COST EFFECTIVE AND SUSTAINABLE PRACTICES FOR PILING CONSTRUCTION IN THE UAE

by

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A dissertation submitted in partial fulfillment of the requirement for the degree of MSc Quantity Surveying

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August 2011

Declaration
I hereby confirm that this dissertation is my own work

______________________________________________
Signature Date
DECLARATION

I, V.K. Saravanan, confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g. ideas, equations, figures, text, tables, programmes) are properly acknowledged at the point of their use. A full list of references employed has been included.

Signed:

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Glossary of terms

UPC  Urban Planning Council
UNEP  United Nations Environment Programme
CEF  Carbon emission factor
GHG  Green House Gas
HEIC  High Energy Impact Compaction
PFA  Pulverised fuel ash
GGBS  Ground granulated blast-furnace slag
UAE  United Arab Emirates
LEED  Leadership in Energy and Environmental Design Method
BREEAM  Building Research Establishment Environmental Assessment
CO₂  Carbon Dioxide
GDP  Gross Domestic Product
IPCC  Intergovernmental Panel on Climate Change
USGBC  United States Green Building Council
BRE  British Research Institute
CFA  Continuous-flight auger
CIRIA  Construction Industry Research and Information Association
CIEF  Construction Industry Environmental Forum
UK  United Kingdom
SIRIS  Stent Integrated Rig Instrumentation System
DIAC  Dubai International Academic City
CNG  Compressed Natural Gas
EGL  Existing Ground Level
HVAC  Heating ventilation and air conditioning
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Sincerely,

V.K.Saravanan
Abstract

UAE construction industry is much affected in the recent global financial crises. In addition to the financial crisis, the ecological crisis faced by humanity is now universally acknowledged by science. Increase of GHG concentration in the atmosphere is the main cause for climate changes. UAE holds 29th rank in CO₂ emission world wide and releases about 170.92 million metric tons of CO₂ in the atmosphere. Due to impacts of climate changes the country’s GDP gets affected up to 5%, and this percentage go as high as up to 20% if no actions are taken to reduce the green house gas emissions. As in the case of UAE, growing demand for energy and increase of CO₂ emissions have become important issues to be resolved. Under this financial crisis in the UAE, business organisations are pressed to look for ways for their competitiveness and long time survival in the market. In this context sustainability is recommended as an appropriate solution to bring the competitive advantage to the organizations with the triple bottom line benefits on Economic, Environmental and the Social aspects.

The morality, survival, organizational benefits and risks are focused for organizational alignment with sustainability. The literature reviews provided an in-depth knowledge on “sustainability” and sustainable practices for the construction industry, particularly with piling construction sector in the UAE. The needs and benefits of sustainability and its contribution for global carbon footprint emission reductions are explored. Various sustainable practices for piling construction which will benefit the organisations to attain cost-effectiveness with the contribution to reduce carbon footprint release were identified. In this context the usage of the low embodies energy materials, re-usable materials, energy saving techniques, and alternative technologies with piling constructions have been identified from various literature reviews. The most comprehensive part of the study assessed five operational areas as part of organizational alignment with sustainability, which are design management, energy and water saving, material usage, and waste management. The barriers to implement the sustainable practices are also identified as part of the research study.

The suitability of the recommended sustainable practices was investigated through an online survey questionnaire sent to various industry professionals to gather their perception to adopt the sustainable practices with the piling constructions in the UAE. A case study on a completed project was also conducted to investigate the benefits of sustainable practices in terms of cost saving and CO₂ emission reductions.

The research findings demonstrated that sustainable practices can contribute up to 15% of cost saving and 18.61% of the CO₂ emission reduction and concludes that sustainable construction practices not only lead to the cost-effectiveness but also significant reduction can be made in carbon emissions as part of the environmental benefit to the UAE.
Chapter 1: Introduction

1.1 Rationale
Construction activities and its output is an integral part of any country’s national economy and industrial development. It is often seen as a driver for economic growth especially in developing countries. Also the construction industry can mobilize and effectively utilize local human and material resources for the development and maintenance of housing and infrastructure to promote local employment and improve economic efficiency (Khan, 2008).

The recent Economic recession affected the construction industry's economic environment, created severe competition and changed the nature of businesses. The severe competition forced organisations to submit very tight price, and pushed the companies to reduce their resources. Companies had to adopt organisational and management shuffling in order to quickly respond to the change. In the UAE, this competition has been further sharpened by the entrance of international contractors looking for new opportunities. The Construction organizations have been pushed to use several strategies, tactics and ideas in a bid to win work in an increasingly competitive environment. Prior to financial crisis the construction industry in the UAE was driven by huge real estate and infrastructure investment, and saw strong growth during 2005 to 2007. The growing economy has been fuelling an unprecedented construction boom and infrastructure development in all emirates of the country, especially in Dubai. The industry has also attracted investors from around the world. Many international construction companies started their operation in the UAE.

As serious as economic crisis, climate change become a serious concern all over the world (WRI Report, 2006) including UAE. Increase of GHG concentration in the atmosphere is the main cause for climate change. IEA data shows that UAE releases annually 170.92 million metric tons of CO₂ in the atmosphere and holds 29th rank in CO₂ emission world wide (Radhi, 2010). At the recent Cancun summit in December 2010 requests were made on rich countries to reduce their greenhouse gas emissions and the developing countries were requested to plan to reduce their emissions (UNFCCC, 2010).
The current global economic downturn and green house gas emission a target provides a unique opportunity to the developing countries including UAE to focus on the more innovative practices for a stronger future. Increasing competitive pressures in the construction industry provide a stimulus for innovation and best practices, which enable organizations to increase their efficiency and effectiveness.

CIEF (2009) suggest sustainable construction as a solution for significant cost savings, to bring innovations and to enhance competitiveness for long time survival of any organisation. According to CIEF (2009) sustainable construction practices not only provides increased market share and profitability but also brings many other intangible benefits such as visible brand name to the organisation in the industry, quality in construction, employee motivation and satisfaction, improved customer’s satisfaction, and complements / Awards from regulatory authorities.

From the time of financial crisis in 2007 the companies specialising in piling construction have also felt the financial squeeze as acutely as any other contractors in the UAE (Roberts Ben, 2010). Prior to financial crises during the construction boom, there were many piling companies started their operation in the United Arab Emirates. During the construction boom, due to the tremendous demand in the market, all the piling companies were able to get enough projects to achieve their market share. After the major down turn in the UAE since the year 2008, the piling companies were not able to get enough projects for execution and they are struggling to survive in this competitive market (Roberts Ben (2010). Therefore, this research study is considered to be important in order to increase the chances of success in the market and further performance improvement of piling companies in today’s competitive market. In this context this research focuses to identify good practices to achieve cost effectiveness through sustainable approach in many aspects of piling construction.

The study attempts to identify sustainable practices in piling construction, to attain cost effectiveness, performance efficiency, and sustainability. In this regard usage of low embodied energy and sustainable materials, energy conservation, plant and resources efficiency improvement and adopting various alternative technologies for the piling construction will be explored to attain sustainability targets as outlined by local and International Green building guidelines (BREEAM, LEED and ESTIDAMA).
1.2 Aim
To identify good practices for cost-effective and sustainable piling construction in the United Arab Emirates.

1.3 Objectives

- To explore the importance of sustainability in the UAE construction industry.
- To identify sustainable practices with piling construction including benefits and barriers to its adoption in the UAE.
- To assess cost savings and CO$_2$ emission reductions by sustainable practices in a completed piling project in the UAE with the help of case study.

1.4 Hypothesis
Piling companies can achieve cost effectiveness and sustainability by implementing recommended sustainable practices.

1.5 Outline of research methodology

Stage-1: Literature Review
A detailed and elaborative literature review through the relevant literature like books, journals, reports, presentations, conference proceedings, and websites was carried out in order to

- Describe the importance of sustainability
- Discuss the environmental impacts by the current construction industry.
- Discuss the current practices with piling construction in the UAE and its impact to the environment.
- Explore cost effective and sustainable practices with piling construction in the UAE.
- Establish the relation between Sustainability and Cost benefits with piling construction.
- Discuss various sustainable practices for piling construction to reduce CO$_2$ emission.

