible to consider emissions or wastes containing biological nutrients as intrinsically healthy or good."* The inherent complexities of ecological systems are confounded further by difficulties around measurement (knowing what to measure and how to measure it). The participants did not consider that New Zealanders regarded sustainability differently from residents of other countries. One exception may be the reliance of New Zealand on primary industries as a main source of national income. In this context, designing products and services to better serve these industries, and to help develop sustainable futures, will likely rely even more on understanding the ecological systems that support the natural systems underpinning primary industries.

Unfortunately, superficial design responses to sustainability issues are common. These are probably due not to designers exploiting consumer demand, but to a failure of designers to understand the complexity of ecological systems. For example, Bhamra and Lofthouse (2007), in their book "Design for Sustainability: a practical approach", describe a compostable mobile phone case that releases a seed on disintegration. This later germinates and grows into a flower. Braungart et al. (2007, p1343) describe a potential Cradle to Cradle design solution where an ice cream wrapper may be designed to contain seeds "… *so that when thrown away, it not only dissolves safely into the ground but also supports the growth of plant life*". It is important to draw attention to the fact that neither author offers insights into the wider ecological implications of these design solutions. While the growing of plants appears on the surface to be a worthwhile ideal, numerous examples exist where "garden plants" have escaped and have subsequently become invasive weeds resulting in considerable ecological destruction (DOC 2002).

The concept of a biological nutrient, as identified by Braungart et al. (2007), represents an exciting opportunity for designers who can play an important role in developing sustainable futures. In doing this, they must engage with science and other disciplines to make the best of new opportunities that may arise from potential paradigm shifts (i.e. Cradle to Cradle framework). Scientists have the ability to understand the complex systems that support sustainable solutions. Designers are experts in packaging "information" (product/systems) to have an "aesthetic/functional/operational" appeal for people. Therefore future collaboration has considerable appeal in a scenario where designers may help to identify human user needs and science may help to develop solutions that are appropriate to the greater environment. Inherent in this is that designers must understand ecological and social systems as they relate to developing sustainable solutions.

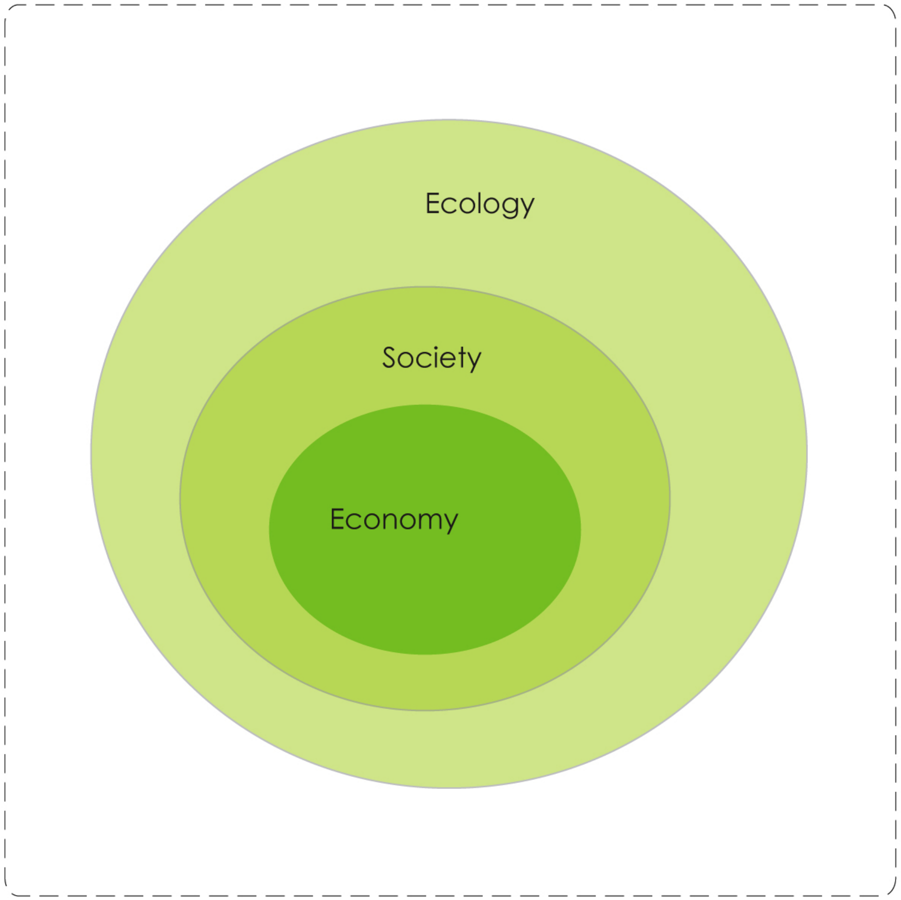
Designers may best act as a conduit between science and industry and effectively and elegantly communicate sustainable solutions to human users and the communities in which they live. The development of sustainable societies relies on clear and accessible dialogue between science and design. This greater level of engagement between disciplines is required to address a range of environmental and social issues facing us. Design decisions must be of real benefit to society and the environment rather than "eco-responses" with good intention but inappropriate or inadequate investment. This requires designers to ask how products might be designed to address sustainability in a meaningful way, rather than just producing consumer objects that are loosely built around preconceived ideals relating to sustainability, but which don't consider the underlying ecological principles required to ensure sustainability at all levels. Thus the challenge for design is to engage across disciplines to capture the true intent of frameworks such as Braungart et al. (2007)'s Cradle to Cradle. This represents an enormous opportunity to make a substantial contribution to the future wellbeing of societies and the environment in which they exist.

SIX. design for ecosystem function: a product design framework to enhance biodiversity

A design framework for the projects that follow is described. The analysis of the key informant interviews was used as a basis for creating a framework to develop opportunities in product design. In particular, I focused on the concept of biological nutrients as a key insight when developing products to provide benefits to natural ecosystems. The concept of biological nutrients, described by Braungart et al. (2007) as products made from non-toxic, biodegradable materials, appears on the surface to be reasonably uncomplicated. However the research undertaken in the previous chapter indicates that many design responses based on this approach could in fact be detrimental to natural ecosystems, and therefore may represent superficial "eco-design" responses. In order to design products that are beneficial to natural systems, rather than just being manufactured from biodegradable materials, an understanding is required of complex ecological systems and what inputs into these systems might be appropriate. In essence, a design framework needs to incorporate the key principles of Cradle to Cradle, while overlaying the need for greater ecological understanding.

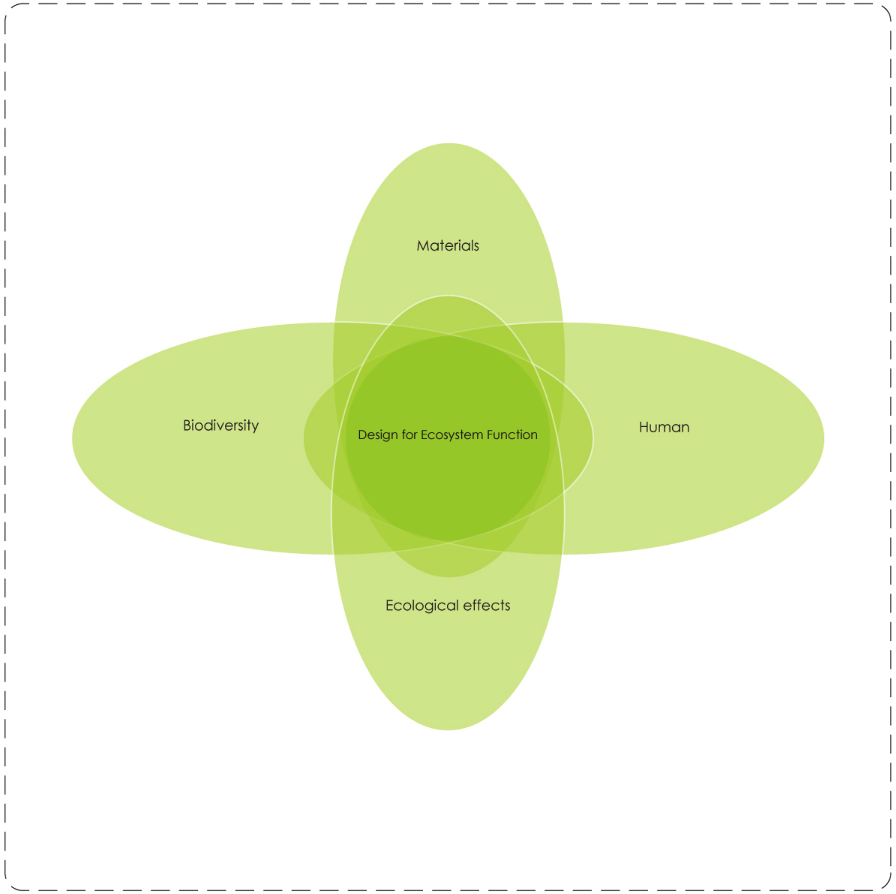
van Roon and Knight (2004) present two simplified models of sustainability. The balanced approach is described whereby ecological needs are weighed against economic and social (WCED 1987). This approach is commonly accepted internationally (and in New Zealand) and represents weak sustainability (van Roon & Knight 2004). They suggest that strong, or ecological, sustainability sees all decision-making being taken within an ecological context (Figure 6.1). This approach recognises that humans are part of ecological systems, and that viewing human activities as separate from nature will ultimately be unsuccessful. van Roon and Knight (2004) argue that the functional capability of ecosystems needs to be central to decision-making processes.

Figure 6.1 Model of strong sustainability (from van Roon & Knight 2004)



A key focus of this study was to use the design process to develop opportunities around a series of interventions that might benefit biodiversity. This means using design as a tool to conserve or preserve species or habitats, or to help people engage with nature, thereby creating an awareness of the role of biodiversity and ecosystems in supporting human systems (Figure 6.1). It is the interface between humans and nature, or areas of cultural biodiversity, where the design process may have the greatest potential to enhance biodiversity and bring a better understanding of the role of biodiversity as an influence for culture and society, thereby increasing opportunities for sustainability. As described earlier, the term cultural biodiversity describes the relationship of people (cultural diversity) with the ecosystems that make up their environment (biodiversity) (Happynook 2000, Jefferies 2006). Cultural biodiversity may be defined as human social systems intimately dependent on an ecological system (Jeffries 2006). Figure 6.2 represents that current society (New Zealand) is generally at odds with natural systems. Ideally well-designed products will increase cultural biodiversity, by enhancing human engagement with nature, as well as enhancing biodiversity by providing nutrients to ecological systems via products during their use, or at the end of their lives. Therefore, biodiversity, and the ecosystems that support it, will be richer and more highly functional. The ultimate aim would be to have high levels of biodiversity in a diverse range of ecosystems, in both urban and rural environments.

Figure 6.2 Interaction between humans and indigenous ecosystems



The interface where people interact with ecosystems was where I first explored sustainable design opportunities. These were based around the concept of biological nutrients (Braungart et al. 2007). Farms and other agricultural systems were identified as being suitable environments for the disposal and decomposition of biological nutrients. In these highly modified "ecological" systems products may be used (end of life) in future food and biological material production. This approach represents an opportunity to develop agricultural systems that function using natural processes, rather than "working against nature", as is commonplace in modern agricultural practices. In closed loop biological metabolisms, similar to those described by Braungart et al. (2007), there is considerable opportunity to minimise the amount of urban and agricultural waste as well as reducing the application of synthetic fertilisers. This may result in the minimising of other environmentally negative aspects of agricultural systems. Limiting human impacts in indigenous systems is a key component of conserving biodiversity, and therefore supports sustainability. This includes the ecologically inappropriate disposal of biological nutrients as discussed earlier.

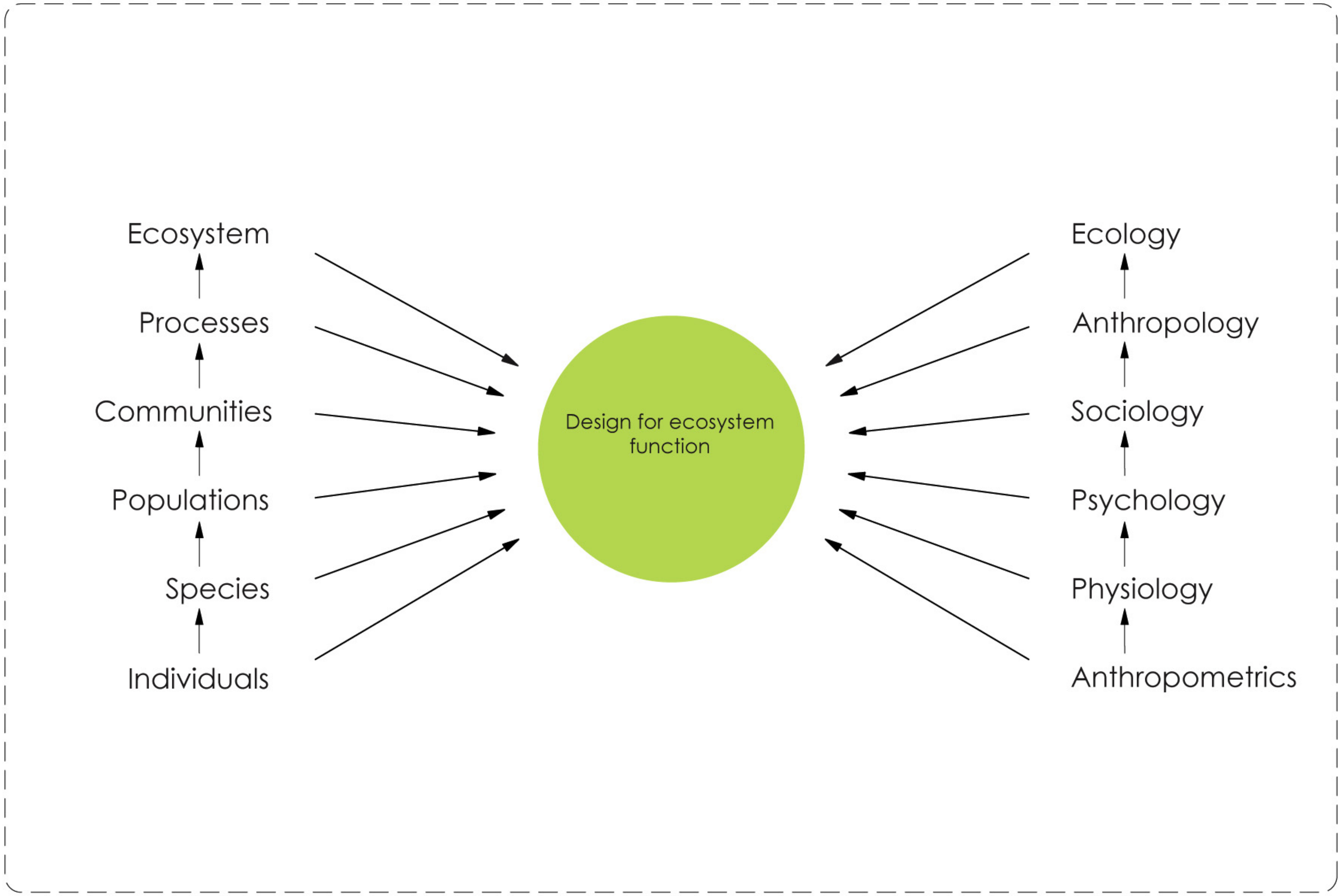
Initially, agricultural systems were explored as areas in which to look for new opportunities around the sustainable design of products. A number of expert interviews were conducted with farmers and other agricultural experts (viticulturalists etc.), to identify areas where products may be developed, or existing products may be redesigned to incorporate the key insights described here. These types of agricultural systems represent the ideal place for the disposal of products manufactured from biodegradable materials. While a number of design opportunities were presented in these systems, I discovered that these systems often did not generate large volumes of material waste relative to the land area (e.g. compared with urban households). However, considerable inputs in the form of biological nutrients would be beneficial in many of these systems. Therefore, agricultural systems may be appropriate systems for the disposal (and therefore the beneficial use) of biological nutrients resulting from products used in other systems (i.e. urban systems). This approach represents a systems approach to sustainability and is beyond the scope of this study.

