Carbon and Environmental Profiling of Hard Landscape Materials

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Preface

The environmental, economic and social consequences of ignoring resource depletion, global warming and associated climate change are likely to be the defining world issues of the 21st century (Daly, 2008; McGuinness et. al., 2009; Monbiot, 2008; Rees, 2009), and there is a strong link between such adverse environmental change, and potential social and economic collapse (Diamond, 2005). After 150 years of industrialisation, the developed world is principally responsible for the higher global temperatures that we are experiencing today through increased $C0_2$ and other greenhouse gas emissions. This rise in temperature and the subsequent changes in climate are set to profoundly alter the world's ecosystems, the places we live, and ultimately, how we live in the world. We must ensure that we move quickly to a more sustainable way of living.

A reduction in CO_2 emissions is widely understood to be an essential component of slowing this global warming. One way in which the profession of landscape architecture can contribute to this reduction is to consider using materials that produce less CO_2 in their manufacture, supply and installation. Such informed decision-making by New Zealand industries would enable us to understand "...what [it would] be like to lead the world in sustainability." (Harre & Atkinson, 2007)

Executive Summary

This study examines the ways in which the choice of hard materials in landscape projects affects the total level of CO_2 emissions from those projects. It aims to better inform landscape design and construction professionals in New Zealand about some of the consequences of their choices. The findings are also relevant to those in other professions or organisations which specify or use hard materials when implementing landscape change.

The research questions are to:

1. Identify and compile a list of typical hard landscape materials and techniques (see table 2);
2. Define the carbon and environmental footprint of selected materials, with reference to embodied energy (see Chapter 4.2); and
3. Develop an outline approach to the ways in which this information could be used as a tool for professional landscape architects, to better inform their decision-making processes in regard to specification of materials and techniques (see Chapter 5).

The study reviewed the application of three key sustainability measurement systems to landscape design (Leadership in Energy and Environmental Design, Green Star and Life Cycle Assessment). The Life Cycle Assessment (LCA) was adopted as a tool to enable evaluation of the full 'cost' of materials used in landscape projects, and therefore facilitate a more informed choice of those materials. A sample of five commonly used materials was chosen for this study in the form of 'functional units', which were defined as $10m^2$ surfaces. The materials were: timber, steel, concrete, aggregate and asphaltic concrete. Timber was found to be the 'least cost' material with regard to CO_2 emissions, while aggregate and asphaltic concrete were 'least cost' with regard to embodied energy and dollars.

Potential tools for the landscape profession that build upon the findings from this study were discussed, and it was noted that there is a substantial amount of landscape and NZ-specific research that still needs to be undertaken to enable more detailed comparisons of materials options to be made for landscape projects.

The preliminary work was conducted by Kirsten O'Connor as part of a Summer Research Scholarship offered by Lincoln University, in partnership with Craig Pocock of Pocock Design:Environment Limited, based in Christchurch New Zealand. Supervision was provided by Mike Barthelmeh and Dr. Shannon Davis from the School of Landscape Architecture at Lincoln University.

Chapter 1
Introduction

1.1 Introduction

The impact of the work of landscape architects on the environment and communities has generally been considered to be constructive, with much of the published material within the profession focusing on the positive impacts of implemented projects on ecosystems, the water cycle, biodiversity and community well-being. There has been very little focus on the potential negative impacts of landscape design and management decisions on the environment and hence associated communities. Such decisions can have an influence on the carbon impact of most aspects of a landscape architect's work, including all stages of design and land planning, and at all scales from residential development to regional master plans. Aspects also include the ways in which practices are run, how landscape construction is implemented, how landscapes are managed and maintained, and how well designs are future-proofed to extend their life expectancy before renewal.

"Each carbon stage has differing degrees of importance. With good management, a landscape firm might, for example, save 300 tons of carbon per year through appropriate office, transportation and energy policies. However, a single flawed design decision, poor material choice, landscape management or maintenance policy could... effectively nullify[ing] any carbon savings from the office." (Pocock, 2007: p88)

Landscape architects specify a considerable amount of material, and since the materials industry is a significant polluter, and a consumer of non-renewable raw materials, the focus of this research is to investigate how material specification could have an influence on the 'environmental cost' of a project.

Landscape architects have a duty of care to minimise the environmental consequences of their design decisions, including potential consequences for global warming, and to make a positive contribution towards sustainable landscape change. Many landscape architects consider that they are already helping to reduce the effects of climate change, specifying planting which absorbs CO_2.
What is not known is how much that planted portion of an implemented landscape design might offset the environmental and carbon impact of the hard materials that are used.

The landscape profession has probably avoided criticism about the potential environmental impacts of its projects due to the perceived 'green nature' of implemented landscapes in comparison with other design professions such as architecture and engineering. Over the last decade, those two professions seem to have come under considerably more pressure to account for the impacts of their work, which has led to their leadership in sustainable structural design with materials and systems-based approaches, while the landscape profession has largely ignored its own environmental footprint.

However, it is likely that the balance between the carbon impact of hard materials and the carbon off-setting of planting will still result in a net negative effect from most projects. "There is a fundamental imbalance in our work; the planting we create cannot possibility off-set the high embodied energy cost of the materials we most commonly rely upon." (Pocock, 2007: p88)

France (2003: p34) also noted that since "…landscape architects pride themselves in being more environmentally sensitive than architects, it may be that such a self righteous attitude needs to be tempered. In the end, perhaps the best that can be said is that, on average, the [landscape] projects published in the professional primary magazines neither harm nor help nature."

Since the goal of sustainable design in landscape projects is becoming increasingly important to the profession, more attention is now being paid to the ways in which we use resources to create those projects. “Appropriate selection, use, manipulation and management of materials and resources, both organic and inorganic, is central to the achievement of sustainable designed landscapes. In fact, it could be argued that deciding the nature and source of materials, and the ways in which they are put together and interact on site, can be the most fundamental and straight-forward way in which designers can influence landscape sustainability.” (Dunnett & Clayden, 2005: p196)

This study looks at some implications of materials choice as a key component of a sustainable design sequence:

rethink (the problem);
reduce (high energy, high CO_2 components);
restore (fix the existing components);
reuse (throw nothing away); and
recycle (add energy to enable reuse).

Understanding the ways in which some hard materials vary in their contribution to more sustainable design is a useful first step towards enabling a broader comparison of a wider range of materials, and the potential impacts that the use of these materials has on global warming. By assessing the impacts of hard landscape materials, the profession will be able to quantify and compare some key potential consequences of its design decisions.

1.2 Study aims and limitations

This study examines one aspect of the carbon footprint of Landscape Architecture, aiming to illustrate the significance of the contribution of hard material specification to climate change, using a Life Cycle Assessment approach. It is intended to support the continuation of a dialogue within the landscape design profession in New Zealand about the role the profession plays in contributing to global warming. This dialogue began in 2006, when judges for the New Zealand Institute of Landscape Architects (NZILA) Sustainability Award (established two years earlier within the Institute's biennial Design Awards) declined to make the award. “…we hope this decision will spark thoughtful and professional debate with a positive outcome for the New Zealand environment...” (Pocock, 2006: p4). The criteria for making a sustainability award had been substantially upgraded for the 2006 competition, and the judges were clear about the need to ensure that award-winning landscape projects in New Zealand exhibited a sustainability focus that was more than just a superficial token, and referenced the embodied energy of materials.

This study will contribute to the development of a critical foundation for design thinking, to enable more informed decisions to be made about materials specified for landscape projects. Such an approach during the initial design phases of a project is likely to avoid the need for later and more expensive mitigation or restoration measures from implementation or occupation of the site.

The research questions are to:

1. Identify and compile a list of typical hard landscape materials and techniques (see Table 2);
2. Define the carbon and environmental footprint of selected materials, with reference to embodied energy (see Chapter 4.2); and
3. Develop an outline approach to the ways in which this information could be used as a tool for professional landscape architects, to better inform their decision-making processes in regard to specification of materials and techniques (see Chapter 5).

There is no attempt to place a simple ‘value’ figure on each material, since the ways in which the material might be sourced, transported or used are highly variable, as are variations in project characteristics such as scale, location, likely lifespan and potential re-use of components. Such complex and competing values would need to be established at each stage of a full material assessment, which goes beyond the scope of this study.

However, even though absolute environmental values for each material have not been established, or exact carbon values for each situation in which the materials are used, the study does help to establish a baseline or general understanding about where certain materials may sit on an environmental profile continuum. This will help designers understand where materials with a significant environmental cost could be reduced, and also consider where their particular attributes are best used.

Future work to advance our understanding of the ‘full’ environmental impacts of material choice is expected to continue from this study.

1.3 Method of Enquiry

The range of commonly used landscape materials was identified. A literature review was undertaken to establish the current levels of knowledge about the implications for global warming of using different construction materials. Methods of establishing carbon values were briefly reviewed, and Life Cycle Assessment (LCA) was adopted as the most relevant tool to enable evaluation of the full 'cost' of materials used in landscape projects, and therefore facilitate a more informed choice between those materials.

A sample of five commonly specified landscape materials were selected for analysis. The sample materials were: timber, steel, concrete, aggregate, and asphaltic concrete.

Relative 'costs' of the materials by weight and volume were obtained from previously published work, and applied to a simple $10m^2$ outdoor surface (a ‘functional unit’) designed from each of the materials. This practical comparison was chosen to determine a fair relative environmental 'cost' of each material investigated in a way that is relevant to landscape architecture.

Chapter 2
Literature Review

2.1 State of the Environment

There are numerous ways in which human activities impact on the environment at a range of scales, including the ways in which raw materials are processed to create products used in construction of the built environment. Production of materials such as concrete, steel, timber, clay pavers or stone may contribute to a range of environmental impacts, depending upon the final form of those materials. All landscape materials sit on a continuum of environmental impacts from minimal to significant and LCA can help us to understand those overall impacts.

The types of environmental issue that may occur at global, regional or local scales during these processes has been categorised by Dunnett & Clayden (2005) with reference to LCA, adapted and summarised in Table 1.

Table 1
Life cycle stage and environmental issues

Stage	Possible environmental issue
raw materials extraction	ecosystem loss; finite resource loss; transport infrastructure effects; air, soil, water pollution; noise, dust; visual consequences
manufacture	energy consumption; finite resource depletion; ecosystem impacts; global warming; air, soil, water pollution; noise, dust; ozone depletion
distribution	energy consumption; transport infrastructure effects; global warming; air, soil, water pollution; noise, dust
construction	emission of hazardous substances; air, soil, water pollution; noise, dust; ecosystem impacts; energy consumption; packaging; waste
use	energy consumption; ecosystem impacts; level of maintenance requirements; ease of maintenance; soil, water pollution;
demolition	energy consumption; ecosystem impacts; noise, dust; level of re-use or recycling capability; air, soil, water pollution; visual consequences

Source: Adapted from Dunnett & Clayden (2005).