Stage-2: Data Collection
In this section all findings from literature reviews are evaluated by the results of an online survey through a structured questionnaire form. Case study of an existing project
was also carried out to examine the various sustainable features which can be incorporated in design and construction stages of any piling construction (in order to attain cost-effectiveness and to reduce the CO₂ emissions).

Stage-3: Data Analysis
Data collected at different stages of this study was scrutinized by both qualitative and quantitative research methods. The questionnaire was examined by statistical analysis and the case study findings were calculated in numerical forms and cost savings and CO₂ reduction levels are presented in values and figures. The dissertation was finalised after a collective analysis and comparison of the results obtained from different analysis.

Stage-4: Writing the research report
This stage involved the writing up of the full research work on the selected topic by summarizing the complete work in the abstract, critically analyzing existing practices / trends in the selected topic and presenting the findings of the literature review. The characteristics of the research types, method of analysis chosen, and analysis of the results obtained from the industry professionals are also described and at the end conclusions and recommendations are presented in the final chapter.

1.6 Structure of the Dissertation

Chapter 1: Introduction
This chapter includes the rationale, aim and objectives of the research study and the hypothesis is presented. In addition outline research methodology and the outline structure of this dissertation is also displayed in this chapter.

Chapter 2: Sustainability and Built Environment
This chapter describes the importance of sustainability in the built environment in terms of various impacts due to increasing level of CO₂ emissions by the current trend, and the necessity to reduce the CO₂ emissions in the UAE. This chapter further discusses the relationship between sustainability and competitive advantage in business and guidelines to implement sustainability in the construction industry. An overview of sustainable constructions and its benefits upon implementation within the construction industry is also discussed in this chapter.
Chapter 3: Construction Industry and its impact to the Environment
This chapter details how the construction industry contributes towards the impact on the environment and presents the current strategy with UAE construction industry and its impact to the environment.

Chapter 4: Sustainable practices for piling construction in the UAE
This chapter explores the regional geology of UAE and current practices with piling construction. The chapter also discusses various sustainable practices for piling constructions in the UAE to achieve cost-effectiveness and CO$_2$ emission reductions. Benefits of sustainable construction practices and barriers to implement these practices with piling constructions in the UAE are also described in this chapter.

Chapter 5: Research design and methods
This chapter describes research strategies and details the chosen methods for data collection and analysis.

Chapter 6: Research results and analysis
This chapter presents the research results obtained from various sources and compares the analysis with the literature review.

Chapter 7: Conclusions and recommendation
This chapter presents the conclusions based on the findings from the research. The limitations of this study and further recommendations also form part of this chapter.

Chapter 8: References
This chapter lists the references used throughout this research study.
Chapter 2: Sustainability and Built Environment

2.1 Introduction.

Sustainability is now a prime concept in the development thinking at all disciplines. Over the last two decades sustainability has got the whole world’s attention when the activities induced by humans created adverse effects on the earths environment. The construction activity has a significant impact on the environment. Contractors play an important role in promoting sustainable development within the context of the construction industry by assuming responsibility to minimize their negative impact on the environment and society and maximize their economic contribution (Tan et. al, 2010). This chapter defines the sustainability and its various impacts, including the necessity for countries including UAE to adopt the sustainability. The concept of sustainability and how it is plays the important role for the built environment is also discussed here with an overview of sustainable construction and its benefits in brief. Given the growing need for sustainability the chapter looks for the guidelines too for achieving sustainability in the construction industry.

2.2 Defining Sustainability

There are a large number of definitions of sustainability by different groups as per their suitability and needs (Langston and Ding, 2004). The World Commission on Environment and Development (WECD, 1987) defined sustainability as “an approach to progress which meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

Glavic P and Lukman R (2007) state that “Sustainable development is a timeline, where principles, approaches, strategies and policies may help us to develop and implement our future vision of a sustainable society that will require different thinking patterns and changes in lifestyles to achieve”

Though these well-established definitions provide a generic definition for sustainability, the following definitions clarify more specific human and environmental parameters for modeling and measuring sustainable developments.
"Sustainable means using methods, systems and materials that won't deplete resources or harm natural cycles" (Rosenbaum, 1993).

Sustainability "identifies a concept and attitude in development that looks at a site's natural land, water, and energy resources as integral aspects of the development" (Vieira, 1993)

2.3 Impacts of un-sustainability

2.3.1 Environmental impacts

Global warming and climate change are the key issues of sustainability. Climate change has been recognized as one of the major threats of the twenty-first century (IPCC, 2007). Mankind has have achieved lot of advancement in various fields including science and technology, which have improved our standard of living and comfortability. Human induced activities led to an increase the greenhouse gas emissions and global warming. Fossil fuel burning has had a major contribution to climate change (IPCC, 2007). The Swedish chemist Svante Arrhenius blames the burning of fossil fuels (oil, gas and coal) for producing carbon dioxide (CO₂), which is the most polluting greenhouse gas blamed for climate change. Today's atmosphere contains 32 per cent more carbon dioxide than it did at the start of the industrial era (Gruder et al, 2007). World wide CO₂ emission level from fossil fuel burning, and CO₂ concentration level in the atmosphere is given below, in figures 2.1 and 2.2 respectively. These figures indicates that CO₂ emissions and concentration levels are increasing every year, resulting in depletion of resources, deterioration of ecosystems and other related impacts (Dobbelsteen, 2004).

![Global Carbon Dioxide Emissions from Fossil Fuel Burning, 1950-2009](image)

Figure 2.1: Global carbon dioxide emissions from fossil fuel burning (Source: Carbon Dioxide Information Analysis Center [CDIAC])
2.3.2 Social impacts

Stern review (2006) states that climate change threatens the basic elements of life for people around the world such as access to water, food production, health, and use of land and the environment. Afgan et. al (1998) give the consequences of unsustainable development in graphical form in figure. 2.3 below.

Figure 2.3: Consequences of unsustainable developments; (Source : Afgan et. al 1998)
Similarly Miller (2004) provides the adverse impacts on human beings and ecology due to the possible effects of global warming in a tabular form. Figure 2.4 indicates the possible effects of a warmer atmosphere.

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Water Resources</th>
<th>Forests</th>
<th>Sea Level and Coastal Areas</th>
<th>Human Health</th>
<th>Human Population</th>
<th>Weather Extremes</th>
<th>Biodiversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shifts in food growing areas</td>
<td>Changes in water supply</td>
<td>Changes in forest composition and locations</td>
<td>Rising sea levels</td>
<td>Increased deaths from heat and disease</td>
<td>Increased deaths</td>
<td>Prolonged heat waves and droughts</td>
<td>Extinction of some plant and animal species</td>
</tr>
<tr>
<td>Changes in crop yields</td>
<td>Decreased water quality</td>
<td>Disappearance of some forests</td>
<td>Flooding of low-lying islands and coastal cities</td>
<td>Disruption of food and water supplies</td>
<td>More environmental refugees</td>
<td>Increased flooding from more frequent, intense and heavy rainfall</td>
<td>Loss of habitats</td>
</tr>
<tr>
<td>Increased irrigation demands</td>
<td>Increased drought</td>
<td>Increased fires from drying</td>
<td>Flooding of coastal estuaries, wetlands, and coral reefs</td>
<td>Spread of tropical diseases to temperate areas</td>
<td>Increased migration</td>
<td>Disruption of aquatic life</td>
<td></td>
</tr>
<tr>
<td>Increased pests, crop diseases, and weeds in warmer areas</td>
<td>Increased flooding</td>
<td>Loss of wildlife habitat and species</td>
<td>Beach erosion</td>
<td>Increased respiratory disease and pollen allergies</td>
<td>Disruption of coastal fisheries</td>
<td>Increased water pollution from coastal flooding</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Contamination of coastal aquifers with salt water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.4: Possible effects of a warmer atmosphere (Source: Miller 2004, p.461)

### 2.3.3 Economic impacts

Although only a limited number of economic studies have been conducted, it is estimated that the economic impact associated with climate change will be about 5 percent of the global gross domestic product (GDP) and the impact could exceed this, if no actions are taken (Stern 2006). The effects of un-sustainability may unbalance countries economy and could bring instability in the growth of the country. The construction industry will be much affected as it is having a direct link on economic growth of the country, with resulting job cuts, un-employment, and high competition within industries and so on. The global economy may shrink by 20% if global warming is not reduced from the present level and if no actions are taken to control the CO₂ emissions (Stern 2006).
2.4 Concepts of Sustainability

The concept of sustainability in building construction is based on **resource flow management** as well as the **reduced consumption of energy and resources**. Furthermore, interferences with the natural environment have to be minimized and any damage to it has to be avoided. Therefore, the use of fossil fuels, land, materials, and water has to be minimized, as well as the production of noise, waste generation, and the atmospheric emissions related to global warming are to be reduced (UNEP, 2003). Cost-effective and alternate construction technologies can play a great role in the reduction of CO₂ emission and thus help in cost effectiveness (Sengupta Nilanjan, 2008).