Throughout these investigations, the concept of a biological nutrient was critiqued. From this emerged the concept of a "structural nutrient". This concept represents the use of a product by an individual species or group of organisms at some stage during the product's life cycle. An analogy for a structural nutrient is the use of artificial reefs for the conservation of marine organisms (Bohnsack & Sutherland 1985). Similarly, products may be designed for use as "artificial habitats" for organisms at some stage during a product's life, with subsequent biodiversity benefits (particularly if threatened indigenous organisms are targeted) (Michael et al. 2004, Lettink 2007a,b, Bowie et al. 2006). This approach is complementary to the Braungart et al. (2007) concept of a biological nutrient. With this approach a product may be used as a structural nutrient (habitat) after its "intended use" before decomposing and becoming a biological nutrient.

During this discourse a decision was made to place biodiversity as a key driver for the design process, making it central to each project. In doing this, the focus was placed on conserving biodiversity, with the challenge then to make products that are appealing and useful to people. This approach I termed "design for ecosystem function". It recognises that the ecosystem is the basic unit of ecology (and therefore biodiversity) and represents the systemic relatedness of everything to everything else (Park 2000). This framework (Figure 6.4) acknowledges the importance of human impacts on ecosystems, and "*the intimate, and reciprocal, relationship between human activity and the health and integrity of ecosystems*" (van Roon & Knight 2004, p269), and attempts to enhance the positive nature of these relationships. This approach is in direct contrast to many current "eco-design" activities, where design is primarily focused toward human users with the intent of minimising or reducing environmental impacts.

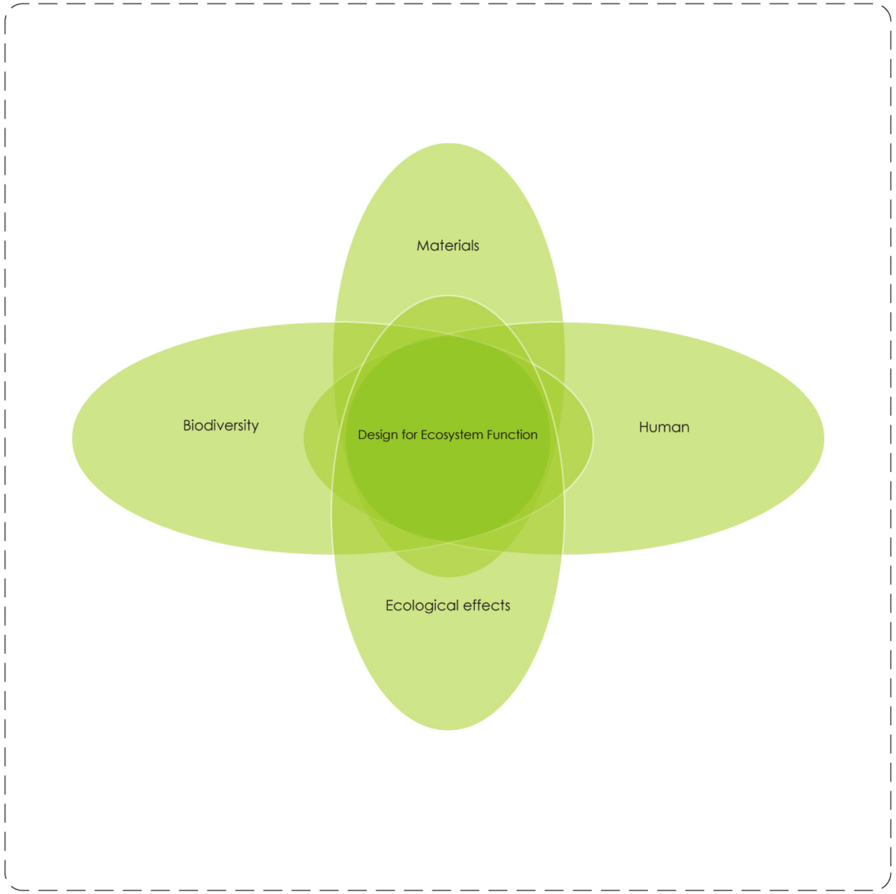
In the proposed framework, human needs are considered alongside environmental needs. Moggridge (2007) describes a hierarchy of complexity with respect to incorporating human factors in design (Figure 6.3). Anthropometrics is positioned at the simplest level of complexity, and represents the role of basic human factors (sizes of people) in designing objects for individuals. Physiology (how the body works), psychology (how the mind works), sociology (how people relate to each other) and anthropology (the human condition) are presented as increasing levels of complexity. Ecology is presented as the highest order, and is described as understanding the interdependence of living things (Moggridge 2007).

Figure 6.3 Hierarchy of complexity (modified from Moggridge 2007) to incorporate ecosystem elements alongside human elements



Design for ecosystem function recognises the basic needs of people, and that the design processes should recognise the importance of a human aesthetic in designing meaningful objects. However, it also addresses the needs of people at higher levels of complexity. These human factors may be less immediately tangible. The impacts of products/human activities are complex, dynamic and long term. Furthermore, they are intimately connected throughout a product's life with the environment. Thus the design framework presented and explored here proposes a holistic view toward human factors as a key component of the design process. This sustainable design framework recognises and embraces opportunities due to the connectedness of individuals and materials in ecosystems. People are highly dependent on the natural systems in which they live, and are an integral part of them. These systems are in turn highly dependent on, and vulnerable to, people's actions and activities. Design for ecosystem function recognises the importance of intact, fully functional ecosystems as highly complex, dynamic and unpredictable biological systems crucial to maintaining the human condition. Ultimately the model recognises that the ecology of the foundation of life, and needs of society (firstly) and economies (secondly), will be met. Therefore design intent should be orientated toward addressing ecological needs to maintain the strongest levels of sustainability.

Figure 6.4 Framework for design for ecosystem function



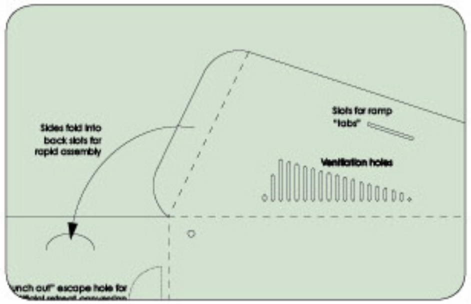
In the context of this framework, an ecosystems function is the sum of its services (Jeffries 2006). Biodiversity is represented in this framework with equal status to human users. This recognises the connection to and dependence of people on biodiversity, ecosystem processes, and ecosystem function (Lyle 1999, Park 2000, van Roon & Knight 2004). Therefore, design considerations (impacts and benefits) for both "user groups" will be addressed in a complementary manner. User factors (both human and non-human) will be assessed for each product along a scale of complexity similar to that proposed by Moggridge (2007). For example, at the simplest level of complexity user needs will be orientated toward specific individual needs, be they animals, plants or people. At higher levels of complexity, the opportunities for products to have positive impacts on wider communities of both people and organisms is considered. The "materials" component of the framework represents the impacts that the material components of a product may have on both human users and ecosystems, and may reflect possible tensions between different user groups e.g. durability (human users) and biodegradability (ecosystems). Within this sphere the positive environmental opportunities for material use shall be considered. The "ecological effects" component represents the intention to understand the impacts (positive or negative) of a product on ecosystems, and to be able to recognise and embrace opportunities to design for positive ecological impacts. It is here that the concept of structural nutrient may be explored for a given product or service.

In order to design products that address sustainability with environmental integrity, I believe that it is important to understand the potential impacts and benefits of a product (or the use of a product) on ecosystems. Following the development of a product, ecological assessment should be undertaken to determine actual impacts on ecosystems. This should be undertaken alongside, and incorporated into, human user assessments with the aim being to improve future products.

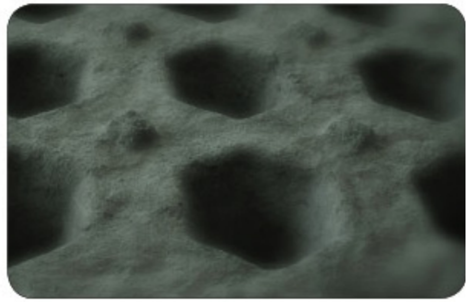
SEVEN. application of the design for ecosystem function framework to design a range of ecological interventions

The following three design projects represent a range of product innovations designed using the "design for ecosystem function" framework to inform the design process. The three products represent a spectrum of design activities along a continuum, from designing to enhance cultural biodiversity in urban environments, to developing a product to conserve an individual species (or specific group threatened by human activities), through to designing a product to enhance biodiversity at an ecosystem level. The three projects described here were carefully selected as opportunities for the exploration, to further the potential practical application of the design for ecosystem function framework.

(i) weta home
design for cultural biodiversity



(ii) Habitrap
design for lizard conservation



(iii) Tree shelter
design for habitat restoration

Design project one. weta home: framing nature for children

Introduction

"*I like to play indoors better, 'cause that's where all the electrical outlets are*." (Fourth Grader, Louv 2005, p10)

In "Last Child in the Woods: saving our children from nature-deficit disorder" Richard Louv (2005) describes the recent process of disengagement or detachment of children from the natural environment. He suggests that society is teaching the young to avoid direct nature experiences by unconsciously associating nature with doom. Healing this broken bond is crucial and paramount to the future mental, spiritual and physical health of humans. Furthermore, it is crucial to the health of the Earth.

The term "nature-deficit disorder" describes the human costs of alienation from nature (Louv 2005). The disorder is not only found in children, but also in families and communities, and may shape human behaviour in cities. Symptoms are described as diminished use of the senses, attention difficulties, and elevated physical and emotional illness. Until recently, people were raised on the land, worked the land, and were buried in the land. The relationship was direct (Louv 2005). Today our lives are electrified. We use air conditioning instead of opening a window, PlayStation "SingStar" instead of starting a band, computers, TV… These all contribute to the rise of "*cultural autism*" (Louv 2005, p63).

Advantages of interaction with nature include (Louv 2005):

- Play in nature is more varied and less time bound than other outdoor play
- Nature is a prop for play and more engaging

- Nature can help protect children from stress
- Nature is needed for the healthy development of senses (seeing, smelling, hearing, touching…)
- Nature is an infinite reservoir of information and learning (and a moral teacher)
- Nature nurtures creativity

Reasons why children don't play outside anymore (Louv 2005):

- Outdoor play takes time
- We largely live in urban areas
- Outdoor activities (such as sports) are over-scheduled and organised and are often not referred to as 'play' by children
- Less leisure time
- Fear of people/strangers
- Ecophobia – as children become disconnected from nature they either fear, or romanticise, what they don't know
- 'Faith' in computers

Urban development has resulted in a loss of connection with nature, and as a consequence, a loss of ecosystem processes. Consequently, we fail to see ourselves as part of nature. This loss of "cultural biodiversity" (as described earlier) has given way to the idea that nature is provided for our use and exploitation. The challenge to develop sustainable futures is to have long-term planning that interrupts the decreasing importance of natural environment in the lives of urban people. Urban people need to be encouraged to develop an awareness and understanding of the importance of ecosystem services and the role they play in urban environments, and ultimately human wellbeing (Ignatieva et al. 2008).

For biodiversity to become more culturally relevant, and therefore valued by communities, it must be visible to and accessible by those communities (Meurk & Swaffield 2000, Louv 2005). People who live in cities need to see the nature surrounding them if more threatened (and often distant) habitats are to be valued and ultimately protected (Ignatieva et al. 2008). Enhancing natural biodiversity in urban environments and engaging urban dwellers with nature may help natural heritage to become integrated with valid cultural values (Ignatieva et al. 2008). Engaging urban children with nature, and maintaining this engagement throughout their life, is not only important to their development (as described above), but is essential to preserve biodiversity and natural systems. This may be difficult in urban areas where there is a paucity of large (visually significant) natural areas, and an abundance of "urban distraction".

One way of encouraging a child to play in nature is to use a "prop" or toy. With an educational toy, the learning experience is an aspect of play and might not be otherwise encountered. For a child with no or limited experience in a particular area, it may not be possible to access these learning (play) opportunities. Furthermore, it appears that in some cases the ability of children to transition from indoors to outdoors is becoming increasingly reduced. A toy may help engage a child's imagination, allowing them to make an emotional investment indoors where they feel comfortable. Following this, full enjoyment of the toy requires that it be used outdoors with the toy supporting the transition into a new environment.

I believe a good toy should:

- Encourage play
- Stimulate imagination
- Engage a child with their environment
- Provide education beyond basic play that will help them develop habits and gain awareness that will enrich their life and those around them

A good toy should have a number of functions or "lives" so that it may be used over long periods of time, thus minimising the likelihood of premature disposal. It should be able to grow with the child, so as a child advances the toy is able to provide additional stimulation. A toy may educate children about the wider community/environment by engaging with them on more than one level. This helps increase the life of or interest in a toy, and may provide opportunities to challenge the user. Toys fall into several different categories, including toys for physical development, sensory stimulation, imagination, and creative and intellectual development (NCCC 2009). Valuable toys are those that promote meaningful learning, respectful play and respect for the environment (TRUCE 2009). When it is fostered, children have a great interest in nature, and find endless joy in simple things such as leaves and other things they find (TRUCE 2009). A child can turn anything into a toy, the more simple, the greater the imaginative potential.