Underpinning the contribution of poor material choice to environmental deterioration is the concept of the minimisation of boundary transfers, i.e. when pollution or wastes from production or use on a site or in a locality are not simply passed on somewhere else. Dunnett & Clayden (2005) suggest that consideration of the movement of energy, resources or waste into or out of the 'site' at a design stage can have an effect on the overall environmental cost of a project. Pocock provides a specific example: "As designers we need to understand the embodied energy of the materials we use. For every one ton of concrete we specify on our plans we are responsible for at least four tons of carbon dioxide produced that ends up in our atmosphere." (Pocock, 2006: p2)

Two key measures are apparent in regard to considering the impacts of material choice on environmental degradation: greenhouse gases, identified as the major contributor to global warming and therefore climate and environmental change; and embodied energy, or the different energy content of all products or materials used in landscape architecture.

2.1.1 Greenhouse gas emissions

The main greenhouse gases (GHG's) are carbon dioxide, methane, nitrous oxide, and fluorocarbons. GHG's are emitted during combustion of fossil fuels and wood used to provide energy for raw material extraction or product manufacture. Emissions are not only a by-product of combustion but also of chemical processes, especially in industrial situations. For example, one part of the process of converting iron ore into steel converts CO to CO_2: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$.

Prior to the industrial revolution, the process of GHG's trapping solar energy in the earth's atmosphere was positive, keeping the planet warm. Increased industrialisation however has resulted in more GHG's (especially $C0_2$) and 'new' GHG's (fluorocarbons) being released into the atmosphere, which has subsequently lead to an unsustainable, and potentially catastrophic, global temperature increase.

Different gases have different life spans and varying levels of warming effect. Global Warming Potential (GWP) is a standard method of aggregating the total impact of all gases into the equivalent impact of carbon dioxide (CO_2). The GWP value of materials makes it easier to understand their overall potential impact on global warming but it can also create the impression that the GWP value summarised as a CO_2 value can be offset by planting. It is important to remember that the GWP value includes gases that plants cannot sequester. Industries or designers who offset the GWP values of the materials within their projects make a valuable contribution, but that does not necessarily make the materials or project CO_2 neutral.

Trees do sequester CO_2, the principle behind carbon credits and emissions trading schemes. While other natural environments such as meadows and salt marsh also sequester CO_2, these are not often included in carbon trading schemes. However, although trees capture CO_2 during the process of photosynthesis, it is important to note that a portion of this carbon is released again at night; a disproportionate area of trees is therefore required to offset a much smaller area of hard landscape such as a concrete paving surface. Also, when plants decompose or burn, some of the carbon is converted back into carbon dioxide although the rest remains as carbon in the soil or ash. Using trees to store carbon is thus only a partial and temporary solution, and so a more holistic approach to reducing total CO_2 emissions is needed.

2.1.2 Embodied energy

Identifying how much energy it takes to manufacture and transport a material or product, from its beginning as raw ingredients to where it will be used (the embodied energy), enables a comparison to be made between the impact one product has on the environment relative to another product. The LCA industry refers to this calculation as being a 'Cradle to Gate' assessment of embodied energy (see Appendix 2 for other types of LCA).

An important distinction made in LCA calculations is whether fossil fuels are considered to be energy, or feedstock. For example, bitumen from crude oil used in surfacing asphaltic concrete roads is considered to be a feedstock because it is used not for its energy content, but for its physical viscosity. Many studies include the feedstock as part of the embodied energy calculations because it is contributing to the depletion of a finite resource but for the purposes of gauging environmental impact from emissions, the energy value of feedstock should be omitted (Alcorn, 2003); the energy used to extract and refine feedstock is accounted for elsewhere in LCA calculations. Each study should state such exclusions in their assumptions, but some fail to clarify the difference between the sources of energy (Alcorn, 2003). This may account for differences between the results of some studies which considered similar materials.

In New Zealand there is a unique situation with energy production which makes it difficult to translate aggregated data from overseas. In 2008, 65% of all electricity generated in New Zealand came from renewable sources (MED, 2009), a relatively high proportion by global standards. Power is derived largely from hydro dams (52%), so the CO_2 emission per Petajoule of energy produced in New Zealand is much lower than other countries that rely on the burning of coal or oil to produce electricity.

2.2 Sustainable development

The definition of 'Sustainable Development' varies enormously, but it is commonly based on the 1987 definition offered by the Brundtland Commission. In their report, Sustainable Development is defined as '*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.* A number of authors (Daly, 2008; Thompson, 2007) believe that the term 'sustainable development' is problematic, in that development is often "…regarded as the continued expansion of human activity and the unceasing pursuit of economic growth…" (Thompson, 2007: p16). Further, the treadmill of continued economic growth is hard to stop: "…nearly everyone likes the idea of using less oil, but nobody wants to take the step of actually mandating a reduction in its production and consumption, because that would require us to dethrone our Holy of Holies - economic growth." (Heinberg, 2010: p9)

The authors of this study prefer to use the terms 'sustainable change' or 'sustainability', rather than 'sustainable development'. This confirms that sustainability does not mean 'business as usual', and that the effects of landscape change must result in a neutral environmental footprint at the very least, but positive where possible.

2.3 General design guides

There are a number of general design guides for more sustainable building or construction, including the Green Guide to Specification (Anderson & Shiers, 2002) and the Green Building Handbook (Woolley & Kimmins, 2000). These guides do include some values for materials aspects such as embodied energy, but they are mostly for architectural materials which are not used in the landscape industry, and they are not based in a New Zealand context. Further, such information is of little value since it cannot be readily applied to landscape works without a great deal of extra information. Calculating values for a 'functional unit' is one method of enabling comparisons between materials that is applicable to landscape works, but these types of guide do not assemble data in this manner.

This study is aimed at establishing some specific information about a limited range of materials that are applicable to landscape works. Readers are referred to the general design guides for more information about broad design approaches.

2.4 Methods of measurement and comparison

The study of the energy and CO_2 components of materials is broad and complex, with most work completed for the building and construction industry relating to built structures and building performance rather than specifically for the landscape industry. There are also a number of methods provided by business and non-profit or government related organisations. They can focus on specific factors, or provide descriptive guidelines, aggregated calculations or point-earning checklists. Like many assessments, a comprehensive analysis is often reduced for ease of application. Nevertheless, such work provides a good resource from which to identify elements such as concrete, timber and steel which bridge both architecture and landscape architecture. The three key systems considered for their application to this study were: Life Cycle Assessment (LCA), Leadership in Energy & Environmental Design (LEED) and Greenstar.

LCA was chosen as the best approach to use to answer the research questions noted in section 1.1, because it provides an opportunity to make a realistic and holistic comparison between material options for a specific use. Aspects such as transport and fuel costs, capital and maintenance costs for plant and machinery, and extraction and processing costs allow realistic comparisons to be made (within specified parameters). It means that some materials which might have a high initial 'cost' may be a better alternative than 'cheaper' materials because of their expected life-span, or improved ability to be re-used at the project disassembly stage.

Most existing materials studies have been LCA-based and completed for the building and roading industries, such as the following BRANZ reports: SR214 Housing life cycle and sustainability - part 1 (2009); SR235 Housing life cycle and sustainability - part 2 (2010); and SR236 Building Energy End-use Study (BEES) Year 3 (2010).

A number of industries and associations that supply certain materials in NZ and overseas have also conducted their own studies, for example the Cement and Concrete Association, the Forest Stewardship Council, and New Zealand Steel. This study is therefore based on a combination of many types of information such as journal articles, reports, conference proceedings, newsletters, industry marketing publications, websites and books. Although there is little standardisation in output from these studies they are generally helpful in promoting emphasis on sustainable outcomes, especially in the design stage. However, they are not necessarily helpful in material selection (Ljungberg, 2007; Haapio & Viitaniemi, 2008).

Integrating the assessment of social, economic and environmental issues is essential for making fully informed decisions about sustainable change, but little has been published on exactly how that might be achieved (Kirkpatrick & Lee, 1999). It appears as though attempts have been made to generate data, but the outcome is neither useful nor objective enough from which to base decisions.

The authors considered LCA software tools to determine whether it was possible to complete a simplified assessment of certain materials that are not provided by the building industry, but the calculations are detailed and access to raw data relevant to New Zealand proved difficult to find.

2.4.1 Life Cycle Assessment

Life Cycle thinking is a holistic approach to understanding the impact a material has on the environment, from its raw unformed state, through manufacture and use, to final deconstruction and potential reuse. The Society of Environmental Toxicology and Chemistry defines Life Cycle Assessment as being an "objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impacts of those energy and material uses and releases to the environment, and to evaluate and implement opportunities to effect environmental improvements." They continue with further definitions regarding the entire life cycle of a product, including the extraction and processing of raw materials, its manufacture, transport and distribution, through to the ways in which products might be reused or recycled, and final disposal (SETAC, 1993).

ISO 14040 defines Life Cycle Assessment as a technique for assessing the environmental aspects and potential impacts associated with a product by:

1. Compiling an inventory of relevant inputs and outputs of a product system;
2. Evaluating the potential environmental impacts associated with those inputs and outputs;

3. Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

It further refers to the study of the environmental aspects and potential impacts throughout a product's life from raw materials acquisition through production, use and disposal. The general categories of environmental impacts that are suggested as needing consideration include resource use, human health, and ecological consequences.

A full Life Cycle Assessment follows a standard ISO protocol, to ensure consistency. LCA are complex (e.g. definition of system boundaries) and rely on data being accurate and specific; aggregated data reduces overall accuracy and confidence in findings. Region-specific information is most accurate, but often it is not available, or cannot easily be extrapolated to the rest of the world. LCAs are expensive and time consuming to complete, but they are supported as a "…means for making informed choices in material selection and guidelines for more sustainable design solutions…" (Dunnett & Clayden, 2005: p196).

Some work has begun in New Zealand on the assessment of materials and processes, especially through LCA, although most of this is related to buildings and other structures (Allan, 2008). In order to understand the breadth of aspects implied by life-cycle thinking the life cycle of concrete has been summarised in Appendix 4, as an example. Through the process there are clear points where the designer or 'end consumer' can make decisions that have significant impacts on the overall sustainability of the ways in which the product will be used.

LCA has become the most widely used approach to fulfil sustainable mission statements used in many industries, including corporations, industrial institutions and governments, according to Gauthier (2005). The origin of LCA stems from a comparison of packaging options completed by Coca Cola some 30 years ago, but since then it has been developed for use in environmental sustainability. Improvements are still being made, but currently the requirements are listed in the ISO14040:2006 and 14044:2006 standards to maintain consistency in the execution of an LCA.

LCA is more than a tool or set of guidelines to follow; it is a useful way of thinking. It allows stakeholders to see the results of a more holistic approach to assessing the consequences of decisions about material choice. Rather than simply considering what a product or material will provide when used in a structure or landscape, an LCA allows stakeholders to see what impacts the product has already had on environmental indicators, and what its potential use is at the end of the project life. This is called 'cradle to cradle' or 'cradle to grave' assessment because it encompasses the following typical phases: raw material extraction, manufacturing or processing, transport to market, use or operation, maintenance, and use after deconstruction (see Appendix 2 for other variants).

Each formal LCA study will state which of these phases are included or excluded. In some cases a study will stop at the supply stage; this type of LCA is 'cradle to gate' because it includes all of the events in a product or material lifecycle right up to supply.