The concept of sustainable construction is an approach to building which promotes the attainment of goals associated with the triple bottom lines, which are Economic sustainability (promotes economic growth), Environmental sustainability (minimises environmental impacts), and Social sustainability (maintains social inclusion with economic growth) (Mohamed Salama and Hana, 2003). The triple bottom concept of sustainability with its interaction on Economy, Environment and Society is given in Figure 2.5 and the elements of sustainability at the organizational level are shown figures 2.6 below.

![Figure 2.5: Triple bottom concept of sustainability (Source: The Concrete Centre, 2007)]
The reduction of greenhouse gases in the building construction sector is based on principles, which have to be appreciated during all activities concerning the entire building process. Compared with the widely accepted building technologies these are in general:

- Minimization of the energy demand for the production, transport, reuse or recycling of building materials,
- Utilization of renewable energies for production, transport and performance,
- Fabrication of products with an extended lifetime,
- Utilisation of building products and materials, which can be reused or recycled,
- Utilization of nature, space and material saving construction methods
- Design of multifunctional buildings with an extended lifetime,
- Design of climate responsive buildings with a minimal consumption of energy.

The effective usage of appropriate plant and equipments, minimizing wastage, economic design and improved quality in construction will lead to winning more projects resulting in increasing market share and profitability. Many researchers have voiced their opinion that sustainability and cost effectiveness are the key elements for the long time survival of any organisation. Therefore it is vitally important to construction companies to implement sustainable construction practices in order to increase their market share and ensure their long term survival.
2.5 Relationship between Sustainability and competitive advantage

Achieving competitive advantage in construction is a cornerstone for any company wishing to remain in market and compete for the future. This necessitates that companies search for new strategies, techniques and processes to keep them competitive. Because of the negative impact of the construction industry to the environment, it is essential that companies working in the construction field strive to deliver sustainable built environment through saving the environment, enhancing society and prospering the economy (Tan et al, 2010). These goals will energise competition between construction professionals and will be better accomplished by integrating innovation and sustainability as an approach for achieving competitiveness in construction. The relationship between innovation, sustainability and competitive advantage is cyclic, as shown in Figure 2.7.

![Figure 2.7: The relationship between sustainability, innovation and competitive advantage, (Source: Othman, 2010)](image)

In terms of construction, innovation is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. Process innovations can be intended to reduce production costs, expedite service delivery or increase quality (Othman, 2010). Additionally Lopez and Brandes (2010) argue that innovation and technology readiness is seen as one of the most important factors for competitiveness, as they enable and ensure sustained productivity improvements and economic growth.
2.6 Guidelines for achieving sustainability

Guiding frameworks can assist contractors in improving their competitiveness by implementing sustainable construction practices. Contractors can implement total quality management systems, ISO 14000 standards and environmental management systems to promote improved environmental performance. Implementation of sustainable construction practices in an effective way, leading to an increase in sustainability performance, will induce an increase in business competitiveness by integrating long-run profitability with their efforts in sustainable developments (Tan et al. 2010). A framework for improving contractor’s competitiveness through implementing sustainable construction practices is illustrated below in figure 2.8.

**Figure 2.8:** A framework to improve contractor’s competitiveness by implementing sustainable construction practices, (Source: Tan et al, 2010)

2.7 Sustainable construction – An overview

Sustainable construction is the application of sustainable development practices to construction, which can have big impact on the quest for a sustainable built environment (Asad and Khalfan, 2007). Sustainable constructions are designed and constructed to high environmental standards and thereby minimise energy requirements, reduce water consumption, use materials which are of low environmental impact (e.g. low embodied energy and resource efficient), reduce wastage, conserve / enhance the natural environment and safeguard human health and wellbeing. Sustainable construction not
only focuses solely on environmental issues. More broadly, sustainable construction encompasses three major areas such as economic, environmental and social performance of the industry.

The UK Government’s strategy for more sustainable construction DETR (2000) suggests some key factors for action by the construction industry by widening these basic objectives. These include

1. Design for minimum waste
2. Applying lean construction principles
3. Minimising energy in construction and use
4. Pollution reduction
5. Preservation and enhancement of biodiversity
6. Conservation of water resources
7. Respect for people and local environment
8. Setting targets
9. Monitoring and reporting in order to benchmark the performance.

Most of these points simply make good business sense eg. minimising waste increases efficiency. Sustainability is of increasing importance to the efficient, effective & responsible operation of business. Similarly Reddy (2009) identified the key working principles of sustainability as shown below in the figure 2.9.

![Figure 2.9: Working principles of Sustainability, (Source: Reddy, 2009)](image-url)
There are some arguments and disagreements between professionals with respect to sustainability and sustainable developments by their different views to sustainable developments. Chaharbaghi and Willis (1999) identified the various perspectives of sustainable developments as illustrated in figure 2.10, showing different views of sustainable developments by various professionals.

![Figure 2.10: Criticism of Sustainability by different professionals, (Source: Chaharbaghi and Willis, 1999)](image)

Lean construction principles can be an appropriate tool for sustainable construction by engaging people and organising the work-place to be more efficient, and reducing cost by minimizing / cutting waste generation to gain the maximum possible amount of value. The essence of lean construction ties directly with construction sustainability. For example, to attain sustainability, there is a need to reduce materials use / consumption (environmental sustainability), which equates to lower costs, which leads to higher profit (economic sustainability) and better job satisfaction and security, personal development and contribution to the community (social sustainability). The linkage between Lean construction and Sustainability is illustrated in figure 2.11 (CIEF, 2009).
2.8 Benefits of sustainable construction

The benefits of implementing sustainable practices in construction can be grouped under environmental, economic and social aspects. All these include improved regulatory compliance requirements; reduction of liability and risk; enhanced reliability among customers and peers; reduction of harmful impacts to the environment; prevention of pollution and waste (which can result in cost reduction); improvements in site and project safety (by minimising injuries related to environmental spills, releases and emissions); improved relationships with stakeholders such as government agencies, community groups, and clients (Christini et al, 2004). In addition, reducing environmental impact ensures optimal use of resources and enforces measures which improve the company’s competitiveness (Kein et al, 1999). WRI Report (2006) summarizes the number of Tangible and Intangible benefits of sustainable construction as mentioned below.

**Tangible benefits**
- Cost saving from improved energy management.
- Cost saving from operation efficiencies
- Increased revenues and new markets from providing low-carbon products and services

**Intangible benefits**
- Competitive positioning in the market
- **Improved shareholder relations**
- **Employee-related benefits**

Sustainable construction cohesively addresses the triple bottom line such as the social, economic and environmental performance of the industry. Economic benefits include increasing profitability by making more efficient use of resources, including labour, materials, water and energy in turn enabling being more competitive (Bharadwaj et al., 1993). The environmental benefits are preventing harmful and potentially irreversible effects on the environment by careful use of natural resources, minimizing waste, protecting and where possible enhancing the environment. The social benefits include improving health and safety, enhancing site and welfare conditions, and avoiding noise and dirt (which would inconvenience local residents) and working closely with clients, suppliers, employees and local communities (Mohamed Salama and Hana, 2010). In addition various benefits of sustainable piling construction are also described in chapter 4.

