



# **Integrating Sustainability into the Engineering Design process using the Global Reporting Initiative Indicators**

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**Faculty of Engineering & Natural Sciences  
University of Iceland  
2014**



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60 ECTS thesis submitted in partial fulfilment of a  
*Magister Scientiarum* degree in Mechanical Engineering

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# Abstract

On a strategic and operational level there is significant evidence of the integration of sustainability into the business environment, however studies have shown that the majority of major organisations do not include the risk and/or opportunities of sustainability in the design and detailed engineering phase of their capital projects.

Much of the discussion on sustainability in capital project management and engineering has centred on the feasibility or pre-project phases; however decisions taken during the design phase have a significant influence on the final outcome of the project, and tools or working methods must be provided to engineers and project managers to facilitate decisions during this phase of a project.

In this thesis a new working method for decision making during the engineering design phase will be developed based on the internationally recognized Global Reporting Index sustainability indicators and Project Management Body of Knowledge (PMBOK) process. The goal of the work is to determine which indicators of sustainability are most relevant to the design phase of an engineering project and then to integrate those indicators into the PMBOK project management process.

A test case is used to determine the suitability and usefulness of the proposed method, and the conclusion is that the method proposed can be used by engineers to analyse their design and inform decision makers with a focus on sustainability of the project.

Key Words: Sustainability, Engineering Design, Project Management

# Útdráttur

Rannsóknir hafa sýnt að flest stærri fyrirtæki taka ekki til greina áhættu og/eða tækifæri til sjálfbærni í hönnunar og verkfræði áfangum í fjármögnunarverkefnum (e. Capital projects). Það virðist þó vera sem að þau samþætti frekar sjálfbærni í rekstrarumhverfinu.

Umfjöllun um sjálfbærni í hönnun hefur aðalega snúist um þann tímapunkti þegar það er verið að skoða hagkvæmni verkefnisins (e. feasibility study) eða í áföngum fyrir verkefnið þó ákvarðanir sem teknar eru á hönnunarstigi hafi veruleg áhrif á endanlega útkomu verkefnisins. Það verður að gefa verkefnastjórum og verkfræðingum þau töl, ferla og aðferðir sem til þarf til þess að geta tekið ákvörðun um sjálfbærni í hönnunar áfanganum.

Í þessari ritgerð er búið að búa til nýja vinnuaðferð til þess að taka ákvörðun í verkfræði hönnunar áfanganum (e. Engineering design phase) sem var byggður á alþjóðlegu ferla og sjálfbærni stöðlunum Global Reporting Index sustainability indicator og Project Management Body of Knowledge (PMBOK).

Markmið verkefnisins er að ákveða hvaða þættir um sjálfbærni eru mest viðeigandi í verkfræði hönnunar áfanga (e. Engineering design phase) verkefnisins og síðan að samþætta það í PMBOK verkefnastjórn ferli.

Tekið er fyrir dæmi til þess að ákvarða hæfi og notagildi fyrirhugaða aðferðar, niðurstaðan er sú að hægt er að nota aðferðina af verkfræðingum til að greina hönnun þeirra og taka ákvörðun um áherslur á sjálfbærni verkefnisins.

Lykilhugtök : Sjálfbærni , Engineering Design , Project Management

# Preface

When I started this thesis I knew almost nothing of the subject of sustainability. Not the best background to begin a Master's thesis, but what I had read on the subject interested me greatly and I wanted to learn more about it. Many companies I have worked for or with in my relatively short professional career have claimed to follow the principles of sustainability, however as I discovered through the making of this thesis, the subject means many things to many different people.

While it is a little unrealistic to expect to make a great contribution to the subject in a Master's thesis, I have learned a great deal about an interesting and important field from the work I have done here, and will aspire to apply the principles of sustainability as much as I can in my professional life.

I want to thank my family for their support through the (too) long process of making this thesis, and in particular my wife Viktoría. There were several false starts on the road to completing this thesis, and without her continued support I doubt I would ever have gotten here.

I also want to thank my thesis advisors Rúnar and Guðmundur. In particular Rúnar deserves special thanks for continuing to reply to my emails after so many delays and postponements. I would have understood if he had given up on me, but for continuing to take my efforts seriously I am extremely grateful.

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# Table of Contents

1	Introduction .....	1
1.1	Research Questions.....	3
1.2	Research Methods.....	3
1.3	Contributions .....	4
1.4	Thesis Flowchart.....	4
2	Background/Literature Review .....	7
2.1	Sustainability Definition.....	7
2.1.1	Economic Sustainability.....	10
2.1.2	Environmental Sustainability .....	10
2.1.3	Social Sustainability.....	11
2.1.4	Strong vs. Weak Sustainability .....	11
2.2	Evidence that better analysis tools are needed .....	12
2.3	Sustainability Measurement Methods .....	13
2.3.1	Sustainability Indicators.....	13
2.4	Project Management Theory .....	20
2.5	Previous work to combine the two fields .....	22
2.6	Summary.....	31
3	Development of the Sustainability Analysis Process.....	33
3.1	Indicator Selection.....	33
3.1.1	Use of the Global Reporting Initiative .....	33
3.2	Division into Project Phases .....	34
3.2.1	Pre-Project Phase.....	34
3.2.2	Project Planning/Feasibility Stage .....	35
3.3	Design, Development and Execution .....	36
3.3.1	Economic Indicators – Design and Development Phase.....	37
3.3.2	Environmental Indicators – Design and Development Phase .....	37
3.3.3	Labour Indicators – Design and Development Phase .....	43
3.3.4	Execution Phase .....	43
4	Use of the Sustainability Analysis Process .....	45
5	Test Case– Nursery School in Fjarðabyggð.....	49
5.1	Test Case Basis.....	49

5.1.1	Battery Limits of Study .....	50
5.1.2	Data Source for Test Case .....	50
5.1.3	Work Breakdown Structure .....	50
5.2	Test Case Design Phase Results .....	50
5.2.1	Labour Indicators .....	50
5.2.2	Economic Indicators .....	52
5.2.3	Environmental Indicators .....	55
5.3	Case Study Execution Phase .....	59
5.3.1	Labour Indicators .....	59
5.3.2	Economic Indicators .....	61
5.3.3	Environmental Indicators .....	63
5.3.4	Social Indicators .....	67
5.4	Test Case Summary .....	68
6	Discussion .....	69
6.1	Research Questions .....	69
6.2	How the Analysis Tool can be used .....	69
6.3	Strengths of the Design Analysis Tool .....	70
6.4	Weaknesses/Issues with the Design Analysis Tool .....	70
6.5	Usefulness of the Design Analysis Tool .....	71
7	Final Words .....	73
8	Bibliography .....	75
Appendix A	.....	A-1
Appendix B	.....	B-1
Appendix C	.....	C-1
Appendix D	.....	D-1
Appendix E	.....	E-1
Appendix F	.....	F-1

# List of Figures

Figure 1: Triple Constraint – Project constraints vs. Sustainability pillars.....	2
Figure 2: Thesis Structure Flowchart .....	5
Figure 3: The 3 Pillars of Sustainability.....	9
Figure 4: Egg of Sustainability model.....	9
Figure 5: Prism of Sustainability.....	10
Figure 6: Strong Sustainability.....	12
Figure 7: Themes included in the CSD Indicator Set.....	16
Figure 8: Relationship between the Project Life Cycle and the Product Life Cycle .....	21
Figure 9: Example Question from the paper “A Maturity Model for Integrating Sustainability in Projects and Project Management”.....	23
Figure 10: Staged Gate Process developed by Labuschagne and Brent.....	24
Figure 11: Timeline for Performance Metrics.....	24
Figure 12: List of Technological Sustainability Indicators .....	25
Figure 13: Indicator Selection Method.....	27
Figure 14: The Sustainable Footprint Methodology .....	28
Figure 15: Cross-section and 3-D Views of pile arrangements.....	29
Figure 16: Sustainability Balance Sheet Example .....	30
Figure 17: Stakeholder Influence chart .....	34
Figure 18: Engineering Process with GRI Sustainability Indicators included.....	45
Figure 19: Explanation of process used for the heating pipework and how the relevant indicators are calculated .....	47
Figure 20: Case Study WBS.....	50
Figure 21: Labour Indicators for Case Study .....	52
Figure 22: Employee Wages and Benefits Summary.....	54
Figure 23: EN1 Material Use Calculation Summary .....	55
Figure 24: Execution Labour Indicators for Case Study.....	60
Figure 25: Planned Salary vs. Actual .....	63
Figure 26: EN1, Summary of Material Waste during Project Execution Phase .....	65

# List of Tables

Table 1: A Comparison of activities included in an engineering project, and day-to-day activities in an organisation.....	20
Table 2 Materials Audit for a domestic construction project.....	26
Table 3: Summary of GRI Indicators included in Design Phase .....	36
Table 4: EC1 Economic Indicators .....	37
Table 5: EN1 Material Use Indicator components.....	37
Table 6: EN2 Recycled Materials Indicator components.....	38
Table 7: EN5 Direct Energy Consumption Indicator components .....	38
Table 8: EN6 Indirect Energy Consumption Indicator components .....	39
Table 9: EN8 Water Withdrawal Indicator components.....	39
Table 10: EN16 Greenhouse Gas Emission Indicator components .....	40
Table 11: EN 17 Other Greenhouse Gasses Indicator components .....	41
Table 12: EN19 Ozone Depleting Substances Indicator components.....	41
Table 13: EN20 Air Emissions Indicator components.....	42
Table 14: EN21 Water Discharge Indicator components.....	42
Table 15: EN22 Waste Indicator .....	42
Table 16: LA1 Workforce Indicator.....	43
Table 17: Indicator Review to Determine Suitability of Assessment Tool.....	44
Table 18: Labour Indicators Calculated for Case Study .....	51
Table 19: Cost Estimate Summary.....	53
Table 20: Employee Wages and Benefits Summary.....	54
Table 21: Building Energy Use Summary, Design Calculation.....	57
Table 22: Water Withdrawal Summary, Design Calculation.....	57
Table 23: Water Discharge Summary, Design Calculation .....	57
Table 24: Execution Labour Indicators for Case Study .....	60
Table 25: EC1.1 Indicators for Case Study.....	61
Table 26: EC1.2 Indicators for Case Study.....	62
Table 27: EN1 Summary of Material Waste during Project Execution Phase.....	64
Table 28: EN22 Waste Indicator .....	65

# Abbreviations

BOQ	Bill of Quantities
BREEAM	Building Research Establishment Environmental Assessment Methodology
CAPEX	Capital Expenditure
CERES	Coalition for Environmentally Responsible Economics
CFC	Chlorofluorocarbon
CO <sub>2</sub>	Carbon Dioxide
EPCM	Engineering, Procurement and Construction Management
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
KPI	Key Performance Indicators
LEED	Leadership in Energy & Environmental Design
NO <sub>x</sub>	Mono-nitrogen Oxides
OPEX	Operational Expenditure
PEH	High Density Polyethylene
PEX	Cross-linked Polyethylene
PM	Project Management
PMBOK	Project Management Body of Knowledge
PP	Polypropylene
PVC	Polyvinyl Chloride
SO <sub>x</sub>	Sulphur Oxides
TBL	Triple Bottom Line
UNCSD	United Nations Commission on Sustainable Development
WBS	Work Breakdown Structure

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# 1 Introduction

In 1987 the World Commission on Environment and Development formally defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”<sup>1</sup>. Since then the subject has matured and developed, and the field has grown in recognition and importance. Sustainability concerns feature more and more often as a core element of policy documents of governments<sup>2</sup>, and organisational strategy of multinational corporations<sup>3,4</sup>.

In the last few decades businesses have experienced an increased pressure to broaden their accountability beyond economic performance for shareholders, to sustainability performance for all stakeholders<sup>5</sup>. This is in line with the rationale of the definition of sustainable development in business terms, which suggests “adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future”<sup>6</sup>. Business has a responsibility to the whole of society to actively engage in the sustainability arena, and either proactively or reactively, companies are looking for ways to integrate ideas of sustainability in their marketing, corporate communications, annual reports and in their day to day actions<sup>7</sup>.

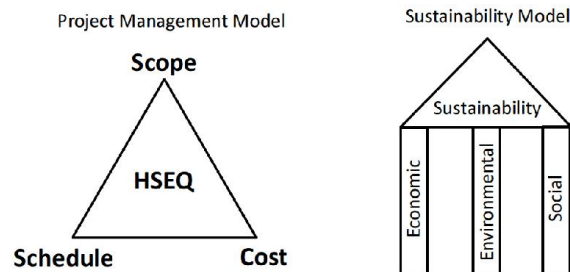
Three levels within an organisation have been identified that can be subjected to change, namely; the Strategic Level, the Process or Methodological Level and the Operational Level<sup>8</sup>. In order for sustainability to fully manifest within a company, the principles need to be implemented on all three levels.

On a strategic and operational level there is significant evidence of the integration of sustainability into the business environment (Corporate Strategies<sup>3,4</sup>, ISO14001, GRI etc.). However, the 2002 PricewaterhouseCoopers Sustainability Survey revealed that of the 101 Fortune 1000 companies that were interviewed, 72% of the respondents do not include the risk and/or opportunities of sustainability in their project, investment and transaction evaluation processes. Adopting sustainable practices at corporate level influences projects, as companies are accountable for the impacts of an implemented project on the society, environment and economy, even long after the project has been completed. In order for projects to achieve sustainable development objectives, the concept of sustainability must be integrated into the planning and management over the whole life cycle of a project.

The Project Management Body of Knowledge (PMBOK)<sup>9</sup> defines a project as “a temporary endeavour undertaken to create a unique product or service”. If this definition of a project is taken as a departure point it can be said that not only will the project itself will have economic, environmental and/or social consequences, but also the “product” or deliverables of the project will have these consequences and impacts. This concept is supported in the financial analyses of projects where the financial implications of the project’s deliverables are included in the Profitability, Return on Investment (ROI) and Net Present Value (NPV) calculations<sup>9</sup>.

In project management, project managers often talk of a “triple constraint” - project scope, schedule and cost - in managing competing project requirements, whereas in sustainability

literature the “constraints” or “pillars” are commonly “Social”, “Environmental” and “Economic”. This is illustrated in Figure 1 below, with the HSEQ signifying Health, Safety, Environment and Quality – those being the features of the traditional project management model which are not for compromise <sup>9</sup>.



*Figure 1: Triple Constraint – Project constraints of Scope, Schedule and Cost vs. Sustainability pillars of Economic, Environmental and Social*

According to the PMBOK, the activities involved in managing a project include;

- Identifying requirements
- Establishing clear and achievable objectives
- Balancing the competing demands for scope, time and cost
- Adapting the specifications, plans and approach to the different concerns and expectations of the various stakeholders

To date, much of the discussion on sustainability in project management has focussed on the type of project e.g. renewable energy, water sanitation etc. <sup>10</sup>. However the engineering design and project management process itself is also important, and thus sustainability considerations need to be embedded fully in the project development cycle. Current academic research suggests that the concept of sustainability is not really recognised in project management yet <sup>11, 12</sup>, or if it is the majority of works concern themselves with qualitative discussion, rather than definitive, measureable terms.

The majority of studies in sustainability indicators for projects have focussed on developing indicators which take a snapshot of the project at a fixed point in time (usually the beginning), and either determine if the proposed solution is classified as “sustainable” or not <sup>11,13</sup>. This work contests that due to the constantly changing parameters during the project design phase, and through the execution phase, it is not possible to make this assumption – these parameters must be tracked throughout, and decisions and trade-offs made during the project to keep the 3 pillars of sustainability in a suitable balance. This is in line with the work done by Oehlmann <sup>12</sup> and Ugwu et al <sup>13</sup>.

As will be shown later, significant literature on indicator selection for sustainability exists <sup>8, 10</sup>, so rather than develop another sustainability indicator set, these works will be used in this thesis to form the basis for a new process which integrates sustainability measurement in the engineering design and design optimisation process. Once the process has been developed, it



will then be tested on a case study project - a nursery school construction for Fjarðabyggð municipality in 2010, and conclusions based on the results will be drawn.

## **1.1 Research Questions**

To develop a new working process which can be used by engineers to analyse and optimise the sustainability of their projects, answers to the following questions are required:

### **Research Question 1**

*Which sustainability criteria are relevant to the design phase of an engineering capital project?*

### **Research Question 2**

*How should these criteria be implemented and monitored throughout the project design and execution phases?*

### **Research Question 3**

*How would an engineer use the criteria to inform design decisions on a project?*

## **1.2 Research Methods**

The background research section takes the form of a literature review. Sources include, but not limited to; textbooks and journal articles, and to a lesser extent websites, visual media, newspaper articles, reports etc. where appropriate. A thorough search of these resources, including all major online academic resources was done, using the terms “project management”, “engineering design process” and “sustainability” to ensure the most current and relevant material has been covered.

The intention of the literature review is not to revisit the basics of the subject and try to propose a new definition, as this has been done many times, but to rather build on what has been established as best practice. Of particular focus will be the limitations of current research into the actual implementation of sustainability theory into the project design and execution processes.

The field of project management is also briefly covered, however again substantial information has been collected in the Project Management Body of Knowledge (PMBOK), so the intention will be to use this established and commonly accepted resource as a basis for the remainder of the study. The contribution in this thesis is to combine the two fields in a meaningful way.

Using the findings of the literature review, a set of assessment criteria is selected and developed which in theory could be used to assess the successful implementation of a sustainability strategy in an engineering design project. By then dividing the established indicators into the relevant project phases (Normal operations, Planning, Design and Execution etc.), this reveals the indicators most relevant to the design phase.

### 1.3 Contributions

The background research and literature review reveals the need to develop a detailed process for analysing and optimising the design of an engineering project with respect to sustainability. By developing such a process, the following contributions are made in this thesis:

- Determine which factors of sustainability are most relevant to the design phase of an engineering project

Not all indicators are relevant at all times in a project, so the indicators will be divided into the most relevant project phase for calculation. This will show the most relevant factors in the design phase. This will be covered in Chapter 3.

- Integration of Sustainability Indicators into the design phase of the PMBOK project management process

In this thesis the indicator data will be integrated into the engineering design using parametric methods, to convert a sustainability indicator from a lagging to a leading indicator. This will allow engineers to optimise the sustainability of a project before construction/fabrication starts, and then provide a basis to track the progress through the execution phase. This will be covered in Chapter 4.

### 1.4 Thesis Flowchart

The thesis is organised as shown below in Figure 2.

Chapter 2 consists of a literature review and background research, in which the current accepted definition of sustainability will be presented, as well as the current theory on how to integrate sustainability concepts into engineering projects. The goal of this chapter is to establish a need to create a new working process for calculating sustainability indicators.

In Chapter 3 the indicator set selected will be introduced and divided into relevant project phases. As stated above in 1.3, it is not efficient to include all indicators in every project phase, so the purpose of this section will be to review the indicators and place them in the project phase where they are most relevant. Special focus will be on the Design Phase of the project, as this is where the need to improve the existing tools has been established.

Chapter 4 will present the new process and provide more detail into how it shall be used to calculate the indicators defined in Chapter 3.

Chapter 5 includes a case study of a real life construction project, where the indicators will be calculated and the working method tested. A nursery school construction project for the Fjarðabyggð municipality, comprising of development of a new 120 child nursery school was chosen as the test case. In accordance with current building regulations, the building shall be between 780-840m<sup>2</sup>, surrounding land between 3600-4800m<sup>2</sup>, with car parking for 23 vehicles. In this case study, the focus will be on the design and development stage as this is where it has been shown there is most opportunity for improvement in the current literature.

Finally, Chapter 6 presents a detailed analysis of the results of the case study, a discussion of the sustainability of the tool presented, and suggestions for further work.

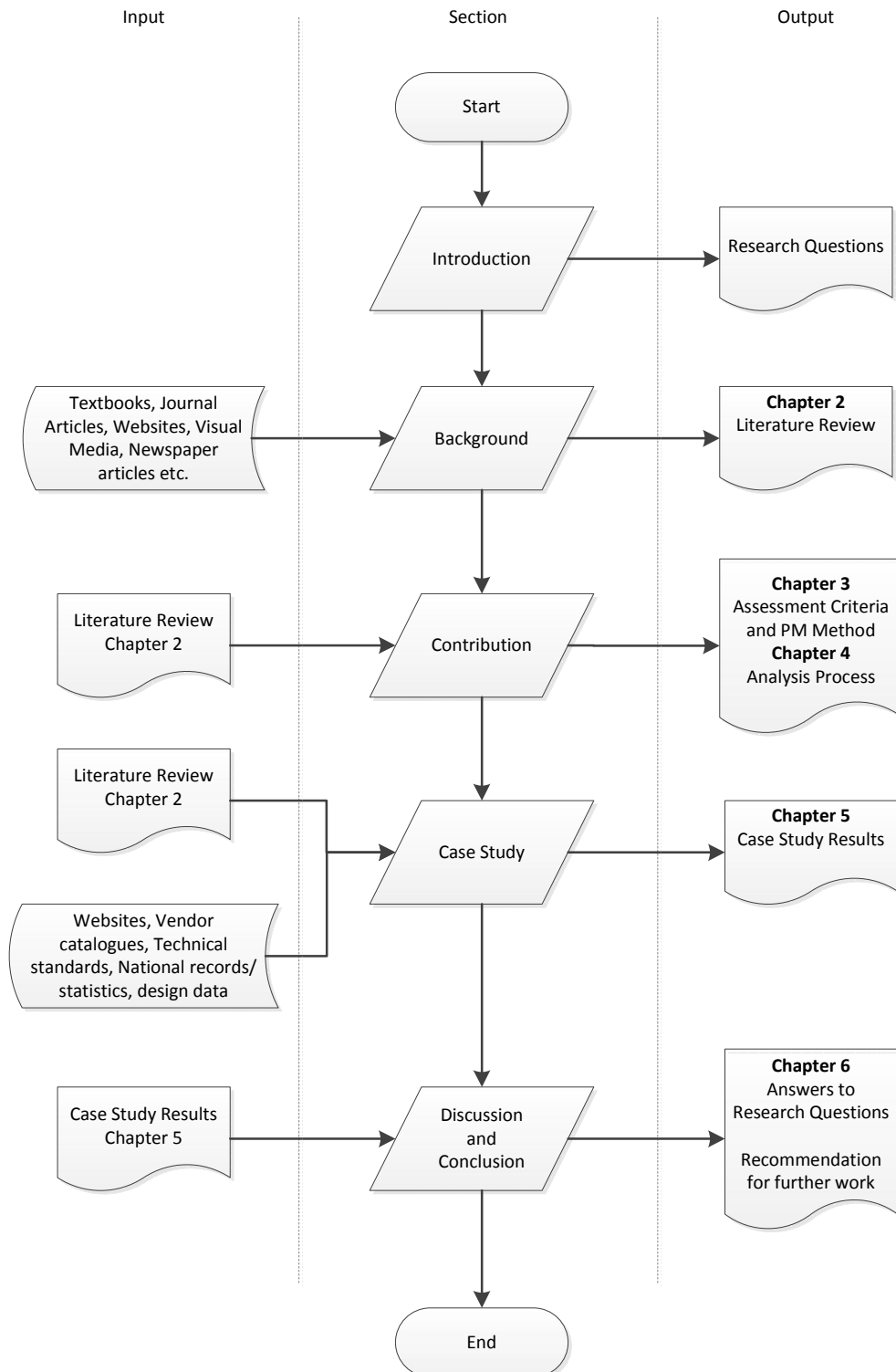


Figure 2: Thesis Structure Flowchart

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## 2 Background/Literature Review

This chapter will review previous work on the subject of sustainability and engineering project management, with the findings forming the basis for the development of the sustainable engineering design process.