2.4.2 LEED

LEED is the acronym for Leadership in Energy & Environmental Design, an internationally recognized green building certification system. It was developed by the U.S. Green Building Council to provide a framework for identifying and implementing sustainable building solutions. LEED provides third-party verification that a building was designed and built using strategies aimed at improving performance across key indicators: energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, stewardship of resources and sensitivity to their impacts.

LEED is one of the most commonly used assessment tools for buildings internationally and includes a landscape section in its framework, but it has not been commonly used in landscape or external environment assessments unless there is a building as part of the project.

2.4.3 Greenstar

Greenstar has been promoted in New Zealand over LEED by BRANZ as the standard assessment programme for the building industry. It is adapted from an Australian model for awarding a final rating to a building based on the achievement of sustainable objectives and is managed by the New Zealand Building Council. It provides a landscape section including recognition of landscape elements, and refers to the positive benefits of pervious surfaces and planting. Like LEED, Greenstar provides third-party verification that a building has been designed and built using strategies aimed at improving performance across key indicators such as energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, stewardship of resources and sensitivity to the impacts on resource use. However, it lacks recognition of embodied energy and CO_2 emissions, and the transport costs of materials.

2.4.4 A holistic approach

An LCA is primarily concerned with environmental impacts, but a holistic approach to assessing the implications of material choice should also include the ethical, social and economic consequences throughout the lifecycle of that material. If the landscape industry was to consider applying an LCA approach to material selection, it may have to consider that wider range of implications. A recent example of this broader scope is the rising awareness of 'fair trade' materials, where local communities offshore benefit from sales in New Zealand of materials such as timber. Adding social and economic as impact categories alongside other environmental categories established in a typical LCA would confirm this broader approach.

Carbon Footprint, Industrial Ecology and LCA tools "…are too ecologically oriented and not enough socially oriented to completely fill the sustainable development deal. Because it has become the most widely used tool of practical environmental policy and environmental management, the Environmental LCA tool has to be improved in that way. Life cycle analogy allows to control 'from gradle [sic] to grave' the environmental impacts and resource use of a specific product, but not the social or societal ones." (Gauthier, 2005: p199)

She goes on to say that "It is therefore necessary to lengthen the list of criteria so as to accommodate the social impact… One corresponding major initiative is the Global Reporting Initiative (GRI) that sets out a coherent, international reporting system for the economic, environmental and social performances of businesses, similar to those already in place for financial reporting." (Gauthier, 2005: p201)

New assessment frameworks are being developed to incorporate the economic and social impacts such as Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA). Petti & Campanella (2009) refer to the proposal for an integration of all three to produce a balanced holistic assessment called Life Cycle Sustainability Assessment (LCSA).

Ljungberg (2005) concludes that a price tag must be determined for every component of a product in every stage of its life cycle but this is a very complex and locally specific matter that evades quantified calculations. Economic viability is one way to influence suppliers to offer improved materials through range and choice, sources of supply, effects of increased transport costs, local alternatives, or creative use of current industrial waste product (e.g. using shredded tyres as safety surfacing in playgrounds).

Life Cycle thinking is about being aware of the consequences of material choice and use by considering the impacts of choice and use at the specification stage, during use and deconstruction. The designer can create adaptive strategies at each stage to reduce overall impacts on the environment.

Chapter 3
Method

3.1 Introduction

Processes used to manufacture products overseas and in New Zealand were considered to better understand exactly where carbon dioxide emissions come from and where energy is used, e.g. the chemistry of producing cement from limestone and other ingredients. The possibility of conducting a series of specific LCAs on typical landscape materials in New Zealand was investigated, but was found to require specialised skill, and significant data collection, financial and analytical resources which were not available. Existing data on building materials was therefore chosen for this study, based upon work completed by Alcorn (2003). Where possible, full process LCA data produced in New Zealand for local industry was used, but where that was not available, overseas data was adjusted to fit New Zealand conditions (e.g. with reference to electricity generation emissions).

This basic information was then assembled in a way that provided a useful comparison for landscape architects, through 'functional units' (Sustainability Aotearoa New Zealand, 2009).

3.2 Study parameters

The concept of 'functional units' allows the comparison of diverse materials as they are applied in landscape projects, rather than using a conventional unit such as kilogram or cubic metre. For example, instead of comparing the 'costs' of a cubic metre of concrete with a cubic metre of timber, the functional unit method could consider the total cost of equal *areas* of timber decking and concrete paving, including all structural and subsurface requirements. From a landscape architectural perspective, this provides a useful method of comparison.

Hard landscape materials used in landscape architecture commonly fall into three structural groups: horizontal surfaces, vertical surfaces, and free-standing elements. In this study, the 'functional unit' chosen was for horizontal surfaces, as a plane of ten square metres in a domestic-scale landscape. Three impact categories were studied: CO_2 emissions, energy consumption and cost. Each has quite a different impact: CO_2 on atmospheric global warming, hence on the environment; energy use is responsible for resource depletion and climate change; financial costs have a wide range of social and cultural consequences, and in design a higher cost material can represent an opportunity cost in terms of other aspects of sustainability that could otherwise have been included in a project. It is beyond the scope of this study to identify which impact category is more significant in terms of the broader implications of sustainable change, but understanding some of the implications of materials choice will contribute to that debate.

The study of wider economic impacts and the use of economic principles to facilitate change is also beyond the scope of this study. However, they are likely to be valuable contributors to encouraging designers and specifiers to consider modifying their materials specification, and thereby reducing the overall environmental impact of implemented projects. Commonly used materials were identified and summarised in Table 2 in Chapter 4.

3.2.1 The process

A free-standing $10m^2$ area of each of the five materials considered in detail in this study was designed and drawn, including any foundation requirements. The amount of material required to build each surface, including any required sub-structure or foundation, was calculated. Three types of 'cost' (CO_2, embodied energy, and financial cost) were then calculated for each of the five surfaces. Chapter 4 summarises the findings, and sketches of each surface with a materials summary are provided in Appendix 1.

Chapter 4
Findings

4.1 Common landscape materials

The landscape materials commonly considered in the literature were found to fall readily into eight key categories noted below in Table 2, with examples of how each might be used also listed.

Table 2
Common Landscape Materials

Material	Examples of use
Concrete	pre-cast paving units; in-situ paving or walls; retaining structures; free standing structures; thin surface plaster
Timber	decking surfaces; structural beams; fencing components; retaining walls - pole, crib, beam; built structures
Metals	**Ferrous** - corten; stainless steels; mild steel (250MPa) - sheet, RHS, tube, rod, flat **Non-ferrous** - brass; lead; zinc; copper - sheet, RHS, tube, rod, flat
Ceramic	brick; tile - mosaic, small and large units
Stone	various sizes of pebble or stone up to boulder; various sizes of crushed aggregate; mixes in different proportions and colours, includes asphaltic concrete (mixed with bituminous compounds)
Plastics	enormous range of product including polycarbonate, polypropylene, butyl rubber, fibreglass - vast range of forms and colours
Glass	range of outdoor forms for surfaces, lighting, barriers
Artisan	‘early’ building materials including mud-brick, straw bale, bamboo

Although this study could only consider a very small proportion of that range, the methods established to prepare comparative data could easily be applied to a wider range of materials. A detailed comparison of more materials and used in a wider range of applications could provide further choices for designers, and therefore help to engage more members of the profession in the consideration of materials specification.

4.2 Material comparisons

The five commonly used materials selected for comparison in this study were: timber, steel, concrete, aggregate, and asphaltic concrete. Three impact categories were chosen to assess the cost of material choice as a functional unit, based on availability of New Zealand data: CO_2 emissions, energy and financial cost.

Table 3 contains data from Alcorn (2003) that has been used to generate the comparisons in Figures 1 to 5:

Table 3
Data to calculate measures for each material functional unit

	Timber	Aggregate	Asphalt	Steel	Concrete
kg of CO_2 per m^3	-696.000	2.400	22.700	9749.000	282.000
kg of CO_2 per kg	-1.657	0.002	0.015	1.242	0.120
Energy per m^3	1252.000	46.700	335.000	245757.000	2242.000
Energy per kg	3.000	0.030	0.200	31.300	1.000

Figure 1 shows the amount of CO_2 emitted to manufacture each material, measured by kilogram. Steel makes the greatest contribution to increasing the CO_2 levels in the atmosphere, over ten times the contribution made by producing concrete which is the next highest emitter. Asphalt and aggregate are at a much lower level of contribution, while it is clear that the production of timber makes a significant contribution to reducing CO_2 levels.