### 2.9 Necessity for Sustainability in developing countries including UAE.

In developing countries the proportion of the construction industry on the total energy consumption and GHG emissions is much higher than in developed countries due to the rapid economic growth and fast urbanization, which increases the energy production and usage. Also, population growth in these countries induces the problem of pollution and waste generation, which produces CO$_2$ emissions in the atmosphere. Urban areas are mostly situated in coastal locations where economic assets and residents increasingly find themselves at elevated risk of climate related events. Case studies show that transportation infrastructure in coastal areas is vulnerable to sea level rise and extreme climate events (Gasper, 2011)

According to the White House Initiative on Global Climate Change, in the developed countries the CO$_2$ emission levels are reducing from 1995 levels whereas this level is increasing in the developing countries from 1995 levels, (Figure 2.12). This shows a clear indication that the developing countries are to be in a critical situation to reduce the CO$_2$ emission levels.
Taking account of United Arab Emirates, it is a developing country. After the discovery of oil and its export in the last four decades; it has experienced very rapid growth (Heagzy, n.d). The growing demand for energy and the increase of CO₂ emissions are two important issues which have become important topics in the UAE. The statistics of the UAE show that the increase in GHG emissions are in the range of 33% to 35% between 1997 and 2006 (Radhi, 2009). The Environment Agency of Abu Dhabi states that activities like fossil fuel combustion, industrial processing, land-use change and waste management are the main causes for the release of greenhouse gases (GHG) emissions into the atmosphere in the UAE.

Mr. Yousuf Jebril, executive vice-president of planning and electricity projects at the Dubai Electricity and Water Authority (DEWA), said at the Dubai Global Energy Forum recently that over the last 11 years, the growth in electricity and water use has been substantial and achieved at 203 per cent and 144 per cent respectively. The consumption of electricity and water in Dubai is expected to grow by 93 per cent and 59 per cent respectively by 2021. Current UAE electricity and water consumption, and CO₂
emissions, per capita, are some of the highest in the world. Dubai’s Green Building Regulations serve as a strategic instrument that should contributes to Dubai’s sustainable development and green future (Bitar Zaher, 2011).

Sustainable construction practices, especially in the developing world have to be achieved as soon as possible, because the building and construction sector in these countries is still under development and growing very fast. Additionally any shift towards sustainability in the construction sector may play an important role to shift the economic structure towards sustainability and to optimise the well being of the society.

2.10 Conclusion

Construction sector and construction activities are considered to be one of the major sources of economic growth, development and economic activities. Construction and engineering services industry play an important role in the economic uplift and development of the country.

It can be regarded as a mechanism of generating employment and offering job opportunities to millions of unskilled, semi-skilled and skilled work force. It also plays key role in generating income in both the formal and informal sector. It supplements foreign exchange earnings derived from trade in construction material and engineering services. Construction sector is a major sector plays vital role in the Economy of any country.

Sustainable construction in essential in order to achieve competitive advantage through innovation and efficiency, more than that to tackle the environmental impacts being faced all over the world. It is more essential for the developing countries as the total CO\textsubscript{2} emission levels are still increasing in the developing countries when this reducing in the developed countries as they have taken more initiatives to tackle this issue. It is obvious that the developing countries must take this as a serious threat to the economic development of the countries. By managing the usage level of the components causes the release of GHG emissions one way the countries economy will strengthen and other hand, the CO\textsubscript{2} level will reduce. By identifying innovative ideas and implementing sustainable practices in businesses and industries, the energy conservation and reduction in the CO\textsubscript{2} emission levels can be achieved. The next chapter provides the level of environmental impacts due to the construction industry and the main sources for CO\textsubscript{2} emission within the industry.
Chapter 3: Construction Industry and its impact to the Environment

3.1 Introduction.

In spite of the crucial role that the construction industry plays towards achieving national and international strategies for social and economic development, it has a major impact on the environment. On one hand, it contributes towards increasing GDP, stimulating growth of other industries and creating job opportunities (Field and Ofori, 1988; Mthalane et al., 2007). In addition, it provides societies with facilities and infrastructure projects that meet their needs and fulfill their requirements (Friends of the Earth, 1995; Roodman and Lenssen, 1995; Khan, 2008). On the other hand the construction industry plays a major role on the environmental impacts. The environmental impacts caused by CO$_2$ emission in the construction industry are associated with three major areas of operation which are Materials manufacture, Construction and Operation, which can be reduced through various methods such as improving the efficiency in the production, minimizing the materials usage and wastage, and utilization of low carbon emission materials. This chapter discusses all these issues and explores the approaches to reduce CO$_2$ emission levels and related benefits due to reduction.

3.2 Impact of construction industry on environment

Worldwide the construction industry accounts for around one-tenth of the world's gross domestic product, seven percent of employment, half of all resource usage and up to 40% of energy consumption. Its impact on our daily lives is huge. On the other hand construction activities have a significant impact on the environment and are considered as a major contributor to environmental pollution (Tan et al, 2010; Said et al., n.d; Sengupta Nilanjan, 2008).

The construction industry is the major user of raw materials. Construction industry worldwide accounts for 40% of CO$_2$ emission (Global Climatic Crisis), 30% of Raw material usage (earth’s resources depletion), 40% of energy consumption (environmental pollution) and 20% of fresh water consumption (Wilkinson and Reed 2007). CO$_2$ emission in the construction industry is associated with three major areas of operation which are Materials manufacture, Construction and Operation. Energy is being used for
materials manufacturing and transportation to the construction site. A long time criticism that the conventional on-site construction methods have low productivity, poor quality and safety records, long construction time and large quantity of waste in the industry (Chen et al, 2010) which in turn accounts for more CO\textsubscript{2} emissions and increases the cost of construction at the same time. An estimate of Global and Industrial CO\textsubscript{2} emissions are shown below.

![Figure 3.1: Global and Industrial CO\textsubscript{2} emissions (Source: Allwood and Cullen, 2009)](image)

### 3.3 Energy use in construction industry and CO\textsubscript{2} emissions

CO\textsubscript{2} emission in construction industry can be broken down further as direct emissions (which are from the burning of fuel) and indirect emissions from the use of electricity from grid supply, and other indirect emissions from the use of company vehicles, business travels and wastages. The direct and indirect and other indirect sources of CO\textsubscript{2} emission is illustrated as Scope 1, Scope 2 and Scope 3 respectively in figure 3.2 below.

![Figure 3.2: Direct, Indirect and other indirect sources of CO\textsubscript{2} emissions, (Source: ENCORD, 2010)](image)
The First Secretary for Energy and Climate Change at the British Embassy in Abu Dhabi has said CO₂ levels emitted globally in 2010 were the highest on record. In 2010, a record level of 30.6 gigatonnes of carbon dioxide was released into the atmosphere, an increase of 1.6 gigatonnes from 2009 levels due mainly to burning fossil fuel for energy production (Emmanulle Landais, 2011). The First Secretary also said that it is not necessarily the need to reduce the overall energy demand as a solution to CO₂ emission reduction, however the key is how the energy is generated, transported and used. If it is generated in a green manner, then it can be matched to the growing demand patterns without having a detrimental impact on the world around us. Especially in UAE where energy is used to desalinate the water and then the water is used for various purposes including construction, irrigation, controlling the water usage also leads the energy demand to decrease significantly he said (Emmanulle Landais, 2011).

3.4 Material use in construction industry and CO₂ emissions

The material usage in the construction industry has been the most significant since the year 1900. The construction industry’s material use has risen to an alarming level (Eddy Krygiel and Bradley Nies, 2008). Figure 3.3 shows the materials flow (in tons) in various industries from the year 1900.