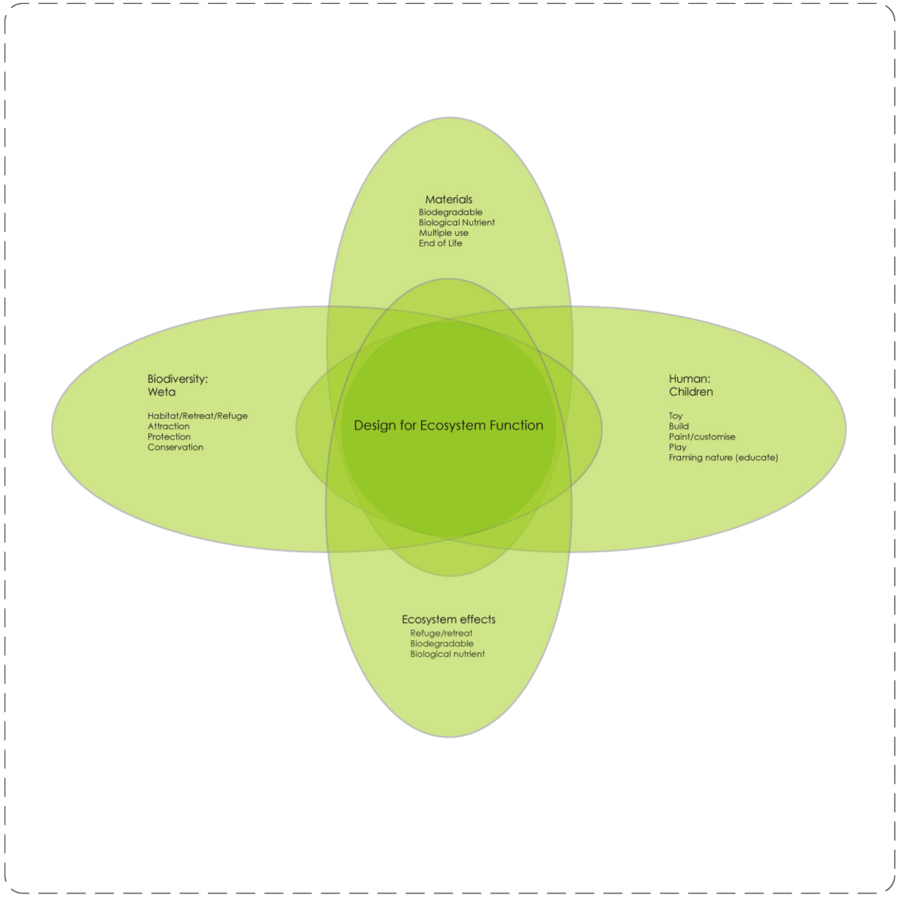
The design brief was to design a toy that is educational, fun and helps engage children with nature in an urban environment.

A weta is an iconic New Zealand insect. It looks ferocious, yet is harmless. It is common throughout New Zealand, and can be easily found in back yards with shrubs and woody vegetation. Weta are recognised as being icons of invertebrate conservation in New Zealand (Sherley 1998), and are therefore an ideal candidate insect to help inspire children to engage with nature. They readily colonise artificial retreats, which are used in invertebrate monitoring programmes (Bowie et al. 2006). Previously, the author developed a wooden toy prototype. This current study represents an opportunity to further develop this prototype, in the context of a new design framework: design for ecosystem function.

Mind mapping processes resulted in a series of new design insights. Ecosystem function was central to the decision-making/mapping process (Figure 7.1). If educating children about the role of nature (and ecosystem processes) was compromised, the project would not be successful in the long term. This is from both an environmental and human user perspective. If key environment drivers fail, then the child–nature relationship will be compromised. A dominant theme of this project was to respond to the environment in a positive way. While the design response was creating a toy, the project is essentially about the need for children to engage with nature. Therefore an ecosystem response was necessary at small (garden) and large (community) scales. Placing ecosystem function at the centre of the design process illustrates the relationship between the design elements, and reflects the importance of a close relationship between people and the environment.

A key innovative design driver that emerged from the mind mapping process was that a toy could be used to “frame” nature for children. Complementing this approach, weta and the environment were viewed as users of the toy. Therefore, design decisions were initially based around providing artificial habitat, or refuge, for weta. For the greatest ecological integrity it was not a requirement for children to view the whole weta (some weta houses are simply flat boxes with lift-up lids), as children may better learn to value animals as they exist naturally in their environments. A substantial proportion of the insect should still be able to be viewed (e.g. if the weta was found in a hole, or under the bark of a tree).

Figure 7.1 Design model for weta home showing key design drivers



Evaluation of prototype

Expert interviews

A number of simple weta house prototypes were given to the sustainability leader (teacher) of a local primary school to use in a class exercise (a rich task focusing on insects). The school is medium sized and located in central Auckland. Following this, expert interviews were conducted with the teacher, and the Deputy Principal of the school. In addition, an expert interview was conducted with an early childhood educator at a central Auckland kindergarten. Similarly, the kindergarten had been provided with a number of simple weta house prototypes for use in a nature education programme.

Key interview themes included:

- Initial impressions (teachers and children)
- Will children be able to assemble/use?
- How might it be improved?
- What is an appropriate life span of the toy (at each stage)?
- How might it fit into the learning outcomes of education programmes?
- What is an appropriate age for this type of learning experience?
- How might the weta home be developed to foster an interaction with the environment?
- How might it be developed to better frame nature in urban areas?

Interview outcomes

The key themes that emerged from the interviews are summarised below:

- Children love and are intrigued by weta

- The children were really excited by the prototypes and the idea of going outside attaching them to trees and shrubs
- The children enjoyed the opportunity to “customise” their weta homes
- Many wanted to be able to take them home at the end of the school term
- The build/play/frame multidimensional aspect of the toy was embraced
- The freedom to customise is an important aspect of this toy
- A greater stability of the body parts is required, as well as for the mechanism to attach it to a tree
- Age appropriateness was recommended to be from pre-school up to 10 years of age
- Younger children may need adult help to build and customise the toy. This is known as “scaffolding” and is a good feature to incorporate into the design
- The “softer” look was regarded as being more appropriate than a realistic form (spikes etc.) as it allows for a greater level of individual customisation, and may function as a better “frame” for the live insect
- The wood was thought to be a tactile material
- Children don’t often initiate outside play in trees etc. The weta home was seen as a good way to encourage children to initiate outside play
- Gardens/trees may not be viewed as “real” nature as we only see what is obvious. We are not used to looking more closely (smaller scale) to see the activity/life in these areas. The weta home was described as a great way to facilitate this
- An attachment mechanism should be simple and strong, to allow children to independently put up and take down the toy (to observe weta)

The key themes that emerged from the interviews, as described above, were used to develop insights that drove prototype development.

Prototype development

The weta home went through a number of design evolutions, to fully capture the essence of the design. An appropriate aesthetic was achieved for the final prototype (Figure 7.2). To enhance a child's ability to customise and engage (develop "ownership") with the artefact it was important that it was archetypical in form. The appearance of the artefact was developed to be representative of the weta form. The features of the actual insect that are often described as making the insect "scary", e.g. antennae and sharp spines, were avoided. It was important that the weta home captured the overall form of the weta, but its appearance was benign enough, when placed in nature, to act purely as a frame for the actual organisms that might inhabit it. To this end, the real "star" once in place in nature must be the live weta, not the frame. The weta home therefore provides an opportunity for a child to know where to find a real weta. They are then able to observe the real weta in its habitat in a way that is non-threatening (to both the child and the insect).

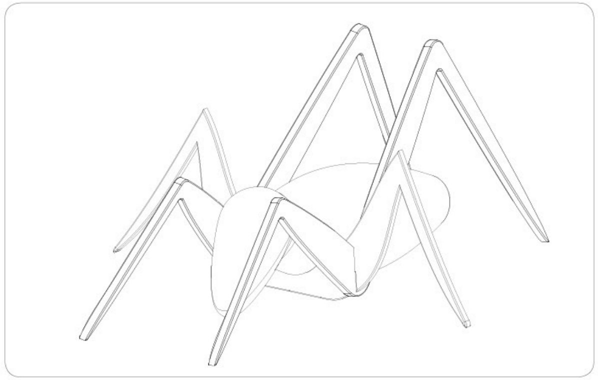
A number of materials were selected for evaluation in the final prototype. All of these were non-toxic and biodegradable. Such a material choice prevents harm to an insect that may inhabit the weta home, but also ensures the artefact can function as a biological nutrient. Where possible recycled or waste materials were utilised. This helps provide added value to these materials, as well as providing a subtle educational message regarding the positive value of recycling. Furthermore, the aesthetics of these materials are visually engaging and more ecologically appropriate. They may also provide a better "canvas" for a child to customise through a "less finished" appearance. While the nutrient input to a system from the artefact may be minimal, the learning associated with the transition from an artefact to compost, or nutrients, may give a child insight into natural processes, and the greater role of ecosystems. The prototype is presented in two forms. Firstly it has been manufactured from reclaimed timber (body), a material suited to the production of smaller numbers. Secondly, an experimental pulp made from post consumer paper and wool fibre waste was used in a moulding process, and may be more suited to large production numbers (similar to egg carton production).

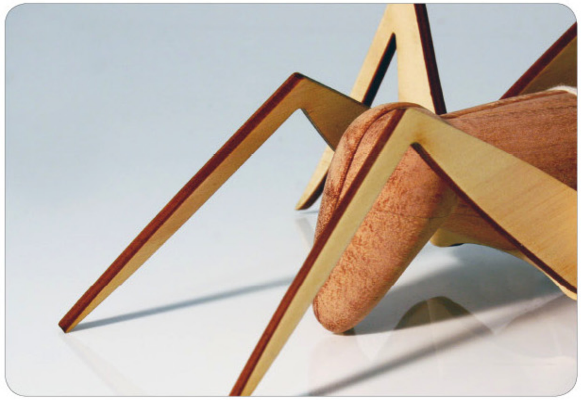
Figure 7.2 Final prototype summary

Weta home prototype summary

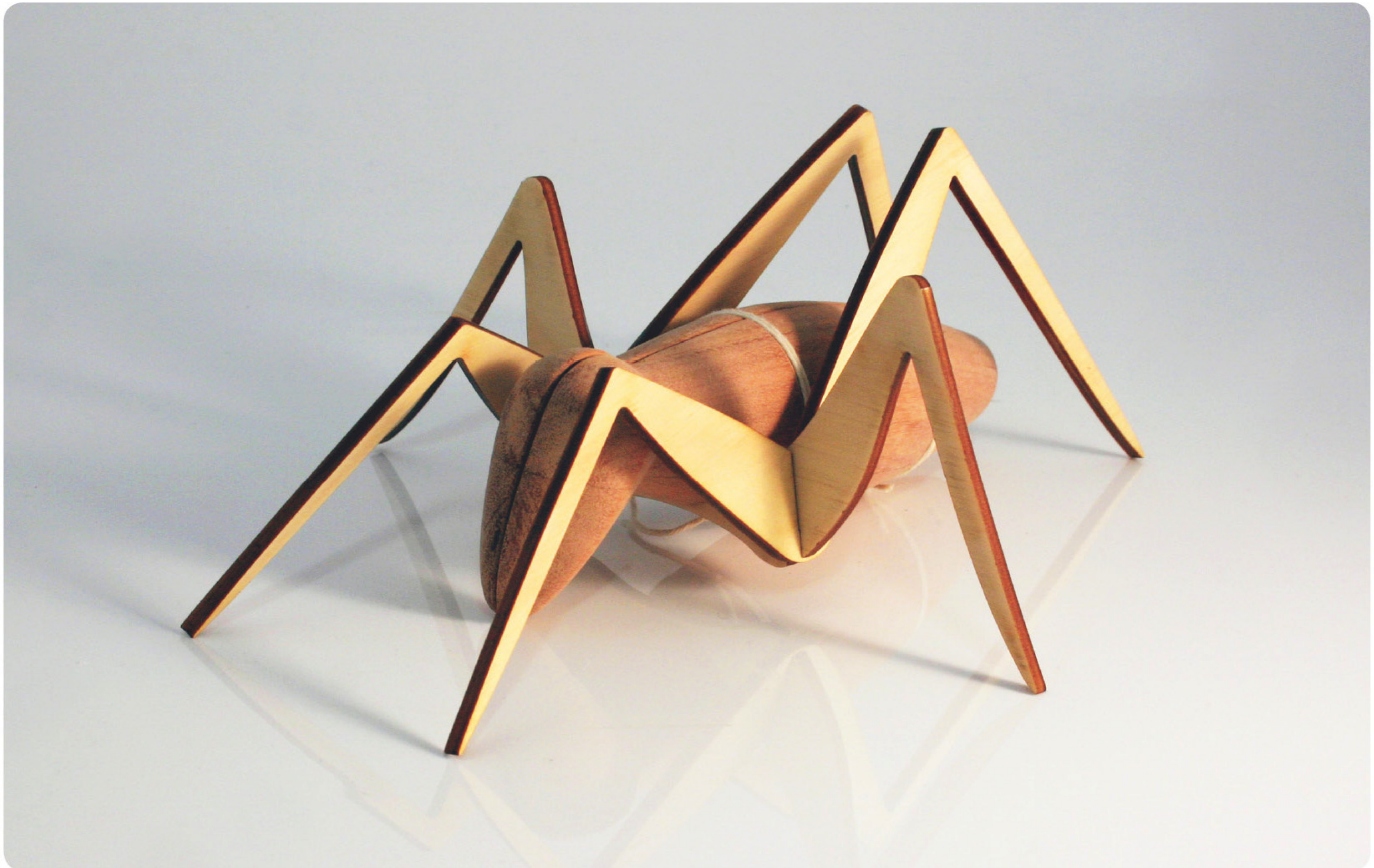
Engaging our children with nature is not only important to their development, but is is essential to maintaining biodiversity. This may be difficult in urban areas where there is an abundance of 'urban distraction'. The weta is an iconic New Zealand insect. It is looks ferocious, yet is harmless. It is common throughout New Zealand, and can be easily found in back yards with shrubs and woody vegetation. Weta are recognised as being icons for invertebrate conservation in New Zealand. The weta home helps educate children about nature and incorporates a number of key design innovations:

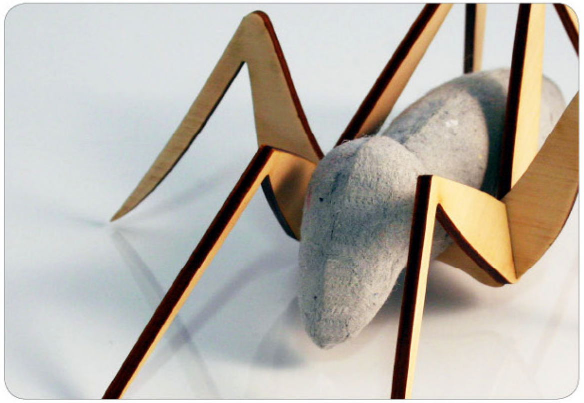
- **Build** Children construct their own Weta Home.
- **Play** The built toy can be used as a part of general play
- **Framing Nature** The child is able to attach their Weta Home to foliage in their garden. Weta (and other insects) are able to 'move' into the abdominal cavity. The child can then observe insects in their "natural habitat".