Figure 1
Carbon Dioxide Emissions per kg of Material

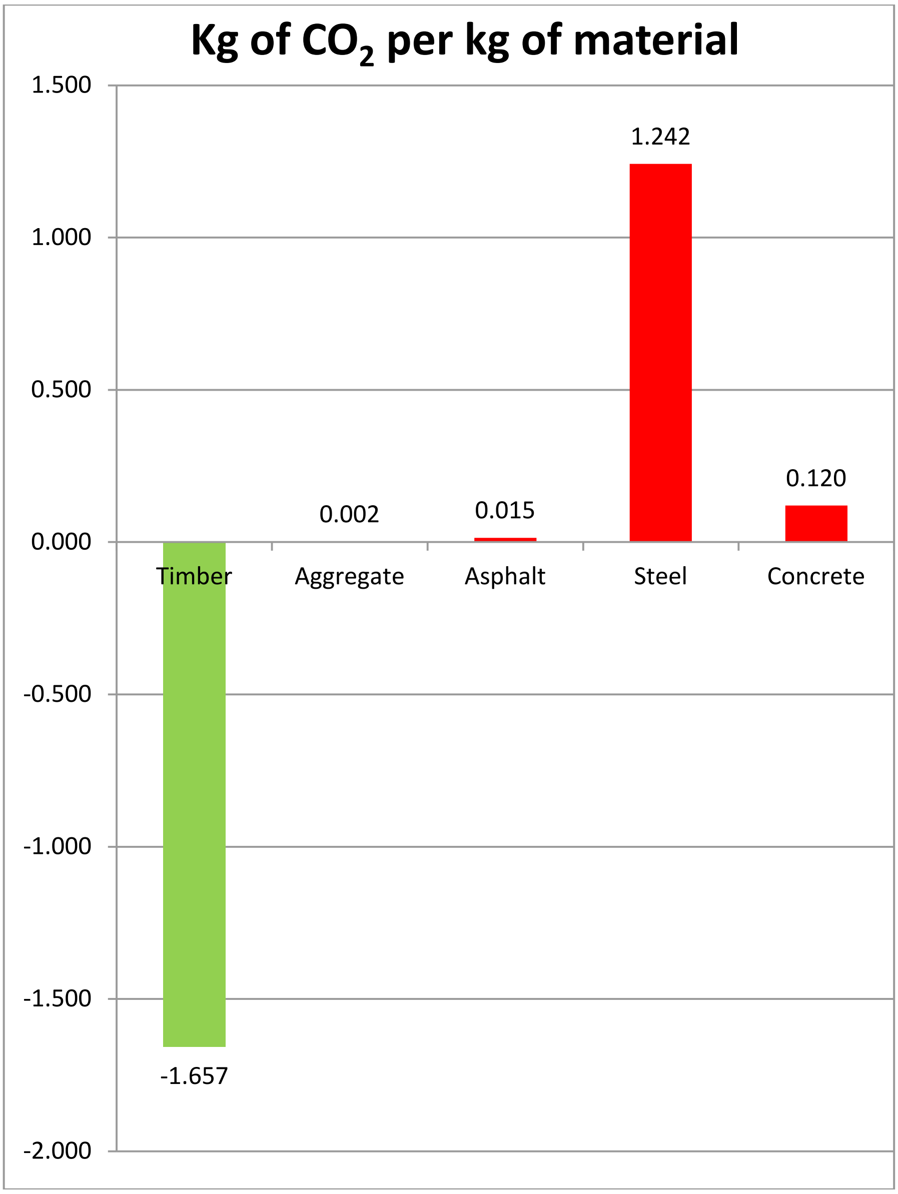
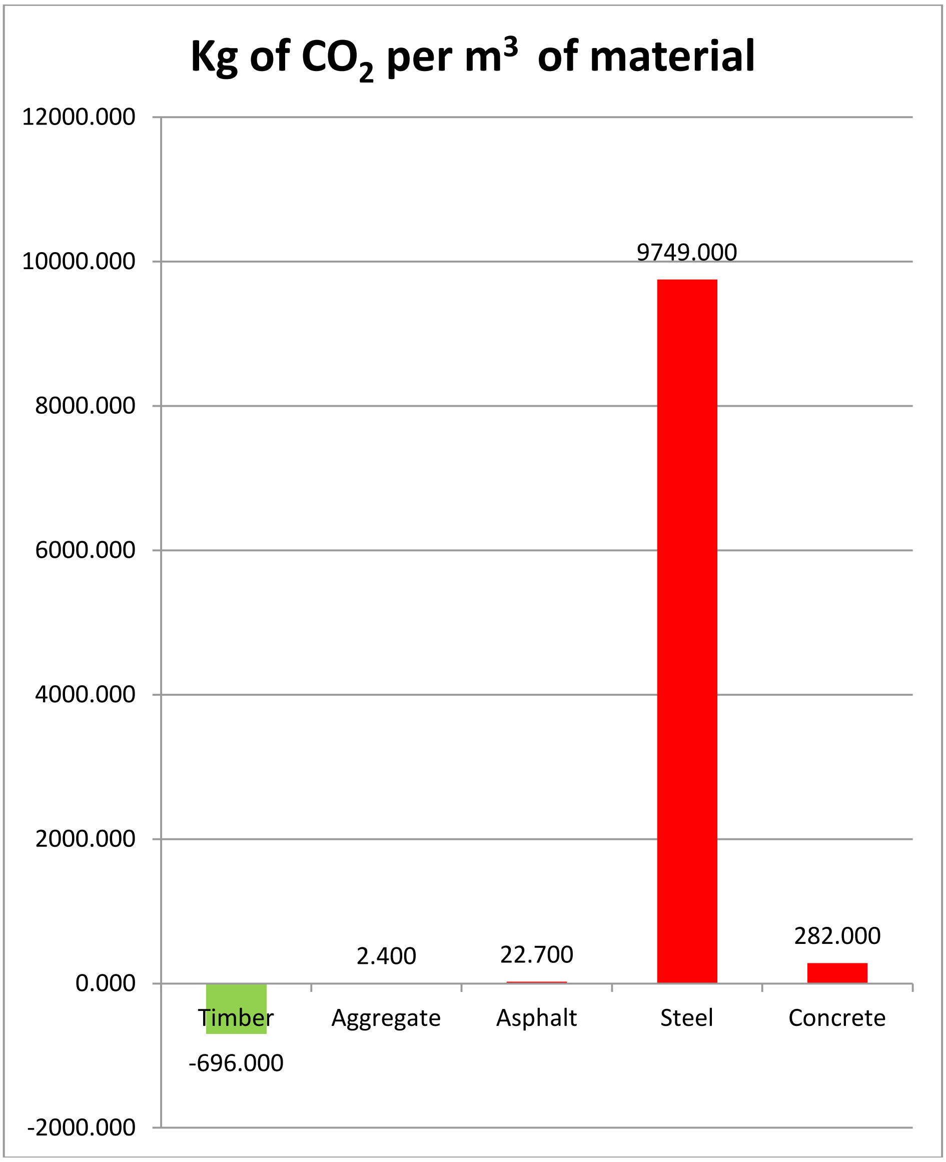


Figure 2 shows the same data as Figure 1, but this time measured by cubic metre of material. Steel is again the greatest contributor of CO_2 to the atmosphere, more than 30 times greater than the contribution made by concrete, again the next highest emitter. This is not surprising, given the difference in mass of each material, but it does highlight the significance of the proportion of steel content in any implemented project. Asphalt and aggregate are much lower than steel or concrete, and again, timber reduces atmospheric CO_2, although by a proportionally smaller amount given the lower mass of timber.

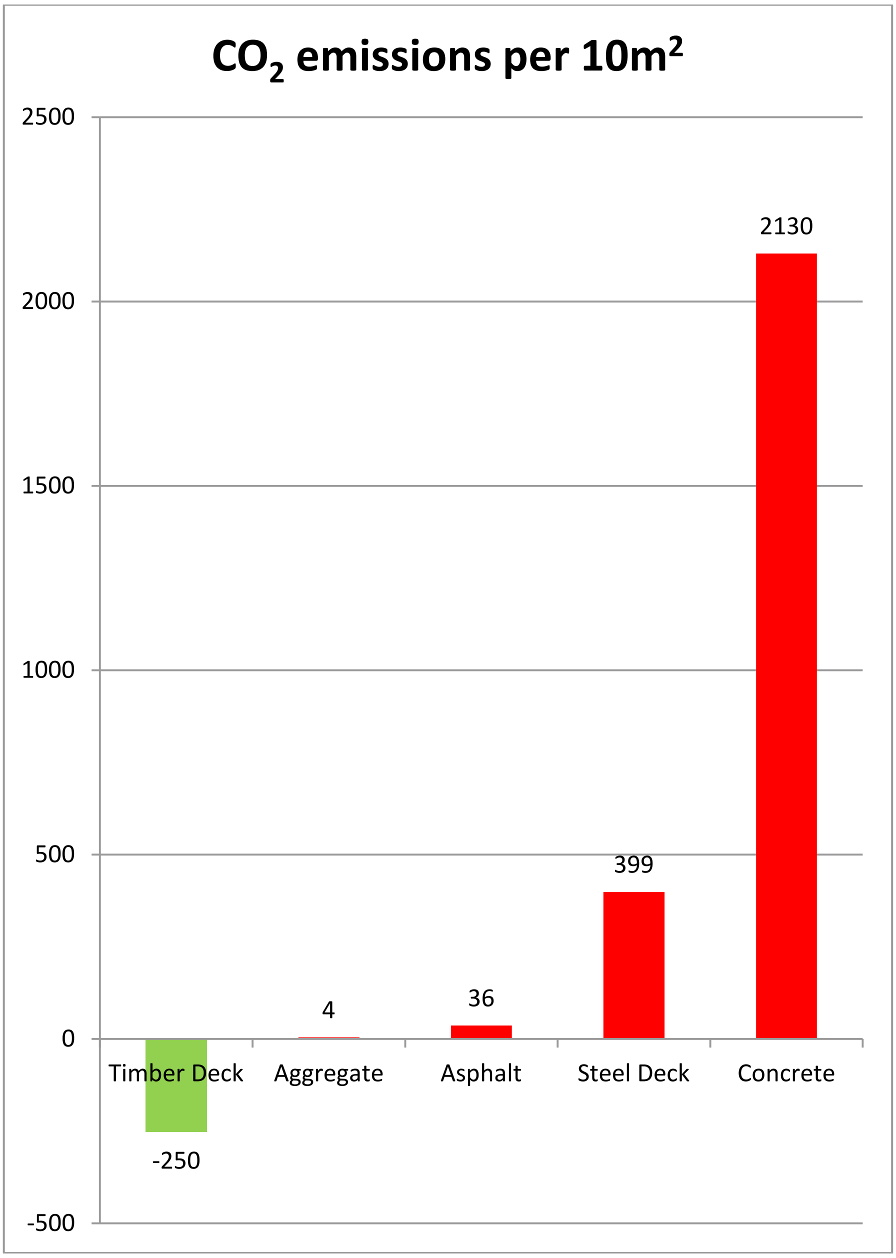
Even though these two figures are showing the same information about CO_2 emissions, the differences between materials can be seen to be exaggerated or diminished depending upon which measure (mass or volume) is chosen. This is one of the reasons suggested by LCA systems to use a 'functional unit' when seeking to compare the impacts of different materials on, for example, atmospheric CO_2 levels.

Figure 2
Carbon Dioxide Emissions per Cubic Metre of Material



The results from Figures 1 and 2 become really interesting when we compare each material as a functional unit (see Appendix 1 for the design of each functional unit). Referring to Figure 3 and looking at CO_2 emissions, a concrete slab becomes the greatest CO_2 emitter, more than five times higher than a steel deck, the next highest (see 5.5 for information on concrete's sequestration potential). Asphalt and aggregate surfaces are responsible for far fewer emissions of CO_2 than either concrete or steel surfaces, while a timber deck continues to be responsible for a net reduction in CO_2 emissions. This net reduction is less than timber on its own, as expected, because there are excavation and concrete 'costs' for the foundations included in the calculations for the deck.

Figure 3
Carbon Dioxide Emissions per 10m² Surface



The embodied energy calculations of the functional units in Figure 4 show a similar trend. The steel and concrete surfaces contain much more embodied energy than timber or asphalt surfaces, which themselves contain more embodied energy than aggregate surfaces.