![Figure 3.3: Materials flow in various industries, (Source: Eddy Krygiel and Bradley Nies, 2008, p.30)](image-url)
3.5 Waste generation

Waste generated from construction sites is one of the main components of landfills and it also involves fuel consumption for transportation for its disposal, and land contamination. Among various types of construction materials, concrete was found to be the most significant element with about 75% collected from general civil works construction site as construction waste (Shen et al., 2009).

3.6 UAE Construction Industry current strategy on environmental impacts

Considering UAE, it is a developing country, after the discovery of oil and its export in the last four decades; it has experienced very rapid growth (Heagzy, n.d). While construction and real estate is a major contributor to Dubai’s Gross Domestic Product (GDP), it is also among the prime resource-intensive sectors. The rapid growth in the UAE with huge construction projects and population growth rates, and a fairly low energy cost, have accelerated the UAE’s energy consumption, making it one of the highest energy consumers per capita in the world (Radhi, 2009). IEA data shows that UAE holds 31st rank (2.539 Quadrillion Btu) in primary energy consumption, 39th rank in net electricity consumption (57.88 billion KWh) and 29th rank in CO\(_2\) emission (Annually 170.92 million metric tons of CO\(_2\)). According to UAE statistics, about 43% of the CO\(_2\) emission is caused by electricity generation and 45% by manufacturing and construction industry, which are mainly influenced by building construction and operation (Radhi, 2010).

Mr. Yousuf Jebril, executive vice-president of planning and electricity projects at the Dubai Electricity and Water Authority (DEWA), said at the Dubai Global Energy Forum recently that current UAE’s electricity and water consumption, as well as CO\(_2\) emissions, per capita, are some of the highest in the world. Green Building Regulations in Dubai serve as a strategic instrument that contributes to Dubai’s sustainable development and green future (Bitar Zaher, 2011).

Thus, growing cities such as Dubai, Abu Dhabi need to plan along sustainable lines in order to reduce their negative environmental impacts and natural resource depletion. There is vast scope for establishing direct links between environmental and economic developmental issues in urban growth. By promoting sustainable lifestyles, cleaner production, renewable energy, water resources management, reduction of solid waste and
sewage treatment, reuse and recycling of materials, ecological urban design and construction, public health, cities can avail long-term environmental sustainability (Marashi, 2006)

3.7 Conclusion

Sustainable construction practices, especially in the developing countries including UAE, have to be achieved as soon as possible, because the building and construction sector in these countries is still under development and growing very fast. Additionally the shift towards sustainability in the construction sector may play an important role to shift the economic structure towards sustainability and to optimise the well being of the society (UNEP, 2003).

Sustainable construction practices are to be followed in all the stages of construction to successfully complete the sustainable construction. There is minimal specific study having been carried out on sustainable piling construction. Hence this dissertation specifically explores sustainable construction practices in the piling construction in the UAE to assess the cost-effectiveness and sustainability as part of this research study.
Chapter 4: Sustainable practices for Piling construction in the UAE

4.1 Introduction

Piling construction is one most complex activity in the construction projects. Many uncertainties are encountered in the underlying soil strata during execution. Due to this fact cost overrun, materials wastages and delay in project completion may arise. In terms of piling construction the sustainable practices will be focused on the volume of materials used, energy consumption, wastage generation, noise and vibration and impact to the ground (Pank, 2002).

Cost effectiveness and sustainability can be achieved by implementing some good practices in piling construction through adequate soil investigation, economic design, and efficient usage of plant, materials and resources. This chapter details the overview of piling construction and its impact to the environment in the UAE, and sets out sustainable practices which can be followed to attain the cost effectiveness and sustainability with piling constructions.

4.2 Regional Geology of the UAE

It is important to describe the regional geology of the UAE, as ground conditions have substantial influence in the foundation works. In UAE most of the urban cities are located in the coastal land which comprises of loose and very weak top soil layer with low load bearing capacity. Due to the poor ground conditions deep foundations systems to be established for the construction of buildings and any other large structures in this region. Specialist piling contractors are employed to carry out the design and construction of deep foundation systems for the projects. Despite poor soil condition in the urban cities, multi-storey building constructions, and deep basement car parking requirements necessitated the involvement of specialized piling contractors in almost all the projects in the country.

The geology of the United Arab Emirates and the Arabian Gulf area has been substantially influenced by the deposition of marine sediments associated with numerous sea level changes during relatively recent geological time. The following excerpts are taken from a typical geotechnical report by Swissboring (A Geotechnical Company based in UAE)
“The deposits of the UAE coastline and the floor of the Arabian Gulf are mostly Pleistocene or recent in age. The Arabian Gulf is an area of extensive carbonate sedimentation and the nature and distribution of the sediments is governed by the recent geological history and the structural setting of the Gulf, the orientation of the coastline and the prevailing winds. The coastline around Dubai and Sharjah is essentially a linear feature and is largely formed from lateral accretion offshore of beach and dune sand overlying Miliolite sandstone. At Dubai and Sharjah, the coastline is dissected by channels or creeks and consists of a beach / dune complex with development of sabkha plains in the hinterland at the head of the creeks. Recent sediments overlying Aeolian carbonate sandstone are therefore generally encountered with occasional development of bioclastic limestone.

However, the Miliolite sandstone represents a former Aeolian deposit and tends to reflect the morphology of the dunes in which it was formed. The surface level of the sandstone therefore varies appreciably over the area, being exposed at ground level in some localities in Dubai and occurring at depths of up to 10 to 12 metres elsewhere. Towards Sharjah, the sandstone passes laterally into sand with cemented and sandstone layers, which is encountered to the depth of penetration of normal site investigation boreholes. In Sharjah, large thickness of recent carbonate sands are encountered, which tend to become cemented with depth to form bands of carbonate sandstone and strongly cemented sand, with un cemented and weakly cemented layers”.

The superficial geology of Abu Dhabi Emirate comprises of five main quaternary deposits. These include sabkha, dune sands, carbonate beach sand deposits, dune sands with interdunal sabkha deposits and Paleodune deposits. The sabkha deposits present problems with bearing capacity and aggressive chloride and sulphate attack on concrete. Sulphates in the form of gypsum and anhydrite tend to predominate in Arabian sabkhas, which may have concentrations over 50%. The Paleodune deposits (aeolianite) are ancient consolidated sand dunes. They comprise fine to medium grained, rounded to well rounded quartz sand and grains of foraminifera, coral, red algae, ooids, shell fragments, evaporate minerals, heavy minerals and micritic carbonate cement. Figure 4.1 shows the geological distribution of the UAE.
4.3 Current practices with piling construction in the UAE

According to the geology of UAE urban areas, deep pile foundations are mostly recommended by the geologist specialist companies / engineering consultants. Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weak compressible strata or through water, onto stiffer or more compact and less compressible soils, or onto rock. They may be required to carry uplift loads when used to support tall structures subjected to overturning forces from winds or waves. Combinations of vertical and horizontal loads are carried where piles are used to support building foundations, bridge piers and abutments, and machinery foundations.

Piles are also used as embedded retaining walls, which will withstand the forces exerted by a vertical or near vertical ground surface. The type of retaining walls are Sheet pile walls, King post walls, Contiguous bored pile walls, Secant pile walls and Diaphragm walls (CIRIA C580, 2003).