"live" weta in weta home cavity

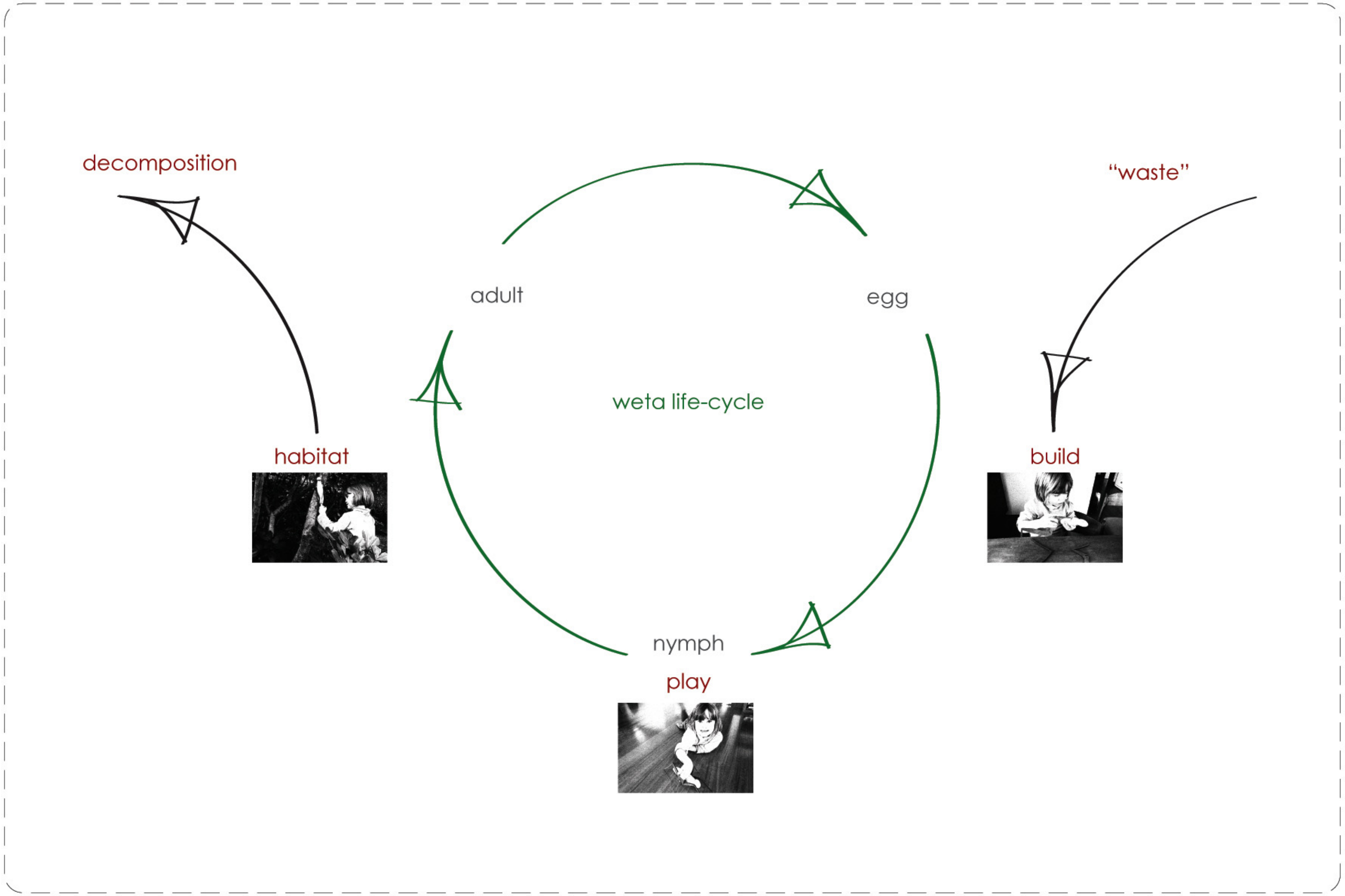




example of weta home customisation by 4 year old (hand painted)

The process of building and using the weta home mimics an insect's "life cycle" (Figure 7.3). The artefact is constructed from waste plant materials (i.e. paper/wood). The child assembles and customises the weta home at the next stage in the cycle. This stage resembles the growth or development of insect larvae. As a frame for nature, the customised toy functions as an "adult" providing habitat (structural nutrient) to aid the regeneration of new weta individuals. Following the weta home's useful life, it decomposes. During this process it may become habitat for other biological organisms, as well as nutrients for other invertebrates and decomposition fungi. These organisms break down the material used in the artefact, so that the nutrients may be further utilised by other organisms (i.e. plants) present in the urban ecosystem.

Figure 7.3 Life cycle of the weta home artefact



Proposed evaluation of final prototype

Further expert interviews will be undertaken. A range of prototypes will be constructed for testing by pre-school and junior school children. The following themes will be evaluated in order to develop an age appropriate and engaging model:

- What are the overall impressions of the toy?
- Is the prototype appropriate for the intended age range (3–10 years)?
- Are children able to easily construct the model? What level of adult assistance is required for the various age ranges?
- Will children be able to engage with the potential learning opportunities in a fun way?
- How are the materials viewed, and what associations might the children have with them?
- Do they like the form? Would they prefer it to look different? How might this vary with age?
- Would there be value as a learning opportunity in providing a school mould and materials so that many weta homes may be constructed, or is this too complicated for most children?
- How does the use/ownership of a weta home affect children's awareness/behaviour/appreciation of nature?

In addition, the prototype will be tested in a number of urban garden areas to evaluate the performance of the materials utilised, as well as the performance of the model as a "habitat" for weta. The following will be evaluated:

- What is the life span of the various materials in the "field"?
- How do different treatments (i.e. paint) affect the life span?
- What proportion of weta homes become occupied by weta in a variety of urban habitat types?
- How long does the model take to decompose once it has become unsuitable as a weta habitat?

Conclusions

- A product (toy) can be developed to incorporate broader educational values to help children engage with a specific organism. In doing so it is possible to encourage a greater awareness of nature, through play and in an urban setting. Therefore there is substantial potential to use toys and other educational "props" to enhance the cultural biodiversity values of those living in urban communities. Correspondingly, these may translate into a wider understanding of the role of the environment (and therefore the protection of natural values and ecosystems) in sustaining people.
- The incorporation of key design drivers, such as biological and structural nutrients, gave the design process ecological integrity, by providing habitat and nutrients to urban ecosystems.
- The implementation of ecological integrity may help to enhance the "value" of the actual artefact, i.e. a child's interaction with it during its use. Therefore an additional layer is added to the artefact's human-centred design.
- The use of "waste" materials provides an opportunity for "value adding", both in an economic sense and by providing additional educational value.

Design project two: the design of a trap for lizard conservation in New Zealand

Introduction

Wildlife populations worldwide are threatened by habitat loss associated with human activities. In New Zealand, there has been considerable anthropogenic landscape modification and degradation to the detriment of endemic flora and fauna populations. Lizards are a group for which significant habitat modification and losses have resulted in substantial impacts on the species (Lettink 2007a,b, Lettink & Cree 2007).

In New Zealand there are 91 species of lizard (Hitchmough et al. 2007). All of these species, except one (rainbow skink), are endemic. Nine species are described as nationally critical or endangered, with 67 threatened (Hitchmough et al. 2007). Factors that further impact on the conservation status of these species include vulnerability to predators (introduced) (Lettink & Cree 2007). Furthermore, females have a low reproductive output (Cree 1994). This limits the speed with which they are able to respond to any conservation efforts (Lettink & Cree 2007). Life history traits further contribute to vulnerability. For example, larger animals have fewer hiding retreats making them more vulnerable to predation. Larger animals also take longer to mature, their first breeding is slower and clutch size is often smaller, compared with smaller animals. Population scale factors that influence species status include the number of populations and whether they occur on predator-free offshore islands (M. Lettink pers. comm.). In New Zealand, lizards are found almost anywhere there are still wild spaces. These include wetlands, drylands, mountains, islands, shrublands, forest, grasslands and dunelands. They are found at altitudes up to 2200 m (Lettink & Cree 2007, M. Lettink pers. comm.).

The effective monitoring of lizard populations is crucial to the longer-term survival of the animals. For many species, very little is known about their conservation status (M. Lettink pers. comm.). In New Zealand, visual search and hand catching (including noosing and lifting natural and artificial cover objects) is the dominant method used in studies of lizard populations. However, this is limited in its effectiveness, in part due to this method being weather dependent (M. Lettink pers. comm.). Some species are nocturnal or difficult to detect, which makes hand capture difficult (Lettink 2007b). Lizard habitat is often inaccessible, and may be particularly dangerous to work in, especially at night (Lettink 2007a). Therefore the trapping of lizards is important for inventory and monitoring. Lizards are also caught for translocation, which can be an important conservation technique (Reinert 1991, Saunders 1995); lizards may be removed from areas being developed (degraded by human activities) or to establish new populations in predator-free areas (Lettink 2007a,b, Lettink & Cree 2007).

Historically, the ecological requirements of reptiles and the development of effective sampling methods have not received as much attention from wildlife managers and researchers as for other vertebrate groups (Thompson et al., 1998). Lettink (2007a,b) and Lettink and Cree (2007) highlight the need for more effective sampling methods.

Any new trap developed must be as effective as the current alternative sampling methods. This includes ensuring that the sample obtained is a true representation of the population. Measures of sampling effectiveness may include catch per unit effort (number of animals caught per person per hour) and the proportion of escapees (animals that evaded capture). Adult sex ratios and size (snout to vent length) distributions need to be comparable to existing methods of capture (Lettink 2007a). The trap designed in this study is to be used primarily to capture ground-inhabiting lizards.

Evaluation of current trap designs

In New Zealand, two types of captive traps are commonly used to capture ground-inhabiting lizards. These are pitfall traps and G-minnow traps. Both traps are baited using tined fruit to attract lizards and are not "attractive" to lizards in the absence of a "bait", although accidental pitfall catches do occur (M. Lettink pers. comm.). In New Zealand pitfall traps are most commonly used, possibly because G-minnow traps have only recently been trialled here. G-minnow (or funnel traps) are commonly used overseas (M. Lettink pers. comm.).

Other monitoring devices include inkpad tunnels (i.e. www.gotchatraps.co.nz) and artificial retreats. Inkpad tunnels are based around an inkpad in a tunnel. Bait is placed in the tunnel and animals move through the tunnel, walking over the inkpad and then onto paper. The ink prints are later assessed to determine animal activity. These were not included in the assessment, as they do not actively capture animals. Artificial retreats do not catch animals, and were evaluated separately with aspects being incorporated into the design process (see below). Sticky or glue traps, designed to catch lizards as pests, were not included in the assessment.

The current trap models were evaluated using a matrix. Note that the effectiveness of the traps was not assessed as an assumption was made that the traps are currently used as they successfully capture lizards. Trap type may influence catch, and some traps may be more suitable or attractive to certain species or life histories (Lettink 2007b, Sutton et al. 1999). Therefore a direct comparison between traps of trap effectiveness for all species is not undertaken. Trap assessment instead focused on usability. Comparisons of trap effectiveness will be undertaken following the development of a suitable prototype, and are seasonally dependent on lizard activity.

A “day in the life” analysis of each trap was undertaken in collaboration with a herpetologist. Each stage of the use of each trap was analysed and key use factors were determined. These were summarised and are presented in Figures 5.4 and 7.5, and in the evaluation matrix below (Table 7.1).

Figure 7.4 Summary of G-minnow trap features

G- minnow trap

Summary
A baited trap lures lizard into funnel. Small hole size and elevation makes escape difficult.

Positive attributes
- effective
- wire mesh provides adequate air flow
- easy to check for animals
- long life

negative attributes
- large and bulky
- storage and transport issues
- requires to be dug in (not suiable for rocky ground)
- not sutable for use in direct sun
- high set up time
- difficult to clear and re-set
- expensive

Figure 7.5 Summary of pitfall trap features

Pit fall trap

Summary
A baited trap lures lizard- falls into trap. Steep and slippery sides prevent escape.

Positive attributes
- effective
- below ground prevents over heating
- easy to check for animals and re-set
- long life
- low cost

negative attributes
- large and bulky (4L paint tin)
- storage and transport issues
- requires to be dug in (difficult in rocky ground)
- high set up time
- large by-catch
- requires flat ground

Key areas of usability and trap design are summarised as follows:

Storage: The ease with which the trap is dissembled and stored for later use. Also includes cleaning and the amount of space required to store the trap (ease of stacking etc.).

Transportation: The ease with which the trap may be transported to a field site. Includes vehicle transportation (car/helicopter), backpacking into a field area and movement (carrying) around a field site.

Assembly: Speed and ease with which an individual trap can be assembled and positioned to capture lizards.

Habitat suitability: "Micro scale flexibility" – the appropriateness of the trap for a wide variety of terrain (see Lettink 2007a).

Trap checking: Speed and ease with which trap contents can be assessed.

Removal of animal: Ease with which animal can be removed, including the potential for accidental escape.

Re-setting: Speed with which trap can be cleaned, re-baited (if necessary) and reset.

Multiple catch: The capability of the trap to capture multiple individuals.

Cleaning: Ease with which trap may be cleaned during use and prior to storage (including the removal of any pheromone; see Thierry et al. (2009)).

Protection: Does the trap provide adequate protection from predators and climate, and minimise capture stress?

Long life: The ability of the trap to withstand conditions associated with storage, transport and use.

Cost: Relative cost of trap.

Table 7.1 Design matrix for the assessment of currently used lizard trap characteristics

	G-minnow	Pitfall
Storage	2	2
Transportation	2	2
Assembly	2	1
Habitat suitability	3	2
Trap checking	4	4
Removal of animal	3	5
Re-setting	4	5
Multi-catch	4	4
Protection	4	4
Cleaning	3	3
Long life	4	4
Cost	1	4
Total score	**36**	**40**

Matrix score: 1 (poor) – 5 (good)

In summary, the current traps perform well in categories around capture and protection of lizards. Traps are able to be checked and re-set easily. However, they are difficult to store and transport, and take considerable time and effort to set up in the field. Currently, difficulties associated with transport into certain areas and set-up time are limiting factors in monitoring programmes. Neither trap is ideally suited for use on cliffs or rock ledges, or areas where rocks prevent the trap from being dug in.

Artificial retreats

Traps that actively catch lizards are required to be checked every day (animal ethics) and are therefore suited to short-term studies or relocation programmes. However, artificial retreats do not catch animals and are used in longer-term monitoring programmes and habitat enhancement (Figure 7.6) (Lettink 2007a,b, Michael et al. 2004). As baits are not used, attraction is based on mimicking desirable refuges.

Lizards select retreat sites based around structural and thermal features (Schlesinger & Shine 1994, Cooper et al. 1999, Langkilde & Shine 2004). The other major factors that contribute to retreat choice include social interactions and predator avoidance (Downes & Shine 1998, Cooper et al. 1999, Amo et al. 2004, Langkilde & Shine 2004). In some cases, the necessity to avoid predators may be greater than the need to maximise thermoregulatory opportunities (Downes & Shine 1998, Amo et al. 2004). Lizards tend to select rocks or crevices as a function of retreat size, width, depth or exposure (sun/shade), all factors that are likely to influence thermal characteristics (Webb & Shine 2000, Kearney 2002, Shah et al. 2004, Goldsbrough et al. 2006). Many species readily utilised artificial structures (Walls 1983, Hare & Hoare 2005, Lettink 2007a,b, Lettink & Cree 2007, Thierry et al. 2009). Artificial retreats should be of sufficient size, remain dry, and have narrow horizontal openings and a top surface that heats rapidly.