Figure 4
Energy Cost per 10m^2 Surface

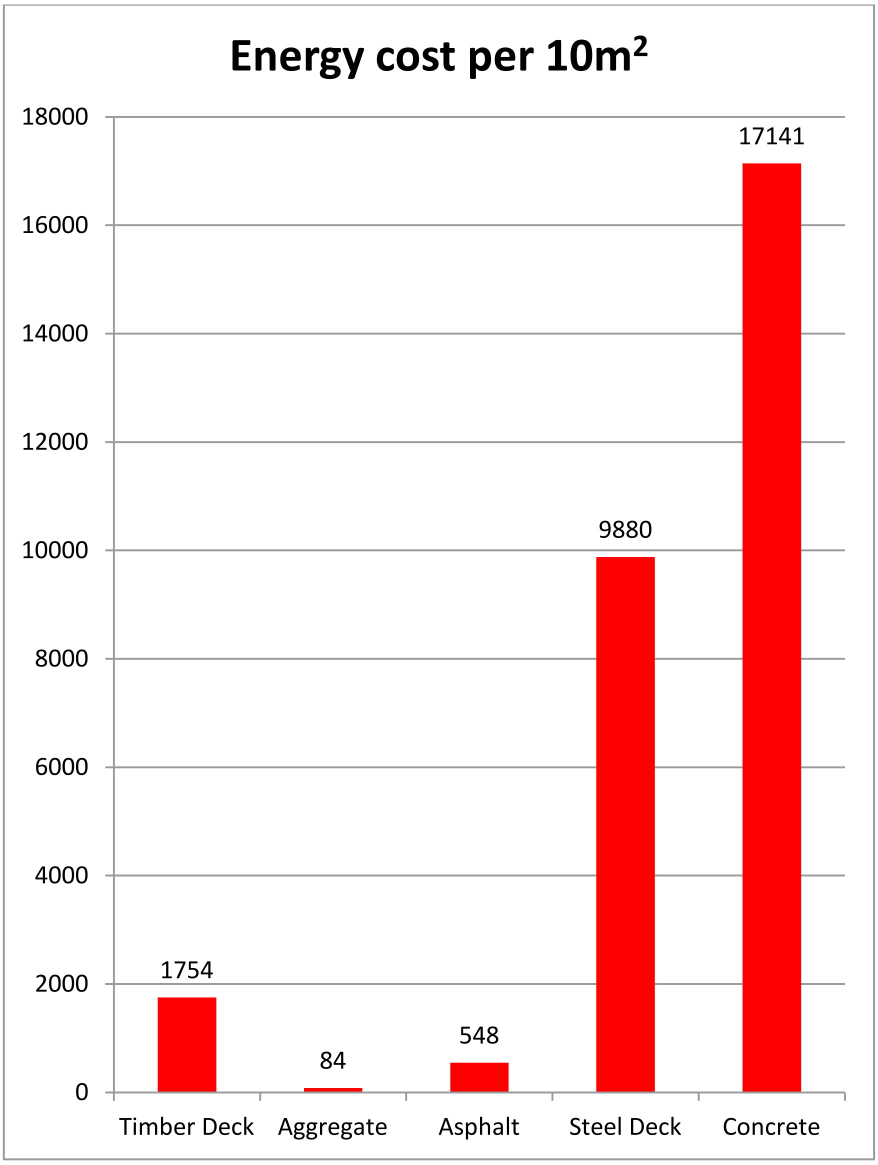
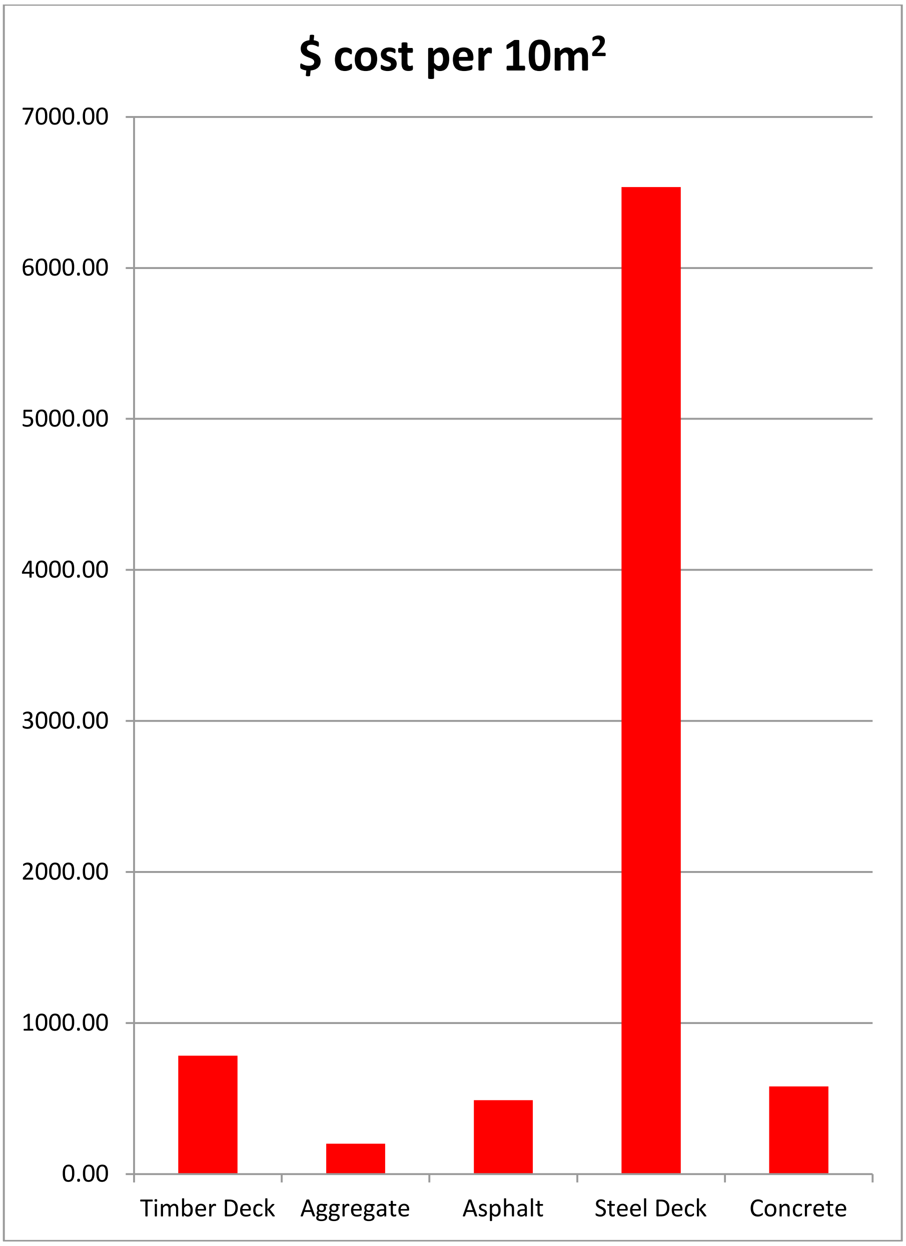


Figure 5 refers to financial cost, where there is far less variation between four of the different surfaces. Steel is the most expensive, about ten times the cost of alternative surface materials. Aggregate surfaces are the cheapest, about half the cost of concrete, asphalt or timber.

Figure 5
Dollar Cost per $10m^2$ Surface



Overall, steel and concrete are consistently at the top of each of these impact measures, while timber's ability to sequester CO_2 keeps it generally near or at the bottom of the measures of impact. In the three measures that particularly looked at CO_2 (per kg, per m^3 and per functional unit of $10m^2$) the charts show that the use of timber can actually help to reduce the overall amount of CO_2 created by the materials used in implementing a landscape project. Aggregate is the only material that is consistently low throughout all three measures of impact: CO_2 production, embodied energy and financial cost.

The difficulty comes in trying to quantify the impact these factors have on sustainability: CO_2 production impacts on the environment, energy use is responsible for resource depletion and climate change among many other secondary impacts, while high dollar cost represents an opportunity cost against other sustainability actions and investments. It is not possible to confirm which impact category is more important without reference to a range of other factors, including those outside of project-based criteria, although the findings indicate the types of material that are more likely to have an adverse impact on the environment.

4.3 Materials in use

The impact a material will have when it is in use must also be considered. In the building construction industry this typically applies to the heating and maintenance of a building and how different materials and design choices influence the energy costs or other building costs throughout its expected lifetime. For the landscape, maintenance regimes, performance and use of materials are as varied as the designs that use them. Appendix 3 notes a range of possible installation, use and maintenance activities for each of the $10m^2$ examples, and the impact categories they may contribute to. No quantitative data could be found for this study on the size of emissions or specific impact each maintenance activity has, but Appendix 3 does illustrate a range of matters for designers to consider.

Chapter 5
Discussion

5.1 Introduction

The profession of Landscape Architecture is uniquely placed to not only reduce the overall CO_2 balance of projects through specification of vegetation, but also to minimise initial emission costs through a strategic design approach in regard to material specification and maintenance requirements. The study found a great deal of information on the cement and concrete industries, some on steel but little on other materials such as timber or stone. However, there was sufficient information for this study to establish the key parameters which would enable a valid comparison of the contribution of different materials to help meet sustainability targets or outcomes.

Much of the published research considers the contribution of materials *manufacture* to environmental damage or climate change. This is only part of the consideration of a material's sustainability, and omits construction, use and decommissioning/recycling costs. However a full LCA 'cradle to grave' assessment is highly complex, as the range of applications for which each material can be used, and the range of design responses available, is too varied to enable meaningful comparative figures for individual material components to be simply established. This type of comparison requires a specific analysis of each application.

The approach used in this study was to analyse differences between the materials using a standardised point of reference, in the form of the materials needed for a $10m^2$ functional unit. The analysis shows that steel and concrete consistently have the highest impact measures, while timber generally has the lowest of the five materials considered. Possible construction and maintenance activities and the impact categories to which they may contribute were also considered for each of the $10m^2$ examples, but were not quantified (see Appendices 3 and 4). The examples do, however, illustrate the range of matters designers need to consider.

In addition to the core findings regarding material 'cost', the study also aimed to support the continuation of a dialogue within the Landscape Architecture profession about its contribution to global warming. Such a dialogue would aid the development of a more critical foundation for sustainable design thinking. The following discussion explores the ways in which the information derived from the comparative analysis could be used by landscape architects to better inform their decision-making processes in regard to specification of materials and techniques.

5.2 Implications for professional practice

A comparison of the relative severity of potential impacts from material or processes options is complex, but this study has indicated some initial approaches. These include an awareness of differences in potential impacts from the use of different materials, and the consideration of offsets through carbon or greenhouse gas sequestration. Developing a further refinement of the design process followed by most landscape architects would also be a useful contribution, i.e. rethink (problem + solution), reduce, restore, reuse and recycle. Such a sequence, highlighting recycling as only the fifth option to consider rather than the first, would provide an opportunity for a change in approach by landscape architects, supported by informed materials choice. An obligation to consider the consequences of choice in landscape architecture is an ethical responsibility of all practitioners (NZILA, 2010a).

Regional and local authorities may eventually require all who propose landscape or land use change to provide an estimate of the carbon-cost or holistic environmental cost of their projects. Those projects which appear to have a high 'cost' may need to demonstrate whether those costs are necessary, and if so, how those costs could be reduced or mitigated through other measures such as carbon offsets through the emissions trading scheme, forestry or re-vegetation schemes, or the perceived benefit of the change to meet broader social or economic goals. In any event, eventually all costs from projects associated with landscape change will need to be minimised.

An increasing awareness of the importance of sustainable design options is also evident in the changing focus of the NZILA biennial design awards sustainability category, which now includes the carbon impact of a design as part of the judging criteria. There are also calls from practitioners for more information and guidance through decision-making processes for material choice. At a broader level, awareness is increasing about the need to fully scope sustainable solutions in terms of their economic, social, cultural and biophysical impacts, not just their contribution to reduced carbon or embodied energy footprints. LCA values and material environmental profiles have become of increasing interest to designers and specifiers.

A simple checklist may be sufficient for many landscape architects, to at least increase their awareness about options for choice, but the limitations of such a checklist will quickly become apparent. Variables such as size of project, location of project, product source and processing, anticipated life-span and level and types of use, durability, carbon sequestration through design elements such as planting (but also see 5.5), availability of material, financial cost, and economic sustainability will all have an influence on final design and specification choices. Weighting the relative importance of such impacts should depend upon the potential contribution of the project to global concerns.