The construction of piles is classified in a number of ways, either by the material of which they are formed, or by the method of installation. The commonly used materials for piles are concrete, steel and timber (occasionally). Piles in terms of installation method are classified in two basic types such as displacement and replacement piles. Displacement piles are piles where the material of the pile, or a former into which the
pile is to be placed, is forced into the ground, by displacing the ground. Whereas Replacement piles the ground is removed by augering, drilling etc and the soil is replaced with cast-in-situ concrete. Replacement piles are the best suited to the UAE and is being constructed in UAE. Replacement piles do not set up vibrations and is not unduly noisy. LDP type piles may create vibrations to setting-up temporary casing tubes using a vibrator, and create noise during sealing in to the ground by using hammer or Kelly bar of the drilling rig. The actual drilling process is free of vibrations and the drilling operation may create some noise due to the engine running and Kelly bar operation in the drilling rig. The CFA pile is the quietest and the method of drilling results in the least vibration. CFA piles are bored using a long continuous flight auger with hollow stem, which is bored in to the ground to the required depth without removing any soil from the ground. Concrete is then pumped to the bottom of auger to fill the pile boring as auger is removed. The size of these piles is limited. It is sensible to consult piling specialist contractors to choose the correct choice of pile type and the equipment needed to construct them (Holland, 1994)

Figure 4.2: Various Pile types (Source: Jones, 2007)

Figure 4.3: Various Displacement pile types (Source: Jones, 2007)
4.4 Environmental impact due to piling construction

In general piling construction is mainly driven by usage of Materials and heavy plants. Concrete and steel is used as the major materials in piling construction. The environmental impacts due to piling construction can be broadly classified in terms of CO$_2$ emission (due to volume of material and energy consumption), waste generation, soil contamination, noise and vibration, and air quality (Pank et al, 2002). The concrete production, usage and transportation are liable to produce CO$_2$ emission. About 460kgCO$_2$ emission results from 1 cubic meter of in situ piling concrete and 1770kgCO$_2$ emission occurs per ton of reinforcement steel. Fossil fuel usage in piling equipments also plays a main contribution to the CO$_2$ emission. 2.62kgCO$_2$ emission released from 1 litre of diesel, and 0.537 kgCO$_2$ per 1 kWh of Electricity usage (NHBC, 2010). NHBC Foundation summarises the embodied carbon emissions for bored pile foundation of 0.3m diameter and 13m long as depicted below in figure 4.5 for different ground conditions. (NHBC, 2010)
Reduction of CO$_2$ emission is mainly associated with minimizing fuel and materials consumption, and reducing waste generation in piling construction, which can be achieved through quality improvement of construction processes by implementing sustainable construction practices.

Noise and Pollution are associated with the selection of method of piling construction, suitable methods and alternative ground stabilization technologies can be used according to the viability to avoid environmental impacts. Sustainable construction practices and alternative ground improvement technologies are discussed in the following section.

4.5 Sustainable practices in piling construction to reduce CO$_2$ emissions

Defects and inefficient processes are the expensive forms of wasting environmental resources and pose a risk to both construction workers and the end users. One of the most important steps towards sustainable construction is to improve the quality of construction, and efficiency and safety in the construction process. It is important to reduce the use of resources in the construction industry. The main areas of improving the quality of construction processes in piling construction are detailed below.

4.5.1 Adequate Geotechnical Investigation

Before foundations are designed and a method of construction determined, it is essential to carry out a site exploration to ascertain the character and variability of the strata underlying the site of the proposed structure. In particular, it is necessary to assess those properties which may affect the performance of the structure and the choice of the method of construction (Khawaja, 2008).

The exploration of a site for an important structure requires exploration and sampling of all strata likely to be significantly affected by the structural load. The extent of this exploration will vary with the site and structure. Exploration should be carried out to a depth which includes all strata likely to be significantly affected by the structural load and the construction operation. The depth of exploration will depend on the type of structure, the size, shape and disposition of the loaded areas and the nature of the strata (BSI, 1998). Ground water levels should be measured in piezometers or simple stand pipes over a sufficient period of time in order to obtain a proper assessment of fluctuations in ground water levels.
As the design of the structure is closely dependent on the actual soil conditions, it is very essential that the exploration activities are adequately supervised and that the interpretation of the results should be closely related to the design and construction operations as a whole. NHBC (2010) indicates that about one third of construction projects are significantly delayed and of those projects, half of the delays are caused by problems in the ground. The foundations are often on the critical path and any delays will be likely to affect all subsequent activities, including completion of the whole project. Inadequate site investigations can also result in the adoption of more conservative design parameters and the need for higher factor of safety as result of greater uncertainty.

4.5.2 Efficient pile design for materials conservation

Foundation design should ensure that foundation movements are within limits that can be tolerated by the proposed structure without impairing its function (BSI, 1998). The engineering property of the underlying rocks or soils and ground water conditions affects the foundation design. Foundation design requires an understanding of the local geology and history of the site. Adequate site investigation enables selection of optimum design parameters for efficient pile design based on improved understanding of the performance requirements of the supported structure and the load settlement response of the piles. Appropriately qualified geotechnical specialists advise throughout the process TO emphasise the best value from the process of pile design and construction and the subsequent validation and testing. If pile testing results show reduced settlements compared to designed settlements, the pile design can be adjusted / optimised (pile length and rebar density changed) based on the pile load vs settlement curves as obtained from the field test results. This in turn reduces the cost and the material usage in piling construction. Also Khawaja (2008) identified that the safety factor used in the foundation design is significantly high in the UAE and this can be adjusted to a more realistic value for cost effective foundation design. Saving 1 m3 of concrete reduces 460kgCO₂ emission and saving 1ton of steel reduces the 1770kgCO₂ emission (NHBC, 2010). Also this materials saving reduces the cost of construction and increases the profit.
4.5.3 Selection of appropriate pile type

Selection of pile types to be considered is based on the practicalities of construction, including site access and available working space, and the effects of pile construction on adjacent foundations and buildings. The implications of obstructions, unstable ground and ground water levels on pile installation must be addressed. Replacement piles will have minimum level of noise and vibration, and the soil arising can be used to verify the ground conditions. The quality of CFA piles is mainly influenced by workmanship and instrumentation, and these piles will generate more spoils. The CFA pile is the quietest and the method of drilling results in the least vibration. The pile type selection requires balancing the practicalities of the construction discussed above to provide maximum efficiency in the production. According to CIRIA Report 181 (1999) the choice of pile type selection is governed by the following Structural, Geotechnical and Environmental aspects (Gannon et al, 1999) as given below in figure: 4.6.

<table>
<thead>
<tr>
<th>Structural</th>
<th>Geotechnical</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load capacity of pile material in compression,</td>
<td>Nature and variability of ground conditions and</td>
<td>Noise</td>
</tr>
<tr>
<td>tension, bending, shear and torsion</td>
<td>ground chemistry</td>
<td></td>
</tr>
<tr>
<td>Ease of handling – transportation, lifting,</td>
<td>Need for ground support (overbreak, base debris,</td>
<td>Vibration or settlement</td>
</tr>
<tr>
<td>stacking, pitching, driving</td>
<td>necking)</td>
<td></td>
</tr>
<tr>
<td>Ease of trimming or extension</td>
<td>Slope of rock surface</td>
<td>Disposal of excavated spoil</td>
</tr>
<tr>
<td>Durability</td>
<td>Excavatability or penetrability (including</td>
<td>Heave or settlement of ground</td>
</tr>
<tr>
<td>Cross-sectional shape</td>
<td>obstructions)</td>
<td></td>
</tr>
<tr>
<td>Wall smoothness</td>
<td>Groundwater</td>
<td>Transport constraints</td>
</tr>
<tr>
<td>Toughness of pile material</td>
<td>Susceptibility to softening</td>
<td>Working space and headroom</td>
</tr>
<tr>
<td>Continuity with substructure or superstructure</td>
<td>Time dependency</td>
<td></td>
</tr>
<tr>
<td>Soundness of the pile material</td>
<td>Stress relaxation</td>
<td></td>
</tr>
<tr>
<td>Driving stresses</td>
<td>Voids in rock</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.6: Factors governing the choice of pile type selection; Source (Gannon et al, 1999).