The first step will be to briefly define what the term “sustainability” means in this context, and why companies are so keen to integrate it into their project management procedures. Following that will be a review of existing tools and processes to measure sustainability such as sustainability indicators and sustainability reporting standards, and then finally a review of what tools and processes have been developed to date, to integrate sustainability into engineering project management and design analysis.

### 2.1 Sustainability Definition

The International Institute for Sustainable Development (IISD) presented the following definition of sustainable development for the business community in 2002 <sup>6</sup>: *“For business, sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future”*.

The concept of sustainable development emerged in the early and mid-1980s (World Commission on Environment and Development <sup>1</sup>) as an attempt to bridge the gap between environmental concerns about the increasingly evident ecological consequences of human activities, and socio-political concerns about human development issues.

Over the more than two decades since publication of “*Our Common Future*”<sup>1</sup>, the idea of sustainable development has been widely, if ambiguously, embraced by a great variety of institutions around the world. There has been much dispute about the meaning and implications of the concept and much criticism of the actual behaviour of bodies that have claimed devotion to it. Gradually, however, some basics have become clear <sup>14</sup>.

- Current paths of development are not sustainable
  - Current resource-intensive development patterns are ecologically and ultimately economically unsustainable. There are also problems of inadequate worker and consumer protection, poverty and exclusion
- Sustainability is about protection and creation
  - Sustainability is often seen as being about protection of amenities (including cultural diversity), but it is equally about continued advancement or *creation*: a better and more just world.
- Requirements of sustainability are multiple and interconnected
  - Sustainability is about intermediate *and* long-term integration: the pursuit of all the requirements for sustainability at once, seeking mutually supportive benefits
- Pursuit of sustainability hinges on integration

- Because of the interconnections among its factors and purposes, sustainable development is essentially about the effective integration of social, economic, and ecological considerations at all scales from local to global, over the long haul
- Transparency and public engagement are key characteristics of decision making for sustainability
  - The importance of context, the benefits of diversity and the inevitability of surprise all suggest that transparency and active public engagement are necessary qualities of governance for sustainability
- Explicit rules and processes are needed for decisions about trade-offs and compromises
  - The objective of sustainability-centred decision-making is to seek positive, mutually supporting gains in all areas. But as this work begins, there will be many cases where no practical option offers benefits of all the required kinds. Inevitably there will have to be trade-offs between goals and there will be winners and losers. Trade-offs will have to be faced and dealt with.

One of the most striking characteristics of the term sustainable development is that it means so many different things to so many different people and organizations. The literature is rife with different attempts to define the term<sup>8</sup> and debates have erupted between those who prefer the three pillars approach<sup>15</sup>, or a more organic vision focussing more on interrelationships between the economic and the environmental dimensions<sup>16</sup>. However Robinson<sup>17</sup> argues that it makes sense for definitions, perhaps many of them, to emerge from attempts at implementing sustainable development, rather than having definitional rigor imposed from the outset, so this lack of definitional precision is not a serious problem.

The Triple Bottom Line (TBL) is to date the most popular definition used to base analysis of sustainability on. Developed by John Elkington in 1994, and later expanded in his book *“Cannibals with Forks: The Triple Bottom Line of 21st Century Business”*<sup>15</sup>, The TBL method has been used for a number of years to categorise the different types of sustainability.

The three key pillars of Elkington’s Triple Bottom Line Sustainability are:

- Economic - Profit
- Environmental - Planet
- Social – People

The 3-pillar concept is illustrated below in Figure 3, where sustainable development is supported by even pillars of economic, environmental and social development.



*Figure 3: The 3 Pillars of Sustainability – Economic Growth, Environmental Protection and Social Progress*

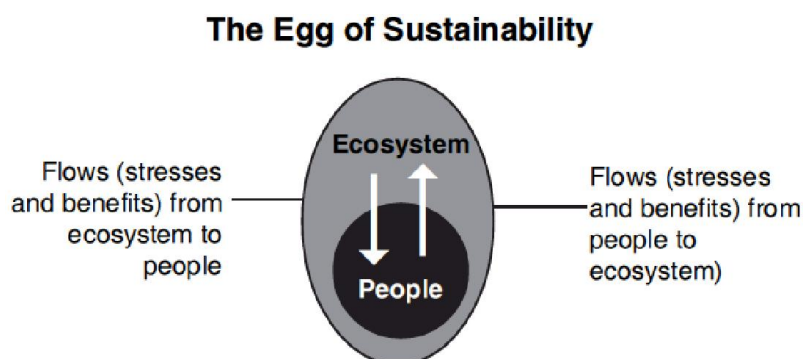
Similar problems beset the ‘pillars’ based approaches adopted in much of the sustainability literature and in many implementation efforts <sup>18</sup>. Most often, three pillars – social, economic and ecological – are identified, though culture and politics are sometimes recognised as additional distinct categories <sup>19</sup>. Important work has also been done in exploring the concepts of social, ecological and economic capital for sustainability, with particular interest in the existence and limits of potential substitutions <sup>20, 21, 22, 23</sup>. In practical applications however, the pillar-focused approaches have suffered from insufficient attention to overlaps and interdependencies, and a tendency to facilitate continued separation of social, economic and ecological analyses <sup>11</sup>.

### **The Egg of Sustainability**

The ‘Egg of Sustainability’ model is an alternative to the TBL method, and was designed in 1994 by the International Union for the Conservation of Nature <sup>24</sup>. An illustration of the “Egg” concept is shown below in Figure 4.

It illustrates the relationship between people and ecosystem as one circle inside another, like the yolk of an egg. This implies that people are within the ecosystem, and that ultimately one is entirely dependent upon the other. Social and economic development can only take place if the environment offers the necessary resources: raw materials, space for new production sites and jobs, constitutional qualities (recreation, health etc.). Thus according to this model:

Sustainable Development = Human Well-Being + Ecosystem Well-Being



*Figure 4: Egg of Sustainability model which illustrates the relationship between people and ecosystem*

## Prism of Sustainability

This model was developed by the Wuppertal Institute<sup>16</sup> and defines sustainable development with the help of four components - economy, environment, society and institution, shown below in Figure 5 as the four corners of the prism. The model suggests that the inter-linkages such as care, access, democracy and eco-efficiency need to be looked at closely as they govern the relationships between the dimensions which could translate and influence policy.

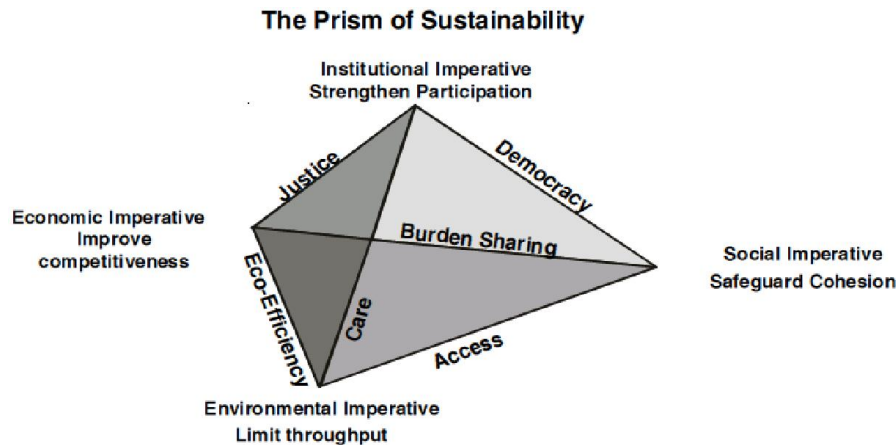


Figure 5: Prism of Sustainability. Sustainable development is modelled as a prism with 4 corners; economy, environment, society and institution, and the relevant inter-linkages; care, access, democracy and eco-efficiency

What is most needed, appropriate and workable to define sustainable development always depends heavily on the context. The detailed elaboration of sustainability requirements, and the determination of appropriate procedures for accepting or rejecting options and trade-offs must respect the place and time of application, and involve those who will live with the results<sup>12</sup>.

Since the “pillar” approach is generally accepted and well understood, an indicator set founded on this approach that will be used to base the new method of project sustainability analysis on. The following sections describe the content of the Economic, Environmental and Social Sustainability pillars in more detail.

### 2.1.1 Economic Sustainability

In the eyes of major corporations, this is the key to accepting a sustainable path - the retention and growth of economic capital. Hicks' definition of income<sup>25</sup> – the amount of financial capital one can consume during a period and still be as well off at the end of the period – is a concise and accurate definition of what is meant by economic sustainability. To economists, resources are a form of capital or wealth that ranges from stocks of raw materials to finished products and factories.

### 2.1.2 Environmental Sustainability

Although Environmental Sustainability is needed by humans, and originated out of social concerns, in itself it seeks to improve human welfare by protecting natural capital, that is



protecting the sources of raw materials used for human needs, and ensuring that sink capacities for recycling human wastes are not exceeded. Natural Capital consists of water, land, air, minerals and ecosystem services; hence much is converted to manufactured or economic capital <sup>26</sup>.

### **2.1.3 Social Sustainability**

Social Sustainability means maintaining social and moral capital. Social capital is investments and services that create the basic framework for society. Only through systematic community participation and strong civil society, including government can a successful project be executed. Cohesion of community for mutual benefit, connectedness between groups of people, reciprocity, tolerance, compassion, patience, forbearance, fellowship, love, commonly accepted standards of honesty, discipline and ethics are all included in Social capital.

As stated earlier interconnectivity must be addressed, as it is decisions taken during projects which have an effect on each “pillar”, and the Project Manager must have a way of making an informed trade-off decision – it is not possible to blindly chase the ideal environmental solution, while ignoring the economical aspect <sup>13</sup>. This concept of substitution of one type of sustainability capital for another is known as either strong sustainability (where no substitution is allowed), or weak sustainability (where some substitution is allowed).

### **2.1.4 Strong vs. Weak Sustainability**

According to Bossel <sup>27</sup>, only healthy, viable systems can develop sustainably. But it is not enough to be concerned with the viability of individual systems: there are no isolated systems in the real world; all systems depend in one way or another on other systems. In early literature, sustainable development was often depicted as expansion of the area where circles of social, economic and ecological quality overlapped (see Fig. 6 below). These depictions were useful in stressing the links among desirable social, economic and ecological qualities and in indicating that much of our current activity lay outside the realm of potential sustainability. However, even where the roles of social and ecological as well as economic factors were respected, the tendency to consider them separately proved hard to overcome <sup>14</sup>.

As sustainability has become more popular, the opposing concepts of strong and weak sustainability have received much attention in the last few years. Under weak sustainability one strives for maintaining “total capital”, defined as the “sum” of all 3 types of capital. This allows the substitution of natural capital by economic capital. Strong sustainability, by contrast, requires that every type of capital is maintained separately. Figure 6 <sup>28</sup> below shows the difference between the two - Strong Sustainability illustrated by 3 equally sized circles, whereas in the Weak Sustainability image the Economic circle is dominant and the Environmental smallest, suggesting that environmental sustainability has been neglected in favour of economic development. The change needed is to consider all 3 types of capital of equal importance.



*Figure 6: Strong Sustainability with an equal emphasis on all three pillars, Weak sustainability with an unbalanced focus on economic growth versus environmental decline, and the change needed*

Of course in a real life engineering project it will be necessary to have trade-offs between improvements to the environmental sustainability versus the additional cost. The purpose of the method developed in this work will be to inform the project team of the impact of any design or cost changes in order to facilitate the correct decision.

## 2.2 Evidence that better analysis tools are needed

Current project management frameworks do not effectively address all three pillars of sustainability – Economic, Environmental and Social. The focus tends to lie on ‘Profit’ because for most projects, economical performance is most important – not necessarily profit in the case of a Capital Expenditure (CAPEX) project however. Several attempts to relate sustainability and projects can be found in literature and practice, but the challenges and potential of relating sustainability and project management have not yet been researched in depth<sup>29, 30, 31</sup>, nor have they found their way into normal business practice in real world projects<sup>32</sup>. There is a mounting pressure on companies to include sustainability theories in their policies and activities<sup>33</sup>. Companies are already integrating the ideas of sustainability in their marketing, corporate communications, annual reports and in their actions<sup>3, 4</sup>. It is evident that sustainability has to find its way into project management methodologies as well, because both sustainability and project management will become more complex and thereby more important.

Besides the external pressure to include sustainability, companies realize very well themselves that sustainability could be a business case in the long-term. Studies show that pursuing sustainable development makes firms more competitive, more flexible in a fast-changing world and more likely to win and maintain customers<sup>34</sup>. Ingraining sustainability in the companies’ policies and actions can also help them to find and keep some of the best employees. Additionally, other benefits are that companies become more attractive to investors and insurers, even as it reduces their exposure to regulatory and other liabilities<sup>35</sup>. However, embedding sustainability involves some risks as well. It requires long-term investments in terms of time and money and very often it is not possible to determine exactly if and when sustainability investments will pay back. Returns may occur in three ways:<sup>36</sup>

- Economic value creation in terms of product performance and production costs: this can be both short-term and long-term

- Long-term value creation by increasing the coherence of various parts of the company and increasing their effectiveness and flexibility
- Long-term value creation by improvements to the company's reputation and image: this is not only important to external stakeholders, but also to internal stakeholders, for example for the motivation of the companies' own employees

Furthermore, it has been noted that while current sustainability initiatives, strategies, frameworks and processes focus on wider national aspirations and strategic objectives, they are noticeably weak in addressing micro-level decision making<sup>37</sup>. The process of translating strategic sustainability objectives into concrete action at project-specific levels is a difficult task and the multi-dimensional perspectives of sustainability such as economy, society and environment, combined with a lack of structured methodology and information at various hierarchical levels, further exacerbate the problem<sup>38</sup>.

The implementation gap exists because of several reasons, including:<sup>37</sup>

- Education and mind set of stakeholders, especially of the construction industry specialists whose daily design-construction decision-making have significant impacts on infrastructure sustainability throughout the project's life cycle
- Short-term focus rather than a long-term view during decision making
- Lack of flexible, user-friendly tools to facilitate quantitative analysis and decision support

Therefore, there is clearly a need for a method which defines how to measure and control sustainability criteria throughout the life cycle of a capital project. In this next section we will look at the existing methods for sustainability measurement and monitoring, and determine what can be used in the PM context.

## **2.3 Sustainability Measurement Methods**

Currently there are a number of accepted methods for calculating and presenting corporate performance in the field of sustainability. The most common is to use a defined set of so-called sustainability indicators, which are then reported formally using one of the international forums (GRI<sup>7</sup> etc.). Since a numerical, data-based system best suits the requirements of an engineering project, it is such a system that will be used to base the engineering analysis tool on.

### **2.3.1 Sustainability Indicators**

The most commonly used technique to analyse the sustainability of a business operation is to use an appropriate set of numerical indicators<sup>39, 40</sup>. These act as a guide to the direction of travel, which means the choice of which indicators to use is critical in monitoring and directing progress towards sustainability<sup>40, 41</sup>.

Sustainability indicators and composite indexes are increasingly recognised as a useful tool for policy making and public communication in conveying information on countries and corporate performance in fields such as environment, economy, society, or technological

improvement. By visualizing phenomena and highlighting trends, sustainability indicators simplify, quantify, analyse and communicate otherwise complex and complicated information.

Neely <sup>34</sup> states that the reasons why participants engage in performance measurement include:

- to check position
- to communicate position
- to confirm priorities
- to compel progress

The need to confirm priorities and compel progress is in line with the conclusions from Singh et al. <sup>42</sup> who states that sustainability indicators and composite index(s) are increasingly recognised as a useful tool for policy making and public communication in conveying information on countries and corporate performance in fields such as environment, economy, society, or technological improvement. By using indicators to visualise phenomena and highlighting trends, sustainability indicators simplify, quantify, analyse and communicate otherwise complex and complicated information. The assertion that indicators are useful for “visualising phenomena and highlighting trends” of course only holds true if the indicators proposed are meaningful to the people being asked to use them - this comes back to the earlier point that engineering teams are not being provided with clear goals.

Summarising from Lundin <sup>42</sup>, and Berke and Manta <sup>43</sup>, sustainable development indicators can be used to:

- Anticipate and assess conditions and trends
- Provide early warning information to prevent economic, social and environmental damage
- Formulate strategies and communicate ideas
- Support decision-making

To develop and implement an effective set of indicators, we must first know what type of indicators we want, as stated by Azapagic <sup>44</sup>, who advises that indicators used should be “quantitative whenever possible; however, for some aspects of sustainability, qualitative descriptions may be more appropriate (e.g. societal aspects)”.

According to Rankin et al. <sup>45</sup>, when developing sustainability indicators the following aspects must be considered:

- The various perspectives of process performance - project, customer, business
- The target audience (participants in the supply chain) - owners, designers, contractors
- The time aspects of project success - pre delivery stage, delivery stage, post-delivery stage
- The endless list of project specific variables - size of project (small, medium, large), type of project (commercial, industrial, residential, civil), method of project delivery and contractual arrangements

According to Singh et al.<sup>41</sup> the classification and evaluation of indicators can be done based on the following general dimensions of measurement:

- What aspect of the sustainability does the indicator measure?
- What are the techniques/methods employed for construction of index like quantitative/qualitative, subjective/objective, cardinal/ordinal, single/multi-dimensional.
- Does the indicator compare the sustainability measure (a) across space ('cross-section') or time ('time-series') and (b) in an absolute or relative manner?
- Does the indicator measure sustainability in terms of input ('means') or output ('ends')?
- Clarity and simplicity in its content, purpose, method, comparative application and focus
- Data availability for the various indicators across time and space
- Flexibility in the indicator for allowing change, purpose, method and comparative application

Hammond et.al<sup>46</sup> states that Indicators have two defining characteristics:

- Indicators quantify information so its significance is more readily apparent
- Indicators simplify information about complex phenomena to improve communication

Summarising the above, the proposed analysis tool must therefore fulfil as many of the following criteria as possible:

- Different dimensions of sustainability are captured (Economic, Environmental etc.)
- Integrated within established PM and Engineering practice
- Provides a working tool to manage operations over a period of time
- Previously lagging indicators become leading indicators by informing decisions up front
- Measures success during project implementation against specified targets
- Indicators are calculated using established standards and practices
- Qualitative measurements are not acceptable in the design and execution phases
- Options can be compared and impacts can be assessed across all dimensions of sustainability with a greater degree of flexibility

Now this list will be compared against commonly used indicator sets to assess their suitability for use as the basis for the proposed sustainability analysis tool.

### **UN Commission on Sustainable Development Indicators**

The United Nations Conference on Environment and Development in 1992 recognized the important role that indicators could play in helping countries make informed decisions concerning sustainable development. The first two sets of CSD Indicators of Sustainable Development (henceforth CSD indicators) were developed between 1994 and 2001. They have been extensively tested, applied and used in many countries as the basis for the devel-

opment of national indicators of sustainable development, with the newly revised 3<sup>rd</sup> revision published in 2007 <sup>47</sup>.

The newly revised CSD indicators contain a core set of 50 indicators, covering the themes listed below in Figure 7.

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<i>CSD indicator themes</i>		
• Poverty	• Natural hazards	• Economic development
• Governance	• Atmosphere	• Global economic partnership
• Health	• Land	• Consumption and production patterns
• Education	• Oceans, seas and coasts	
• Demographics	• Freshwater	
	• Biodiversity	

---

*Figure 7: Themes included in the Commission on Sustainable Development CSD Indicator Set*

From their inception, the overarching purpose of the CSD indicators has been to inform policy at the national level. In addition to using indicators to assess overall progress towards sustainable development, many countries successfully use them to measure success within the framework of their national sustainable development strategy. Comparing to the list of criteria above, the strengths and weaknesses of the CSD indicator set are as follows:

Strengths of the UN CSD Indicators:

- Clear and concise guide as to what to report and how
  - This eliminates the grey area of what is included in “sustainability”
- Covers all pillars of Sustainability – in this case Economic, Environmental, Human and Social
  - As stated earlier, there can be an unbalanced focus on one factor of sustainability, whereas by using CSD Indicators this is avoided
- Peer reviewed and tested by international experts
  - This is preferred to a set of indicators developed for one specific solution which might not be suitable for general application – this is the only way to ensure a unified measurement system

Weaknesses of the UN CSD Indicators:

- Indicators are lagging indicators – reported at end of time period based on historical information
  - Indicators need to be able to be estimated ahead of the actual project execution, so as to inform decisions
- Reporting does not provide a working tool to manage operations
  - Meaning that by reporting data at the end of a project/time period, engineers and project managers are missing the opportunity to guide operations toward a more sustainable solution

- Covers a significant number of governmental level concerns, such as Life expectancy, which cannot be controlled in any way by a construction or engineering project
  - The indicator set used to manage engineering projects must be mainly concerned with factors which are within the scope of the project –other items of a wider concern can be considered in a feasibility study for example

## **Global Reporting Initiative**

The Global Reporting Initiative (GRI) <sup>7</sup> was formed in 1997 by the Coalition for Environmentally Responsible Economies (CERES) in collaboration with the Tellus Institute, and has rapidly become the leader among voluntary worldwide sustainability reporting systems <sup>48</sup>. From its inception, the GRI has possessed a clear mission “to enhance responsible decision making by promoting international harmonization in reporting relevant and credible corporate economic, environmental, and social performance information” (GRI, 2002). To this end, the GRI has developed and published reporting guidelines based upon the broad TBL concept first developed by Elkington <sup>15</sup>.

The GRI Reporting Framework is intended to serve as a generally accepted framework for reporting on an organization’s economic, environmental, and social performance. It is designed for use by organizations of any size, sector, or location. It takes into account the practical considerations faced by a diverse range of organizations – from small enterprises to those with extensive and geographically dispersed operations. The GRI Reporting Framework contains general and sector-specific content that has been agreed by a wide range of stakeholders around the world to be generally applicable for reporting an organization’s sustainability performance.

Sustainability reports based on the GRI Reporting Framework disclose outcomes and results that occurred within the reporting period in the context of the organization’s commitments, strategy, and management approach. Reports can be used for the following purposes, among others:

- Benchmarking and assessing sustainability performance with respect to laws, norms, codes, performance standards, and voluntary initiatives
- Demonstrating how the organization influences and is influenced by expectations about sustainable development
- Comparing performance within an organization and between different organizations over time.

The Sustainability Reporting Guidelines (the Guidelines) consist of Principles for defining report content and ensuring the quality of reported information. It also includes Standard Disclosures made up of Performance Indicators and other disclosure items, as well as guidance on specific technical topics in reporting.