The use of artificial retreats has been found to be a more effective method of capturing some species (i.e. sand skinks (*Neoseps reynoldsi*), common geckos (*Hoplodactylus maculates*) than pitfall traps (Lettink 2007b, Sutton et al. 1999). Furthermore, artificial retreats offer advantages such as simple and rapid installation (Lettink 2007b). Pitfall traps take considerable time to set up and require continued maintenance (Kjoss & Litvaitis 2001). Retreats may cause less habitat disturbance (Sutton et al. 1999) and require less skill to use than other techniques (Lettink & Pattrick 2006). Retreats don't capture animals; therefore accidental deaths due to heat stress or predation are rare (Grant et al. 1992).

Figure 7.6 Summary of key features of artificial retreats

Artificial retreats

Summary
An artificial habitat provides long term shelter and protection from predators, and solar warmth.

Positive attributes

- effective population monitoring tool only
- enhances habitat in degraded areas
- easy to check for animals and re-set
- long life
- low cost
- not baited so animals attracted to "habitat characteristics"

negative attributes

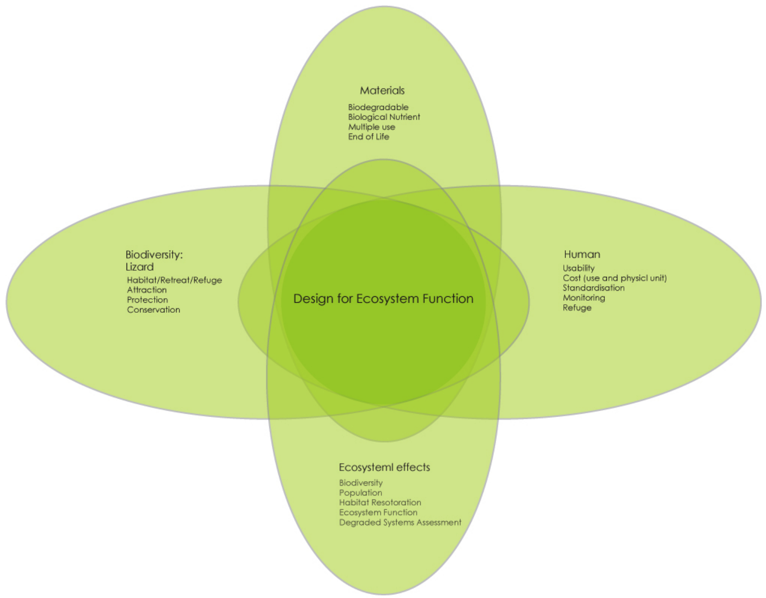
- large
- storage and transport issues
- doesn't capture animals

Design process for a new trap

The initial design process was established using mind maps to scope the key design insights. Ecosystem function was placed central to the decision-making/mapping process to ensure that the ecosystem was central to the design process. The goal in ecological studies is to respond to the environment in a positive way that minimises human impacts (disturbance/pollution etc.). Therefore an ecosystem response was necessary at a small scale (impacts on the ecosystem where the trap is used) as well as large scales (the community, impacts of manufacturing, etc.). Placing the ecosystem at the centre of the design process demonstrated the inter-relationship between all elements from each user category.

A key innovative design driver that emerged from the mind mapping process was that it was important to view the lizard as a dominant user of the trap (Figure 7.7). Therefore design decisions were initially based around providing artificial habitat for lizards. By making the lizard a key user, it was anticipated that the trap would function more effectively, to attract individuals and contain them safely. If the trap is a desirable space or refuge (from the lizard's perspective) there is potential for escape attempts to be minimised, and captive stress reduced. To this end the design was anticipated to incorporate aspects that would exploit the behaviour and habitat preference of lizards.

Figure 7.7 Model for lizard trap design identifying key design drivers



A design chart helped ensure the key characteristics were considered during the ideation process. The design process was viewed as having three distinct stages (phases). These were developed from the mind map and design model to ensure the correct representation of all characteristics that might need to be incorporated into the design process (see Figure 7.8). While the stages appeared independent from each other (visually – for the design process) they were inter-related.

A review of the desirable trap characteristics from the evaluation of current traps and artificial retreats is summarised (Figure 7.9). The existing traps and retreats have many desirable traits for catching lizards. However they are essentially adopted from use with other animals, rather than being purpose built. Consequently, human user and environmental needs were not satisfactorily incorporated. The design drivers for this project were based around the needs of the lizard, user and ecosystem. These were not viewed as competing; rather a synergistic approach was taken. For example, what was good for the lizard was explored for benefits for the human user and environment. The dominant design drivers were around creating a simple, compact refuge or retreat, from lightweight and low-cost materials that had either minimal impacts or if possible positive benefits to the environment.

Three sketch models are summarised (Figure 7.10), and evaluated using the design matrix described above. In addition, an expert user was consulted on the potential suitability of the sketch models. The box trap model was chosen as the best model to refine to a working prototype. If it could be designed to be flat-packed, then it would provide superior storage and transportability compared to the current traps being used. The box trap was deemed most suitable for placement in a variety of field situations and would most easily be able to be manipulated to take advantage of lizard behaviour to maximise trap catch (i.e. placement alongside cliff faces etc.). The "opening" of the box trap was seen as being able to replicate the attractive aspects of the artificial retreats, thereby exploiting an aspect of lizard behaviour to help maximise trap catch potential.

Figure 7.8 Analysis of user needs design chart

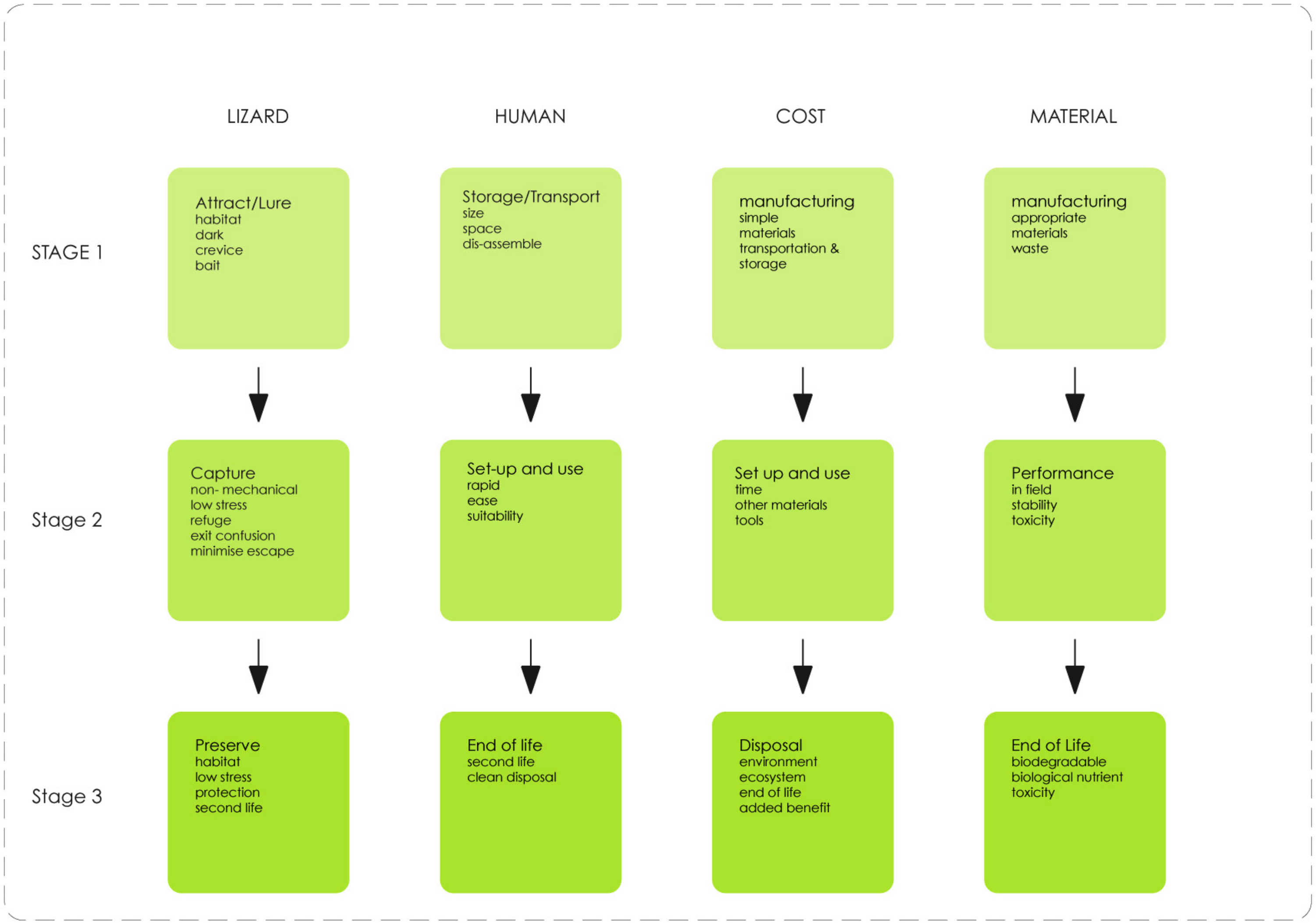


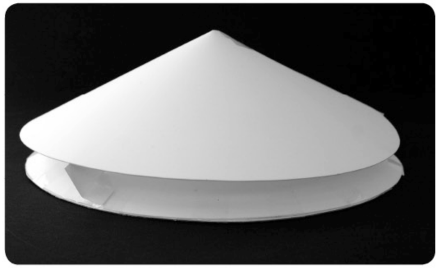
Figure 7.9 Review of desirable characteristics for incorporation into sketch models

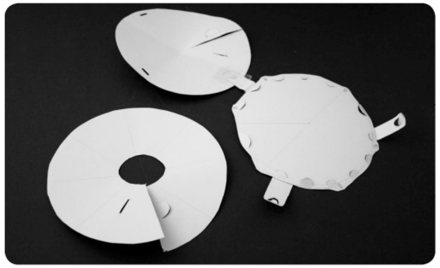
Figure 7.10 Summary of three lizard trap sketch models

Object reuse (bottle trap)

- low cost reusable object
- light weight
- not standardised (differen bottle sizes)
- would require painting
- 'glasshouse'- over heating potential
- small size
- may require 'digging in' to be effective
- difficult to clean and check
- dispsal pre-determined with no material choice

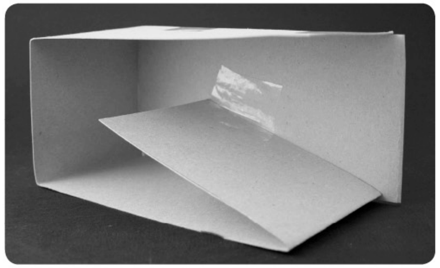
Circular trap





- large trapping area
- able to be flat packed (complex)
- light weight and low cost
- attractive fron all sides (to lizard)
- bsed on no-dig pitfall principle
- large area required to generate pitfall height
- not suitable for use on hills or cliffs

Box trap



- simple design based on pitfall
- one direcion entry provides small entry area
- cavity for lizard to hide- sloping ramp caters for range of lizard sizes
- no digging required
- potential for easy assembly in flat pack (1 piece)
- low storage and transport space
- use on cliffs, in crevices etc.

Table 7.2 Design matrix to determine best sketch model

	Bottle trap	Circular trap	Box trap
Storage	2	3	5
Transportation	2	3	5
Set up	3	4	5
Habitat suitability	3	3	5
Trap checking	1	2	4
Removal of animal	2	3	3
Re-setting	2	3	3
Multi-catch	3	3	3
Protection	2	3	3
Cleaning	2	4	5
Long life	n/a	n/a	n/a
Cost	n/a	n/a	n/a
Total score	**23**	**31**	**41**

Matrix score: 1 (poor) – 5 (good)

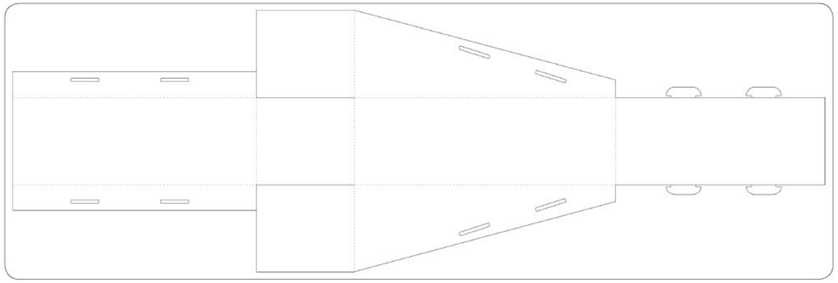
Development of a new lizard trap

The key design drivers fundamental to decision-making were as described above. Trap size was largely determined by lizard size, and this dictated the fall height required to prevent escape.

During the development of the trap, preliminary effectiveness tests were undertaken (Low Impact Collecting and Research Application Permit CA – 13485 FAU (Department of Conservation)). These involved capturing a skink and placing it in a large container with a single non-baited trap. While this test lacked any scientific rigour, it was undertaken to see if the skink was able to enter the trap and be captured, and whether it was able to escape. The skink did enter the trap fairly soon after being placed into the plastic bin, and did not escape from the trap overnight. Food was placed into the trap following the skink's entry. While this trial gives no indication as to the potential attractiveness of the trap in a field situation, and only one species was tested, it does indicate that the trap has potential to be effective, and warrants further refinement. Similar tests were undertaken throughout the development phase and similar results were achieved. The trap was designed during the autumn and winter months when lizards are not active. Therefore final field evaluation will be undertaken following the submission of this project.

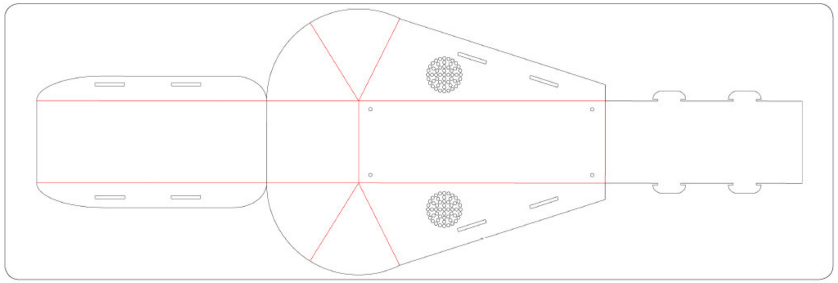
Making a series of prototypes led to the development of the final prototype. After each prototype was made and assembled, it was analysed for potential improvements. This process went through 12 iterations before a final prototype was derived. These are summarised in Figure 7.11, where key changes are described.