4.5.4 Improved Energy and material management through operational efficiency and quality work.

Reducing energy consumption by implementing energy efficiency and conservation measures is often a key component in a company’s strategy to reduce GHG emissions. From a financial perspective, this is simply good business, as better energy management
can result in significant gains. This is particularly true when energy prices are high. Construction companies can save money by cutting fuel consumption in company vehicles and on-site plant and equipments such as Piling Rigs, Service Cranes, Excavators etc, as well as by using less electricity in company facilities. One of the most important outcomes of measuring GHG emissions is finding ways of reducing them. In addition to energy-related savings, these opportunities for emission reductions can also stem from correcting operational inefficiencies. Such inefficiencies may be related to defective site works, poor quality, and excess usage of resources. By focusing on them, companies can capitalize on opportunities to reduce emissions and costs. Piling construction is involved with heavy equipments like Piling rigs, Cranes, Generators, Vibro-hammers etc. Huge fuel consumption is required for these heavy equipments. Regularly servicing these equipments and use of appropriate tools can achieve fuel conservation and energy efficiency. Efficient operation of these equipments by a skilled operator also leads to fuel conservation. Proper tool box talks, Risk assessments, Safety meetings, Employees motivation, and incentives for best performance will lead to operational efficiency in piling construction (Dutco Balfour Beatty, 2011).

In my experience the excess concrete consumption (over and above the theoretical quantity) is a usual problem in piling construction. The excess consumption of concrete is due to the over break in the pile bore. Over break arises due to the local collapses of the pile bore walls resulting in cavities. The quality and level of the bore support fluids are required to be kept under tight control during pile bore drilling to avoid such bore wall collapses. Rapid withdrawal of the drilling bucket during pile drilling must be avoided as it may create a ‘piston-effect’ resulting in significant reduction in pressure and bore hole collapse (Geotechnical Engineering Office, 2006). Efficiency in the drilling operation will reduce the risk of borehole collapse, resulting in a reduction in excess concrete consumption. Similarly if the temporary casing is extracted too rapidly with insufficient head of concrete, defects may occur in the pile construction due to soil contamination of the concrete (Fleming and Sliwinski 1977).

Post construction remedial works is one of the main issues in piling construction. Soon after completion of piling construction the main civil or building contractor will start their activities. If any defects are found in the piles, it is the responsibility of the piling contractor to rectify it to the satisfactory level. Since the site is handed over to the main contractor, the piling contractor has to work as per the main contractor’s convenience for the remedial works. This will lead to huge cost incurrence to the piling contractor to
rectify the piles. And, if any delay to the main contractor due to the defective work by piling contractor, huge penalty will be imposed to the piling contractor. The skill of experience operator is important during concreting stage in ensuring pile quality construction. Proper co-ordination in the rate of concrete injection and the rate of extraction of auger in CFA piles is necessary to avoid necking in the piles. There is extensive plant and equipment instrumentation that has been developed to help monitoring the drilling and concreting operations. The UK based company STENT has developed an in-house instrumentation called Stent Integrated Rig Instrumentation System (SIRIS) to ensure the quality in CFA pile construction (Dutco Balfour Beatty, 2011). Similarly Reffat (2004) states that defects and inefficient processes are expensive forms of wasting environmental resources and pose dangers to both the construction workers and the end users of the product. One of the most important steps to sustainable construction is quality construction and efficiency and safety in the construction process.

4.5.5 Use of Sustainable Materials and changing consumption patterns.

Concrete production, usage and transportation produces the majority of CO₂ emission in the piling construction. Concrete is the major quantity of material being used in the piling construction next to steel. Concrete accounts for 5 to 7 % of the world’s CO₂ emissions (Pank et al, 2002). To produce 1 tonne cement uses 4000 to 7500 MJ energy and releases 1 to 1.2 tonnes CO₂. Cement replacement materials like PFA or GGBS can make concrete more sustainable. Up to 50% CO₂ can be reduced by using GGBS or PFA in concrete. GGBS will also reduce the embodied carbon footprint of a typical building by 25% and increases the durability and fire resistance capacity to the building structures. (Ecocem, 2009)

Next to concrete steel is being used in piling construction, however steel is reusable, but in piling construction it is unlikely steel reinforcement bars can be recovered even after demolition of the structures because it is more expensive to extract the piles from deep ground than the scrap value of the steel. Hence as much as possible the percentage of steel reinforcement must be reduced by economic pile design. British Standard BS 8004:1986 recommends that the steel reinforcement bars can be reduced to 0.4% and even curtailed below the level where the bending moment becomes zero or negligible in the pile (BSI, 1998). Hence the steel quantity can be reduced below the zero moment depth in the pile design subject to approval of the concerned authorities. In some projects epoxy coated steel is being used for piling construction in the UAE as corrosion
protection to the reinforcement. The coating factories consume lot of energy for this process, resulting GHG emissions. El-Atrouzy (n.d) asserts that there are many other methods of protection against reinforcement corrosion such as increasing concrete cover, using calcium nitrate admixture in the concrete. These options can be easily adopted in the construction process which can be a stainable option while comparing with epoxy coating. El-Atrouzy (n.d) also argues that unless the epoxy coating process is done properly and satisfying all the code’s provisions, and unless those coated bars are handled very carefully during transportation, forming and placing in forms before concreting, the final result of using those coated bars will not serve the purpose. Though it is allowed by codes of practice to use patching material as touch-up to repair damaged surfaces of epoxy layers, yet this present study proved that such patching material did not prevent the coated bars from corrosion. In this context the other options can lead to quality construction and at the same time reduce the CO$_2$ emission.

Potable Water is being used for concrete manufacturing and for pile drilling activities when stabilization fluids are used. Potable water is being produced in the UAE by desalination process using sea water. For this process lot of fossil fuel is burned which in turn creates CO$_2$ emission in the atmosphere. The construction industry in UAE depends on desalination plants to supply water, and due to the growing nature of the construction projects, more desalination plants are required to meet the water demand. This provides a two way pollution source coming from the construction industry and the desalination plants (Saber, 2010). By reducing water consumption or finding some alternate source of water, enables reduction in CO$_2$ emission. Qader (2009) concludes that to solve the electrical consumption in water desalination, priority must be given to some alternative technologies for water production. In this context an “Airwaterwell” is a unique and electricity-free solar based system, which can be used to produce clean, drinkable water directly from the surrounding air and can be used as an alternative source for water production in the UAE. The water production capacity can be decided based on the requirement, there are units suitable for small scale production and large scale production (GN Focus - Special report, 2011). A small scale Airwaterwell unit and large scale Airwaterwell water farm are shown below in Figures 4.7 and Figure 4.8 respectively. The interesting part is that the water farm’s production capacity will be mainly determined by the amount of solar energy in hand, this is ideally suited to the hot climate countries like UAE.
Figure 4.7: An Airwaterwell Unit; (Source: GN Focus - Special report, 2011)

Figure 4.8: An Airwaterwell Water Farm; (Source: GN Focus - Special report, 2011)

Figure 4.9: Desalination of seawater from sea wave energy (Source: www.airwatergreen.com)
DesalWave (Figure 4.9) is a new desalination technology for **large-scale production of clean drinking water from sea water without the need of grid electricity**. DesalWave's ability to operate without the need of grid electricity has a huge impact on the desalination plant's cost efficiency and the environment. It has a unique low operating expenditure and it has no need of external electricity and needs no onshore electricity grid connection. It incurs a significantly lower capital expenditure than other desalination alternatives. It has no by-production of brine and hence no ocean pollution occurs.

The concept of Reuses and Recycling describes the idea that all components and materials can ever be reused, refurbished and recycled, support life and never have to be deposited as waste. The utilisation of recycled / recyclable materials saves cost, resources and environment. In this context, by using removable / re-usable tie-back anchors (Figure 4.10) instead of steel strand tie-back anchors with cement grouting (being used currently in UAE as part of earth retaining pile wall system), sustainability can be achieved. These re-usable tie-back anchors are cost-effective, no drilling and cement grouting is required, and it can be screwed into place with minimum time taken and resources. As no cement grouting is required this also saves the cement usage resulting in CO₂ emission reduction and soil contamination by avoiding drilling. More over these tie-back anchors are being produced 90% from the recycled materials. (Chance civil construction, 2011).