Indicator Protocols exist for each of the Performance Indicators contained in the Guidelines. These Protocols provide definitions, compilation guidance, and other information to assist

report preparers and to ensure consistency in the interpretation of the Performance Indicators. Users of the Guidelines should also use the Indicator Protocols.

Some critics complain that the GRI framework is overly complicated, and that some of the information that it requires to be disclosed is difficult to obtain and of questionable actual value. The complainants include some of the early movers on reporting who have found themselves on a “reporting treadmill” - spending so much time gathering data that they have too little resource to actually create change in their organisation <sup>49</sup>. Comparing the GRI to the defined requirements of an engineering project, the following strengths and weaknesses are found:

#### Strengths of the GRI:

- Clear and concise guide as to what to report and how
  - The guidelines define exactly what to report, when to report it and even what units of measurement shall be used
- Fair comparison of companies of all different sizes and industry sectors
  - The indicators are scalable so they do not favour a small company over a large one, and vice-versa
- Qualitative measures are kept to a minimum
  - As specified earlier, qualitative measures are of little use in an engineering project, and the GRI tends towards detailed calculations and data

#### Weaknesses of the GRI:

- Reporting does not provide a working tool to manage operations
  - The GRI is only a reporting guideline, not an operational procedure/standard
- Results are only known at period end when data collection is made – making them lagging indicators!
  - Linked to the point above – indicators need to be able to be estimated ahead of the actual project execution, so as to inform decisions
- Report in itself does not show success in regard to achieving company targets
  - For example, the report will simply state the energy used per annum in kWh – this does not clarify if this is above or below company target

### **UN Global Compact**

The United Nations Global Compact <sup>50</sup>, also known as Compact or UNGC, is a United Nations initiative to encourage businesses worldwide to adopt sustainable and socially responsible policies, and to report on their implementation. The Global Compact is a principle-based framework for businesses, stating ten principles in the areas of human rights, labour, the environment and anti-corruption. Under the Global Compact, companies are brought together with UN agencies, labour groups and civil society.

The Global Compact is the world's largest corporate citizenship initiative and as voluntary initiative has two objectives: “Mainstream the ten principles in business activities around the



world” and “Catalyse actions in support of broader UN goals, such as the Millennium Development Goals (MDGs)”.

The Global Compact is not a regulatory instrument, but rather a forum for discussion and a network for communication including governments; companies and labour organisations, whose actions it seeks to influence; and civil society organizations, representing its stakeholders.

The Compact itself says that once companies declared their support for the Global Compact principles “This does not mean that the Global Compact recognizes or certifies that these companies have fulfilled the Compact’s principles”.

Many civil society organizations believe that without any effective monitoring and enforcement provisions, the Global Compact fails to hold corporations accountable. Moreover, these organizations argue that companies can misuse the Global Compact as a public relations instrument for “blue-wash”, as an excuse and argument to oppose any binding international regulation on corporate accountability, and as an entry door to increase corporate influence on the policy discourse and the development strategies of the United Nations.

An informal network of organizations and people with concerns about the UN Global Compact, called Global Compact Critics, levels a variety of criticisms at the Global Compact:

- The compact contains no mechanisms to sanction member companies for non-compliance with the Compact's principles
- A corporation's continued participation is not dependent on demonstrated progress
- The Global Compact has admitted companies with dubious humanitarian and environmental records in contrast with the principles demanded by the Compact.

Comparing the UN Global Compact to the defined requirements of an engineering project in 2.3.1, the following strengths and weaknesses are found:

Strengths of the UN Global Compact:

- Internationally recognised and respected forum
- Covers all pillars of Sustainability
  - As stated earlier, a broad view of all aspects of sustainability is required for the tool to be successful

Weaknesses of the UN Global Compact:

- Focusses on general principles rather than detailed, data-driven analysis
  - This is not suitable to be used to analyse an engineering project
- Companies are not audited prior to signing up, nor monitored after they do for compliance with the guiding principles
  - This makes the UN Global Compact an unreliable measure of a company’s commitment to sustainability

## 2.4 Project Management Theory

Project management is defined by the Project Management Body of Knowledge (PMBOK) <sup>9</sup> as “the application of knowledge, skills, tools and techniques to project activities in order to meet stake-holders needs and expectations from a project”.

Virtually all projects are planned and implemented in a social, economic and environmental context, and have intended and unintended positive and/or negative impacts. The project team should consider the project in its cultural, social, international, political and physical environmental contexts.

### CAPEX vs. OPEX

Since a project can be defined as “a temporary endeavour undertaken to create a unique product or service” <sup>51</sup>, the life cycle of this “product or service” must also be taken into account. The project life cycle and that of its product, the operational activity, is often viewed as one life cycle. There is, however, a vast difference between these two activities. In engineering economics, commonly two different types of expenses are discussed <sup>52</sup> – operational expenditure (OPEX), and capital expenditure (CAPEX).

As can be seen from the sustainability literature, management of operational activities (OPEX) lends itself better to the indicator and reporting structure currently favoured by large companies (GRI, UN Global Compact etc.) rather than shorter term capital expenditure projects. A system must therefore be developed which considers both the short term management of designing, procuring, installing and commissioning the “asset”, and the long-term operation of the “asset”.

Table 1 summarises which activities are commonly classed as either short term project activities (capex), or longer term operational activities (opex).

*Table 1: A Comparison of activities included in an engineering project, and day-to-day activities in an organisation<sup>53</sup>*

Project Activity	Operational Activity
<ul style="list-style-type: none"> <li>• Produces a new specific deliverable</li> <li>• A defined start and end</li> <li>• Multidisciplinary team</li> <li>• Temporary team</li> <li>• Uniqueness of project</li> <li>• Work to a plan within defined costs</li> <li>• Canceled if objectives cannot be met</li> <li>• Finish date and cost more challenging to predict and manage</li> </ul>	<ul style="list-style-type: none"> <li>• Delivers same product</li> <li>• Continuous</li> <li>• Specialized skills</li> <li>• Stable organization</li> <li>• Repetitive and well understood</li> <li>• Work within an annual budget</li> <li>• Continual existence almost assured</li> <li>• Annual expenditures calculated based on past experience</li> </ul>

### CAPEX

CAPEX refers to all assets, whether tangible or intangible, that is made use of, to generate more business and thus, revenues. CAPEX is an investment in the business. It adds to shareholders value. These are expenditures made keeping in mind future benefits. These investments could be on machinery, equipment, property or upgrade of apparatus. It is usually shown in the financial statement as cash flow or investment in plant, machinery or similar head. Depreciation of such assets takes place every year until it becomes zero.

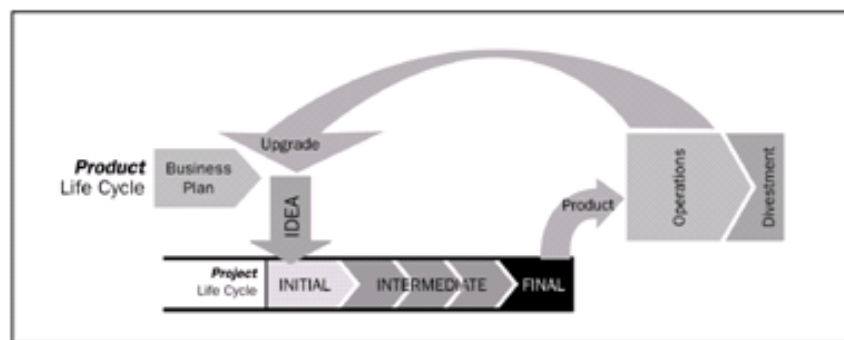
## OPEX

Operating Expenditure (OPEX) refers to expenses that are incurred on maintenance and running of assets generated through CAPEX. Day to day running expenses for sales and administration and R&D are taken as OPEX. Thus OPEX are expenses that are necessary to maintain capital assets. Earnings before interest, the magical figure in which everyone from shareholders to the management are interested in, is arrived at deducting OPEX from the operating revenue.

Sustainability indicators developed to date are more suited to OPEX - this work will aim towards project management of CAPEX projects.

## Project Life Cycle

The project life cycle and the Work Breakdown Structure (WBS) have come to the forefront in recent years as key frameworks or structures for subdividing the project's scope of work into manageable phases or work packages<sup>53</sup>. Where the WBS is a hierarchical subdivision of the scope of work, the project life-cycle subdivides the scope of work into sequential project phases. The process and phases involved in a project from initiation to completion is illustrated below in Figure 8.



*Figure 8: Relationship between the Project Life Cycle which concludes at the introduction of the new product, and the Product Life Cycle which continues through operations to disinvestment<sup>51</sup>*

The classic project life cycle only considers the project from concept to handover. However, if the project is to build a facility, a factory, a computer system or sports stadium then (looking at the project from the client's perspective) the efficient operation of the facility and the return on investment should also be considered. To look at the wider picture we use the product life cycle which considers the facility from the cradle to the grave.

## PMBOK Project Phases

Pre-project phase: Normal operation of the organisation. Projects normally evolve from the work environment or market within which the company normally operates. There is usually some event which triggers the start of the project.

Concept and Initiation Phases: The first phase starts the project by establishing a need or opportunity for the product, facility or service. The feasibility of proceeding with the project is investigated and on acceptance of the proposal moves to the next design phase.

Design and Development Phase: The second phase uses the guidelines set by the feasibility study to design the product, outline the build method and develop detailed schedules and plans for making or implementing the product.

Implementation or Construction Phase: The third phase implements the project as per the baseline plan developed in the previous phase.

Commissioning and Handover Phase: The fourth phase confirms the project has been implemented or built according to the design, and terminates the project

Operation Phase: Although the operation phase may be the whole purpose of the project, it usually falls outside of the project manager's sphere of influence. However the project manager would interface with the operations manager with respect to:

- Handover
- Maintenance
- Upgrade and Expansion
- Disposal

Maintenance Phase: The maintenance phase(s) are embedded in the operation phase to keep the facility functioning. Ease of maintenance and minimum impact on production are important design considerations

Upgrade/Expansion Phase: At some point the facility will require a major upgrade, refit or expansion to keep it running efficiently and competitively. Ease of upgrade or expansion is a consideration here – has it been allowed for in the original design?

Decommissioning and Disposal: The final part of the product life-cycle is decommissioning and disposing of the facility. As people become more aware of the environment, so the impact of disposing of a facility needs to be considered at the design phase. Normally the actual decommissioning is taken as a separate project, but it should be considered in the original project.

## **2.5 Previous work to combine the two fields**

Despite the definition of sustainability being more clear today than it has ever been, and the existence of extensive academic work and established practice in project management, the processes and tools for project management and engineering design fail to seriously address the sustainability agenda <sup>11</sup>, nor has it been properly explained how to translate the concept into practical decision making at the project levels <sup>13</sup>. However, there have been a number of studies to address the limitations of current sustainability theory and project management practice, and to try to combine them into a process for sustainable project management and design.

Gilbert and Silvius <sup>11</sup> took the approach of developing a maturity model for the incorporation of sustainability in projects and project management processes, as in their words “the standards for project management fail to seriously address the sustainability agenda”.

In their work they argue that when considering sustainability in project management the total life cycle of the project (e.g. initiation - development - execution – testing - launch - end) should be taken into account. Furthermore, the life cycle of the project is not sufficient, as the project will produce a result or product which also needs to be considered over its full life. Simply “the life cycle of whatever result the project realises and also the life cycle of the resources used in the realising should be considered” – thereby “stretching the systems boundaries of project management”.

This conclusion of stretching the system boundaries of project management, and encouraging a more long term vision is in line with the work of many other studies, however the authors state that the process maturity approach does not adequately address the specific aspects and considerations of sustainability, preferring instead to focus on a qualitative assessment of the “depth of vision” of the project. An example question is shown below in Figure 9.

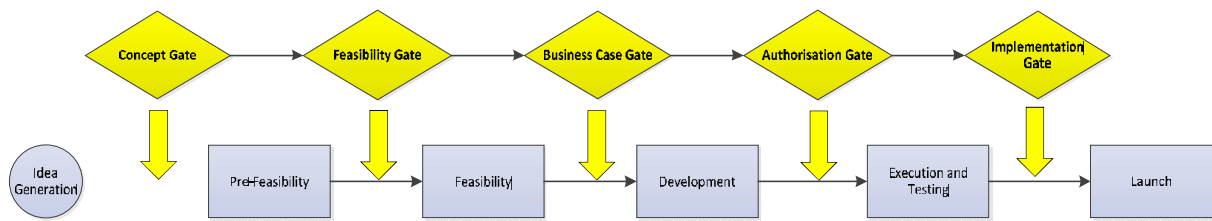
***In which way does the project try to minimize its waste?***

	Actual situation	Desired situation	
A.	<input type="checkbox"/>	<input type="checkbox"/>	No specific policies on this point.
B.	<input type="checkbox"/>	<input type="checkbox"/>	Waste in the project is separated in recyclable and non-recyclable and collected by the local waste handling companies.
C.	<input type="checkbox"/>	<input type="checkbox"/>	The project has policies (e.g. double sided printing) to minimize waste and waste in the project is separated.
D.	<input type="checkbox"/>	<input type="checkbox"/>	The project is designed to minimize waste and necessary waste is as much as possible recycled in the project itself.
E.	<input type="checkbox"/>	<input type="checkbox"/>	The project and the result it delivers are designed to minimize waste and necessary waste is as much as possible recycled in the project or result itself.

*Figure 9: Example Question from the paper “A Maturity Model for Integrating Sustainability in Projects and Project Management” <sup>11</sup>.*

Using this method, the project is assessed via a series of questions and the project team select either “Actual Situation” if the described behaviour is present on the project or “Desired situation” if they are not yet at that stage. Based on the results of the checklist, organisations can discuss their ambition levels on the different perspectives, develop an action plan and monitor their progress. However, in contradiction to the discussion in Section 2.3.1, the progress will be difficult to monitor accurately, as no specific values are discussed. Targets are therefore set inaccurately, and results given on a qualitative judgement by the project stakeholders – providing ample opportunity for results to be skewed in their favour.

In a later work by Labuschagne and Brent <sup>54</sup>, they address the lack of detail in the target setting above, which further focussing on the life cycle and boundary stretching of the PM method. The work focuses on assigning sustainability indicators to decisions in a staged gate process – a commonly used tool in project management <sup>54</sup>. See Figure 10 below:



*Figure 10: Staged Gate Process developed by Labuschagne and Brent<sup>55</sup>. Project is divided into the phases Pre-Feasibility, Feasibility, Development, Execution & Testing and Launch. The project is assessed on the completed activated and deliverables at the end of each phase, before it passes through the “gate” to the next phase*

The limitation of this work is that the indicators proposed as targets for each of the gate reviews stop at Gate 3, thereby eliminating the important phases of execution, testing and operation. Given that the execution phase is where the actual work is done, this method omits a large part of the actual process of the project – the indicators therefore provide a target, rather than a defined measure of the success or failure of the project “product”.

The work by Rankin and Fayek et al.<sup>55</sup> addresses the limitation of a lack of detail by having detailed indicators for project management focused metrics. They state that any work to incorporate sustainability in project management must consider:

- The various perspectives of process performance – project, customer and business
- The target audience (participants in the supply chain) – owners, designers and contractors
- The time aspects of project process – pre-delivery stage, delivery stage and post-delivery stage
- The endless list of project specific variables – project size, type of project, delivery method etc.

They propose a project timeline framework for any metrics for sustainability in project management – see below Figure 11.

*Figure 11: Timeline for Performance Metrics. Project is divided into phases Planning, Design, Tendering, Construction, Defect Liability Period and Lifetime of Project*

The list of indicators proposed is extensive, and the majority are in line with those proposed in the PMBOK<sup>9</sup> as standard project control and change management - an example of a question of this type is shown below:

### ***Time for Change Demand***

Change, attributable to client approved change orders originating from the client/client representative, between the actual construction times at available for use and the estimated construction time at the commit to construct, expressed as a percentage of the estimated construction time at the commit to construct.

**Formula:**  $\text{Approved time for change} / (\text{total project time} \times 100)$

This level of detail can be useful, however the value in measuring every time change due to project change management is questionable – can this information be tracked regularly given the number of changes made in the execution of a large project? Furthermore, their treatment of sustainability indicators is not very detailed as shown below:

### ***Sustainability – Design***

A measure of the improved level of sustainability in the design as measured against a checklist of standard practices (eg. Measured against LEED for buildings) from begin detailed design to begin procurement.

**Formula:** Comment on sustainability for site, water usage, energy usage, materials and indoor environment etc.

This superficial, qualitative treatment of sustainability issues means that the metrics proposed in this work are heavily skewed in favour of established project management metrics, and again is reliant on a qualitative judgement from project stakeholders. The value of proposing a set of PM metrics when the PMBOK is established as the industry standard for this is also questionable – as stated earlier, the goal of this thesis is to define more detailed sustainability metrics and fit them in to established PM practice.

Work by Sandborn and Myers<sup>56</sup> and Asif et al.<sup>57</sup>, both separately attempt to improve the criticism that sustainability indicators are lacking in sufficient depth in a project case.

The work by Sandborn and Myers focuses on Technological Sustainability of an asset in operation. They define sustainability in this instance as “a means of keeping an existing system operational and maintaining the ability to manufacture and field visions of the system that satisfy the original requirements. They propose the following as a potential set of measures for the sustainability of an asset, as shown below in Figure 12.

Reliability	Diagnostic ability	Maintainability	Availability
Obsolescence	Qualification/Certification	Regression Testing	Total Cost of Ownership
Testability	Reparability	Spares	Cross-Platform Applicability
Warranty/Guarantee	Configuration Control	Upgradability	Technology Insertion

*Figure 12: List of Technological Sustainability Indicators developed by Sandborn and Myers*

The work however does not propose if this is an exhaustive list, if it needs to be, or when in the life cycle of the asset the owner needs to consider the indicator valid.

Furthermore, items such as “Warranty” and “Cost of Ownership” can be considered commercial issues which are better addressed in Economic Sustainability. Also, the information sought in the table is not frequently available in sufficient detail to enable an informed decision – items such as “Availability” for example.

Asif et al. address the need for more detail in a different manner, this time focussing on the embodied energy (the sum of all the energy required to produce goods or services) and the environmental impacts (CO<sub>2</sub>, SO<sub>2</sub> etc.) of building materials used in a domestic construction project. By calculating the embodied energy per material type, and the quantity used in the project, they are able to provide figures for the overall system in great detail. A graphical summary of the result is shown below in Table 2:

*Table 2 Materials Audit for a domestic construction project. Includes Materials Used, Material Quantities, Embodied Energy in MJ, and Environmental Impacts (CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>)<sup>57</sup>*

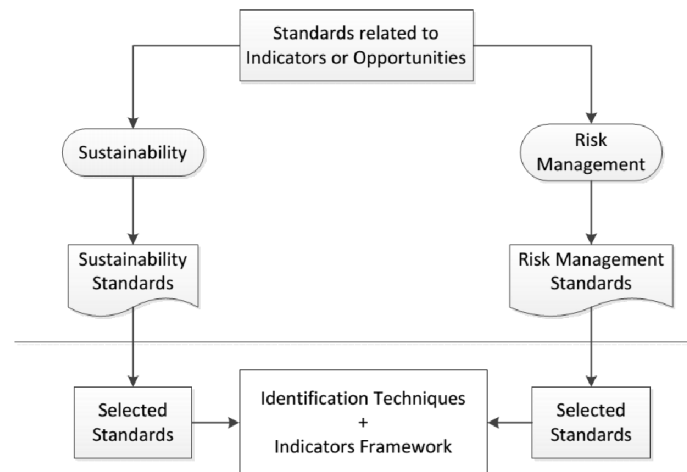
Material	Quantity (kg)	Embodied Energy (MJ)	Environmental Impacts		
			CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
Timber	5725	30000	664,1	5,7	5,7
Concrete	130800	130800	605454	16194	7403
Glass	313,6	4077	178,4	13,8	0,6
Aluminium	25,3	5870	48,1	0,3	0,1
Slate	432	43,2	3,5		
Ceramic Tiles	4030	32240	2301	16,1	205,5
Plasterboard	1080	5400	286,2	3,2	2,2
Damp Course	28,3	1889	25,4	0,2	0
Mortar	2400	2400	9600	2400	120

While the concept of embodied energy can be useful in determining the effectiveness of energy-producing or energy-saving devices in the construction project, the assertion that one figure can be applied for use of timber, for example, is a gross simplification, as there are many factors which vary from project to project which can either increase or decrease this value. However it is possible that these factors could be gathered during the feasibility stage of the project specific to the project locale, thereby making the figures more accurate.

Also, while the authors make no claims at trying to cover the whole field of sustainability in their assessment, it must be remembered that sustainability requires a multi-disciplinary approach covering a number of features, and environmental impact is just one piece of the puzzle.

The work by Fernández-Sánchez and Rodríguez-López<sup>58</sup> aims to incorporate sustainability into the project management framework, in this case choosing to base the foundation of the work on established standards in risk management. The basis for the proposed methodology is to identify sustainability indicators by considering sustainability as opportunities for the project, and to establish indicators for measuring and controlling these opportunities. The methodology for development of their indicator set is shown below in Figure 13.





*Figure 13: Indicator Selection Method*

The proposed set of indicators using this methodology are roughly in line with those proposed using other established methods (GRI etc.) however, unlike the work discussed above, no consideration of the timeline of the project is given, so it is unclear if these indicators are intended to be a target at the feasibility study stage, or a measure at the completion phase. Furthermore, there does not appear to be many indicators for use during the construction phase. Again, though the authors do not claim to make any attempt to incorporate the metrics/indicators from standard project practice, and as explained earlier it is necessary to include these factors as a meaningful delivery of the project for all stakeholders.

In the work by Ugwu and Haupt <sup>13</sup>, they address the requirement for sufficient detail in an indicator set, while at the same time making the concession to the more qualitative requirements of social sustainability. They propose an assessment method for different indicators, split into 5 different brackets (Titled A-E) depending on the indicator, which includes both quantitative and qualitative methods as follows:

**Method A** - Credit-based scoring system: This method is adopted for those indicators that are difficult to quantify. Examples include indicators listed under Visual Impact category, Health and Safety category, etc.

**Method B** - Scaled scoring: This is suitable for those criteria in which upper and lower limits are set in statutory documents such as legislations, guidelines, quality objectives etc. (e.g. by local authorities). Values are assigned proportionally, based on the designer's judgment.

**Method C** - Comparison with benchmark or other available options: This method is suitable for indicators that are not to any statutory requirements (i.e. legislation) or guidelines regarding sustainability performance. Indicators like direct cost, land acquisition, etc. fall under this assessment criterion.

**Method D** - This method involves using a credit system. However, the assessment process involves making use of a flow chart, as appropriate.

**Method E:** This method involves subjective marking, which is often based on the assessor's own judgment. As an illustration, the assessor could judge the quality of contract documents

In the method described above, the authors suggest that the resource utilisation and project management are measured quantitatively during the construction phase, while the 3-pillar assessment aspects are the focus on the feasibility and design phases of the project. While this is a strong contribution to the literature due to the detail and scope of the study, the assertion that the sustainability specific factors can be properly captured by using established project management and control techniques has already been shown to be somewhat incorrect <sup>59</sup>.