A more complex decision-tree or chart that accommodates such variables is the logical next step, but it would have to be flexible enough to accommodate dynamic changes such as fuel cost and availability, changing transport options globally and locally, the development of new materials or processes, and demand for particular products. For example, the best material for a particular use may not be an economic option for a small scale project, but could be the obvious choice where economies of scale make it effective. Not just cost, but machinery required to install the material may also have an impact on overall suitability ratings.

A better solution is likely to be a web-based interactive intelligent decision support system that is dynamic and regularly updated at both global and regional scales. The key point is that increased availability of information to all involved in landscape change is likely to have a longer term benefit. The more knowledge we have about consequences, the more creative the solutions may be to avoid negative impacts and increase positive contributions. Such a tool could provide an ability to continue evaluating the success of a design through monitoring implementation processes, using a post-occupancy evaluation approach. For example, during project implementation a record of types of machinery used, all fuel consumed, boundary transfers of all resources and pollutants, and labour-hours could be kept. This would create a collection of accurate data to use in future assessments.

One output of such a system could be in the form of a matrix that could be printed onto a master plan like a plant list, to show visually the carbon-heavy components of a design. A representation of the total carbon dioxide output minus the carbon sinks to identify the net carbon dioxide emissions and its possible impacts on the local environment, could be a useful additional tool.

Publicity is also a powerful way to positively reinforce the motivation to change behaviour. Articles that highlight holistic efforts in sustainable design plus meaningful sustainable design awards, rather than articles and awards which might be seen to promote aesthetics over environmental impacts, would make a significant contribution to positively reinforce behavioural change.

Perhaps a before and after image of a planned project could contribute to the feeling of making a difference, showing the impacts from typically used materials compared with the improvements from carefully selected materials. The immediate environmental benefits of particular choices could be highlighted, as well as cumulative benefits over the life of the project such as reduced maintenance requirements, and re-use of a higher proportion of the components.

Such a series of tools could easily be supported by case studies, hosted on the NZILA website, which would support motivation to change behaviours.

5.3 Design implications

Different projects will have different design requirements, with a balance to be found between economic, environmental and social imperatives. The design process must include an assessment of the sustainable goals for each project, actively investigating ways of minimising the use of resources, embodied energy or CO_2 emissions that will still meet the design objective. Each project will therefore exhibit a unique combination of factors that will suggest to the designer an ideal balance which will also allow the design objectives to be met.

This might mean, for example, that aggregate surfaces become more prevalent, but it does not mean that only aggregate surfacing will be seen in future. The significance of this study is that it highlights the consequences of material choice in a tangible way (although for a limited range of materials), thus validating consideration of choice as a valuable component of design thinking.

Choosing materials is important, but we cannot sequester all impacts; we need to design with sustainability in mind. If designers are encouraged to re-use existing materials or use other recyclable materials to further reduce negative impacts, it follows that we should also design components to be easily reused or recycled. “As an industry, we need to encourage research into new materials, manufacturing techniques, construction methods and management and maintenance practices; and to come up with a palette of options that have the lowest possible embodied energy factors, waste production and overall environmental impact.” (Pocock, 2007: p89)

The following list of examples illustrates suitable types of design and construction approach that explicitly consider potential for future use:

- Design modular components, so that they can be easily de-constructed and reused elsewhere;
- Avoid using composite materials that cannot be separated, e.g. plastic mixed with wood fibre, unless the whole composite is reusable;
- Keep timber in lengths as long as possible, with accurately recorded details of preservative levels if softwood;
- Use screws and bolts to join materials rather than rivets, nails or glue.

5.4 Innovation

There are some encouraging signs of innovation in the materials industry. For example, a partnership between Resene Paints, 3R Group and Firth Industries is currently trialling 'Paintcrete', where paint collected by Resene as part of its recycling initiatives is used as an additive to concrete used in block fill. “...the addition of randomly mixed, waterborne acrylic and latex paint to concrete, at the prescribed dose rates allows the cement content to be reduced, lowering both the carbon footprint and the embodied energy of the concrete.” (Resene news, 2009: p1)

The Paintcrete partnership is also investigating the use of crushed glass in concrete ('Glasscrete'), to replace some of the aggregate content. Trials are currently underway (Resene news 4/10) to overcome the alkali-silica reaction where alkali-rich cement paste reacts with silica-rich glass, causing cracking. Once this problem has been solved, crushed glass that often ends up in landfill can make a valuable contribution to reducing the amount of new material that needs to be extracted in the manufacture of concrete.

Dulux paints have joined a similar scheme with 3R, where recovered paint will be available to community groups for graffiti covering, as well as for other uses such as PaintCrete and GlassCrete.

“Volunteer product stewardship programmes like this and Resene PaintWise are an excellent way for manufacturers to take responsibility for managing the environmental impacts of products through their lifecycle. It’s a ‘cradle to cradle’ methodology which shows a proactive and sustainable response to waste minimisation. It also reflects the growing demand for environmental responsibility amongst consumers, businesses and government alike.” (Resene 2010: p2)

A further example of potential innovation is the specification of high-strength concrete which contains a by-product from steel manufacturing to partly replace Portland Cement. This could enable the use of a smaller volume of concrete to achieve the same structural requirements.

It is known that concrete can also sequester CO_2 through carbonation, although a range of factors including pore size, moisture content and the use of mineral admixtures will have an influence on how effective that process is (Chun et al, 2007).

Other research is looking at how to minimise CO_2 produced from the manufacture of cement by investigating the replacement of calcium atoms with magnesium atoms (MIT, 2007). They found that the strength of concrete from the cement paste does not accrue from the calcium itself, but in the organisation of the atoms as packed nanoparticles. If it is possible to use magnesium, and if it does not require the same high temperatures used to manufacture cement, then global CO_2 emissions could be reduced by a significant amount.

Chapter 6
Conclusions

This study examined one aspect of the carbon footprint of Landscape Architecture, illustrating the ways in which hard material specification has implications for climate change. Of the five materials examined (timber, steel, concrete, aggregate and asphaltic concrete), timber was the 'least cost' material with regard to CO_2 emissions, while aggregate and asphaltic concrete were 'least cost' with regard to embodied energy and dollars. This study did not set out to provide absolute environmental values for each material, or exact carbon values for each situation in which the materials are used. However the results contribute to establishing a baseline or general understanding about where certain landscape materials may sit on an environmental profile continuum, and demonstrate how, through appropriate material choice, the profession of landscape architecture can contribute to an overall global reduction of CO_2 emissions.

It is important to note that even though a reduction in CO_2 is possible, it is unlikely in the near future that we can create carbon-neutral urban landscapes, or landscapes without negative environmental impacts, whether the impacts are from the initial choice of materials or ongoing maintenance requirements. Nonetheless, consideration at the design and planning stage, careful choice of appropriate materials at the detailed specification stage and future-proofing designs to create enduring landscapes can all contribute to a reduction in the environmental costs of landscape construction. “If landscape architects and urban designers are empowered with the responsibility for the investment of carbon within communities and national landscapes, then this needs to be done wisely. We need to know how carbon is built into each of the four stages of a project with the aim to minimize [sic] and offset as much carbon as possible... As a priority we need to create ‘enduring landscapes’ in which the material landscape components stay in static form for a very long period of time making the most of the initial high carbon cost. This requires design and projects that will survive changing demographics, community growth, charges [sic] in fashion, and physical weathering.” (Pocock, 2007:p89)

The study has identified gaps in information and the types of knowledge that designers need in order to specify materials that improve outcomes for sustainability. A range of approaches can be taken such as developing simple or comprehensive tools, using case studies through the NZILA, raising awareness of CO_2 emissions by manufacturers, running best practice workshops etc. There is also a need for more material-specific research to identify the carbon profiles for a broader range of hard materials typically used in landscape applications in New Zealand.

Accurate data needs to be accessed direct from industry players in New Zealand, and ideally a full LCA conducted for materials specific to the local landscape industry. Although this study only considered a small proportion of commonly specified landscape materials, the methods established to prepare the comparative data could be applied to other materials. A detailed comparison of more materials and uses in a wider range of applications will provide further choices for designers. Examples of site-specific uses for which more information is needed include: bark or rubber mats used under playgrounds; weed mat, from woven plastic; and prefabricated site furniture.

Once a more comprehensive database has been completed, further steps can be taken to ensure that the landscape profession and industry make better and more informed environmental choices. This would prompt the materials industry to make sure that more environmentally friendly options were available to designers.

This study will be made available through a link on the NZILA website to support other best-practice documents. This will assist in raising the awareness of the contribution that landscape architects can make to reduce global CO_2 emissions, develop tools to assist their decision-making, and encourage further adoption of a socially, economically and environmentally-responsible ethic for all landscape practitioners as outlined in the draft NZILA Aotearoa-New Zealand Landscape Charter (NZILA, 2010b). The profession should continue to make places that endure for people, and ensure that designs can be implemented with a minimum cost to the environment.

If designers and specifiers are aware of the full costs of materials, including their source and their embodied energy components, then it is hoped that they will be more likely to investigate different product offerings, and consider research and development into improving the efficiency or performance of existing products. Knowledge of the dynamics of these broad issues should encourage designers to find ways to avoid potential negative impacts from poor material choices, mitigate such impacts by developing new ways to use products, or use different products for a particular purpose.

It is important to note that from a designer's perspective, consideration of the environmental impact of material selection is currently still a choice and not an obligation; it is an ethical issue not a compulsory requirement. Ethical issues are potentially more challenging however, in regard to changing behaviour. There is an significant role for the NZILA in promoting the importance of an ethical choice of materials as being a fundamental part of the role and responsibility of being a landscape architect in New Zealand.