Figure 7.11 Summary of prototype development



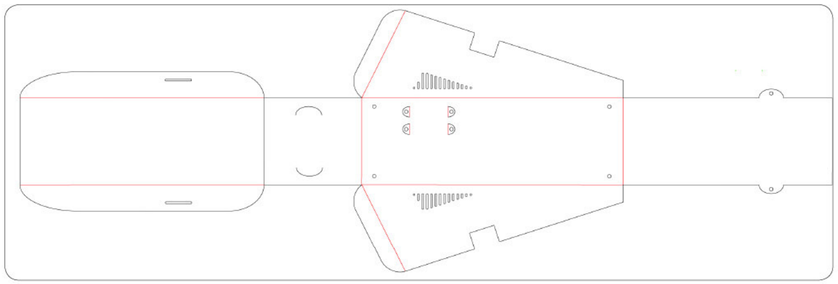
Trap version 1

- box design (vertical back)
- sloping top to provide even entry cavity
- system of flaps for closing and holding
- one piece system
- gentle slope (for pitfall ramp)
- dark entry cavity
- twin tab ramp holding system



Trap version 3

- incorporation of breathing vent
- sloping back of box to increase escape confusion
- system of folds at rear to seal exit



Trap version 7

- single tab ramp system
- trap anchored to ground using twin peg system
- slots for ramp assembly held together by lid
- anchor pegs hold trap together
- back simplified to small flap design
- simpler and more intuitive assembly
- vent modification
- slots in based for drainage and peg holding (when not assembled)

Final prototype (Habitrap – habitat/trap)

The final prototype (Figures 7.12 & 7.13) incorporates numerous small detail changes that improve the assembly, functionality and appearance of the trap. It also includes a significant improvement around the final use of the trap. An optional exit hole (Figure 7.12) was incorporated in the rear wall of the trap. This could be pushed out making the trap unable to capture lizards, but allowing them to utilise that trap as an artificial refuge. Lizards would be able to enter the "trapping ramp" for protection (predator) and increased thermal enhancement. The lower containment cavity provides a cooler dark refuge. It was thought that this additional feature, though simple, would give the trap an additional function that may have significant benefits to lizard conservation. One possible use of the trap may be to catch lizards for relocation. They could then be transported (using the trap) to a new area where the exit hole would be removed and the lizards could continue to utilise the trap while establishing in the new area. The presence of its own pheromones in the trap may help it to transition from the old habitat to the new more successfully. The disabled trap could be used as an artificial retreat, similar to those described above. While the retreat area would be smaller than for those currently used, this trap would be considerably easier to transport into areas that are difficult to access. These scenarios would have to be tested rigorously before definitive statements around these alternative uses could be made. This would include evaluating the trap's attractiveness as an artificial retreat in the absence of bait.

Figure 7.12 Final prototype template

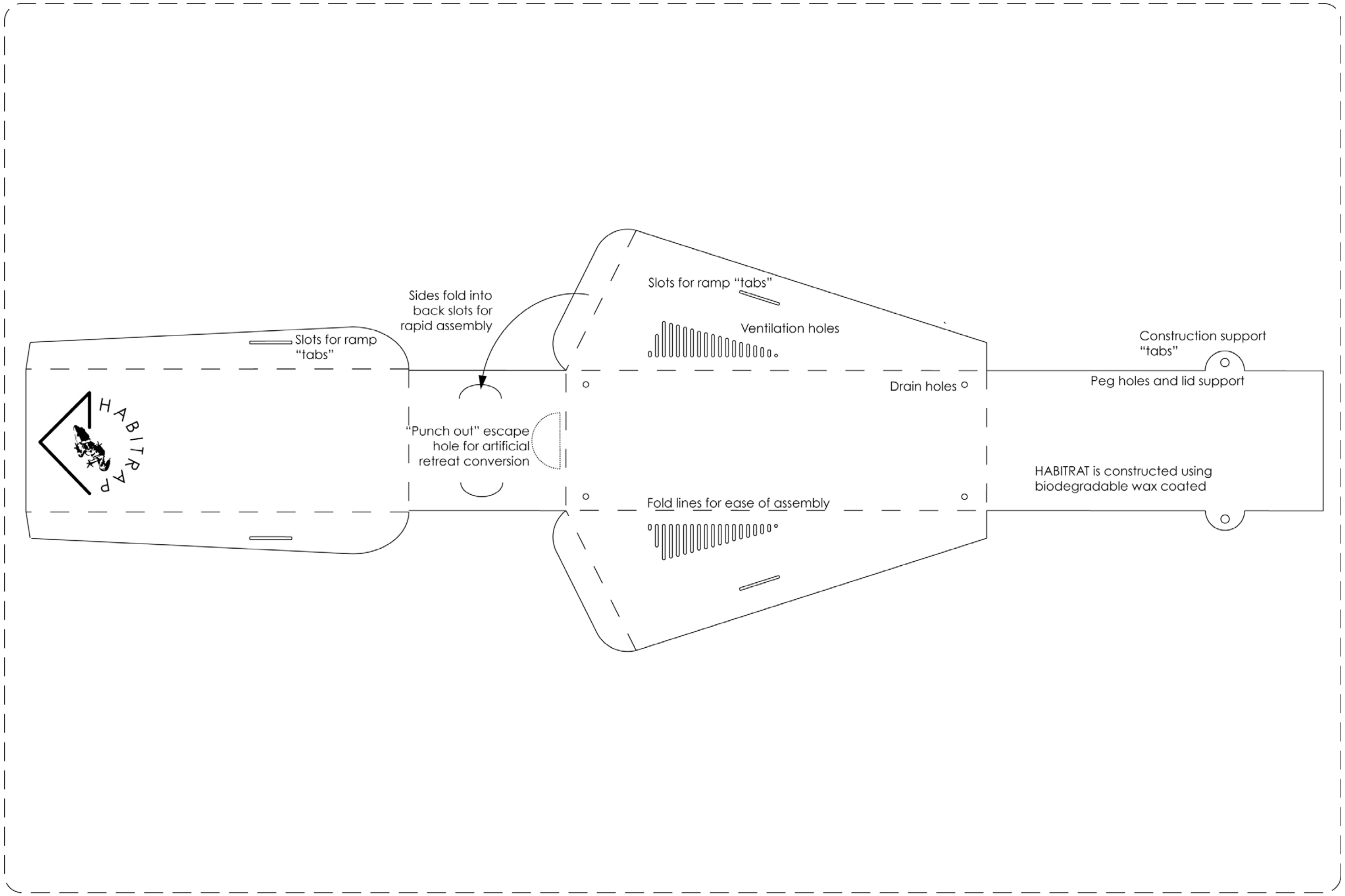
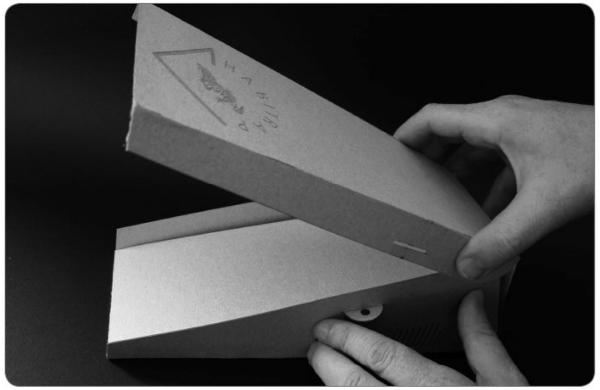


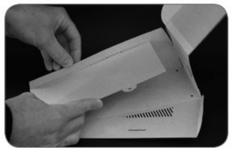
Figure 7.13 Final prototype summary

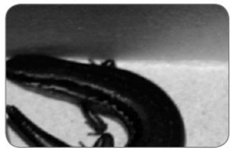
Weta home prototype summary

The HABTRAP is a lizard trap that has been designed, developed and tested as a low cost and lightweight tool for lizard monitoring studies. It is a valuable new tool to enhance the sustainability and conservation of some of New Zealand's most threatened animals. HABITRAP incorporates a number of key design innovations to enhance the capture and monitoring of lizards:

- simple low cost flat pack design
- rapid set up under firld conditions
- enhances attractivess and minimises animal stress
- artificial habitat in translocation programmes
- does not require "digging in"
- made from biodegradable recycled materials








HABITRAP


HABITRAP


HABITRAP


HABITRAP

Materials

The trap must be able withstand the elements in the field but still be biodegradable within a reasonable time period. If the trap is lost or destroyed in conservation areas it will decompose, minimising the chance of negative environmental impact. Correspondingly, the trap prototype is manufactured from low-cost, wax-coated recycled card. The final material components will be evaluated following extensive field-testing of the prototype, and consultation with users. The biodegradable, non-toxic nature of the material used means that the trap may be categorised as a biological nutrient. It is not intended that the trap be discarded (at end of life) in natural systems, but it may be "composted' in an area where the input of additional nutrients is beneficial.

Prototype testing

The trap was developed during the winter months when lizards are not active. Therefore, it was not possible for it to be tested in situ before the completion of this study. Field testing of the prototype will be undertaken in a trial evaluating the trap's effectiveness alongside a range of currently used monitoring methods. Measures of trap effectiveness may include the following (Lettink 2007a,b):

- Catch-per-unit-effort (i.e. number of lizards captured per person hour)
- The proportion of animals that evaded capture
- Adult sex ratios and size (snout–vent length)
- Comparisons of species distribution using each captured method
- Assessing whether artificial retreats and searches of natural cover produced similar samples

Factors that may influence sampling methodologies include time of year and site factors. These will be accounted for during trap evaluation programmes. The safety of the traps to lizards will also be evaluated. In particular, the potential for traps to reach high internal temperatures will be assessed using temperature data loggers placed both inside and outside the traps. The use of shades (both natural and artificial) will be investigated if internal trap temperatures are found to be excessive.

Conclusions

- Design for ecosystem function successfully achieved for a single group (lizards).
- Trap design successfully incorporates multiple functions throughout the trap's life: lizard trap (conservation), biological nutrient (structure), biological nutrient (biodegradable).
- In situ biodegradability not appropriate for many areas where trap may be used (i.e. DOC estate, indigenous areas).
- Considerable benefits to human user over existing traps. Significant potential for cost savings ($), as well as transportation, set-up time and storage benefits.
- Potential for considerable benefits to lizards, due to reduced stresses compared with existing traps. Additional benefits include the potential for the trap to be used as a structural nutrient, and used as habitat for translocated lizards, or for habitat enhancement in degraded areas.

Design project three: development of a tree shelter to enhance biodiversity in native forest restoration plantings

Introduction

Concern for the disappearance of intact natural systems and indigenous biodiversity has meant recognition of ecological restoration to reverse habitat degradation (Bradshaw 1983, Jordon et al. 1987, Cairns 1988, Saunders et al. 1993, Hobbs & Norton 1996, MacMahon & Holl 2001). Areas of degraded lands are increasing, and in some cases these may become the only areas available for conservation. The term restoration implies that the original system was perfect or near perfect (Francis et al. 1979). Rehabilitation attempts to restore aspects of a functioning ecosystem that may not result in the restoration of a complete system, while reclaiming an area refers to an attempt to rehabilitate a severely degraded site (MacMahon & Holl 2001). Ecological recovery is the process of allowing systems to follow successional process to reach a "natural" outcome, while re-creation at the opposite end of the scale is an attempt at complete ecosystem reconstruction of severely disturbed sites (MacMahon & Holl 2001). Restoration efforts are best aimed at the ecosystem level, rather than at individual species (MacMahon & Holl 2001), as individual species may be difficult to maintain in the absence of functioning ecosystems.

Current ecological theory may provide the means to restore degraded land as self-sustaining natural systems with considerable potential for biodiversity conservation (Ewel 1987, Norton 1991, Main & Lambeck 1993). However, if it is to be successful in conserving biodiversity, restoration must go beyond the reconstruction of structure, composition, and appearance of a site (Ewel 1987, Andersen 1993) and restore biological interactions, processes, and integrity to ensure long-term health and viability (Aronson et al. 1993a,b, Bradshaw 1993, Saunders et al. 1993, Hobbs & Norton 1996, MacMahon & Holl 2001). Recreating structure and composition without restoring function, or recreating function in the absence of structure and composition, fails to constitute complete restoration (Westman 1991, Berger1993, Hobbs & Norton 1996).

Restoration success can be viewed as a continuum from the successful establishment of the initial planting through to the successful establishment of those attributes that ensure a self-sustaining, functioning natural system. Although the later stages of this continuum are the most likely goals for restoration projects, the initial stages must be successful if the longer-term goals are to be met (Majer 1989). Through success in the initial plantings, restoration becomes a tool to conserve biodiversity as new individuals colonise the restored habitat. Following the successful establishment of those conditions required for recolonisation and establishment, individuals and species become a part of and contribute to the maintenance of the system. If conditions are suitable for the first stage of restoration (species colonisation and establishment), then it is likely that the restoration will develop to a latter stage (Reay & Norton 1999a).

It is usually assumed that correct species selection in the initial planting is essential to facilitate and condense the early stages of plant succession (Aber 1987, Norton 1991, McClanahan & Wolfe 1993). However, Reay & Norton (1999a) found that this was not as relevant in restoring woody vegetation in a Canterbury restoration planting. This result contrasts with those of other studies (MacMahon 1987, McClanahan & Wolfe 1993, Chambers et al. 1994), which suggest that initial floristic composition is important to develop successful restoration plantings.

Often it is not possible to manipulate individual species. Therefore, it may be more useful to manipulate ecosystem architecture that targets the promotion of ecosystem processes and patterns of ecosystem components. Such activities may be both horizontal (dispersion) and vertical (architecture) (MacMahon & Holl 2001). The concept of habitat structure refers to the three-dimensional arrangement of physical matter and is often overlooked by ecologists when considering subsequent ecological successional stages (Byrne 2007). Ecological patterns and processes are influenced by the structure of habitats, which modify communities by providing resources (e.g. shelter) and mediating interactions between species (e.g. predation) (Bell et al. 1990, Tews et al. 2004). Habitat structure has a dominant influence on landscape patterns and ecosystem processes (Lovett et al. 2005). Three dimensions of habitat structure are important (Byrne 2007). These include heterogeneity (type of structure), complexity (amount) and scale. Plant cover is important to developing fauna, and the provision of adequate floristic and structural diversity, and the presence of logs and litter are also important for the full range of native animal recolonisation in restoration plantings (Majer 1989, Andersen 1993, Simmonds et al. 1994, Reay & Norton 1999a).

A major limiting factor in the restoration of forests is the difficulty associated with establishing woody species, particularly in disturbed environments and in grasslands dominated by tall, vigorous introduced grass species (Close et al. 2007). However once this step has been initiated (e.g. by planting), succession natural processes are often strong enough to move a planting in the direction of indigenous forest (Reay & Norton 1999a,b). Weed mats, mulch and tree shelters are in widespread use in tree plantings and significantly enhance the survival and growth of woody species by limiting competition from surrounding weeds as well as providing shelter in exposed areas (Navarro et al. 2005). In particular, tree guards have been shown to alter microclimates (e.g. temperature, light, humidity, wind, soil moisture, etc.), and to protect seedlings from herbivory and competition from weeds (Lai & Wong 2005, Dubois et al. 2000, Opperman & Merenlender 2000, Sweeney et al. 2002, Close et al. 2005, del Campo et al. 2006, Close et al. 2007). In particular, a twin wall design has been found to increase moisture availability (del Campo et al. 2006). The use of shelters is described as favourable for plant growth (height and diameter) and enhancing plant survival (Dubois et al. 2000, Lai & Wong 2005, del Campo et al. 2006, Close et al. 2007).

The main objective of this study was to redesign tree shelters used in indigenous forest restoration plantings so that they may support the re-establishment of ecosystem functions beyond the protection of planted trees.