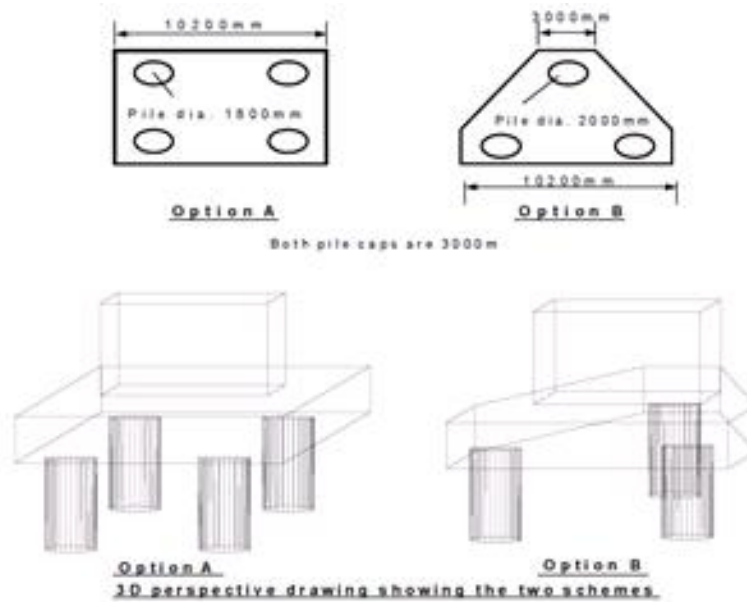
Oehlmann <sup>12</sup> addresses this point by aligning business methodologies with the principles of sustainable development, by choosing to divide indicators in a 3x3 matrix – People, Planet, Profit at the top, and three stages of the project on the side – Pre-phase, Project Execution and Asset Operation. This breakdown is shown in Figure 14 below.

The Triple Bottom Line			
	1. People	2. Planet	3. Profit
Level 1 Project Pre-Phase	1.1.1 Stakeholders	1.2.1 Design Options	1.3.1 Expected Economic Performance
	1.1.2 Customers	1.2.2 Land & Biodiversity	1.3.2 Expected Financial Health & Stability
	1.1.3 Politics and Legislation	1.2.3 Environmental Plan	1.3.3 Expected Shareholder Involvement
	1.1.4 Team Participants	1.2.4 Product	
	1.1.5 Health & Safety Plan		
Level 2 Project Execution	2.1.1 Stakeholders	2.2.1 Transport	2.3.1 Market Presence
	2.1.2 Society	2.2.2 Emissions & Waste	2.3.2 Macro Economic Effect
	2.1.3 Suppliers	2.2.3 Materials	2.3.3 Commercial Performance
	2.1.4 Communication	2.2.4 Water	2.3.4 Capability Management
	2.1.5 Human Resources	2.2.5 Energy	2.3.5 Environmental Expenditures
	2.1.6 Health & Safety	2.2.6 Noise & Vibrations	
Level 3 Operation of the Asset	3.1.1 Stakeholders	3.2.1 Transport	3.3.1 Market Presence
	3.1.2 Society	3.2.2 Emissions & Waste	3.3.2 Macro Economic Effect
	3.1.3 Suppliers	3.2.3 Materials	3.3.3 Efficiency of the Asset
	3.1.4 Community Capital	3.2.4 Water	3.3.4 Environmental Expenditures
	3.1.5 Human Resources	3.2.5 Energy	3.3.5 Long-Term Planning
	3.1.6 Occupational Health & Safety	3.2.6 Maintenance of the Asset	3.3.6 Realized Economic Performance
		3.2.7 Decomposing of the Asset	

Figure 14: The Sustainable Footprint Methodology

Further work by Ugwu et al. <sup>39</sup>, further expands on the need for project-level sustainability assessment by looking closely at established sustainability KPI's, mathematical models and computational methods. In this work the authors have attempted to improve the tools available to designers and project managers to address sustainability at the front end of the project, as this is an important and influential stage of a project.

The conclusion of the work is to develop a tool used to make decisions between different design options, the design options being analysed in comparison with the indicator set. An example is shown below in Figure 15.



*Figure 15: Cross-section and 3-D Views of pile arrangements*

A score is then assigned for each different solution, and the one with the preferable score is selected. The case study in this work shows that sustainability appraisal at the design stage could generate substantial savings and facilitate better decision making before the construction stage where design decisions could be difficult or impossible to retract. It also shows that detailed problem structuring include development of indicators, computational methods for the multi-criteria decision analysis (MCDA) problem (i.e. sustainability appraisal).

In the paper by Sánchez <sup>60</sup> a method utilizing stakeholder demands and business strategy to inform project selection is developed. The method proposed comprises four steps:

- Cover stakeholders' concerns by means of stakeholder analysis
- Define a Strategy Map
- Conduct sustainability analysis
- Perform a global optimization of projects

The framework takes into account profits and economic, environmental, and social impacts, and for each goal KPIs, appropriate targets and projects are defined. The optimisation problem is then used to analyse planned and ongoing projects, and then provides a ranked list of projects based on achievement of updated strategic goals.

This work is effective as it informs company management of which projects are most effective related to stakeholder sustainability goals. Project selection is not the focus of the work in this thesis, however the comparison and decision making aspect of this method is something which is required in the design analysis tool to be developed here.

Corder et al. <sup>61</sup> propose a system known as Sustainable Operations (SUSOP) which is an approach for the integration of sustainable development principles into the design and operation of industrial processes.

There are three major elements of the SUSOP framework:

- Sustainability opportunities and risks identification. This element is made up of four steps:
  - Familiarisation with sustainability concepts and project context
  - Goal scoping and opportunities and risks identification
  - Analysis of sustainability opportunities and risks
  - Prioritisation of sustainability opportunities and risks.
- Sustainable development (SD) assessment –to conduct a detailed evaluation of the shortlisted or high-priority opportunities and risks.
- Decision support – provide assistance with decision making at project gates.

Once the project team has been through these steps, the main outputs from SUSOP are presented in the Sustainability Register which works in a similar manner to a conventional risk register. The project team then track the implementation of these concepts through the project execution. Ongoing review occurs through the Sustainability Register to ensure that the sustainability opportunities and risks continue to be examined as the project progresses through subsequent phases of development are either implemented or removed (for justifiable reasons) from the register.

Based on the outcomes from this assessment, the Sustainability Register is updated and SD Balance Sheets are generated, which schematically show the positive and negative impacts of the opportunities and risks compared with the business-as-usual approach.. Figure 16 below shows an example of how a Balance sheet is presented.

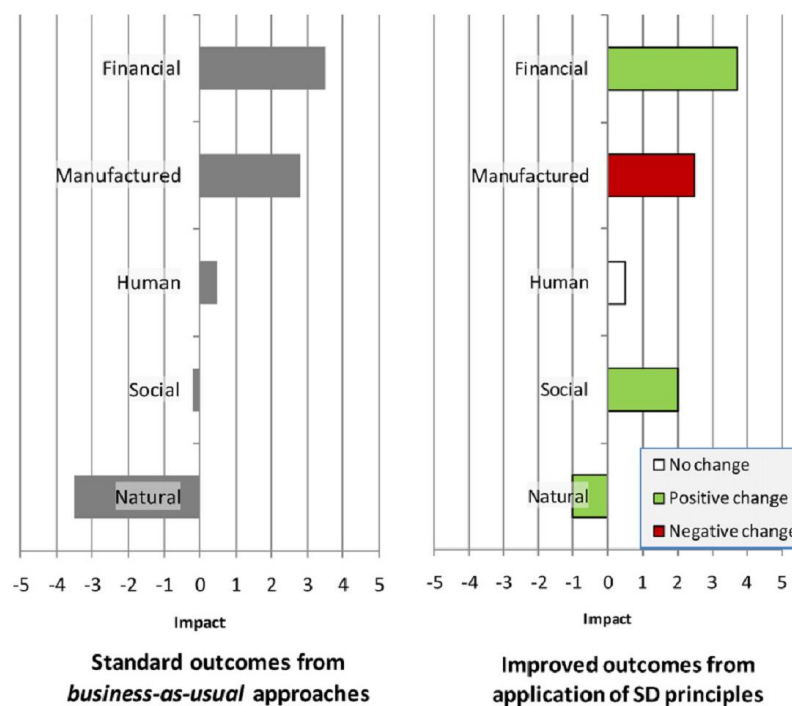


Figure 16: Sustainability Balance Sheet Example <sup>61</sup>

On a positive note, this method covers all elements of sustainability, and in some detail, however combining the different sustainability factors into a combined score for “Financial” capital for example directly contradicts the concept of Strong Sustainability introduced earlier in Section 2.1.4. This could be acceptable if the decision to “substitute” one form of capital for another were explained sufficiently, however the authors do not cover the details of the trade-offs in their paper.

## **2.6 Summary**

The result of the literature review is that a need has been established for a method of sustainability assessment which is integrated within established engineering design and project management processes. Such decision aids must capture the different dimensions of sustainability, as well as the various levels and depths of their associated key performance indicators (KPIs) in a structured manner. The measurement process must be sufficiently detailed and easily understood by all stakeholders, and be included at all phases of the project life cycle.

It has been shown that established practice in project management and engineering design processes are sufficiently defined and accepted, so the goal of this work needs to be development of a process to evaluate and optimise an engineering project design, and then form a baseline for the execution of the project. It must produce results which inform project-level decision makers, while at the same time be able to be reported at a high level to corporate management.

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# 3 Development of the Sustainability Analysis Process

It is apparent from the literature review that the focus and management of sustainability in the engineering design process would be greatly improved by development of a new analysis process using a set of standard sustainability project Key Performance Indicators which are used to plan, design and execute a project solution, regardless of what that project may be. This chapter will cover the selection of this set of indicators, and then in the following chapter it will be developed into a working process as described.

## 3.1 Indicator Selection

As stated in the previous chapter, the scope of this work is not to develop a new indicator set, since a large body of work in this field already exists. What is done here is to select an existing indicator set which is commonly in use and divide it into the operations and project phases as defined by the PMBOK (Project Management Body of Knowledge). This indicator set will then provide a baseline set of sustainability criteria for the preparation, design, planning and execution of a capital project, which should be used in parallel with detailed specifications for the project.

The sets of indicators, or reporting frameworks considered for use were the UN Commission on Sustainable Development Indicators, UN Global compact and the Global Reporting Initiative. Recalling section 2.3.1, the criteria the selected indicator set must fulfil are as follows:

- Different dimensions of sustainability are captured (Economic, Environmental etc.)
- Integrated within established PM and Engineering practice
- Provides a working tool to manage operations over a period of time
- Previously lagging indicators become leading indicators by informing decisions up front
- Measures success during project implementation against specified targets
- Indicators are calculated using established standards and practices
- Qualitative measurements are not acceptable in the design and execution phases
- Options can be compared and impacts can be assessed across all dimensions of sustainability with a greater degree of flexibility

### 3.1.1 Use of the Global Reporting Initiative

It was decided that for the purpose of this work the Global Reporting Initiative indicator set would be used as a base set of indicators to divide into the operations-planning-execution phases, and then use to develop the KPI's required for a capital project.

The other indicator sets considered as potential base cases did not provide the detail required to properly assess the design, planning and execution, which was only found in the GRI set.

## 3.2 Division into Project Phases

The following sections describe how the indicators listed in the GRI set were divided into each phase of a capital project. As stated in Chapter 2 the process developed in this work will focus on the design phase of the project, as previous research has focussed on the feasibility and operational phases. Another motivator to focus on this phase is that the ability of the stakeholders to influence the final characteristics of the project's product gets progressively lower as the project progresses through the execution phase, so the influence over the sustainable development of the project solution is greatest in this phase. As can be seen in Figure 17 below, the cost of making changes and correcting errors generally increases as the project continues, thus greatly affecting at least the economic sustainability of the project.

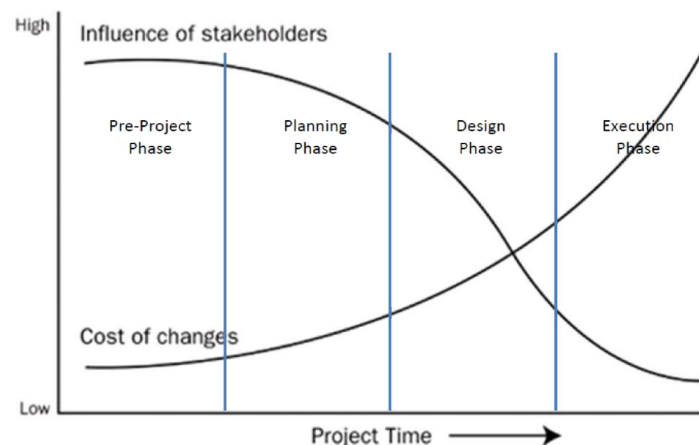


Figure 17: Stakeholder Influence chart – Pre-Project Phase, Planning Phase, Design Phase, Execution Phase, and the decreasing stakeholder influence and increasing cost of change as the project progresses

### 3.2.1 Pre-Project Phase

This first phase of the project is not actually part of the project itself; rather it is normal operations of the organisation – this is the phase where the GRI indicators have been traditionally used. Projects normally evolve from the work environment or market within which the company normally operates. The objectives of projects and operations are fundamentally different. The purpose of the project is to attain its objective and then terminate, conversely the objective of an on-going operation is to sustain the business. The criteria for a GRI indicator to be classified in this section are therefore as follows:

- Variables don't change on a project to project basis
- Indicator is concerned with general company policy/strategy or operations initiatives

Some examples of GRI Indicators classified in this phase are:

- EN18 (Environmental No.18) : Initiatives to reduce greenhouse gas emissions and reductions achieved
- SO2 (Social No.2): Percentage and total number of business units analysed for risks related to corruption



- HR6 (Human Rights No.6): Operations identified as having significant risk for incidents of child labour

For the interested reader, the full list of indicators which are classified in the pre-project phase is shown in Appendix A.

It is apparent that according to the criteria above, the Human and Social factors are most affected by the company's actions in this project phase i.e. those activities which are driven mainly by high-level company policy.

The indicators defined in this section will not be considered further in this work, as the guidelines for how to apply the indicators to a normal company operations are well defined in the GRI guidebook.

### **3.2.2 *Project Planning/Feasibility Stage***

Otherwise known as the Concept and Initiation Phases - The first phase of the project, this phase starts the project by establishing a need or opportunity for the product, facility or service. The feasibility of proceeding with the project is investigated and on acceptance of the proposal moves to the next design phase. The criteria for including the indicators in this phase of the project are as follows:

- Data defined and fixed in feasibility stage once a business case/idea has been generated
- Has an effect on project but data is not dependant on resulting project technical design

The indicators defined by the GRI which can be categorised as pre-planning or feasibility study related are as listed in Appendix B – note: all data collected for these indicators are specific to the project, and is obtained prior to work starting. Of course, the reporting organisation should continue collecting and reporting data for day-to-day operational activities not directly related to the project of concern.

Some examples of GRI Indicators classified in this phase are:

- EC6 (Economic No.6): Policy, practices, and proportion of spending on locally-based suppliers at significant locations of operation
- EN9 (Environmental No.9): Water sources significantly affected by withdrawal of water
- LA10 (Labour No.10): Average hours of training per year per employee by employee category

These indicators will not be analysed further in this work as the intended scope is for the design phase, however some data relevant to this section was collected and used in the Case Study, such as “*Ratios of standard entry level wage compared to local minimum wage*”. The data will be included in the relevant appendix.

### 3.3 Design, Development and Execution

The second phase of the project uses the guidelines set by the feasibility study to design the product, outline the build method and develop detailed schedules and plans for making, or implementing the product. Indicators used in this phase must satisfy the following criteria:

- Data specific to project which can be directly influenced by the project technical design
- Traceable through execution phase to determine success of project

The indicators in this phase will be calculated in the next Chapter as part of the case study phase of this work. The details for each indicator including; Relevance, Compilation, Definition, Documentation and References is included in the following sections Table 3 below shows a summary of the included indicators, while the detailed descriptions follow later.

*Table 3: Summary of GRI Indicators included in Design Phase*

Economic		Environmental	
No.	Description	No.	Description
EC1	Direct economic value generated and distributed	EN1	Materials used by weight or volume
		EN2	Percentage of materials used that are recycled input materials
		EN3	Direct energy consumption by primary energy source
		EN4	Indirect energy consumption by primary source
		EN8	Total water withdrawal by source
		EN16	Total direct and indirect greenhouse gas emissions by weight
		EN17	Other relevant indirect greenhouse gas emissions by weight
		EN19	Emissions of ozone-depleting substances by weight
		EN20	NOx, SOx, and other significant air emissions by type and weight
		EN21	Total water discharge by quality and destination
		EN22	Total weight of waste by type and disposal method

Labour	
No.	Description
LA1	Total workforce by employment type, employment contract, and region

Social	
No.	Description
	None

Note: In the following sections the Indicator reference numbers (EC1, SO4 etc.) have been presented in their original form from the GRI documentation to ensure full traceability to the reference indicator. This explains why they are included out of numerical order after division into the project phases.

### 3.3.1 Economic Indicators – Design and Development Phase

EC1: Direct economic value generated and distributed, including revenues, operating costs, employee compensation, donations and other community investments, retained earnings, and payments to capital providers and governments. Compilation of the EC1 Indicator is shown below in Table 4:

*Table 4: EC1 Economic Indicators*

No.	Economic Indicator	Data Source
EC1.1	Operating Costs	Project Cost estimate
EC1.2	Employee wages and benefits	No. of employees, employee salaries/average salary statistics, manpower plan
EC1.3	Payments to providers of capital	Shareholder payment terms, capital borrowing agreements
EC1.4	Payments to government - gross taxes	Taxable income data

Data on the creation and distribution of economic value provide a basic indication of how the organization has created wealth for stakeholders. The way the indicator is applied here, it will be used as a measure of how effectively the project team has spent the project budget. Cost control data is normally readily available on engineering projects, so calculation of this indicator should be straightforward.

### 3.3.2 Environmental Indicators – Design and Development Phase

EN1: Materials used by weight or volume

*Table 5: EN1 Material Use Indicator components*

No.	Environmental Indicator	Data Source
EN1.1	Raw materials (i.e., natural resources used for conversion to products or services such as ores, minerals, wood, etc.);	Bill of Quantities (BOQ), Product catalogues
EN1.2	Associated process materials (i.e., materials that are needed for the manufacturing process but are not part of the final product, such as lubricants for manufacturing machinery);	BOQ, Equipment technical data
EN1.3	Semi-manufactured goods or parts, including all forms of materials and components other than raw materials that are part of the final product	BOQ, Product catalogues
EN1.4	Materials for packaging purposes	BOQ, Packaging design

This Indicator describes the reporting organization's contribution to the conservation of the global resource base and efforts to reduce the material intensity and increase the efficiency of the economy. These are expressed goals of the OECD Council and various national sustainability strategies. This indicator shall be used here to inform decisions on material use on the project – does saving some material weight or volume (within technical constraints) have an impact on the cost of the project for example.

EN2: Percentage of materials used that are recycled input materials

*Table 6: EN2 Recycled Materials Indicator components*

No.	Environmental Indicator	Data Source
EN2.1	Identify the total weight/vol. of materials used as reported under EN1.	BOQ, Product catalogues
EN2.2	Identify the total weight or volume of recycled input materials.	BOQ, Product catalogues
EN2.3	Percentage of materials used that are recycled input materials Report the percentage of recycled input materials used by applying the following formula: $EN2.3 = \frac{\text{Total recycled input materials used} \times 100}{\text{Input materials used}}$	BOQ, Product catalogues

This Indicator seeks to identify the reporting organization's ability to use recycled input materials. Using these materials helps to reduce the demand for virgin material and contribute to the conservation of the global resource base. The calculation of this data will be similar to EN1, but in this case only recycled material shall be reported. By including this indicator in the design phase, it gives the engineers the opportunity to assess the best materials to use in the project (either recycled or not) to ensure sustainability across the 3 pillars.

EN3: Direct energy consumption by primary energy source

*Table 7: EN5 Direct Energy Consumption Indicator components*

No.	Environmental Indicator	Data Source
EN3.1	Identify primary energy sources purchased by the reporting organization for its own consumption. This includes: <ul style="list-style-type: none"> <li>• Direct non-renewable energy sources including: Coal, natural gas, Fuel distilled from crude oil</li> <li>• Direct renewable energy sources including: Biofuels, Ethanol and Hydrogen</li> </ul>	Sources to be used to provide energy for equipment
EN3.2	Direct energy sources produced	Only relevant if energy will be generated
EN3.3	Direct energy sources sold	Only relevant if energy will be generated
EN3.4	Calculate total energy consumption using the following equation: Total direct energy consumption = direct primary energy purchased + direct primary energy produced - direct primary energy sold	Calculations on equipment requiring a power source i.e. Boiler, under-floor heating, electrical equipment etc.
EN3.5	Report total direct energy consumption in joules or multiples by renewable primary source	Calculations on equipment requiring a power source i.e. Boiler, under-floor heating, electrical equipment etc.
EN3.6	Report total direct energy consumption in joules or multiples by non-renewable primary source	As 3.5

The ability of the reporting organization to use energy efficiently can be revealed by calculating the amount of energy it consumes. Energy consumption has a direct effect on operational costs and exposure to fluctuations in energy supply and prices. The environmental footprint of the organization is shaped in part by its choice of energy sources. Changes in the

balance of these sources can indicate the organization's efforts to minimize its environmental impacts.

#### EN4: Indirect energy consumption by primary source

*Table 8: EN6 Indirect Energy Consumption Indicator components*

No.	Environmental Indicator	Data Source
EN4.1	Identify the amount of intermediate energy purchased and consumed from sources external to the reporting organization. This includes <ul style="list-style-type: none"> <li>• Intermediate energy purchased and consumed from non-renewable energy sources as listed under EN3</li> <li>• Intermediate energy purchased and consumed from renewable energy sources</li> </ul>	Calculations on input and output energy from energy generating equipment

The amount and type of energy the reporting organization uses indirectly through the purchase of electricity, heat, or steam, can indicate efforts by the organization to manage environmental impacts and reduce its contribution to climate change. The particular effect indirect energy usage has on climate change depends on the type of primary energy used to generate intermediate energy. Intermediate energy refers to forms of energy that are produced by converting primary energy into other forms. This Indicator measures the energy required to produce and deliver purchased electricity and any other intermediate energy products (such as district heat) that involve significant energy consumption upstream from the organization's reporting boundary. While not relevant in the case study in this thesis, this indicator is relevant if the project is for an energy producing facility, such as a power plant, as it can be used as a measure of the efficiency of the equipment purchased.