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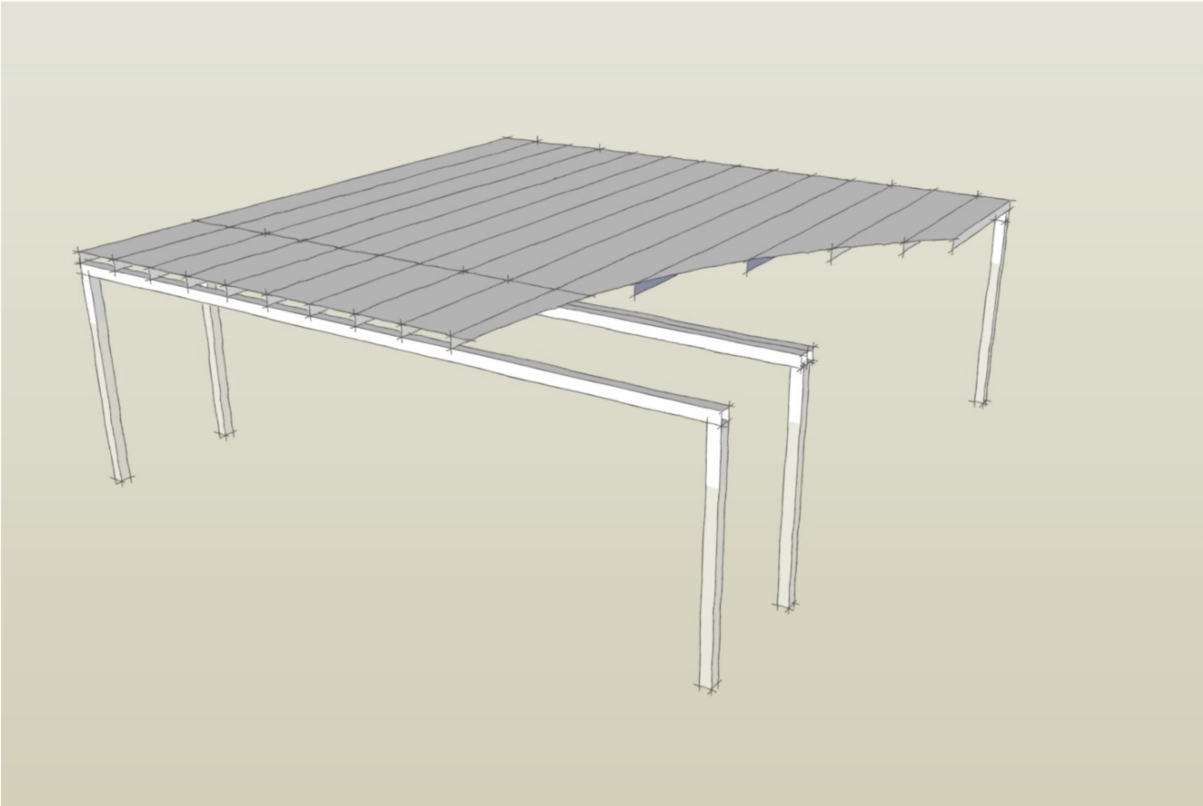
Appendix 1
Functional-unit surfaces

Figure 6
Timber Deck

Timber deck, with timber posts, bearers and joists; posts concreted in ground

Decking:	100 x 20mm dressed
Joists:	100 x 50mm RS
Bearers:	100 x 100mm RS
Posts:	700 x 140mm diameter in 300 x 300mm square hole, 400mm deep
Concrete:	17.5MPa

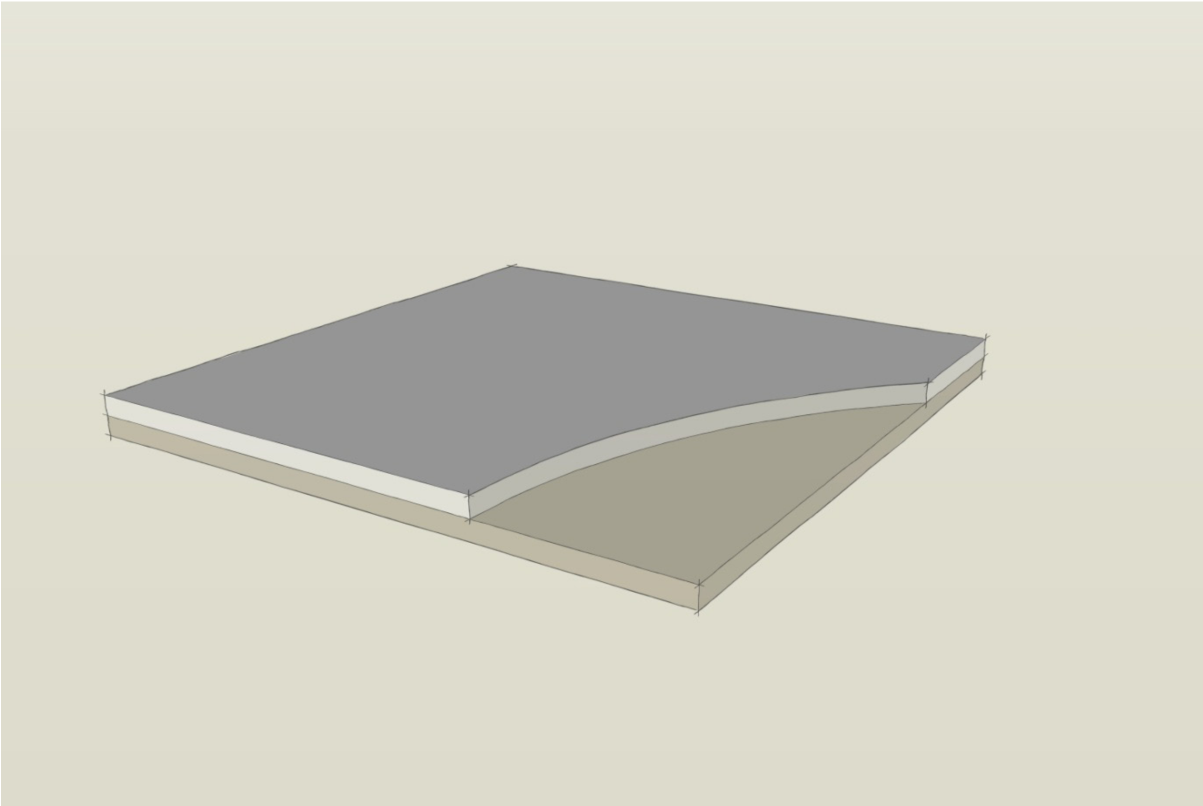
Figure 7
Steel deck



Steel plank deck, with rhs posts and joists; posts concreted in ground

Decking:	230 x 50 x 2mm Tilley's planks
Joists:	50 x 50 x 3mm galvanised RHS
Posts:	50 x 50 x 3mm galvanised RHS in 300 x 300mm square hole, 400mm deep
Concrete :	17.5MPa

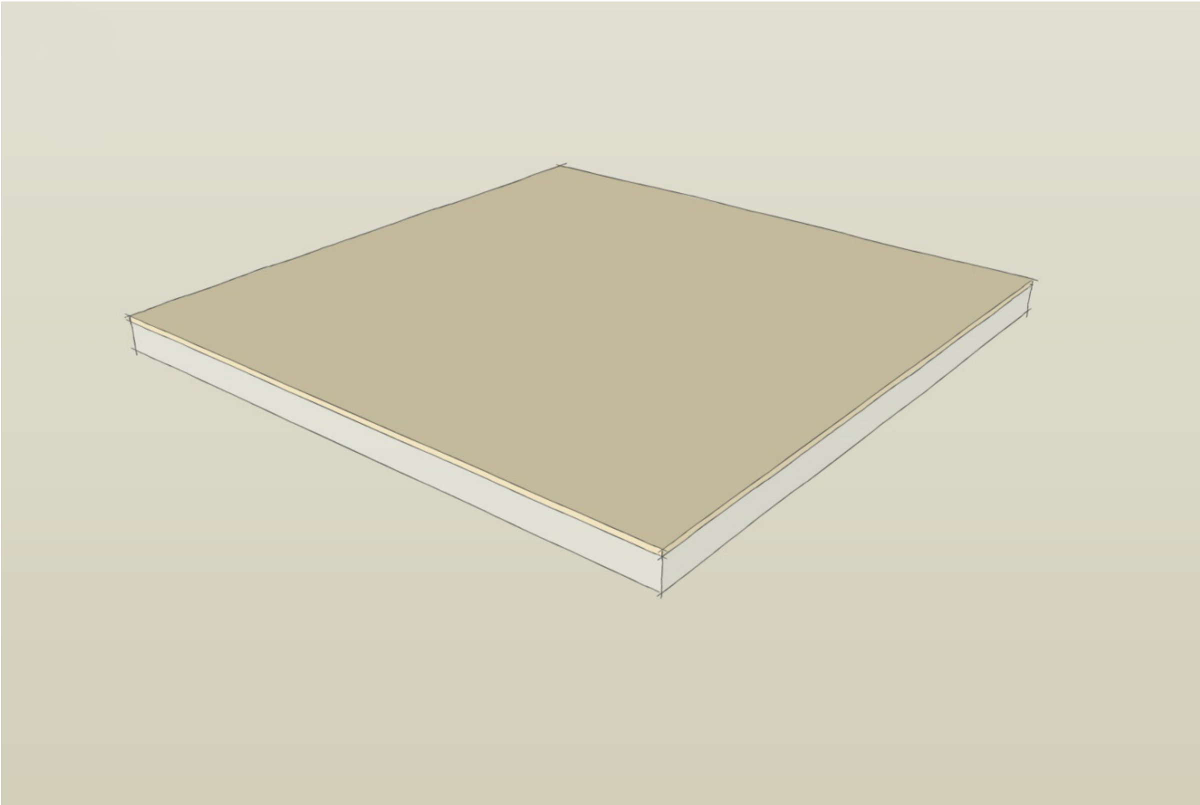
Figure 8
Concrete slab



Concrete slab, with base course

Excavation :	3160 x 3160 x 150mm removed and re-used on site
Slab :	3160 x 3160 x 75mm unreinforced 17.5MPa
Base course :	3160 x 3160 x 75mm compacted basecourse

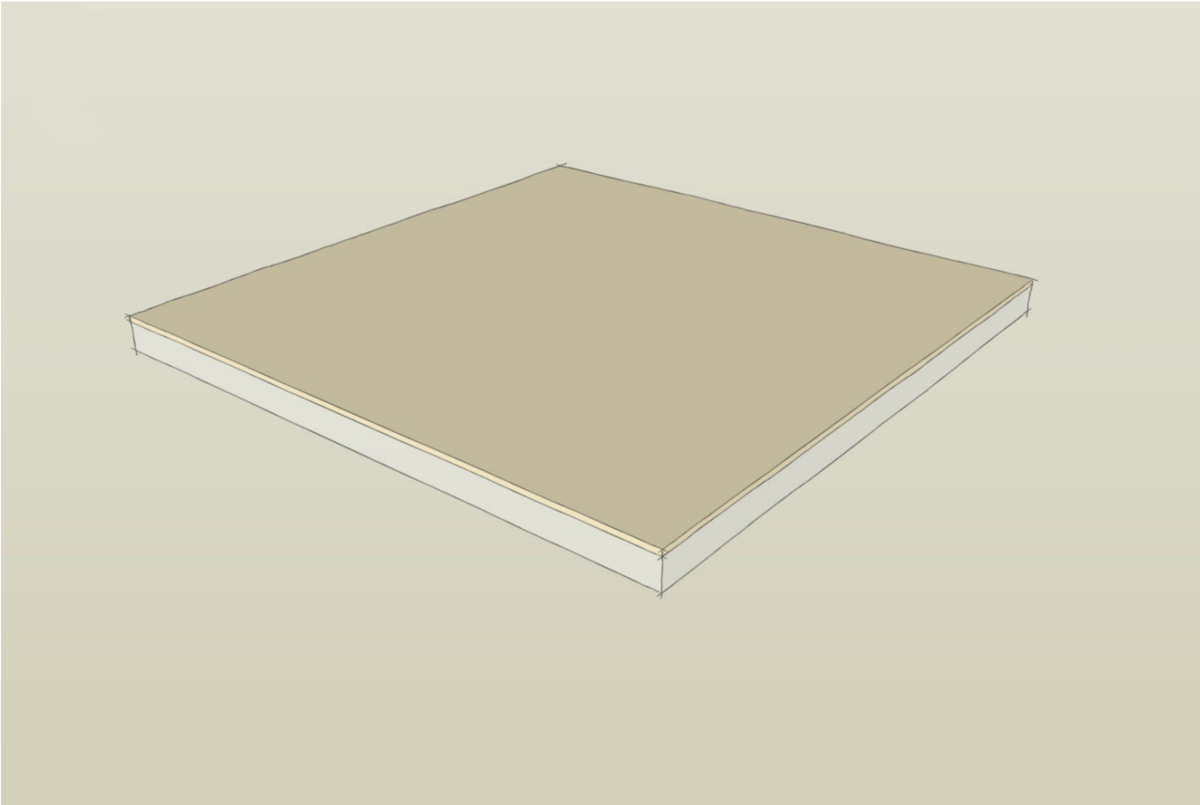
Figure 9
Aggregate surface



Aggregate surface, with base course

Excavation :	3160 x 3160 x 150mm removed and re-used on site
Wearing course:	3160 x 3160 x 30mm of 10-20mm crushed metal
Base course :	3160 x 3160 x 120mm compacted basecourse