Evaluation of current tree shelter designs and weed suppressant methodologies and designs

Currently two general methods, weed suppression and tree shelter devices, are employed to aid tree establishment as described above. Examples of tree shelters currently available are summarised below:

Figure 7.14 Examples of restoration plantings

Tree shelter and weed mat used in roadside restoration plantings

The majority of weed suppressants and tree shelters are low cost and short term solutions. Product success seldom goes beyond survival of the tree planted. While the product is often cheap, the materials used may not be environmentally friendly, and installation may be labour intensive.

Figure 7.15 Examples of tree shelter designs

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In general, current tree shelter designs are simple tubular structures. Materials are usually plastic and may be recyclable. Some are reported as manufactured from biodegradable plastics. The majority require staking to support the shelter. In some cases four corner stakes are used, which makes planting a labour-intensive process. In order to be successful, tree guards need to be used in association with a weed suppressant, either a mulch or physical barrier. Often recycled carpet is utilised for this purpose, although more expensive biodegradable materials are available.

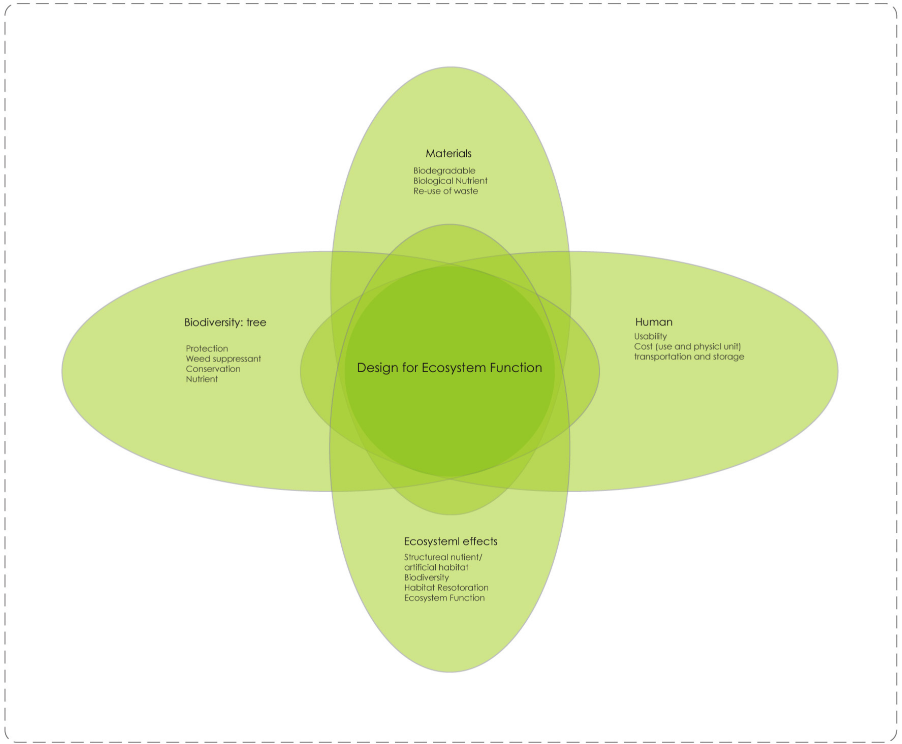
Design process for a new shelter

The initial design process was established by using mind maps to scope the key design insights. Ecosystem function was placed central to the decision-making process. A main goal in this project was to respond to the environment in a positive way that maximises benefits to the environment while minimising human impacts. Therefore an ecosystem response was necessary. A key innovative design driver that emerged from the mind mapping process was that it was important that the forest ecosystem was viewed as a dominant user of the shelter, in tandem with people who would be using the shelter when establishing plantings. Therefore design decisions were initially based around providing protection for trees, and structural habitat for newly colonising and existing species, as well as designing the shelter to be cost effective and easy to transport and assemble. In particular, a new, innovative opportunity was presented by using the “design for ecosystem function” framework to extend the function of the shelter beyond tree establishment, to having a key function in the application of ecosystem establishment. The early colonisation of additional species will help initiate and maintain ecosystem processes, and will contribute to overall ecosystem function.

A number of indigenous invertebrate and reptile species have been shown to utilise artificial shelters. For example, Hodge et al. (2007) found that 60% of tree-mounted artificial shelters were utilised by spiders in a study of nature reserves near Canterbury, New Zealand. A variety of retreats have been found to be used by invertebrates, including flat pieces of timber or ceramic tiles lying flat on the ground, corrugated card or bubble wrap tied around trees and wooden shelters with access holes (Horváth et al. 2001, Bowie & Frampton 2004, Lettink & Patrick 2006, Bowie et al. 2006, Hodge et al. 2007). Bowie et al. (2006) report 96% occupancy of artificial shelters by a diverse range of invertebrates after 12 months.

Species such as spiders have been advocated as being valuable to assess biodiversity (Cardoso et al. 2004). In addition, spiders and other invertebrates have been used to measure the progress and success of ecological restoration efforts (e.g. Reay & Norton 1999a, Longcore 2003, Perner & Malt 2003). Invertebrate sampling often involves broad spectrum trapping techniques, which kill a range of invertebrates. This may be counter-productive if sampling is undertaken to determine the nature of threatened populations (Hodge et al. 2007). Therefore artificial retreats have the potential to be used as standardised sampling units for a range of species (e.g. Horváth et al. 2001, Bowie et al. 2006, Hodge et al. 2007, Lettink & Cree 2007). Additional benefits of using artificial shelters include regular inspection, and the ability to monitor prey species, phenology and information on individual mortality and migration (Hodge et al. 2007). Therefore to be able to utilise the tree shelters as a tool to monitor the success of restoration plantings may represent a significant contribution to biodiversity and conservation studies.

Figure 7.16 Design for ecosystem function framework for a new tree shelter design



During the design process a number of innovative insights were made using the “design for ecosystem function” model. These key areas of usability and shelter design are summarised as follows (Figure 7.16):

Storage: The ease with which the shelter may be stored, including the amount of space required to store the shelter (ease of stacking etc.).

Transportation: The ease with which the shelter may be transported to a field site. Including vehicle transportation (car/helicopter) into an area and movement (carrying) within a field site.

Assembly: Speed and ease with which each shelter can be assembled.

Self-supporting: The shelter preferably should not require staking for vertical stability and support.

Long life: The shelter must be able to withstand the elements for periods of up to several years (water resistant).

Non-toxic: The shelter must be manufactured from non-toxic materials.

Biodegradable: The shelter should be designed using biological nutrients for decomposition in situ (doesn’t require removal and disposal following use).

Low cost: Including the use of non-toxic waste materials where possible.

Shelter and protection: A wide range of tree species should be protected.

Moisture retention: The potential for the shelter to prevent vegetation desiccation by capturing moisture and returning it to the soil, or by preventing localised evaporation of soil moisture.

Weed suppressant: The shelter should protect trees/seedlings from being overgrown by more competitive weed species.

Colour: Shelter colour and transparency may influence tree survival and growth (influence light – important in hot, dry environments).

Ventilation: Appropriateness of airflow for microclimatic conditions.

Size: The shelter should be of a compatible size to support a range of tree and plant species, without compromising storage and transportation.

Habitat refuge: Explore the role of the shelter as a structural nutrient – artificial habitat to support colonisation of additional biodiversity (i.e. insects, spiders and lizards).

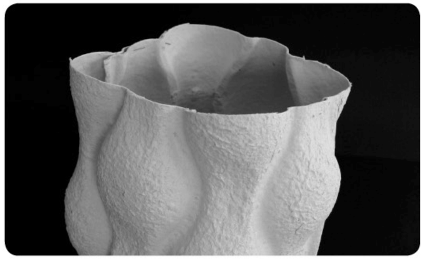
Monitoring: Opportunities to use the shelter as a standardised tool to assess the success of restoration plantings and ecosystem health using non-destructive sampling of colonising animals.

A number of sketch models were developed and evaluated using a design matrix based on the key design insights (Figure 7.17). There was not a substantial difference with regard to the matrix assessment between the different sketch models (Table 7.3). However, a greater level of structural complexity is likely to be preferable with respect to species colonisation.

Figure 7.16 Review of desirable characteristics

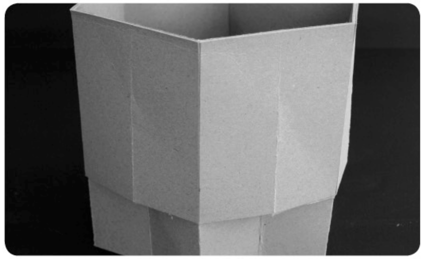
Figure 7.17 Review of tree shelter sketch models

Object reuse (fruit tray)



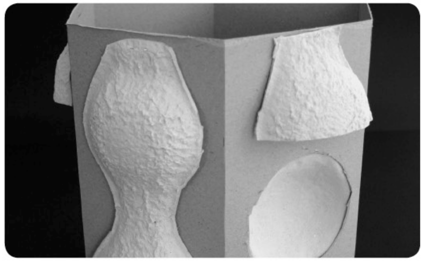
- low cost reusable object
- light weight
- would require water restance treatment
- rough surface appropriate
- limited "dark/protective" habitats
- moderatly stable/self supporting
- biodegradable
- able to be flat packed
- no weed suppressant
- single wall
- rapid assembly
- internal structral complexity good habitat

Twin wall



- strong self supporting structure
- able to be flat packed
- light weight and low cost
- twin wall provide large cavity area
- smooth walls less suitable for colonisation
- require water resistance treatment
- potential for moisture
- more complex assembly required for flat packing
- no internal structure/limited habitat

Combination



- complex manufacture
- single wall
- cavity
- self supporting
- potential for easy assembly in flat pack (1 piece)
- low storage and transport space
- lightweight
- more complex external/internal structure

Table 7.3 Design matrix for the assessment of tree shelter sketch model characteristics

	Object reuse	Twin wall	Combination
Storage	4	4	3
Transportation	4	4	4
Assembly	4	3	3
Self supporting	2	5	4
Long life	2	4	4
Non-toxic	3	4	4
Biodegradable	3	3	3
Low cost	4	3	3
Manufacture (ease)	4	4	3
Weed suppressant	2	2	2
Habitat refuge	2	4	3
Total score	**34**	**40**	**36**

Matrix score: 1 (poor) – 5 (good)

Development of final prototype

The final prototype was developed to incorporate the desirable features developed from analysis of the sketch models (Figures 7.18 & 7.19). Relative to the sketch models, greater emphasis was placed on the incorporation of three-dimensional structural properties. The potential for these structural features to be utilised by invertebrates and other organisms was explored as part of the design process. In addition, a prototype was made using pulp-based recycled paper and waste wool fibre. While these may not be the actual materials utilised in the final prototype, it does demonstrate the potential for incorporating such organic-based materials. As these materials on their own have limited longevity outside, it is anticipated that biodegradable plastic components may be added to provide water resistance and structural integrity, and will greatly extend the life of the shelter in the field.

A final completed testing prototype was outside of the scope of this study. However, this presentation demonstrates the potential for such a structure to be designed for easy storage and transportation and for rapid installation and assembly. It is anticipated that the base would have a “slot” cut into it so that it could be arranged around the base of a newly planted tree. Following this, the top part of the shelter could be folded around the tree and “snapped” into the base. The base may be fixed to the ground using biodegradable plastic pegs.

The “snap”-together assembly will allow the shelter to be disassembled for easy removal if necessary. Disassembly may also be beneficial to help observe or monitor the colonisation of animals (or other plants/fungi), especially those utilising the internal cavity.

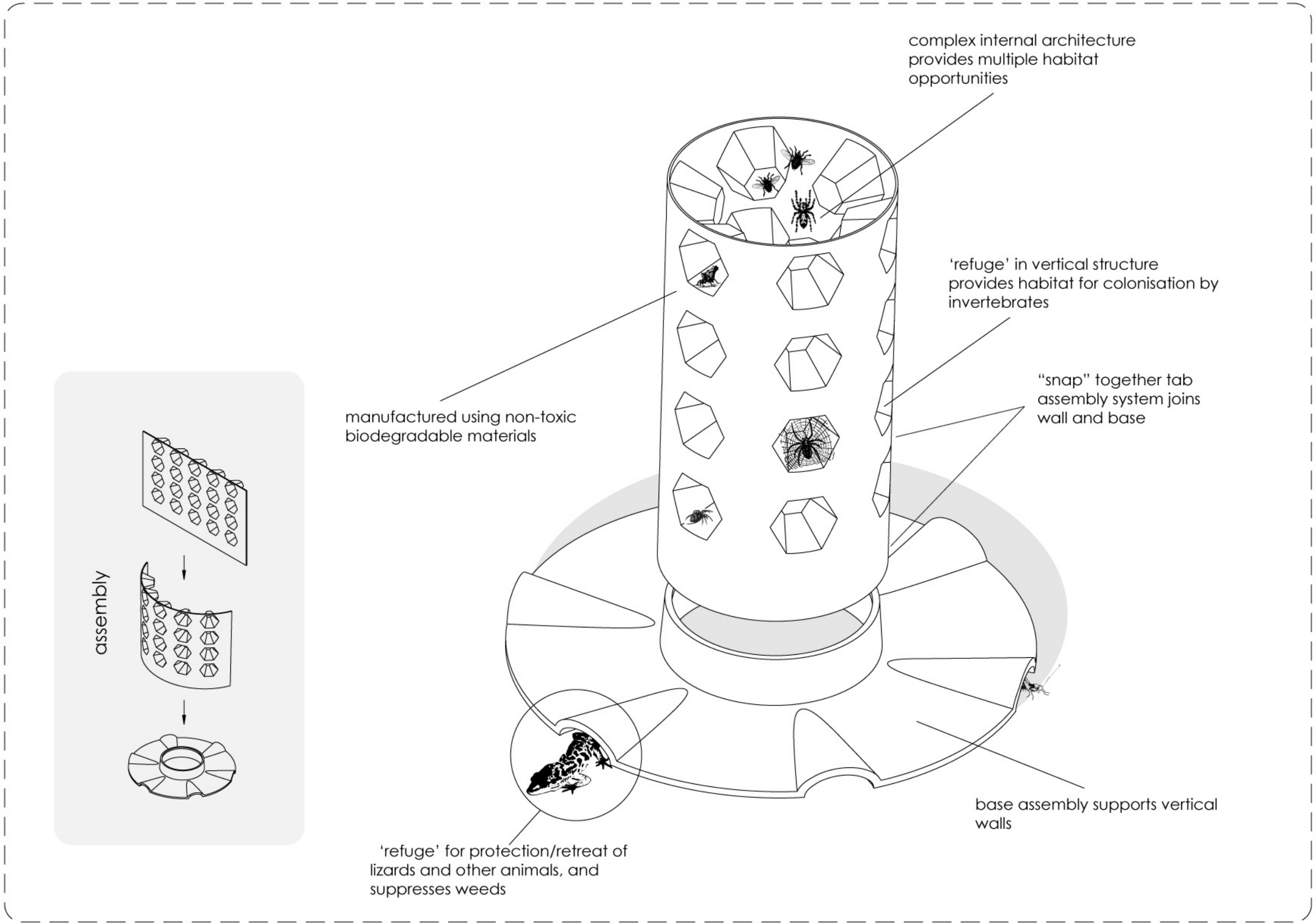
Figure 7.18 Final tree shelter prototype summary

Tree shelter prototype summary

Thetree shelter has been designed and developed as a low cost and lightweight barrier to protect newly planted tree seedlings for forest restoration. In addition, it prives a number of innovations to enhance restoration plantings to maximise their potential to become established forest ecosystems.