#### EN8: Total water withdrawal by source

*Table 9: EN8 Water Withdrawal Indicator components*

No.	Environmental Indicator	Data Source
EN8.1	Identify the total volume of water withdrawn from any water source that was either withdrawn directly by the reporting organization or through intermediaries such as water utilities. This includes the abstraction of cooling water.	Calculations for equipment using district water supply - domestic water, under-floor heating, air conditioning etc.
EN8.2	Report the total volume of water withdrawn in cubic meters per year (m <sup>3</sup> /year) by the following sources: <ul style="list-style-type: none"> <li>• Surface water, incl. water from wetlands, rivers, lakes, and oceans;</li> <li>• Ground water;</li> <li>• Rainwater collected directly and stored by the reporting org.;</li> <li>• Waste water from another organization; and</li> <li>• Municipal water supplies or other water utilities</li> </ul>	Calculations for equipment using district water supply - domestic water, under-floor heating, air conditioning etc. - as applicable for the sources mentioned

Reporting the total volume of water withdrawn by source contributes to an understanding of the overall scale of potential impacts and risks associated with the reporting organization's water use. The total volume withdrawn provides an indication of the organization's relative size and importance as a user of water, and provides a baseline figure for other calculations relating to efficiency and use.

## EN16: Total direct and indirect greenhouse gas emissions by weight

*Table 10: EN16 Greenhouse Gas Emission Indicator components*

No.	Environmental Indicator	Data Source
EN16.1	Identify direct emissions of greenhouse gases from all sources owned or controlled by the reporting organization, including: <ul style="list-style-type: none"> <li>• Generation of electricity, heat, or steam (as reported in EN3);</li> <li>• Other combustion processes such as flaring;</li> <li>• Physical or chemical processing</li> <li>• Transportation of materials, products, and waste;</li> <li>• Venting; and</li> <li>• Fugitive emissions</li> </ul>	Technical data of equipment which produces and Greenhouse gasses, such as diesel engines, coal burning furnaces etc.
EN16.2	Identify indirect emissions of greenhouse gases resulting from the generation of purchased electricity, heat, or steam (this corresponds with energy consumption reported under EN4.1)	As above, but from energy generating equipment such as diesel generators or district heating plant
EN16.3	Report total greenhouse gas emissions as the sum of direct and indirect emissions in tonnes of CO <sub>2</sub> equivalent	Sum of EN16.1 and EN16.2

Greenhouse gas emissions are the main cause of climate change and are governed by the United Nations Frame-work Convention on Climate Change (UNFCCC) and the subsequent Kyoto Protocol. As a result, different national and international regulations and incentive systems (such as trading climate certificates) aim to control the volume and reward the reduction of greenhouse gas emissions.

### **Direct Emissions:**

Direct Emissions consist of emissions from sources that are owned or controlled by the reporting organization. For example, direct emissions related to combustion would arise from burning fuel for energy within the reporting organization's operational boundaries.

### **Indirect Emissions:**

Indirect Emissions consist of emissions that result from the activities of the reporting organization but are generated at sources owned or controlled by another organization. In the context of this Indicator, indirect emissions refer to greenhouse gas emissions from the generation of electricity, heat, or steam that is imported and consumed by the reporting organization.

## EN17: Other relevant indirect greenhouse gas emissions by weight

*Table 11: EN 17 Other Greenhouse Gasses Indicator components*

No.	Environmental Indicator	Data Source
EN17.1	Identify the greenhouse gas emissions resulting from indirect energy use.	Identification of sources – not including those identified in 16.2
EN17.2	Identify which of the reporting organization's activities cause indirect emissions and assess their amounts (e.g., employee commuting, business travel, etc.). When deciding on the relevance of these activities, consider whether emissions of the activity: <ul style="list-style-type: none"> <li>• Are large compared to other activities generating direct emissions or energy related indirect emissions (as reported in EN16);</li> <li>• Are judged to be critical by stakeholders;</li> <li>• Could be substantially reduced through actions taken by the reporting organization</li> </ul>	Depends on selected battery limits, but could include transportation data for material supply, business travel data etc.
EN17.3	Report the sum of indirect GHG emissions identified in tonnes of CO <sub>2</sub> equivalent	

In this indicator, emissions that are consequences of the activities of the reporting organization but are generated at sources owned or controlled by another organization are reported. In the context of this Indicator, indirect emissions do not include those generated from imported electricity, heat, or steam consumed by the reporting organization (e.g., transport, packaging).

## EN19: Emissions of ozone-depleting substances by weight.

*Table 12: EN19 Ozone Depleting Substances Indicator components*

No.	Environmental Indicator	Data Source
EN19.1	Report emissions of substances covered in Annexes A, B, C, and E of the Montreal Protocol on Substances that Deplete the Ozone Layer incl. CFCs, HCFCs, halons, and methyl bromide	Technical data of equipment which produces these substances – if available!
EN19.2	Identify emissions of ozone-depleting substances using the following formulas: Emissions = Production + Imports- Exports of Substances Production = Substances Produced- Substances Destroyed by Technology- Substances used entirely as feedstock in the manufacture of other chemicals	Technical data of equipment which produces these substances – if available!
EN19.3	Report the emissions of specific ozone-depleting substances in tonnes and tonnes of CFC-11 equivalent	Technical data of equipment which produces these substances – if available!

Measuring ODS emissions enables an assessment of how well the reporting organization complies with current and future legislation, and its likely risks in this area. This is particularly relevant for organizations whose processes, products, and services have used ODS and must transition to new technologies in order to comply with phase-out commitments. The reporting organization's results on ODS phase-out can help indicate its level of technology leadership and competitive position in markets for products and services affected by ODS rules.

EN20: NO<sub>x</sub>, SO<sub>x</sub>, and other significant air emissions by type and weight

*Table 13: EN20 Air Emissions Indicator components*

No.	Environmental Indicator	Data Source
EN20.1	Report the weight of significant air emissions (in kilograms or multiples such as tonnes) for each of the following categories: <ul style="list-style-type: none"> <li>• NO<sub>x</sub></li> <li>• SO<sub>x</sub></li> <li>• Persistent organic pollutants (POP);</li> <li>• Volatile organic compounds (VOC);</li> <li>• Hazardous air pollutants (HAP);</li> <li>• Stack and fugitive emissions;</li> <li>• Particulate matter (PM); or</li> <li>• Other standard categories of air emissions identified in regulations.</li> </ul>	Technical data for equipment selected for use in the project

This Indicator measures the scale of the organization's air emissions and can demonstrate the relative size and importance of these emissions compared to other organizations.

EN21: Total water discharge by quality and destination

*Table 14: EN21 Water Discharge Indicator components*

No.	Environmental Indicator	Data Source
EN21.1	Report the total volume of planned and unplanned water discharges in cubic meters per year (m <sup>3</sup> /year) by: <ul style="list-style-type: none"> <li>• Destination;</li> <li>• Treatment method; and</li> <li>• Whether it was reused by another organization</li> </ul>	Calculations on water discharge for building - sewage, grey water, black water etc.

The amount and quality of the water discharged by the reporting organization is directly linked to ecological impact and operational costs. By progressively improving the quality of discharged water and/or reducing volumes, the reporting organization has the potential to reduce its impact on the surrounding environment.

EN22 Total weight of waste by type and disposal method

*Table 15: EN22 Waste Indicator*

No.	Environmental Indicator	Data Source
EN22.1	Identify the amount of waste created by the organization's operations, by: <ul style="list-style-type: none"> <li>• Hazardous waste (as defined by national legislation at the point of generation)</li> <li>• Non-hazardous waste (all other forms of solid or liquid waste excluding wastewater)</li> </ul>	Civil engineering design for waste producing equipment  Construction plan if waste calculations are to include construction phase
EN22.2	Report the total amount of waste in tonnes by type as identified in 2.1 for each of the following disposal methods: <ul style="list-style-type: none"> <li>• Composting;</li> <li>• Reuse;</li> <li>• Recycling;</li> <li>• Recovery;</li> <li>• Incineration (or use as fuel);</li> <li>• Landfill;</li> <li>• Deep well injection;</li> <li>• On-site storage; and</li> <li>• Other (to be specified by the reporting organization)</li> </ul>	Civil engineering design, construction plan



Data on waste generation figures over several years can indicate the level of progress the organization has made toward waste reduction efforts. It can also indicate potential improvements in process efficiency and productivity. From a financial perspective, the reduction of waste contributes directly to lower costs for materials, processing, and disposal.

### 3.3.3 Labour Indicators – Design and Development Phase

LA1: Total workforce by employment type, employment contract, and region.

*Table 16: LA1 Workforce Indicator*

	<b>Labour Indicators</b>	<b>Data Source</b>
LA1.1	Identify the total workforce (employees and supervised workers) broken down by gender working for the reporting organization at the end of the reporting period.	Project manpower plan, data on employee gender
LA1.2	Identify the contract type and full-time and part time status of employees based on the definitions under the national laws of the country where they are based	Project manpower plan, HR contract data
LA1.3	Report the total workforce broken down by employees and supervised workers, and by gender	Project manpower plan
LA1.4	Report the total number of employees broken down by employment contract and gender	Project manpower plan, HR contract data, employee gender
LA1.5	Report the total number of permanent employees broken down by employment type and gender	Project manpower plan, employment type, gender
LA1.6	Report the total workforce broken down by region and gender, based on the scale of the organization's operations	Project manpower plan, region of operation, gender

The size of a workforce provides insight into the scale of impacts created by labour issues. Breaking down the workforce by employment type, employment contract, and region (region refers to 'country' or 'geographical area') demonstrates how the organization structures its human resources to implement its overall strategy. It also provides insight into the organization's business model, and offers an indication of job stability and the level of benefits the organization offers. As a basis for calculations in several other Indicators, the size of the workforce is a standard normalizing factor for many integrated Indicators. A rise or fall in net employment, evidenced by data reported over the course of three or more years, is an important element of the organization's contribution to the overall economic development and sustainability of the workforce.

### 3.3.4 Execution Phase

Implementation or Construction Phase: The third phase implements the project as per the baseline plan developed in the previous phase. The indicators must satisfy the following criteria to be included in this phase:

- Variables defined in the Design and Development phase...but now the actual data when the project is completed
- Project execution data which cannot be planned for i.e. Loss time accidents. These are of course planned as zero!

The Indicators included solely in the execution phase are listed in Appendix C. Note: Since this is the execution phase of the project, the indicators for the Design and Develop phase

shall be reported during this phase at suitable time intervals – common reporting periods are monthly or quarterly depending on the scale of the project, but it can vary according to the needs of the specific project.

Some examples of GRI Indicators classified specifically in this phase are:

- EN23 (Environmental No.23): Total number and volume of significant spills
- LA2 (Labour No.2): Total number and rate of employee turnover by age group, gender, and region
- SO4 (Social No.4): Actions taken in response to incidents of corruption

### 3.4 Review of Indicator Division

Recalling Section 2.6, the requirements listed below in Table 17 were specified for the analysis tool, and it can be seen that so far that the proposed tool satisfies these criteria:

*Table 17: Indicator Review to Determine Suitability of Assessment Tool*

Criteria	Comment	Pass/Fail
Different dimensions of sustainability are captured	Economic and Environment are well covered, however Human is only briefly included, and Social not at all	Pass – Human and Social are covered well in the FS stage as this is where these can be influenced more
Integrated within established PM and Engineering practice	This has been done – process follows PMBOK and normal engineering project standards	Pass
Indicators become leading indicators by informing decisions up front	Yes, the project team can perform basic design work and see what effect this has on the indicators	Pass
Measures success during project implementation against specified targets	All data produced in the design phase can be tracked in the final product	Pass
Indicators are calculated using established standards and practices	All of the indicators can be calculated using standard engineering tools and methods	Pass
Qualitative measurements are not acceptable in the design and execution phases	No qualitative measures are used	Pass
Options can be compared and impacts can be assessed across all dimensions of sustainability	Other than Social, all indicators are linked parametrically to the design data so the engineers can instantly review the effect of any changes	Pass

However, the following observations are made from the split into the different project phases of the GRI sustainability indicators:

- Main areas of focus are in the Economic and Environmental sections
- Design phase has little or no influence on Social or Labour Indicators
- Majority of social sustainability concerns are addressed pre-project in the Feasibility study phase

## 4 Use of the Sustainability Analysis Process

In this chapter, the proposed analysis process is introduced, along with a detailed explanation of how it should be used to analyse and optimise an engineering project for sustainability. The process is shown below in Figure 18.

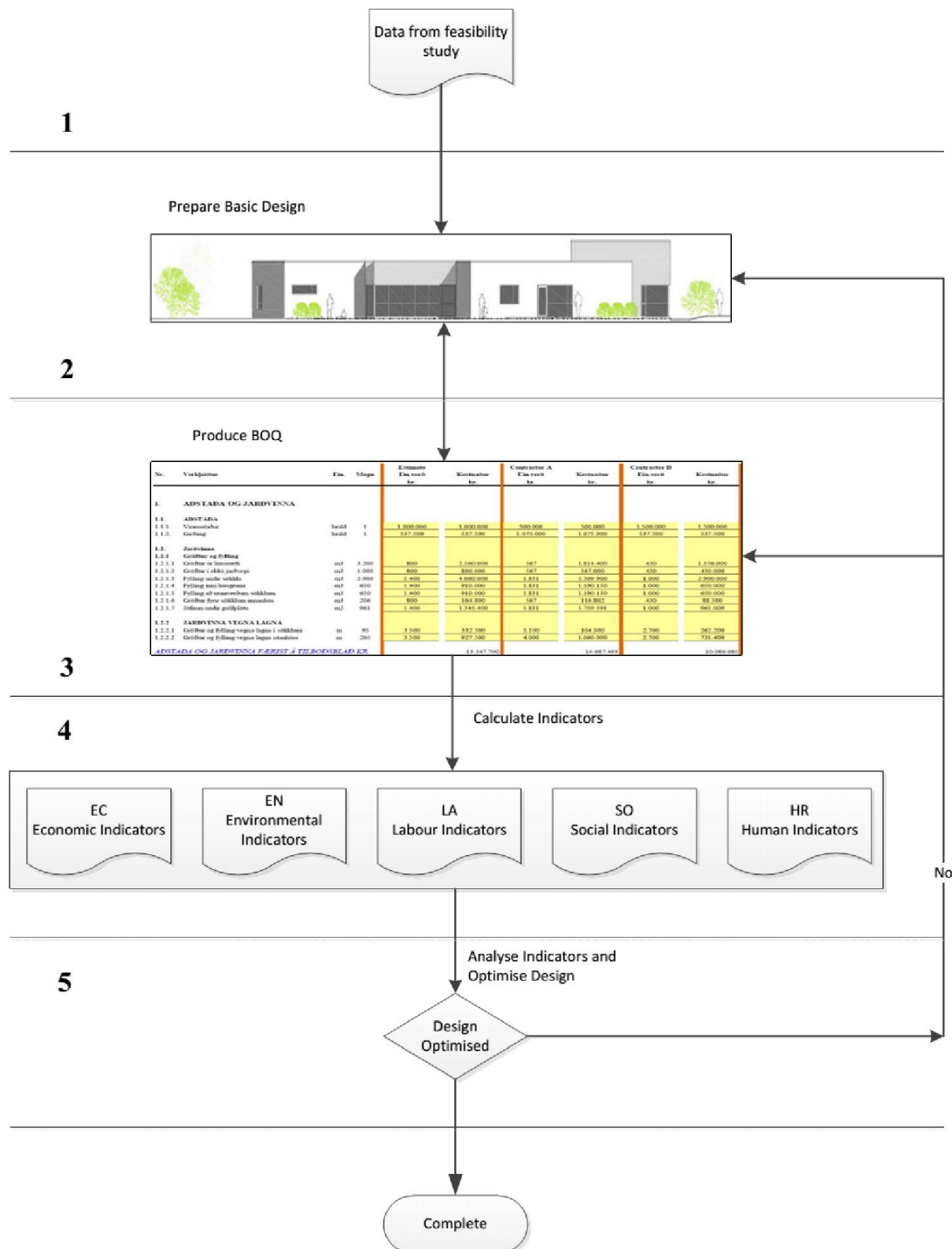


Figure 18: Engineering Process with GRI Sustainability Indicators included

The analysis process is designed to be used in between completion of the basic design and conclusion of detailed design. Once the basic framework of the project engineering is established, the indicators listed above are calculated in coordination with the Bill of Quantities (BOQ), and the engineers review the impact of changes on the design with respect to the sustainability indicators.

The following steps describe in more detail how the process should be used to perform the sustainability analysis and optimisation of the project:

### **Step 1**

The first step is to collect and analyse all external data from the feasibility study and pre-project phases which will have an impact on the design of the project solution. This can include, but is not limited to the following:

- Employee salary data
- Location and environmental data
- Water sources and relevant data

### **Step 2**

The next step is to lay out the basic design of the project and perform the rough calculations and preliminary engineering. This enables an initial draft of the Bill of Quantities to be produced.

### **Step 3**

Next, the detailed BOQ is produced from the basic design data which lists all the components included in the project, such as steel work, concrete, piping, ventilation ducts etc. The BOQ is linked to the design software (AutoCAD for example), which means any subsequent changes in the design update the BOQ automatically.

### **Step 4**

Next the BOQ is used to automatically generate the indicator data for the indicators identified in Section 3.3 as being part of the design phase. Background data collected in Step 1 is used here as required.

### **Step 5**

Finally, once the indicators have been generated the project team are free to work with the design to try to optimise the design using the indicators as a guideline to ensure a focus on the sustainability of the solution. Once the optimisation process is complete the project is ready for the execution phase. The indicators calculated in this stage now form a baseline for the execution of the project.

As further explanation, Figure 19 below shows in more detail how the data is built up for the heating pipework related to the Test Case project which will be introduced in more detail in the next Chapter.

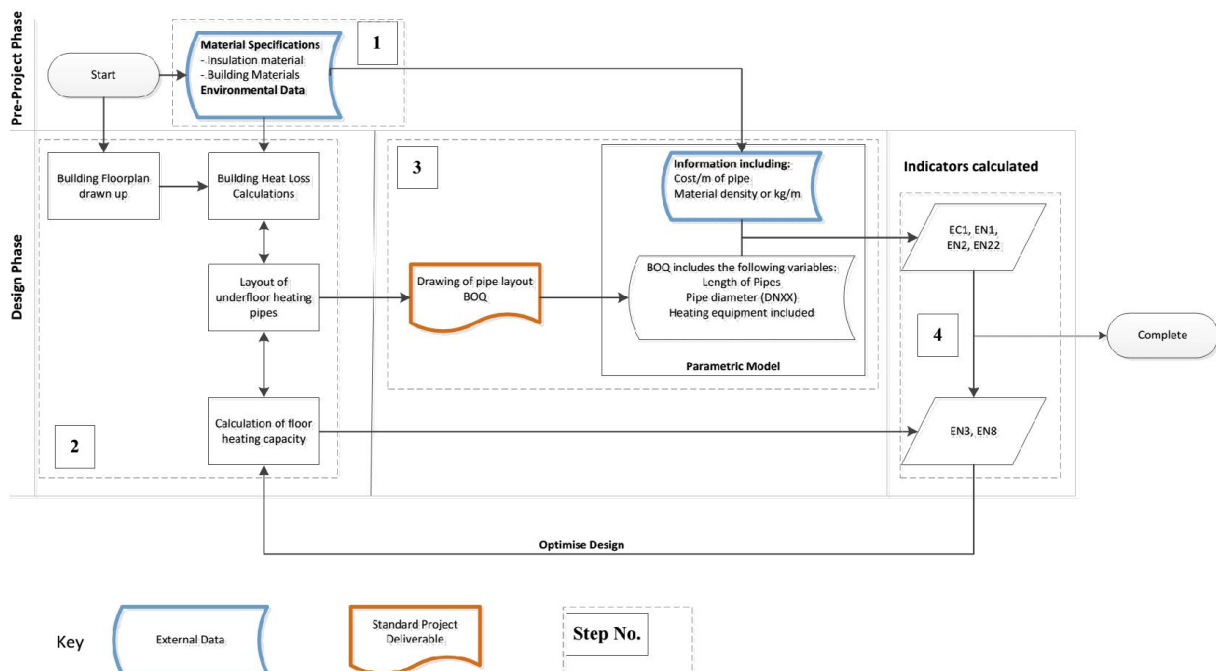


Figure 19: Explanation of process used for the heating pipework and how the relevant indicators are calculated

The process to calculate the indicators for the underfloor heating pipework is shown above in Figure 19, and is as follows:

### Step 1

The first step is to establish the basic design of the building floor plan, and collect the relevant external data such as what insulation material is to be used, external and internal building dimensions, environmental conditions (temperature etc.).

### Step 2

Once this is done the engineer draws out the first draft of the underfloor heating layout, which provides the basis for the calculation of the heat load. Using the information collected in Step 1, the expected heat loss of the building envelope is determined – this is the basis for heating requirement of the building.

Using the drawings and data on the building envelope design, the heat loss from the building is then calculated. The designer/engineer then draws out the proposed pipe layout, and calculates the expected heat load produced by the system (standard calculation involving pipe length, flow rate, pipe size etc.).

### **Step 3**

Once the layout of the pipes has been determined, the system Bill of Quantities (BOQ) is produced automatically. This includes a detailed breakdown of exactly what equipment is included in the system.

### **Step 4**

By then combining the BOQ with data on the pipes to be used in the system, such as Cost/m of pipe, kg/m of the pipe (or material density and pipe size), the Indicators EC1, EN1, EN2 and EN22 are automatically generated. Furthermore, the heat load calculation provides a direct input for the indicators EN3 and EN8.

### **Step 5**

Once this basis has been established, the engineer is now free to adjust any variable described above, and the effects are instantly shown in the indicators. The linkage between the engineering design and the sustainability indicators is the basis of the tool developed in this work, so it is now necessary to test the system in a test case project to see if it works as intended.

In the next chapter, the proposed process will be tested in a real life case study example. As the process is intended to be used during the design phase, this is where the focus will be – it is assumed the project has already gone through the earlier phases successfully. The purpose of the study will be to determine if the indicators are a) suitable, b) in the correct phase and c) the process is easy to work with.

## 5 Test Case– Nursery School in Fjarðabyggð

This chapter will cover the case study used to test the process developed in the previous section. The project comprises development of a new 120 child nursery school. In accordance with current building regulations, the building shall be between 780-840m<sup>2</sup>, surrounding land between 3600-4800m<sup>2</sup>, with car parking for 23 vehicles.

The study will be executed as follows:

- Prepare WBS and planning of case study project – using actual case study example
- Collect data and calculate relevant GRI indicators from the design phase of the project
- Discuss the results

The relevant project stakeholders are listed below:

Owner/Client:	Fjarðabyggð Municipality
Architectural design:	P-Ark Architects, Reykjavík
Electrical Design:	RTS Verkfræðistofa
Civil Engineering work:	Mannvit hf.
Building services:	Mannvit hf.
Construction Management:	Mannvit hf.

The reason this project shall be used as a case study example is as follows:

- Good access to data and design
- Multi-discipline project (civil, electrical, mechanical)
- Easy comparison with previous works in this field which mostly focus on building or construction work
- Good comparison with current standards and methods – Building Research Establishment Environmental Assessment Methodology (BREEAM), Leadership in Energy & Environmental Design (LEED) etc.

### 5.1 Test Case Basis

In this thesis case study, focus will be on the design and development stage as this is where it has been shown there is most opportunity for improvement in the current literature. Several previous works exist on the feasibility stage – focussing on aspects such as government debt, local labour availability etc., however this work will propose the steps after that to design and implement sustainability theory into the design of the project.