Figure 10
Asphalt surface



Asphaltic concrete surface, with base course

Excavation :	3160 x 3160 x 150mm removed and re-used on site
Wearing course:	3160 x 3160 x 25mm of 8-10mm hotmix (no kerb)
Base course :	3160 x 3160 x 125mm compacted basecourse

Appendix 2
LCA variants

(http://en.wikipedia.org/wiki/Life_cycle_assessment)

A2.1 Cradle-to-grave

Cradle-to-grave is a full Life Cycle Assessment from manufacture ('cradle') to use and disposal ('grave'). For example, trees produce paper, which can be recycled into low-energy production cellulose (fibre paper) insulation used as an energy-saving device in the ceiling of a home for 40 years, saving 2,000 times the fossil-fuel energy used in the production of the insulatio. After 40 years the cellulose fibres are replaced and the old fibres are disposed of, possibly incinerated. All inputs and outputs are considered for all the phases of the life cycle...

A2.2 Cradle-to-gate

Cradle-to-gate is an assessment of a partial product life cycle from manufacture ('cradle') to the factory gate (i.e., before it is transported to the consumer). The use phase and disposal phase of the product are usually omitted. Cradle-to-gate assessments are sometimes the basis for environmental product declarations (EPD).

A2.3 Cradle to cradle

Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. From the recycling process originate new, identical products (e.g., glass bottles from collected glass bottles), or different products (e.g., glass wool insulation from collected glass bottles).

A2.4 Gate-to-gate

Gate-to-Gate is a partial LCA looking at only one value-added process in the entire production chain.

A2.5 Well-to-wheel

Well-to-wheel is the specific LCA of the efficiency of fuels used for road transportation. The analysis is often broken down into stages such as "well-to-station" and "station-to-wheel, or "well-to-tank" and "tank-to-wheel".

Appendix 3
Potential impact after supply

Timber deck (life expectancy: 30-50 years)	Possible impacts
Installation	
delivery of materials	machinery, emissions from fuel use
foundation concrete	as for concrete
bolts, nuts, washers, nails, z-nails, galvanised brackets, nail-plates	as for steel, plus use of Zn in galvanising
sawing timber	machinery to cut or drill timber - electricity use
preservative for cut-ends of softwood	human health, leaching toxins to soil, atmosphere or water
sawdust	human health
timber off cuts	solid waste
noise	social nuisance
stains for timber	human health, leaching toxins to soil, atmosphere or water
Use	
treated timber piles	leaching toxins to soil
Maintenance	
re-painting	VOC's, toxins to soil and water, human health
re-staining	VOC's, toxins to soil and water, human health
water blasting	resource depletion
replacing broken decking boards	financial cost

Aggregate (life expectancy: >100 years)	Possible impacts
Installation	
delivery of aggregate	machinery, emissions from fuel use
base course preparation	materials, machinery, emissions from fuel use
spreading and compacting	machinery, emissions from fuel use
edge restraints if needed: timber or concrete etc	materials use, machinery to construct
Use	
levelling	machinery, emissions from fuel use
Maintenance	
top-up level of aggregate	supply and installation costs
weed spray	toxins to soil, water and air. Human Health

Asphaltic concrete (life expectancy: 20-40 years)	Possible impacts
Installation	
delivery of asphaltic concrete	machinery, emissions from fuel use
laying asphaltic concrete	VOC emissions from hot material, emissions from fuel combustion by laying
Use	
surface wear	bituminous material enters water or soil
Maintenance	
surface coating on 15 year cycle	as for installation

Steel planks (life expectancy: dependent on surface treatment - could be >100 years)	Possible impacts
Installation	
delivery of materials	machinery, emissions from fuel use
bolts, nuts, washers, nails, z-nails, galvanised brackets, nail-plates	as for steel, plus use of Zn in galvanising
build supporting structure	materials use, machinery to construct
assembly of steel surface	materials use, machinery to construct
noise	social nuisance
Use	
noise	social nuisance
reflecting sunlight	human health
Maintenance	
re-paint or re-surface	VOC's, toxins to soil and water, human
clean off dust and grime	VOC's, toxins to soil and water, human health

Concrete (life expectancy: >100 years)	Possible impacts
Installation	
delivery by concrete mixer	emissions from fuel combustion
water used to clean equipment	pollution of water
boxing	material use
nails, bolts etc	as for steel, plus use of Zn in galvanising
vibrators, power floats	machinery, emissions from fuel use
water for curing concrete	high pH run-off to soil or waterways
excess concrete mixed	solid waste

Use	
thermal heat transfer	heat island effect (social & ecology
reflection of sunlight	human health and social nuisance
Maintenance	
water blasting	resource depletion
moss treatments	toxins to soil and water, human health
polish surface	machinery use, and water-borne particles
re-paint	VOC's, toxins to soil and water, human

Appendix 4
Life-cycle of concrete

A4.1 Introduction

The following brief description of the life of concrete from inception to decomposition includes impacts or emissions e.g. acidification potential and water pollution. For example the potential pH change in waterways caused by wash-water from concrete trucks has not been confirmed; it may or may not be an issue but until thorough LCA studies are conducted, the following are indicative impacts from concrete production and use.

Concrete is made from water, cement, and different-sized aggregate particles (including sand) in various proportions, and so each ingredient must be considered.

A4.2 Cement

Extraction of raw ingredients (limestone from quarries),
Preparation of limestone. Grinding up the rock

- Wet process used by Milburn plant – higher energy requirement but less dust emission.
- Dry process used by Golden Bay Cement plant.

Heating the ground rock to very high temperature to sinter the compounds and create the “clinker.” A rotating kiln or preheated tower is used depending on whether the wet or dry process was used in the preparation of ingredients. Various fuels such as oil, wood or coal are burned to heat the kiln. CO_2 is emitted from this combustion and from the calcination reaction: $CaO_3 \rightarrow CaO + CO_2$. One kg of CaO_3 when calcinated contributes 0.44kg of CO_2 to the air.

Clinker is cooled by forcing air into the kiln.

Clinker is ground by steel balls and heavy machinery powered by electricity either supplied by the grid or generated on site. Water is also used to cool machinery and clinker.

Gypsum and other additives to adjust the properties of the final product are added before or during the grinding stage. Internationally, these include by-products from other processes or other industries to amplify the cement such as fly ash, blast furnace slag, pozzolana etc. Some of these provide additional strength properties.

Dust is given an electric shock treatment to remove static and allow it to fall onto plates, reducing dust emissions and improving product loss.

A4.3 Aggregate and sand

Making concrete requires aggregate and sand. Most aggregate is extracted from our rivers or quarried. In New Zealand there is an abundance of aggregate from many rivers and in some cases, this removal of aggregate prevents pro-grading and therefore reduces the chances of flooding to adjacent land.

Extracting and processing of aggregate into different grades requires heavy machinery that burns fuel. The operation causes a lot of noise, produces dust and has the potential to disturb natural land forms. However, most of this normally happens close to the site of extraction, and away from human habitation. In some cases, the operations are followed up with remedial restoration.

A4.4 Transport

Cement powder is then transported by truck or ship to one of 40 different concrete batching plants around New Zealand.

Cement is packaged and may have other substances mixed-in like furnace slag or plastic fibres for sale at local retailers, or sold in bulk to paver manufacturers like Firth or Urban Paving.

A4.5 Batching plants

Concrete plants that mix the cement, water, sand and aggregate just before it is required for something like e.g. a footpath or retaining wall foundation.

Concrete trucks and batching plants need washing to be kept clean, which uses large volumes of water. Because of concerns about potential pollution of adjacent waterways, many plants recycle 100% of their wash water for further washing.

A4.6 Use

Poured concrete needs vibration to ensure no pockets of air are trapped, which reduce the integrity of the final product. This vibration uses energy, creates noise pollution and can lead to blood circulation problems for people operating the vibration machinery.

A4.7 Maintenance.

Concrete requires very little in the way of maintenance. Depending on its location and use, concrete could require any of the following:

- Sweeping of debris out of corners (a design issue, and not just for concrete)
- Water blasting
- Pesticides to kill moss, lichen and weeds
- Painting

A4.8 Reuse options

Obsolete concrete can be crushed and used as aggregate in new concrete. There are some drawbacks associated with using crushed old concrete in place of aggregate such as higher shrinkage due to the concrete aggregate absorbing more water than rock aggregate would. Such problems are quickly being resolved with new technologies and additional ingredients.

Steel reinforcing embedded in the concrete can be separated and recycled. In New Zealand 90% of steel reinforcing comes from recycled steel.

Objects can also be designed with concrete blocks or units in such a way that they can be dismantled and reused in other projects, much like Lego pieces.

Appendix 5
ISO Impact categories and indicators

(Scientific Applications International Corporation, 2006)

Impact indicators are typically characterized using the following equation:

Inventory Data × Characterization Factor = Impact Indicators

For example, all green house gases can be expressed in terms of CO_2 equivalents by multiplying the relevant Life Cycle Inventory results by a CO_2 characterisation factor and then combining the resulting impact indicators to provide an overall indicator of global warming potential.

Characterisation can put these different quantities of chemicals on an equal scale to determine the amount of impact each one has on global warming. The calculations show that ten kilograms of methane have a larger impact on global warming than twenty kilograms of chloroform.

Figure 11
Characterisation Factors

Global Impacts	
Global Warming	Global Warming Potential: Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Ozone Depletion	Ozone Depletion Potential: Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Resource Depletion	Resource Depletion Potential: Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Regional Impacts	
Acidification	Acidification Potential: Converts LCI data to hydrogen ion (H+) equivalents.
Local Impacts	
Photochemical Smog	Photochemical Oxidant Creation Potential: Converts LCI data to ethane (C_2H_6) equivalents.
Human Health	LC50. Converts LC50 data to equivalents; uses multi-media modelling, exposure pathways.
Terrestrial Toxicity	LC50. Converts LC50 data to equivalents; uses multi-media modelling, exposure pathways.
Aquatic Toxicity	LC50. Converts LC50 data to equivalents; uses multi-media modelling, exposure pathways.
Eutrophication	Eutrophication Potential: Converts LCI data to phosphate (PO_4) equivalents.
Land Use	Land Availability: Converts mass of solid waste into volume using an estimated density.