- simple low cost flat pack design
- rapid set up under field conditions
- twin wall design for strength as well as moisture retention
- complex structural form provides multiple habitats for insects, spider and reptiles
- standardised sampling substrate for use in monitoring studies
- made from biodegradable recycled materials
- self supporting
- weed suppressant

Figure 7.19 Final tree shelter prototype summary



Materials

The tree shelter must be able withstand the elements in the field but still be biodegradable within a reasonable time period. After its useful life protecting trees and as a refuge to support animals the trap may decompose to become a biological nutrient. If manufactured from organic material, forest floor decomposers (invertebrates and fungi) will be able to utilise these components as a food source and transform them into nutrients for uptake by trees. This means that on-going site maintenance is minimised, as shelters do not need to be removed and disposed of (as with many plastic shelters currently available). Correspondingly, the trap prototype may be manufactured using a significant component of low-cost, recycled organic materials. The final material components will be evaluated following extensive field testing of the prototype, and consultation with users. The biodegradable, non-toxic nature of the material will mean the shelter may be categorised as a biological nutrient.

Prototype testing

Field testing of the prototype will be undertaken in a series of trials evaluating the shelter's effectiveness alongside currently used tree shelters. Measures of shelter effectiveness may include the following:

- Usability and ease of set-up
- Field life of shelter
- Tree survival and growth
- Cost-benefit analysis (i.e. tree growth and survival vs. cost of shelter and assembly)
- Establishment of biodiversity
- Assessment of use as a monitoring tool to measure ecosystem success

Factors that may influence sampling methods include time of year and site factors. These will be accounted for during shelter evaluation programmes.

Conclusions

- Design for ecosystem function successfully achieved.
- Shelter design successfully incorporates multiple functions throughout the shelter's life – ease of assembly, tree protection (conservation), biological nutrient (structure) and biological nutrient (biodegradable).
- Biodegradability following long life.
- Considerable benefits to human user over existing designs. Significant potential for physical (%) cost savings as well as transportation, time and storage benefits.
- Potential for considerable benefits to conservation of biodiversity. The shelter has the potential to support a diverse range of organisms beyond vegetation. Additional benefits include the shelter's use in studies to monitor the success of restoration plantings.

EIGHT. discussion

This research explored opportunities for sustainable product design in New Zealand. In order to go beyond eco-design principles (Tischner & Charter 2001), this project aimed to design for strong sustainability (as described by van Roon & Knight 2004). This meant framing design decision-making within an ecological context. O'Riordan and Stoll-Kleemann (2002) describe the abundance of biodiversity as revealing the extent of co-operation between people and nature. Therefore, biodiversity was considered key to the design process alongside people. Biodiversity is an indicator of the health of the planet; "*for humans to be at peace with themselves they need to find peace with biodiversity*" (O'Riordan & Stoll-Kleemann 2002, p19). Consequently, the study of biodiversity provides a mechanism to measure sustainable development.

> "*…the social and economic elements of sustainability may not seem apparent, and yet if they are not sustainable there will be an unmistakable imprint on the biological diversity. So nature provides an uncompromising yardstick for measuring our way*" Lovejoy (2002, p43)

The development of a design framework for this project was the result of an attempt to apply the discipline of design to current ecological issues. Critical review of current sustainable design models from the perspective of designing for ecological systems identified the potential for a more specific framework. Subsequent key informant interviews with a number of leading New Zealand scientists identified additional perspectives that helped shape the design process. Design for ecosystem function is a qualitative approach to design. It acknowledges that we do not have the ability to know or measure everything, but guides the decision-making process to help us make conscious, well-informed, best-practice decisions with regard to sustainable design.

Three ecological design interventions

The three ecological interventions developed in this study represent strong sustainable design, where ecosystems (environment) were considered central to the design process from its initiation. Not only did this result in the development of three new and innovative products, but it also ensured that the products developed have an underlying ecological integrity that will benefit biodiversity and natural systems (and therefore our communities). In addition to making ecological contributions, human users were considered central to the design process. Consequently, the resulting design outcomes for people range from more simple and easily measured anthropogenic attributes right through to more complex and less tangible community benefits (ecology).

The design process in this research was undertaken in such a way that the development of the design framework was informed by a variety of sources, including literature and experts. This framework was then used to help generate design ideas and realise opportunities. Following this, it was used to form the foundation of the design process for the three design projects. As each project was undertaken, insights resulting from the research and design process were subsequently used to inform and "test" the framework, with any additional insights being utilised to further develop the project, as well as to inform subsequent projects.

Consequently, the three design projects evolve in levels of ecological complexity with respect to the framework. The first design project, the weta home, is a toy that focused on a method to help develop cultural biodiversity in children living in urban environments. One aim was to explore how an awareness of cultural biodiversity might be improved by the manufacture, use/ownership and disposal of a product. From a biodiversity perspective the weta home may be manufactured from biodegradable, reusable materials so that it could be categorised as a biological nutrient. However in this capacity, due to the size and potential number of products that may be made, it is unlikely that significant benefits to biodiversity will occur (i.e. benefits resulting from degradation in gardens or back yards). As a structural nutrient its application is also limited, as the object is capable of supporting only a small number of weta (or other insects). However, the potential benefits for biodiversity (and sustainability) may be greater due to the enhanced awareness of nature a child may gain by using the toy as intended. However, even short-term benefits are difficult to measure, therefore the potential long-term benefits may be impossible to ascertain. Despite this the design intent was to "plant the seed" in children that human social systems are intimately dependent on, and a part of, nature.

The second research project evolved with a greater level of ecological integrity, resulting from the design process being informed by the first project (weta home). Habitrap is a design response to a conservation problem, where lizard-monitoring efforts were being constrained by the trapping options available. From a human perspective the traps used in monitoring programmes were large, bulky, time-consuming to install in the field and sometimes expensive. From a lizard's perspective, the current commonly used traps were not designed for use by lizards, but were generalised animal trap designs (one commonly utilised in insect studies). This design project focused on a single animal group. However the design for ecosystem framework helped to generate the insights that resulted in developing user requirements specifically for lizards. This in turn resulted in the development of the opportunity to design the traps for additional use in relocation programmes, where the trap may be utilised as an artificial habitat by lizards. Additional benefits from designing the trap as a "habitat" include making the trap more attractive, and therefore a more effective sampling may be achieved per trap effort. Furthermore capture stress may be reduced. In this project designing the trap to function as a structural nutrient was a main focus. The capacity for the Habitrap to be utilised as a biological nutrient was less important. As previously discussed, Braungart et al. (2007) describe the concept of a biological nutrient, where products are designed to be reabsorbed back into natural biological cycles. However, with respect to this project, the utility of the biological nutrient concept is more complex. While it is important that the traps are manufactured from non-toxic and biodegradable materials, it is inappropriate and ecologically naive to recommend that they be disposed of in the environments in which they are most commonly used (wilderness areas), where discarding used traps would be tantamount to littering. It is appropriate that the traps be manufactured in such a way that they would be able to be composted in an appropriate facility following their end of life. Furthermore, should the traps be lost (i.e. moved by animals, etc.) in conservation areas, the biodegradability of the traps will help ensure that impacts are minimised.

The third design project (tree shelter) is the least developed, in terms of constructing a fully functional prototype. However, it represents the culmination of the design for ecosystem function process, developed in part from the first two projects and the engagement of their design to inform the framework. A key driver for this project was to use the framework to generate a community (ecological) response to a conservation problem. Therefore the project required an understanding of ecological knowledge that successfully negotiated the use of the structural nutrient concept. The use of a product as a structural nutrient, alongside the idea of forest restoration as a tool to develop or advance the successional development of native tree plantings so that they may become self-sustaining and dynamic systems, resulted in an innovative response to the simple problem of tree mortality in restoration plantings. The concept of a structural nutrient was developed further by identifying an opportunity to design the shelter as a sampling device to allow it to be used in monitoring programmes that help determine whether restoration plantings actually achieve the intended level of success. This has significant benefits for restoration ecology studies, as the data collected may be generated more quickly and be more informative, providing the opportunity for more powerful analysis. Greater benefits may also be observed in specific monitoring programmes to ensure that entities with vested interests are able to meet their contractual obligations. For example mining companies may be allowed to degrade or destroy significant intact natural areas only if they undertake to fully restore them. Substantial bonds are paid and are released when certain restoration and environmental criteria are successfully met. Additional benefits for biodiversity result from using the shelter as a sampling method, as fewer individuals will need to be trapped (and killed) as is common in monitoring programmes (especially invertebrate). A commonly used trap (i.e. pitfall trap) may be an especially undesirable method in areas where rare or threatened organisms may be present.

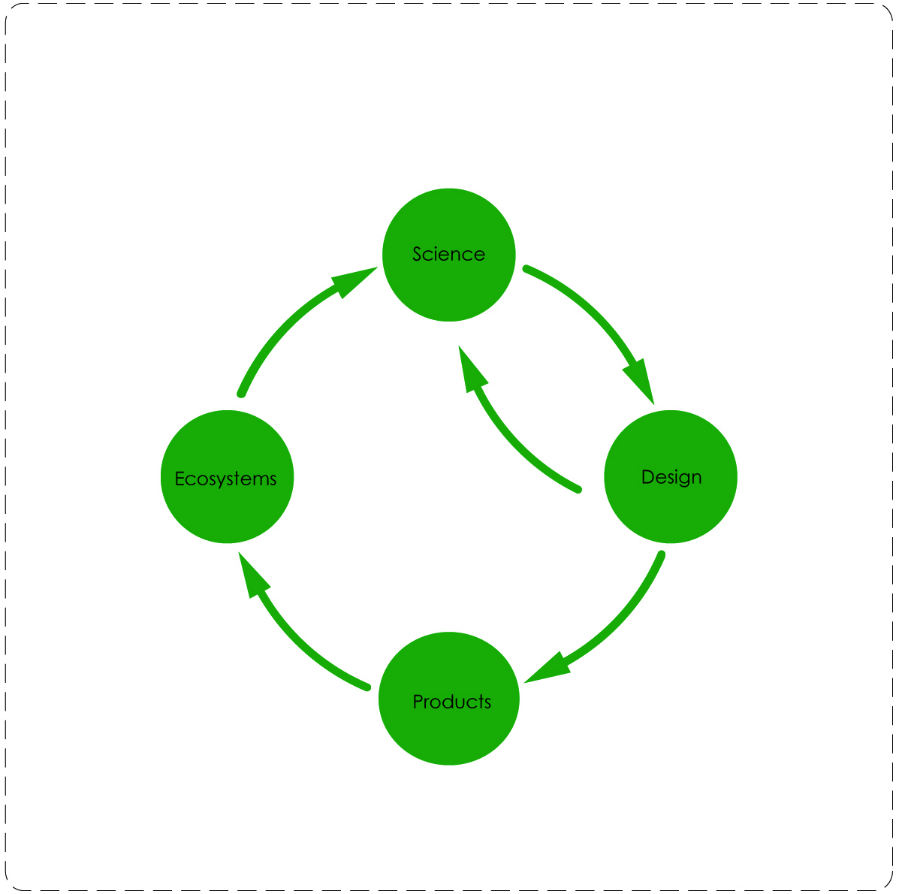
The interaction of science and design

The sustainable design framework (Cradle to Cradle) proposed by environmental chemist Michael Braungart and architect William McDonough (2002) was used as a starting point to explore the relationship between science and design, with regard to opportunities for sustainable design in New Zealand. A group of New Zealand scientists were asked to explore sustainable design, using the "Cradle to Cradle" design framework as a basis to determine the potential for this type of approach in the design of New Zealand-made products, as well as to explore additional opportunities for sustainable design. The subsequent discussion and analysis provided a number of insights that were then used to inform the design process. One of the dominant themes that emerged was the high level of complexity when dealing with issues of sustainability, especially with regard to ecological systems. Designers that have not been specifically trained in this area cannot be expected to negotiate the complex and dynamic factors influencing ecosystems. This study illustrates that science and design can meet at this interface to negotiate the needs of both people and nature in a collaborative and meaningful way.

Design for ecosystem function recognises that ecosystems are the basis of consumption (Figure 8.1). It is in this context that Braungart and McDonough's (2002) concept of biological nutrients most substantially contributes to sustainable design. By extrapolating the application of a biological nutrient, ecosystems may be designed to facilitate the cycling of large quantities of waste material. This may subsequently be used in productive agricultural systems, therefore providing immediate human (i.e. food, disposal of materials) and sustained (i.e. contributing to ecosystem processes and the protection of natural systems) benefits. This ecosystem approach recognises the importance of scale in ecosystems, and that ecosystem units are inter-connected (Lyle 1999). However, for such an approach to be successful the complexity and diversity of these connections must be recognised to minimise the impacts of designed ecosystems on surrounding "natural" systems.

While this approach might appear to be arrogant, humans have been doing this for around 12, 000 years (Lyle 1999). Lyle (1999) describes "human ecosystems" as a combination of productive areas where succession occurs, but is continually impeded by human activity to maintain high productivity, and protected natural areas where natural succession is allowed to proceed to mature, stable (yet unproductive) states. Ecosystems that are shaped by human activities will be structurally and functionally different from the original "natural" system, but will respond to similar natural forces. Lyle (1999) suggests that designing ecosystems is difficult due to ecosystem complexity. He suggests that all available ecological knowledge should be used to shape systems that contribute to human purposes, as well as being sustainable and supporting non-human communities. However, efforts should not dominate nature, but participate in nature's processes (Lyle 1999). The products designed in this study indicate the potential benefits for both society and nature when design participates with a greater level of ecological consciousness. Sustainably designed products, such as those described in this study, may be incorporated into greater ecological design projects (such as ecosystem design) to help develop sustainable living while enhancing natural ecosystems.

Figure 8.1 The interaction between science and design to transform ecosystems into beneficial products of sustainable consumption



Sustainable product design could not be successfully undertaken in the absence of an understanding of ecology and intimate knowledge of ecological systems. This design study brought the application of ecological process to innovative sustainable product design. It recognises that ecosystems are the basis of human consumption and should be incorporated as an integral part (the foundation) of society to ensure the development of strong environmental, social and economic sustainability.

We are faced with designing for a challenging future. Ecological understanding is vital to engage in sound and rigorous debate around issues of sustainability, with the level of integrity that is now expected by society. A specialised designer with new modes of design process thinking is required to help negotiate these challenges, and actively engage with communities and the environment. Innovation is bred from interactions at inter-disciplinary boundaries. The successful development of this sustainable design framework was the result of such cross-disciplinary collaboration, and indicates the potential for further collaborative approaches to design sustainable products.

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