Unfortunately since the project used as a test here has not yet progressed to the execution phase yet, there is limited opportunity to analyse how suitable the indicators would be. However the design engineering work was completed, and bids were received for the work, so this information will be used as a test case, with estimates made as suitable for the rest.

### 5.1.1 Battery Limits of Study

Project battery limits is the imaginary line where the scope of work ends. In a report of the sustainability of a project this is very important as it defines where the responsibility and decision making of the project owner end. The battery limits can be varied as required by the project team to ensure the scope of the study is manageable, but still covers a suitable range of factors. In each section below (divided by Sustainability category), the battery limits are defined. These of course could be either expanded or reduced at the request of the Project Owner, but it is important they are clearly stated.

### 5.1.2 Data Source for Test Case

Data for the case study was collected from the following sources:

- Design and project management data (Mannvit hf, P.Ark Architects)
- Technical and commercial resources – websites, catalogues, brochures
- Statistics Iceland

### 5.1.3 Work Breakdown Structure

The Work Breakdown Structure for the project design phase which was executed by Mannvit hf. is shown below in Figure 21. Building design, landscaping and electrical designs were produced by others.

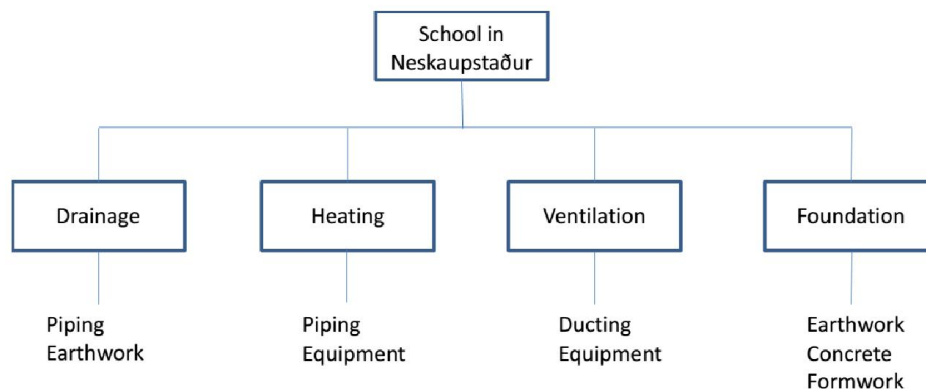


Figure 20: Case Study WBS

## 5.2 Test Case Design Phase Results

In this next section the results of the indicator calculation for the Case Study are detailed.

The design detail is based on the actual project data for the Fjarðabyggð School. If the design team were to actually use the method proposed here it can be assumed that they would use the indicators to optimise the design before proceeding the construction phase. However, since no optimisation was done the data is presented as is.

### 5.2.1 Labour Indicators

In this section the Labour Indicators for the design phase is calculated and presented.



Battery limits of the Labour Indicators:

- Employee hours only based on Mannvit design team. Could however be extended through installation contractor, EPCM team, supervision, commissioning etc.
- Contract type based on employment status within Mannvit, not on project, since all project employees are on a temporary contract.
- Region refers to the Fjarðabyggð region in the East of Iceland – original project plan was to have all employees in that area

Project workforce calculations and the resulting Labour Indicators based on the project plan are shown below in Table 18.

*Table 18: Labour Indicators Calculated for Case Study*

Engineer	Planned Hours
1	40
2	220
3	100
4	0
5	110
6	200
7	300
8	0

Indicator	Description	Qty.	Gender
LA1.2	Contract Type	6	Male
		0	Female
LA1.3	Gender	6	Male
		0	Female
LA1.5	Employment Type	6	Male
		0	Female
LA1.6	Region	6	Male
		0	Female

Total	970
-------	-----

The table above shows the Engineer (numbered 1-8) and the hours planned for their work on the project. Note: Employees 4 and 8 were not planned to be involved in the project, however they were subsequently added to the project team. Therefore they are included here in the plan, with actual data to be shown later. The table shows that the total hours the project manager assigned to the team was 970.

Recalling the indicator explanations in Section 3.3.3, the table shows that of the 6 employees planned on the project, all were male, full-time employees based in the Fjarðabyggð region.

Unfortunately the planning on this project did not go into a monthly breakdown on the engineering resources, which would be required for the sustainability analysis to satisfy the time series requirement. However, using the actual project engineering schedule it is possible to estimate the number of hours each engineer was expected to work on the project each month. This will be used for comparison with the actual data later on. The manpower curve with a month by month breakdown is shown below in Figure 21, and the full data is included in Appendix E.

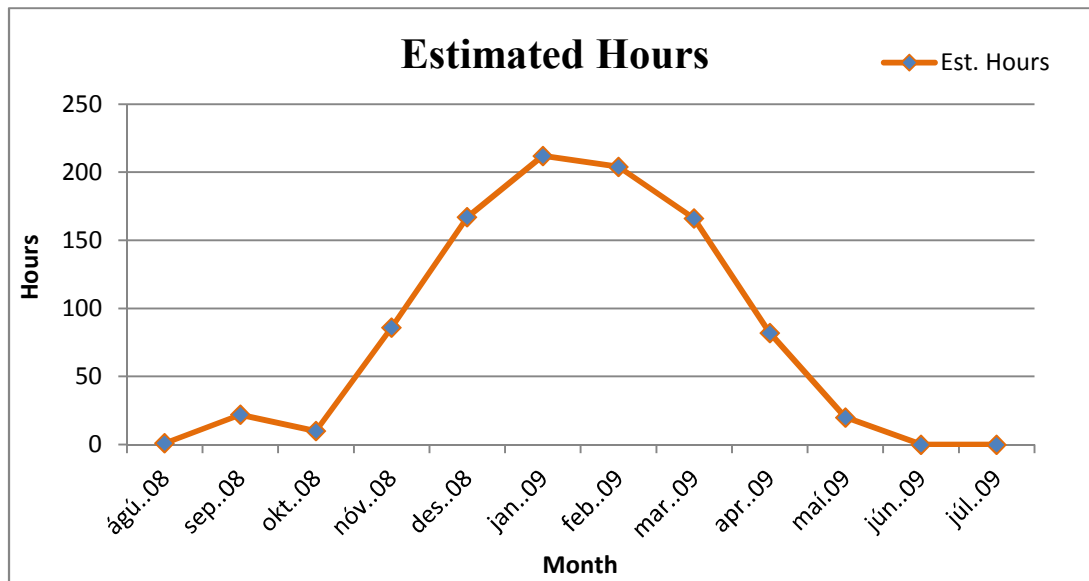


Figure 21: Labour Indicators for Case Study

This shows that the project team was expected to be established in August 2008, rise to approximately 200 hours per month by January 2009, then decline and complete the project by June/July 2009.

Based on this plan, the project management would produce a cash flow estimate covering the expected cost of the employees for each month. This would then form the basis of Economic Indicator EC1.2 which is described in Section 5.3.2

### 5.2.2 Economic Indicators

The economic data collected and calculated using parametric estimating for the design phase is detailed in the following section.

Battery limits of the Economic Indicators:

- “Employees” in this case describes those persons employed by Mannvit for the project
- Costs for employees engaged by contractors is included in “Operating Costs” as direct cost
- Operating Cost data is only related to direct spend with suppliers
- No consideration of operating costs of the asset. Assumption is made that this is done as part of the FS to prepare a business case. Payback calculated through experience in normal operations
- Project overhead costs (included in EC1.1) such as building rent, computers, stationary etc. not included as detailed information is limited for this case study

### EC1.1 – Operating Costs

The summary table of calculation of the “Operating Costs” indicator is provided in Table 19 below. This is formulated from the project cost estimate for materials and construction:

*Table 19: Cost Estimate Summary*

No.	Item	Cost Estimate (kr.)
1	Mobilisation & Earthwork	13.547.700 kr.
2	Foundations	36.697.470 kr.
3	Pipes	25.249.150 kr.
4	Electrical	9.277.336 kr.
5	Completion Inside	16.934.472 kr.
7	Completion Outside	19.423.974 kr.
8	Landscaping	19.470.559 kr.
9	Other	3.400.000 kr.
	<b>Grand Total</b>	<b>144.000.660 kr.</b>

This cost estimate was produced by linking the Bill of Materials produced by the design software and the item unit rates. Therefore, if the project team were to change any design details (i.e. heating pipe length) this table would be automatically updated. This allows the designers to make design changes, instantly see the effects, and ideally optimise the cost of the project. Once the design is fixed however, the cost estimate is complete and the project goes to tender.

As shown above in Table 19, the total cost estimate for the project is approximately 144 million ISK. In the real life case, a value improvement exercise was not undertaken to see if any reductions in cost could be made, but the data is linked effectively to allow the project team to do this.

To satisfy the requirement of sustainability indicators to be reported in time series, this estimate should be broken down as a cash flow plan based on the project schedule. Unfortunately since the project has not been approved for construction as yet, no such schedule exists in sufficient detail. However, this is standard practice on a project of this scale, and it is assumed an experienced project team could easily produce this plan.

### **EC1.2 – Employee Wages and Benefits**

Table 20 below summarises the employee wages estimated for the design phase of the project. This shows the breakdown per employee, average wage for their position (based on data from Statistics Iceland), planned hours on the project and then planned salary (hours x hourly wage). The project management would use these figures in planning cash flow and total cost of the project.

Table 20: Employee Wages and Benefits Summary

Engineer	Ave. Wage (kr/hr)	Planned Hours	Planned Salary (kr)
1	3050	40	122.000
2	3050	220	671.000
3	3050	100	305.000
4	3050	0	0
5	3050	110	335.500
6	3050	200	610.000
7	3050	300	915.000
8	3050	0	0
Total		970	2.958.500

As stated in earlier, it is a requirement of the sustainability indicators that they are reportable in time series. This is done in this instance by combining the salary cost above, with the manpower plan presented in 5.2.1. This chart is shown below in Figure 23.



Figure 22: Employee Wages and Benefits Summary

This curve has a similar shape as the manpower plan as expected, and shows that the monthly manpower cost rises to just below 600.000 ISK in January 2009. The full breakdown of this chart is included in Appendix E.

### Economic Indicators not included in Study

The following indicators are not included in the study due to lack of information.

#### EC1.3 – Payments to Providers of Capital

This indicator is related to the cost of Capital provided by Lenders and Equity Investors (i.e. shareholders). No information is available on this cost related to the Case Study project.

### ***EC1.3 – Payments to Government – Gross Taxes***

No information/data is available for this Indicator for the Case Study Project.

Once all of these figures are calculated from basic design data, they can be easily recalculated using unit rate based estimation techniques. This provides the link between economic and other pillars of sustainability which is required for an effective decision making tool. In theory the link between the cost estimate and the parametric design data works well – the project team can instantly review the impact changes made during the design phase have on the overall cost of the project.

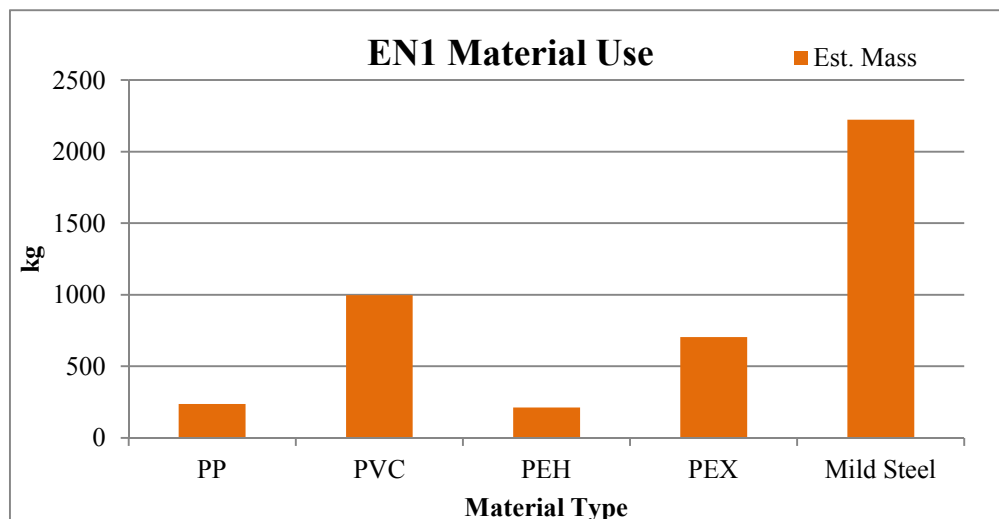
### ***5.2.3 Environmental Indicators***

The battery limits of Environmental Indicators are as follows:

- In this case the limit for waste, water, energy etc. was only for equipment in the final solution – could be designed to include construction phase (i.e. waste and water consumption during construction etc.)
- The boundary of the site is where disposed materials are assumed to be waste – material such as earth which is distributed throughout the site is not considered waste
- Materials use does not include items such as paint thinners, cutting fluids, power tool consumables etc., only materials directly used in construction

### **EN1 Materials used by weight or volume**

Figure 24 below summarises the results of the mass calculation performed in the case study:



*Figure 23: EN1 Material Use Calculation Summary*

The data was linked to the design parameters produced automatically from the BOQ; therefore any subsequent changes to the detail design would automatically update the mass calculations. This allows the designers to review options to reduce the materials used in the design and minimise environmental impact while still meeting the project requirements.

The materials PP, PVC and PEH were planned for in the design of the sanitary water system, the PEX pipes were planned for the underfloor heating and the steel was for the ventilation ducts. The chart shows that by far the highest amount of material is used in the ventilation ducting.

### **EN3 Direct energy consumption by primary energy source**

#### *EN3.1 Energy for Building Heating*

Based on the building design data from the architect and civil engineers, the calculated heat loss from the building under normal conditions was 60.145 W (approx. 60 kW).

This calculation is based on a number of factors including: wall surface area, number of outward facing walls, window surface area, wall thickness and material etc. From this value the mechanical engineers design the heating network. The full data is included in Appendix F.

The total energy used to power the boiler for the under floor heating network is calculated to be 99 kW. This is calculated automatically based on standard data for water pipes, plus the length of heating loops throughout the building. By increasing the variables for the piping system, such as length, pipe diameter, number of heating loops, this figure can go up or down as required. It is not clear why the designers chose to have the energy use of the heating system rated at almost 40kW higher than required.

The length and diameter of heating pipes is linked directly to the cost estimate data. Any changes in pipe length affects the energy required and also the cost of the pipes, therefore the link between the calculations works as expected.

#### *EN3.2 Energy for Hot and Cold Water*

The energy required for the boiler to heat the hot water system for the building is calculated to be 12kW. This is calculated using standard pressure drop and water use calculations for hot water systems. Again, this can be easily linked to the length of the water pipes, equipment used etc., and the link is also established with the cost estimate, so all calculations are working as expected.

#### *EN3.3 Energy for Electrical Equipment*

No data was available for electrical equipment (lights etc.) on the case study – however this can be defined as follows:

- Power (W) rating for all equipment multiplied by expected usage, producing a value in kWh.

#### **EN3 Energy Summary**

For all power calculations, we need to define reporting period and convert kW into kWh or GJ as this is the accepted unit for this indicator, and the billing unit for energy. Normally this is one year, so assuming normal working hours (08:00-16:00, 5 days per week) as the operating time; the power used in one year is summarised below in Table 21.

Table 21: Building Energy Use Summary, Design Calculation

No.	Item	kW	kWhr/yr
1	Heating	99	158.400
2	Hot Water	12	19.200
	TOTAL	111	177.600

## EN8 Total water withdrawal by source

Table 22 below shows the expected water withdrawal in l/s for all the equipment in kitchens and bathrooms in the school.

Table 22: Water Withdrawal Summary, Design Calculation

	Cold Water			Hot Water			
Equipment	Qty	Flow (l/s)	Total Flow (l/s)	Qty	Flow (l/s)	Total Flow (l/s)	
Kitchen Sink	6	0,2	1,2	3	0,2	0,6	
Toilet (Type 1)	19	0,1	1,9	17	0,1	1,7	
Shower Drain	1	0,15	0,15	1	0,15	0,15	
Floor Drain	2	0,2	0,4	0	0	0	
Childs Sink	18	0,2	3,6	17	0,2	3,4	
Dishwasher	1	0,2	0,2	0	0	0	
Toilet (Type 2)	16	0,1	1,6	0	0	0	
Washing Machine	1	0,2	0,2	0	0	0	
		Total (l/s) Cold	9,25			Total (l/s) Hot	5,85

The accepted indicator unit in this case is m<sup>3</sup>/yr, so converting the totals to m<sup>3</sup>/yr using the following working hours (08:00-16:00, 5 days per week, est. 5% operational time) produces the following:

$$\text{Total Cold (m}^3\text{/yr)} = 319.7 \text{ m}^3\text{/yr} \quad \text{Total Hot (m}^3\text{/yr)} = 202.2 \text{ m}^3\text{/yr}$$

## EN21 Total water discharge by quality and destination

Table 23: Water Discharge Summary, Design Calculation

Equipment	Qty	Max Flow (l/s)	Total (l/s)
Sink 530x400x160mm	5	0,3	1,5
Sink for Children	2	0,5	1
Cleaners Sink 530x500x300mm	2	1	2
Kitchen Sink 500x500x160mm	1	0,3	0,3
Kitchen Sink 720x500x160mm	1	0,3	0,3
Floor Drain ø40/ø50	4	0,5	2
Dishwasher	1	1,2	1,2
Washing Machine	1	1,2	1,2
		Total (l/s)	9,5

As with EN8, the accepted indicator unit is m<sup>3</sup>/yr, so converting the totals to m<sup>3</sup>/yr using the following working hours (08:00-16:00, 5 days per week, est. 5% operational time) produces the following:

$$\text{Total Water Discharge (m}^3\text{/yr)} = 328.3 \text{ m}^3\text{/yr}$$

### **EN22 Total weight of waste by type and disposal method**

Other than waste water which was captured in EN21, the equipment in this building does not produce waste, so this indicator is zero. This study does not include waste by the operation of the school itself, as this would normally be accounted for in the Environmental Impact Assessment.

Comments on Environmental Indicators:

- Environmental factors form the main part of technical design
- Difficult data collection for some items, but this would improve if sustainability reporting gained wider acceptance

Once all these indicators have been calculated and reported satisfactorily, the project would be reviewed by the Owner and then approved for execution. The following section will cover what should be done with the above indicators, and how they can be used to effectively manage the construction of the project.

### **Environmental Indicators not included in Study**

The following indicators are not included in the case study due to lack of information.

### **EN2 Recycled Materials**

No data on recycled materials for the products used in this project. This needs to be improved by manufacturers for future sustainability reporting, as limited information on the recycled content of construction materials was available through the research.

### **EN4 Indirect energy consumption by primary source**

No indirect energy produced by the equipment in this project, so this indicator is omitted.

### **EN16 Total direct and indirect greenhouse gas emissions by weight**

No greenhouse gasses identified as directly produced by the equipment within the battery limits of the study. This indicator is omitted.

### **EN 17 Other relevant indirect greenhouse gas emissions by weight**

No greenhouse gasses identified as directly produced by the equipment within the battery limits of the study. This indicator is omitted.



## **EN 19 Emissions of ozone-depleting substances by weight**

No ozone-depleting substances identified as emitted by the equipment within the battery limits of the study. This indicator is omitted

## **EN20 NO<sub>x</sub>, SO<sub>x</sub>, and other significant air emissions by type and weight**

No other significant air emissions identified as directly produced by the equipment within the battery limits of the study. This indicator is therefore zero.

## **5.3 Case Study Execution Phase**

Once the design phase is satisfactorily complete, and the project owner has committed to go ahead with implementation of the project, the project enters the execution phase.

Note: Since the project has not yet entered the construction phase, estimates will be used where real project data is not available. This will be stated clearly in the text.

### ***5.3.1 Labour Indicators***

In this section the Labour Indicators will be presented for the execution phase of the project engineering. Since the project has not yet entered the construction phase, the battery limit of the study will only be the engineering design phase. On a real project this should of course cover all stages from design, procurement, installation and commissioning.

Notes - In the execution data, Region 1 refers to the Fjarðabyggð region in the East of Iceland, Region 2 refers to other municipalities out with this area but still within Iceland

Recalling Section 3.3.4, the following Indicators should also be included in the Execution Phase, as well as those calculated above in Section 5.2.1.

**LA1.2:** Total number and rate of employee turnover by age group, gender, and region.

**LA1.7:** Injuries, occupational diseases, lost days, absenteeism and number of work-related fatalities by region. Since the project has not been completed yet, there is no data for this indicator. However, reporting these types of statistics is standard on any construction project – assumed that the Project team would have no issue reporting this information.

### **Project Execution LA1.1-1.7**

Therefore the execution data for the Labour Indicators is as follows:

Table 24: Execution Labour Indicators for Case Study

Engineer	Planned Hours	Actual Hours	Variance (hrs)	Variance (%age)
1	40	46	6	15%
2	220	255	35	16%
3	100	81,5	-18,5	-19%
4	0	8	8	N/A
5	110	118	8	7%
6	200	152,5	-47,5	-24%
7	300	404	104	35%
8	0	18,5	18,5	N/A
<b>Total</b>	<b>970</b>	<b>1084</b>	<b>113,5</b>	<b>12%</b>

Indicator	Description	Planned Qty.	Actual Qty.	Gender
LA1.2	Contract Type	6	8	Male
		0	0	Female
LA1.3	Gender	6	8	Male
		0	0	Female
LA1.5	Employment Type	6	8	Male
		0	0	Female
LA1.6	Region 1	6	6	Male
		0	0	Female
	Region 2	0	2	Male
		0	0	Female
LA1.7	Turnover	0	-7%	Male
		0	0	Female

Table 24 shows that there was a 12% increase in hours spent on the project from the initial plan (1084 vs 970), which is not a particularly large amount and would probably be included in a contingency calculation. There was also an increase in the team from 6 to 8, which is reflected in the indicators LA1.2, 1.3, 1.5, 1.2 and 1.7.

### Time Series reporting of Labour Indicators

Recalling Figure 22 presented in 5.2.2, if the manpower plan is execution exactly as expected, actual paid hours on the project should match the curve shown on that chart. However, by comparing the actual invoiced hours on this project, we can see in the chart below that there was some difference:

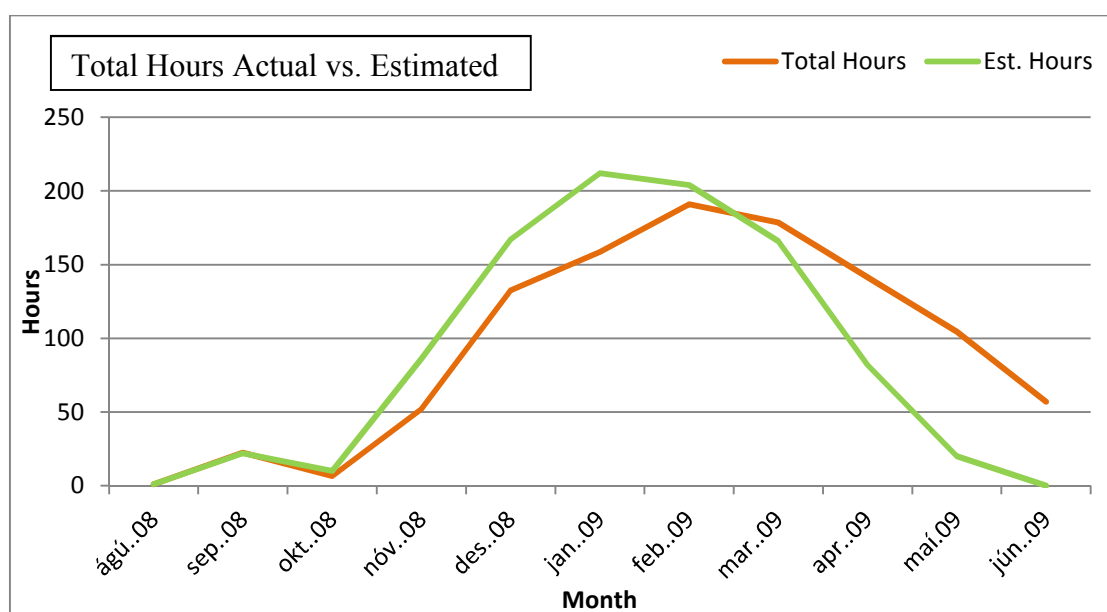


Figure 24: Execution Labour Indicators for Case Study

As can be seen in Figure 25, there seems to have been some delay in completion of the project which has shifted the manpower curve to the right. This would mean an impact on project cash flow for payment to the engineering team – illustrated below by the modified chart for EC1.2.

As before, this shows the extension of the project schedule, meaning the owner is still paying for employee salaries long after the project was expected to be finished. This is not an effective use of resources, and long term on a larger project this could have serious financial impact for all stakeholders.

It would be expected that the Project Manager would review this data on a monthly basis, and as the curve started to slip (Nov/Dec 2008 on the chart above), they would review with the team to see why the hours were not as planned.

### 5.3.2 Economic Indicators

#### EC1.1 – Operating Costs

Table 25 below shows the actual bids received for the work detailed in the cost estimate

*Table 25: EC1.1 Indicators for Case Study*

No.	Item	Cost Estimate	Contractor 1	Contractor 2	Variance 1	Variance 2
1	Mobilisation & Earthwork	13,547.700 kr.	14,687.493 kr.	10,086.680 kr.	8%	-26%
2	Foundations	36,697.470 kr.	38,897.146 kr.	39,470.745 kr.	6%	8%
3	Pipes	25,249.150 kr.	25,904.490 kr.	26,463.029 kr.	3%	5%
4	Electrical	9,277.336 kr.	7,769.782 kr.	7,919.330 kr.	-16%	-15%
5	Completion Inside	16,934.472 kr.	17,479.655 kr.	17,063.724 kr.	3%	1%
7	Completion Outside	19,423.974 kr.	24,093.730 kr.	27,221.782 kr.	24%	40%
8	Landscaping	19,470.559 kr.	23,776.779 kr.	24,268.015 kr.	22%	25%
9	Other	3,400.000 kr.	2,790.000 kr.	2,880.000 kr.	-18%	-15%
	<b>Grand Total</b>	144,000.660 kr.	155,399.075 kr.	155,373.305 kr.	7,92%	7,90%

Of course this is only a comparison of the bids for contractor selection. Once the work is in progress, the cost could rise or fall depending on whether there are significant design changes or additions to the contractor scope of work.

What we can see in Table 25 is both contractor bids were higher than the initial cost estimate. This means that the capital expense for the project is higher than expected, and the business case will need to be checked to ensure the project is still viable. Recalling that the requirement for a sustainable project is that the project must meet the need of the business today, while still being able to meet the needs of the business in the future, it is important that the following is considered:

- Is the project still financially viable given the higher costs
- Does the initial outlay on this project mean costs will have to be cut elsewhere?

Since the cost estimate and bids were developed on a unit rate basis, it is easy for the Project team to revisit the estimate to see where they may have went wrong, or to revise the design to reduce costs (if possible).

Unfortunately there is no detailed procurement schedule which would allow the project cash flow to be reviewed in any detail, however as stated in Section 5.2.2, this is standard practice on any project and a number of tools are available to analyse this data.

## EC1.2 – Employee Wages and Benefits

Table 26 below shows the comparison between the actual salary paid to the project employees and the planned salary.

*Table 26: EC1.2 Indicators for Case Study*

Engineer	Ave. Wage (kr/hr)	Actual Wage (kr/hr)	Plan		Actual		Variance	
			Planned Hours	Planned Salary (kr)	Actual Hours	Actual Salary	kr	%age
1	3050	3750	40	122.000	46	172.500	50.500	41%
2	3050	3450	220	671.000	255	879.750	208.750	31%
3	3050	3150	100	305.000	81,5	256.725	-48.275	-16%
4	3050	3750	0	0	8	30.000	30.000	N/A
5	3050	2340	110	335.500	118	276.120	-59.380	-18%
6	3050	2850	200	610.000	152,5	434.625	-175.375	-29%
7	3050	2550	300	915.000	404	1.030.200	115.200	13%
8	3050	2550	0	0	18,5	47.175	47.175	N/A
Total			970	2.958.500	1083,5	3.127.095	168.595	6%

Overall, a variance of 6% (168.595 kr.) on a planned spend of roughly 3 million ISK is not a great amount, and it would be likely the project management would have set aside a contingency fund which would more than cover this amount.

## EC1.2 Time Series Data

Figure 26 below shows the month by month breakdown of how much was paid in salary to the employees engaged on the project, compared with the planned chart presented in Section 5.2.2. The actual salary does not increase as sharply in November 2008, and stays flatter towards the end. This shows that the project team is behind schedule and are still working to catch up near the end of the project. Overall the cost is not a great deal more, but the main impact for the Owner will be the change in cash flow for payments to employees.

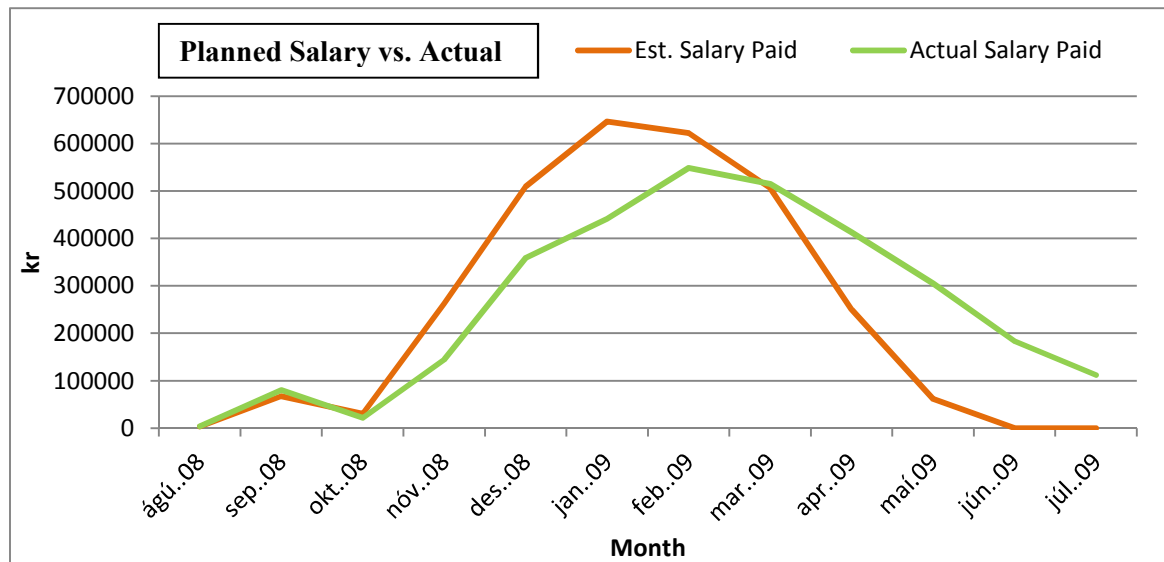


Figure 25: Planned Salary vs. Actual

### Economic Indicator unchanged in Execution Phase

The following indicators have not changed from the Design Phase to the Execution Phase.

#### *EC1.3 – Payments to Providers of Capital*

No change in this indicator from Section 5.3.1.

#### *EC1.3 – Payments to Government – Gross Taxes*

No change in this indicator from Section 5.3.2.

In summary, the data presented from the project execution phase shows that the project could be completed slightly higher than budget, but would be at risk of delay due to the late completion of the engineering. It is the responsibility of the project manager to justify this delay if possible, as it could be due to unforeseen scope changes or changes to the design basis. The purpose of the Economic Indicators is only to report the data and inform management of the resources – something which the indicators above do very well.

### 5.3.3 Environmental Indicators

In this next section, the execution data for the Environmental indicators will be presented. Since this method of design and reporting of sustainability indicators was not being used when this project was done, and the project has not actually went ahead yet, the data for actual equipment is limited. As stated earlier, estimates will be made where appropriate to test the effectiveness of the indicators.

In addition to the indicators presented in Section 5.2.2, the following indicators will also be reported during the project execution phase:

**EN23:** Total number and volume of significant spills.

**EN24:** Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally

**EN28:** Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with environmental laws and regulations.

**EN29:** Significant environmental impacts of transporting products and other goods and materials used for the organization's operations, and transporting members of the workforce.

**EN30:** Total environmental protection expenditures and investments by type.

Unfortunately, as stated earlier, the case study project has not yet proceeded to the execution stage, so there is no data to report for these indicators. What follows will be a short discussion and examples of how the earlier indicators should be used to report the execution of the project.

### **EN1 Materials used by weight or volume**

Since the method of project analysis proposed in this work is not in use in real life, plus the project hasn't gone ahead with construction yet, there is no data as to how much material was actually used in the construction of the school. However an estimated 2,5% rate of material waste is assumed – this is based on the findings of Meghani et al <sup>61</sup>.

This information is summarised below in Table 27 and Figure 27:

*Table 27: EN1 Summary of Material Waste during Project Execution Phase*

<b>Material</b>	<b>Est. Mass (kg)</b>	<b>Actual Mass (kg)</b>	<b>Waste (kg)</b>
PP	237	267	30
PVC	999	1024	25
PEH	212	217	5
PEX	705	722	18
Mild Steel	2223	2321	98
<b>Total</b>	<b>4375</b>	<b>4551</b>	<b>176</b>

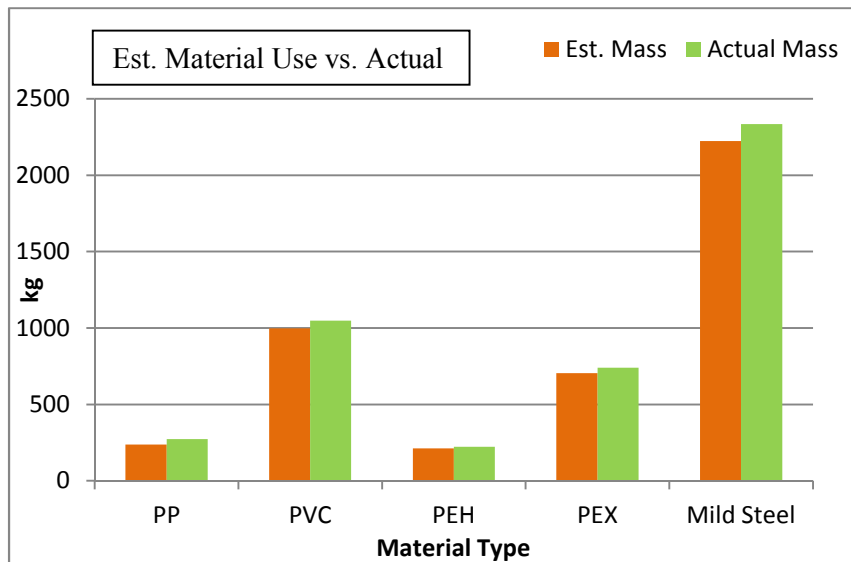


Figure 26: EN1, Summary of Material Waste during Project Execution Phase

The columns in the figure show that the actual material used (shown in green), is higher than the planned value (orange). Of course this is simplified due to the use of the estimated value of 2,5%, but in a real project the fluctuation would vary and the results would be well illustrated. In the project execution report, it would therefore be apparent that excess materials were used in the construction of the school, and it would then be necessary to explain why this happened, and to propose more effective planning measures for the next project.

This indicator is useful as it allows the possibility for the engineers to use materials which are lighter than planned (thinner walled pipes for example) providing this suits the technical constraints of the project, and then report a reduction in the materials used. It could be assumed that these pipes could be more expensive than the planned material, so this increased cost would be noticeable in the EC1.1 Indicator – it is therefore up to the Project Owner to make the decision to change to the lighter pipes, the purpose of the indicator is only to facilitate an informed decision, which it does very well.

## EN22 Total weight of waste by type and disposal method

Recalling the estimated waste for the project was 5%, the waste data would be reported as shown in Table 28, reflecting the increase in material mass from 4375 kg to 4551kg.

Table 28: EN22 Waste Indicator

Material	Est. Mass (kg)	Actual Mass (kg)	Waste (kg)
PP	237	267	30
PVC	999	1024	25
PEH	212	217	5
PEX	705	722	18
Mild Steel	2223	2321	98
<b>Total</b>	<b>4375</b>	<b>4551</b>	<b>176</b>

Since this was only an estimate, there is no information on the disposal method. Of course this information would be readily available in a real project.

## **EN2 Recycled Materials**

As stated in Section 5.3.2, there was no consideration of the use of recycled material in the design of this project. However it could be assumed that the data would be reported in a similar manner to EN1 – with the estimated material mass plotted in a chart compared to the actual. Again, the project team is also informed of the cost impact in the EC1.1 indicator of using extra recycled materials (if there is any).

## **EN3 Direct energy consumption by primary energy source**

### *EN3.1 Energy for Building Heating*

This indicator is also tracked as part of normal company operations and is difficult to report over short time periods. Therefore the accuracy of the design estimate will be revealed over time – thus revealing the success of the decisions made on the project, which was another target feature of the analysis tool. In the short term at project conclusion, it could be reported what the kW rating of the boiler installed was, compared with the estimate.

### *EN3.2 Energy for Hot and Cold Water*

As above, the accuracy of the energy use calculations will only become apparent over a long time period. An effective way to measure the accuracy of the estimate would be to compare quarterly utility bills with the expected energy consumption – this is why the data was presented in kWhr.

### *EN3.3 Energy for Electrical Equipment*

Same comment as EN3.1 and EN3.2 for this indicator – the success of the estimate will only be revealed over a long period of time.

## **EN8 Total water withdrawal by source**

As with the energy use indicators, the accuracy of the water withdrawal calculations will only become apparent over a long time period. Again, an effective way to measure the accuracy of the estimate would be to compare quarterly utility bills with the expected water use.

## **Environmental Indicators unchanged from Design Phase to Execution Phase**

The following indicators have not changed from the Design Phase to the Execution Phase.

## **EN4 Indirect energy consumption by primary source**

No indirect energy produced by the equipment in this project, so this indicator remains zero.



**EN16 Total direct and indirect greenhouse gas emissions by weight**

No greenhouse gasses identified as directly produced by the equipment within the battery limits of the study. This indicator is therefore zero.

**EN 17 Other relevant indirect greenhouse gas emissions by weight**

No greenhouse gasses identified as directly produced by the equipment within the battery limits of the study. This indicator is therefore zero.

**EN19 Emissions of ozone-depleting substances by weight**

No ozone-depleting substances identified as emitted by the equipment within the battery limits of the study. This indicator is therefore zero.

**EN20 NO<sub>x</sub>, SO<sub>x</sub>, and other significant air emissions by type and weight**

No other significant air emissions identified as directly produced by the equipment within the battery limits of the study. This indicator is therefore zero.

**EN21 Total water discharge by quality and destination**

As with EN8, the accuracy of the water discharge calculations will only become apparent over a long time period. Again, an effective way to measure the accuracy of the estimate would be to compare quarterly utility bills with the expected water use.

**5.3.4 Social Indicators**

Recalling 3.3.4, the following indicators are part of the execution phase, and during construction of the school this data should now be reported.

**SO4 Actions taken in response to incidents of corruption.**

No incidences of corruption were reported during the design phase of this project

**SO7: Total number of legal actions for anticompetitive behaviour, anti-trust, and monopoly practices and their outcomes.**

No legal actions were taken against any company involved in this project in the timeframe in question

**SO8: Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with laws and regulations.**

No fines or sanctions were applied to any of the companies involved in this project in the timeframe in question

This concludes the Execution phase. In the next chapter the result of the case study will be discussed

## **5.4 Test Case Summary**

In this Section the indicators identified as part of the design and execution phases have been calculated and the proposed method tested using a real life school project in Fjarðabyggð.

The test case has shown that the tool and indicator set proposed for the engineering design phase of a project in Section 3 can be used to facilitate decisions when trade-offs are required between different dimensions of sustainability (Economic, Labour, Environmental etc.) during the design phase.

Despite the time consuming data collection, through effective linkage with parametric design data, the indicators show good results and could in theory be used to more closely manage the sustainability focus of an engineering project

## 6 Discussion

This Section will include a review of the answers to the research questions posed in the Introduction. Then a discussion will follow on the strengths and weaknesses of the sustainability design process developed in this work based on the findings of the Test Case, as well as suggestions for future work to improve or expand on the work presented here.

### 6.1 Research Questions

#### Research Question 1

*Which sustainability criteria are relevant to the design phase of an engineering capital project?*

By placing the Global Reporting Initiative (GRI) indicators into the relevant project phase in Section 3.3, and then subsequently testing them in the test case presented in Chapter 6, it is evident the indicators proposed for the design phase in this work are the most relevant to the engineering design of a capital project, and can be used to assess the suitability of the design and inform decisions. Other indicators in the GRI list are not subject to influence by the detail design of the project, and as such are not relevant for consideration in that phase.

#### Research Question 2

*How should these criteria be implemented and monitored throughout the project design and execution phases?*

The sustainability criteria identified as relevant to the design phase are used to optimise the design after the basic specification criteria have been met – this is to ensure that the heating in a house meets relevant government standards for example. Once the project moves to the execution/construction phase, the same estimates are then compared with the actual results to test the effectiveness of the project execution.

#### Research Question 3

*How would an engineer use the criteria to inform design decisions on a project?*

As was demonstrated in the Test Case in Chapter 6, the criteria are linked with the bill of quantities and are used to inform decisions for the design team so that the effect of changes can be seen immediately. Once a baseline is established with the initial design, the engineer can make changes to the design and immediately see the effect on the relevant sustainability indicators.

### 6.2 How the Analysis Tool can be used

The tool developed in the case study can be used to facilitate decisions when trade-offs are required between different dimensions of sustainability (Economic, Labour, Environmental etc.) during the design phase. Once the design has been fixed and a project specification is

produced, these indicators become the KPI's for the execution phase, as well as the indicators identified in Section 3.2.3.

Most modern engineering design software facilitates the automatic creation of a BOQ from which the indicators above can be calculated. It is this link between the design and the indicator data which the engineering design team and the project management must use to optimise and manage the trade-offs between the different dimensions.

### **6.3 Strengths of the Design Analysis Tool**

The main strength of integrating sustainability indicators into the design process is that the focus in the design phase shifts the GRI indicators from being lagging indicators (reported at the end of the time period), to leading indicators which are used to drive performance and design standards. If the engineers or project manager can instantly see the effect adding 5m of ventilation duct has on both the Environmental and Economic dimensions of the project, they will be better placed to make the correct decision regarding the sustainability of the solution.

Another of the proposed processes strengths is that with sufficient forward planning by the project management it satisfies the requirement by providing time series data. All the data can be broken down to a selected time period and the time series reported for the execution.

### **6.4 Weaknesses/Issues with the Design Analysis Tool**

The main issue with development and use of the sustainability indicators presented here is the time consuming data collection. The detail required to make the tool useful means that a lot of data collection must take place prior to starting work, such as employee salaries, weight/m of ventilation duct for example. However, the data required for most of the indicators is data which is normally collected and reported during construction projects.

Also, the issue of how to ensure that by optimising the design the engineers do not break some basic rules of the project specification – the example earlier being the minimum required heating of the building. Of course it would reduce cost and materials used if the insulation material was reduced by 50%, but this is not practically possible. Some work therefore needs to be done to ensure basic design criteria are met.

The process is limited, or rather the work is significantly more complex, if more environmentally friendly technology requires vastly different detail design – direct comparison therefore becomes difficult and time consuming changes can dramatically affect the other indicators. This however is an issue which would need to be managed by the project management team on a case by case basis.

A further issue is with the lack of Social sustainability indicators in the final set. The tool developed was required to have a spread of indicators over all pillars of sustainability. However after careful review of the GRI indicators, it is apparent that the design phase has little to no influence over the social sustainability of the project – the influence of the project on the social aspects is determined much earlier in the process. There it can be determined this is not a big issue.

Finally, the study becomes a very detailed and lengthy document to define all the above items for each work package if the project is very large – however as stated earlier, all the data used in this study was already calculated in a real life project, so it is expected that in actual fact the project team would have all this information anyway, but it is just not being used effectively.

## **6.5 Usefulness of the Design Analysis Tool**

As stated in Section 2.6, the proposed design analysis tool must satisfy the following criteria to be considered useful:

- Different dimensions of sustainability are captured
- Integrated within established PM and Engineering practice
- Provides a working tool to manage operations
- Indicators become leading indicators by informing decisions up front
- Measures success during project implementation against specified targets
- Indicators are calculated using established standards and practices
- Qualitative measurements are not acceptable in the design and execution phases
- Options can be compared and impacts can be assessed across all dimensions of sustainability

After testing the method in the case study, it is clear that the process developed here fulfils all of the criteria above. The engineers are informed up front what impacts their decisions have on all dimensions of sustainability, conflicts can be identified and resolved, and the relevant data is easily presented and understandable to all stakeholders.

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## 7 Final Words

In the introduction, the question was posed as to whether it is possible to create a working method or process which uses existing sustainability indicators in such a way as to be more relevant and useful to engineers and project managers. Existing research and literature focuses on the feasibility stage, or on high level “lagging” indicators, which are reported at regular intervals.

The work in this thesis has gone some way to producing a system to use the GRI indicators to analyse the technical design for engineering projects, and to inform decisions at all levels of the project team. The analysis in the case study reveals some interesting data which is not normally produced or analysed on a project level, and by using this process the sustainability of the final solution would be greatly improved.

As stated in the previous section however, the process here is not without its flaws, and further work to improve the process is required in the following areas:

- Data collection for all indicators in the design and execution phases

In sections 5.2 and 5.3 some indicators had to be omitted as there was no data or relevant calculations available. To fully test the suitability of the system all indicators must be completed as fully as possible.

- Testing on a new project

As stated in the Case Study introduction the design data presented was from an existing project which was not designed with sustainability in mind. To determine the benefit of using a sustainability focussed design process, a new build project should be used as a test, and the process used for the engineering design from the beginning.

After review of the available tools and indicators, it is clear that by developing a working process such as that presented in this thesis, engineers and project managers would be able to more rigorously analyse and develop projects with sustainability in clear focus. All of the data calculated for the case study was done using current best practice and standards for building design – the next step is only to focus the engineers on the three pillars of sustainability and how they interact in the project, and ensure the best path is chosen.

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# **Appendix A**

## **Pre-Project Indicators**

In this Appendix, the Indicators which were classified as relevant only to the Pre-project or normal operations phase are listed in detail

### **A1.1 Economic Indicators**

EC3: Coverage of the organization's defined benefit plan obligations.

EC9: Understanding and describing significant indirect economic impacts, including the extent of impacts.

### **A1.2 Environmental Indicators**

EN5: Energy saved due to conservation and efficiency improvements.

EN6: Initiatives to provide energy-efficient or renewable energy-based products and services, and reductions in energy requirements as a result of these initiatives.

EN7: Initiatives to reduce indirect energy consumption and reductions achieved.

EN10: Percentage and total volume of water recycled and reused.

EN14: Strategies, current actions, and future plans for managing impacts on biodiversity.

EN18: Initiatives to reduce greenhouse gas emissions and reductions achieved.

EN26: Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation

EN27: Percentage of products sold and their packaging materials that are reclaimed by category.

### **A1.3 Labour Indicators**

LA8: Education, training, counselling, prevention, and risk-control programs in place to assist workforce members, their families, or community members regarding serious diseases.

LA9: Health and safety topics covered in formal agreements with trade unions. Health and safety topics covered in formal agreements with trade unions.

LA11: Programs for skills management and lifelong learning that support the continued employability of employees and assist them in managing career endings.

LA12: Percentage of employees receiving regular performance and career development reviews.

LA13: Composition of governance bodies and breakdown of employees per category according to gender, age group, minority group membership, and other indicators of diversity.

LA14: Ratio of basic salary of men to women by employee category.

#### **A1.4 Human Indicators**

HR1: Percentage and total number of significant investment agreements that include human rights clauses or that have undergone human rights screening.

HR5: Operations identified in which the right to exercise freedom of association and collective bargaining may be at significant risk, and actions taken to support these rights.

HR6: Operations identified as having significant risk for incidents of child labour, and measures taken to contribute to the elimination of child labour.

HR7: Operations identified as having significant risk for incidents of forced or compulsory labour, and measures taken to contribute to the elimination of forced or compulsory labour.

HR8: Percentage of security personnel trained in the organization's policies or procedures concerning aspects of human rights that are relevant to operations.

#### **A1.5 Social Indicators**

SO2: Percentage and total number of business units analysed for risks related to corruption.

SO5: Public policy positions and participation in public policy development and lobbying.

SO6: Total value of financial and in-kind contributions to political parties, politicians, and related institutions by country.

# **Appendix B**

## **Project Planning/Feasibility Study Phase**

In this Appendix, the Indicators which were classified as relevant only to the Project Planning or Feasibility stage of the project are listed in detail

### **A2.1 Economic Indicators**

EC2: Financial implications and other risks and opportunities for the organization's activities due to climate change.

EC4: Significant financial assistance received from government.

EC5: Range of ratios of standard entry level wage compared to local minimum wage at significant locations of operation.

EC6: Policy, practices, and proportion of spending on locally-based suppliers at significant locations of operation.

EC7: Procedures for local hiring and proportion of senior management hired from the local community at significant locations of operation. (In this case the project location!)

EC8: Development and impact of infrastructure investments and services provided primarily for public benefit through commercial, in-kind, or pro bono engagement.

EC9: Understanding and describing significant indirect economic impacts, including the extent of impacts.

### **A2.2 Environmental Indicators**

EN9: Water sources significantly affected by withdrawal of water.

EN11: Location and size of land owned, leased, managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas.

EN12: Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas.

EN13: Habitats protected or restored.

EN15: Number of IUCN Red List species and national conservation list species with habitats in areas affected by operations, by level of extinction risk.

EN25: Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the reporting organization's discharges of water and run-off.

### **A2.3 Labour Indicators**

LA3: Benefits provided to full-time employees, which are not provided to temporary or part-time employees by major operations.

LA4: Percentage of employees covered by collective bargaining agreements.

LA5: Minimum notice period(s) regarding significant operational changes, including whether it is specified in collective agreements.

LA6: Percentage of total workforce represented in formal joint management-worker health and safety committees that help monitor and advise on occupational health and safety programs.

LA10: Average hours of training per year per employee by employee category.

### **A2.4 Human Indicators**

HR3: Total hours of employee training on policies and procedures concerning aspects of human rights that are relevant to operations, including the percentage of employees trained.

### **A2.5 Social Indicators**

SO1: Nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities, including entering, operating, and exiting.

SO3: Percentage of employees trained in organization's anti-corruption policies and procedures



# Appendix C

## Execution Phase Indicators

The following Indicators are those which are relevant only to the Project Execution phase.

### A3.1 Environmental Indicators

EN23: Total number and volume of significant spills.

EN24: Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally

EN28: Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with environmental laws and regulations.

EN29: Significant environmental impacts of transporting products and other goods and materials used for the organization's operations, and transporting members of the workforce.

EN30: Total environmental protection expenditures and investments by type.

### A3.2 Labour Indicators

LA2: Total number and rate of employee turnover by age group, gender, and region.

LA7: Rates of injury, occupational diseases, lost days, and absenteeism, and total number of work-related fatalities by region.

### A3.3 Human Indicators

HR2: Percentage of significant suppliers and contractors that have undergone screening on human rights and actions taken.

HR4: Total number of incidents of discrimination and actions taken.

HR9: Total number of incidents of violations involving rights of indigenous people and actions taken.

### A3.4 Social Indicators

SO4 Actions taken in response to incidents of corruption.

SO7: Total number of legal actions for anticompetitive behaviour, anti-trust, and monopoly practices and their outcomes.

SO8: Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with laws and regulations.

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# Appendix D

## Labour Indicator Data

The tables containing the actual data the labour Indicators were based on are shown below:

### Manpower Plan

Month	ágú. 08	sep. 08	okt. 08	nóv .08	des. 08	jan. 09	feb. 09	mar .09	apr. 09	maí .09	jún. 09	júl. 09	Total
Eng. 1	1	10	2	0	5	0	4	10	8	0			40
Eng. 2	0	4	0	8	32	40	48	64	16	8			220
Eng. 3	0	8	8	16	24	12	8	8	12	4			100
Eng. 4	0	0	0	0	0	0	0	0	0	0	0	0	0
Eng. 5	0	0	0	30	56	4	8	12	0	0			110
Eng. 6	0	0	0	32	18	32	64	24	30				200
Eng. 7	0	0	0	0	32	124	72	48	16	8			300
Eng. 8	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Est. Hours</b>	1	22	10	86	167	212	204	166	82	20	0	0	<b>970</b>

### Actual Hours

Month	ágú. 08	sep. 08	okt. 08	nóv .08	des. 08	jan. 09	feb. 09	mar .09	apr. 09	maí .09	jún. 09	júl. 09	Total
Eng. 1	1	14,5	1	3	2,5	4	11	2,5	3,5	0	3	0	46
Eng. 2	0	2,5	0	0	15	25,5	32,5	59	44	38,5	38	0	255
Eng. 3	0	5,5	5,5	9	23	3,5	3,5	5	0	0	0	26,5	81,5
Eng. 4	0	0	0	8	0	0	0	0	0	0	0	0	8
Eng. 5	0	0	0	32	53,5	5	0	24	0	0	0	3,5	118
Eng. 6	0	0	0	0	7	28,5	57,5	19	27	13,5	0	0	152,5
Eng. 7	0	0	0	0	31,5	92	86,5	67	61	42	16	8	404
Eng. 8	0	0	0	0	0	0	0	2	6	10,5	0	0	18,5
<b>Est. Hours</b>	1	22,5	6,5	52	132,5	158,5	191	178,5	141,5	104,5	57	38	<b>1083,5</b>

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# Appendix E

## Economic Indicator Data

The actual data the economic Indicator EC1.2 was based on is shown below:

EC1.2 – Employee Wages and Benefits

Salary Estimate

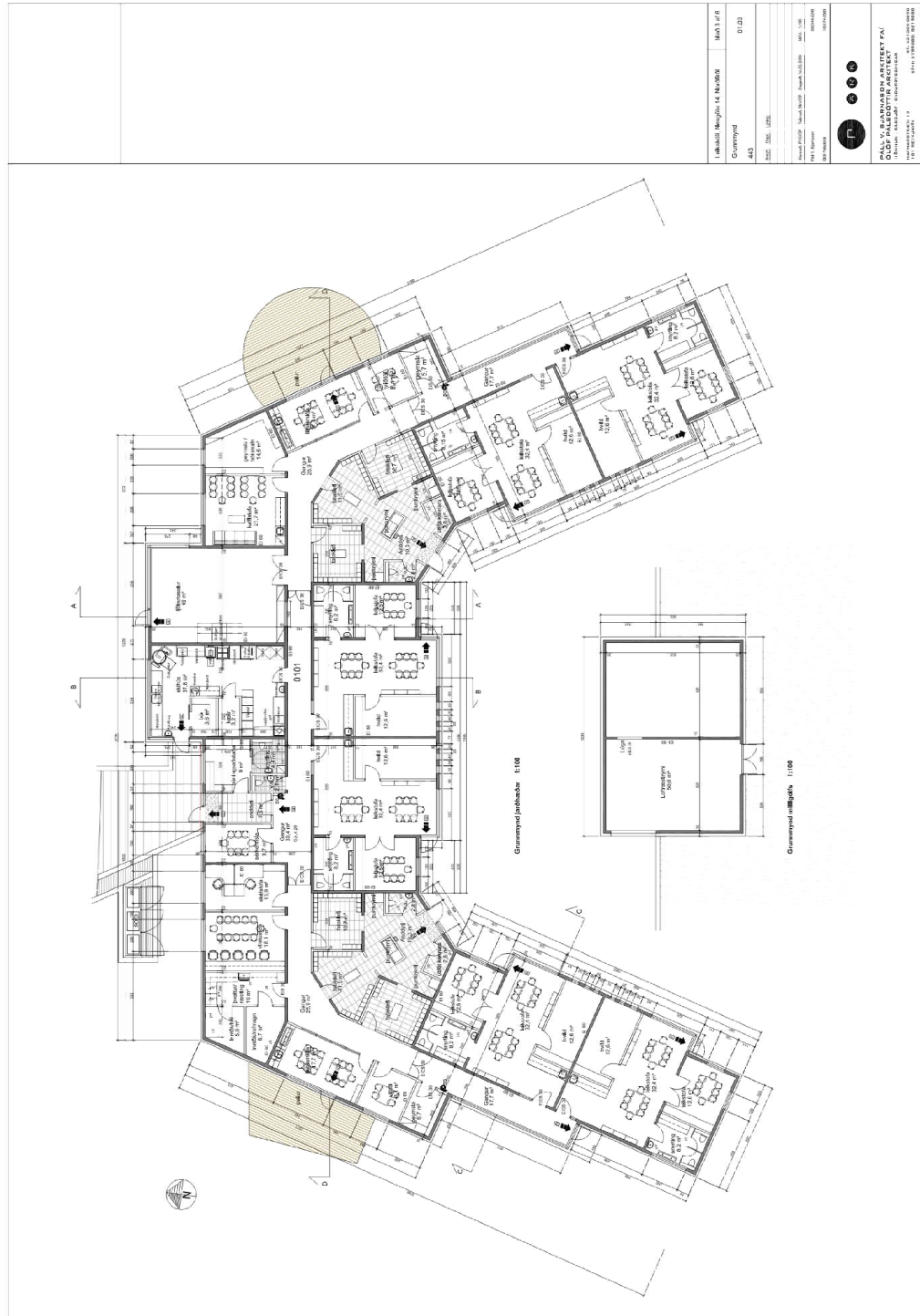
Month	ágú.08	sep.08	okt.08	nóv.08	des.08	jan.09	feb.09	mar.09	apr.09	maí.09	jún.09	júl.09	Total
Eng. 1	3750	37500	7500	0	18750	0	15000	37500	30000	0	0	0	150000
Eng. 2	0	13800	0	27600	110400	138000	165600	220800	55200	27600	0	0	759000
Eng. 3	0	25200	25200	50400	75600	37800	25200	25200	37800	12600	0	0	315000
Eng. 4	0	0	0	0	0	0	0	0	0	0	0	0	0
Eng. 5	0	0	0	70200	131040	9360	18720	28080	0	0	0	0	257400
Eng. 6	0	0	0	91200	51300	91200	182400	68400	85500	0	0	0	570000
Eng. 7	0	0	0	0	81600	316200	183600	122400	40800	20400	0	0	765000
Eng. 8	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Salary Estimate</b>	3750	76500	32700	239400	468690	592560	590520	502380	249300	60600	0	0	<b>2816400</b>

Actual Salary Data

Month	ágú.08	sep.08	okt.08	nóv.08	des.08	jan.09	feb.09	mar.09	apr.09	maí.09	jún.09	júl.09	Total
Eng. 1	3750	54375	3750	11250	9375	15000	41250	9375	13125	0	11250	0	172500
Eng. 2	0	8625	0	0	51750	87975	112125	203550	151800	132825	131100	0	879750
Eng. 3	0	17325	17325	28350	72450	11025	11025	15750	0	0	0	83475	256725
Eng. 4	0	0	0	30000	0	0	0	0	0	0	0	0	30000
Eng. 5	0	0	0	74880	125190	11700	0	56160	0	0	0	8190	276120
Eng. 6	0	0	0	0	19950	81225	163875	54150	76950	38475	0	0	434625
Eng. 7	0	0	0	0	80325	234600	220575	170850	155550	107100	40800	20400	1030200
Eng. 8	0	0	0	0	0	0	0	5100	15300	26775	0	0	47175
<b>Total Salary Paid</b>	3750	80325	21075	144480	359040	441525	548850	514935	412725	305175	183150	112065	<b>3127095</b>

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In this Appendix the data and drawings used to calculate indicator EN3 are presented



## Building Layout Drawing

BMs-1



Rými	Hæð	Heiti rýmis	Álag	Loft- skipti	Út- veggur	Kulda- brú	Yra gölf	Inna gölf	Þak	Glaggar	Úndyr	Álag	Loft- skipti	Leibr- stúðull	Varma- tap	Varma- tap	Varma- tap	Athugasemd
[m <sup>2</sup> ]	[m]		[okt]	[l/s]	[W]	[W]	[W]	[W]	[W]	[W]	[W]	[W]	[W]		[W]	[W/m <sup>2</sup> ]	[W/m <sup>2</sup> ]	
27	1	Hvöld	3	0,8	107	0	31	94	0	55	0	17	386		690	55	17	
28	1	Leikstofa	3	0,8	92	0	56	199	0	627	0	58	704		1827	70	22	
29	1	Fjölnissalur	2	0,8	219	0	113	369	0	841	378	58	1495		3473	71	22	
30	1	Snyrtng	2	0,8	0	0	0	77	0	0	0	2	250		328	40	12	
31	1	Leikstofa	3	0,8	134	0	41	85	0	116	0	23	382		780	63	19	
32	1	Karlsstaða	3	0,8	170	0	52	162	0	156	0	32	663		1237	57	18	
33	1	Fanaleif og Þorriðskápur	3	0,8	160	0	49	373	0	21	200	48	1343		2194	50	15	
34	1	Geymsla / Þokaauðin	4	0,8	288	0	81	73	0	123	0	51	447		1063	73	22	
35	1	Litastöðja	3	0,8	184	0	71	104	0	321	189	52	521		1441	85	26	
36	1	Vöðul	3	0,8	104	0	35	48	0	153	0	20	247		607	75	23	
37	1	Leikstofa	3	0,8	131	0	41	85	0	128	0	23	382		790	63	19	
38	1	Snyrtng	2	0,8	0	0	0	77	0	0	0	2	250		328	40	12	
39	1	Geymsla	4	0,8	239	0	62	5	0	0	0	27	176		509	88	27	
40	1	Leikstofa	3	0,8	63	0	49	266	0	627	0	60	903		2059	63	20	
41	1	Hvöld	3	0,8	107	0	31	94	0	55	0	17	386		690	55	17	
42	1	Hvöld	3	0,8	107	0	31	94	0	55	0	17	386		690	55	17	
43	1	Leikstofa	4	0,8	289	0	107	219	0	627	0	112	903		2347	72	22	
44	1	Leikstofa	4	0,8	295	0	90	46	0	256	0	62	382		1130	91	28	
45	1	Snyrtng	4	0,8	267	0	74	18	0	85	0	40	250		733	90	28	
46	2	Loftrennir	4	0,8	594	0	0	0	0	381	0	88	901		1964	41	21	
47	2	Fjölnissalur 2	4	0,8	608	0	0	0	395	0	0	90	933		2025	41	20	

9.730.055

Leikskóli Neskaupstaður

Stofnlagnir

Stærðir og þrýstítap

Samkvæmt kafla 6 í Hitun Húsa frá RB skal við hönnun hitalagna styðjast við eftirfarandi hámarksgildi  
Vatnshraði í pípum:  $v < 0,5$  m/s      Þrýstifall í pípum:  $\Delta p < 150$  Pa/m

$T_f$	40 °C	Hitastig í framrás		
$T_b$	29 °C	Hitastig í bakrás		
$\Delta T$	11 °C	Hitastigs mismunur milli fram- og bakrás		
$\rho$	996 kg/m <sup>3</sup>	Eðlisþyngd	k, mm	
$\mu$	7,990E-04 (Ns)/m <sup>2</sup>	Viscosity	0,001-0,005 Ný	gler, kopar, léttmálmar og plast (Drawn)
$\nu$	8,022E-07 m <sup>2</sup> /s	Viscosity, Kinematic	0,01-0,05 Ný	stálrör (Drawn)
C	4180 J/(kg °C)	Eðlisvarmi	0,03-0,10 Ný	soðin og saumlaus stálrör
g	9,81 m/s <sup>2</sup>	Þyngdarhröðun	0,1-0,5	Riðguð
k	0,050 mm	Grófleiki (Hrífni)	1,0-4,0	Mjög riðguð
$v_{max}$	0,5 m/s	Hámarkshraði	0,1-0,3 Ný	Heitzinkhúðuð
$\Delta p_{max}$	150 Pa/m	Hámarks þrýstifall		
AFL Upp	103 W			

Einstakar lagnir í kerfinu:		Rennsli	$d_i$ ( $v_{max}$ )	DN	DN valið	v	Re	Haaland	$\Delta p$	Lengd	$\Delta p$	Rennsli	
nr.	Afl W	l/s	mm	mm	mm	m/s		fl	Pa/m	m	Pa	l/min	
1	2.297	0,050	11,30	12,00	15,00	0,28	5.307	0,040	108	89,2	9629	3,01	SL1
2	3.046	0,067	13,01	15,00	15,00	0,38	7.038	0,038	178	118,3	21074	3,99	SL2
3	2.742	0,060	12,35	15,00	15,00	0,34	6.336	0,039	148	106,5	15732	3,59	SL3
4	2.299	0,050	11,31	12,00	15,00	0,28	5.313	0,040	108	89,3	9658	3,01	SL4
5	2.742	0,060	12,35	15,00	15,00	0,34	6.336	0,039	148	106,5	15732	3,59	SL5
6	3.046	0,067	13,01	15,00	15,00	0,38	7.038	0,038	178	118,3	21074	3,99	SL6
7	2.382	0,052	11,51	12,00	15,00	0,29	5.503	0,040	115	92,5	10645	3,12	SL7
8	2.665	0,058	12,17	15,00	15,00	0,33	6.158	0,039	140	103,5	14532	3,49	SL8
9	2.701	0,059	12,26	15,00	15,00	0,33	6.241	0,039	144	104,9	15085	3,54	SL9
10	2.426	0,053	11,61	12,00	15,00	0,30	5.604	0,040	119	94,2	11195	3,18	SL10
11	2.900	0,063	12,70	15,00	15,00	0,36	6.700	0,038	163	112,6	18373	3,80	SL11
12	2.235	0,049	11,15	12,00	15,00	0,28	5.165	0,041	103	86,8	8933	2,93	SL12
13	2.622	0,057	12,07	15,00	15,00	0,32	6.057	0,039	136	101,8	13884	3,43	SL13
14	3.086	0,067	13,10	15,00	15,00	0,38	7.131	0,038	182	119,9	21854	4,04	SL14
15	2.595	0,057	12,01	15,00	15,00	0,32	5.996	0,039	134	100,8	13495	3,40	SL15
16	2.485	0,054	11,75	12,00	15,00	0,31	5.741	0,040	124	96,5	11968	3,26	SL16
17	3.051	0,067	13,03	15,00	15,00	0,38	7.050	0,038	179	118,5	21169	4,00	SL17
18	2.742	0,060	12,35	15,00	15,00	0,34	6.335	0,039	148	106,5	15724	3,59	SL18
19	2.288	0,050	11,28	12,00	15,00	0,28	5.287	0,040	107	88,9	9530	3,00	SL19
20	2.288	0,050	11,28	12,00	15,00	0,28	5.287	0,040	107	88,9	9531	3,00	SL20
21	2.742	0,060	12,35	15,00	15,00	0,34	6.335	0,039	148	106,5	15724	3,59	SL21
22	3.047	0,067	13,02	15,00	15,00	0,38	7.040	0,038	178	118,3	21087	3,99	SL22
23	2.979	0,065	12,87	15,00	15,00	0,37	6.884	0,038	171	115,7	19809	3,90	SL23
24	2.937	0,064	12,78	15,00	15,00	0,36	6.786	0,038	167	114,1	19037	3,85	SL24
25	2.674	0,058	12,19	15,00	15,00	0,33	6.179	0,039	141	103,9	14672	3,50	SL25
26	2.711	0,059	12,28	15,00	15,00	0,33	6.264	0,039	145	105,3	15238	3,55	SL26
27	3.008	0,066	12,93	15,00	15,00	0,37	6.949	0,038	174	116,8	20338	3,94	SL27
28	2.899	0,063	12,70	15,00	15,00	0,36	6.699	0,038	163	112,6	18367	3,80	SL28
29	2.235	0,049	11,15	12,00	15,00	0,28	5.164	0,041	103	86,8	8930	2,93	SL29
30	2.696	0,059	12,24	15,00	15,00	0,33	6.229	0,039	143	104,7	15005	3,53	SL30
31	2.915	0,064	12,73	15,00	15,00	0,36	6.735	0,038	165	113,2	18640	3,82	SL31
32	2.299	0,050	11,31	12,00	15,00	0,28	5.313	0,040	108	89,3	9658	3,01	SL32
33	3.041	0,066	13,00	15,00	15,00	0,38	7.026	0,038	178	118,1	20975	3,98	SL33
34	2.742	0,060	12,35	15,00	15,00	0,34	6.336	0,039	148	106,5	15732	3,59	SL34
35	2.742	0,060	12,35	15,00	15,00	0,34	6.336	0,039	148	106,5	15732	3,59	SL35
36	3.046	0,067	13,01	15,00	15,00	0,38	7.038	0,038	178	118,3	21074	3,99	SL36
37	2.299	0,050	11,31	12,00	15,00	0,28	5.313	0,040	108	89,3	9658	3,01	SL37
Total (W)		99.655											

Heating load and water flow calculations