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**Figure 4.10: Removable / re-usable anchors system (Source: Chance civil construction, 2011)**
Soldier piles (king posts) are installed into the ground at designed intervals, as part of earth retaining system with wall made up of horizontal laggings. The horizontal laggings may comprise steel, pre-cast concrete or timber (CIRIA C580, 2003). Currently pre-cast concrete panels are being used in almost all projects in the UAE. When using timber panels instead of pre-cast concrete panels, as part of soldier pile earth retaining systems, CO₂ emissions as well as the cost can be reduced significantly. Replacing 100 m² of concrete panels with wooden panels can save about 10 m³ of concrete and 0.620 MT of steel reinforcement. This will result in cost saving and CO₂ reduction. About 4598kg of CO₂ reduction by avoiding concrete and 1098kg of CO₂ reduction by avoiding steel reinforcement can be achieved (NHBC, 2010). Also timber panels are cost effective and less installation cost is involved when compared with pre-cast concrete panels (for which heavy cranes are needed to install). Usage of timber panels also to avoid the usage of concrete for which limited sources of raw materials are available when compare with wood. Figure 4.11 below shows soldier pile shoring construction with wooden panels and re-usable tie-back anchors in an overseas country. Figure 4.12 shows soldier pile shoring construction with steel strand tie-back anchors (non reusable) and pre-cast concrete panels in a project in DIAC, Dubai.

Figure 4.11: Soldier pile shoring construction with re-usable tieback anchors and wooden panels in developed country; (Source: Chance civil construction, 2011)
By changing the consumption patterns of the daily business use materials like paper, printer cartridges, the wastage can be avoided and related cost benefits can be realised. This will also lead to the environmental sustainability. Each 1 tonne of recycled papers saves 3 tonnes of wood (24 trees), 8,750 gallons of water, 1,124 lbs of solid waste, 17 Million BTU’s of energy and 2,108 lbs of CO\(_2\) (Environmental Paper Network, 2011). The energy used for lighting in project sites, site offices and companies business main offices also influences CO\(_2\) emissions. By changing conventional lighting to energy efficient lighting will lead to environmental as well as cost benefits. Studies have proved that CFL bulbs are 66% more energy-efficient and cause no environmental problems. Menon R (2011).

Bi-fuel vehicles can be used for the office transportation and site vehicles. Duel fuel engines, comprising natural gas (CNG) and conventional petrol, are being manufactured. It is possible to switch between the fuel types while driving. Use of these vehicle types, results in significant reduction of harmful emissions and environmental pollution. Saving in cost also will be made due to the lower price of CNG compared to petrol (UAEinteract, 2011). As an initiative to encourage the usage of energy efficient vehicles, the DIAC in Dubai allocated 5% of the dedicated basement parking to such vehicles.

There are some fuel-saving devices called “Hiclone fuel-saving devices”. When these are devices installed in vehicles, they improve fuel economy and engine efficiency to the vehicles while helping to decrease air and noise pollution. This Hiclone devices can
reduce CO₂ emission by 60%, reduce fuel consumption by 20% and also increase the vehicles power by 10% (Hiclone, 2011).

4.5.6 Use of Piles for Multiuse (Re-use of existing piles & Use of Piles as Geothermal piles)

Energy piles are piles used for both structural use as well as for thermal function such as to reduce the heat in the summer and increase warmness in the cool climate within the building. Energy piles (Figure 4.13) are being constructed and successfully being used in developed countries such as UK. The concept of these piles can also be used in the UAE and the related advantages can be gained by reducing the energy requirement for the HVAC in the building. Energy piles provide the link between the soil mass and a heat-pump system. Ground Sourced Heat Pump Systems" (GSHPS) can reduce annual HVAC operating costs by up to two-thirds, relative to conventional systems, and reduce CO₂ emissions by up to 75% (Balfour Beatty Ground Engineering, 2011; Skanska, 2011).

![Energy Piles Diagram](source: Katzenbach, 2010)

Figure 4.13: Energy Piles; (Source Katzenbach, 2010)

4.5.7 Combined Pile-Raft Foundation for cost saving against traditional piles

Piled raft is a new design approach for highly loaded pile groups by using the design philosophy of the Combined Pile-Raft Foundation (CPRF) as a hybrid geotechnical composite structure with the design reduction factor of 0.25 to 0.30 compared to the traditional pile foundation. Adequate consideration of Soil-Structure Interaction is indispensable for a reliable design of CPRFs and leads to saving of resources (material, energy, time and money) (Katzenbach, 2010).
4.5.8 **Ground improvement alternatives against pile foundation**

For many types of low-rise development, pile foundation may be either uneconomical or unsuitable due to environmental constraints, or impractical. Ground improvement techniques have therefore become a major area of geotechnical engineering and a large number of treatment methods have been developed to suit a wide range of ground conditions and foundation problems. Ground improvement is generally more environmental friendly than pile foundations. The following ground improvement techniques can be adapted for an increased range of ground conditions and environmental constraints.

### 4.5.8.1 High Energy Impact Compaction

The high energy and relatively large depth of influence of the Landpac ground improvement equipment makes it an effective mechanism of improving the engineering properties of deep in-situ fills and weak natural soils. In-situ ground improvement using the high energy compaction and monitoring technologies comprises the improvement of the engineering properties of in-place ground materials at depth, both above and below the ground water level. Material strength is increased and compressibility and future settlements are decreased as a result of the densification process. The primary objective of this in-situ ground improvement process is to convert a heterogeneous material into one that has more uniform and better engineering properties (LandPac, 2008). The main advantage of this system is quicker completion, no excavation is needed (which results no environmental related impacts) and this process involves very lesser equipments requirements in comparison with pile foundations. Hence it is cost effective, quicker and an environmental friendly construction.

![High energy impact compaction Equipment working in UAE](image)

Figure 4.14: High energy impact compaction Equipment working in UAE (Source LandPac, 2008)
4.5.8.2 Vibro stone columns (VSC)

Vibro stone columns are continuous columns of interlocking aggregate constructed vertically in the ground to reinforce weak soils, improve bearing capacity, and control settlements. Stone columns are a proven foundation solution for many types of buildings including commercial warehouses, retail parks, housing developments, plants, tank farms and office buildings. Vibro stone columns are highly economical and sustainable alternatives to piling foundation solutions. VSC are cheaper than piling (up to as much as half the cost of piling foundations) and quicker than pile foundation in construction. More importantly carbon footprint is much less than when comparing with piling foundations. In addition recycled aggregates can be used within the stone columns which in turn reduces the cost of construction and reduces CO$_2$ emission levels (Pennine, 2011).

![Typical method of construction of vibro stone columns](image)

Figure 4.15: Typical method of construction of vibro stone columns; (Jones, 2007)

4.5.8.3 Rapid Impact Compaction

Rapid impact compaction is a technique utilising a 7 ton hydraulic piling hammer which repeatedly hits the ground with a heavy 1 to 1.5m diameter steel foot. Recurring blows at each treatment position create imprints, which are subsequently filled with granular fill materials. The pattern is repeated at offset locations in order to provide treatment depths of around 3 metre. This technique can be employed for low-rise building foundations and light industrial buildings. This technique is low cost and fast in construction, and has very low carbon footprint levels (Pennine, 2011).
4.5.9 Key barriers and obstacles for sustainable construction practices in piling construction

In addition to environmental protection, sustainable construction development has the potential to become an engine for economic regeneration. Sustainable construction practices provide an important pathway to a stronger, green economy, however there are a number of barriers which are preventing the value potential of sustainable constructions. This chapter looks at the potential barriers in the broad sense of the implementation of sustainable construction practices with piling construction in UAE, including the planning and design phase as well as consideration for barriers in the construction and post construction phases.

Pearce and Fischer (2002) identifies the barriers for sustainable construction as - Resistance to change, Lack of necessary knowledge, Risk of failure, Lack of management buy-in, Lack of resources, Lack of incentives/rewards, Unclear payoffs/measures of success, Existing procedures / standards, and Conflict with Mission Requirements. Though these are common barriers applicable for construction industry, there are some specific barriers for sustainable piling construction which are detailed below.
4.5.9.1 Lack of necessary knowledge

In any country piling is regarded as a specialist operation. The procedure for tendering this work is either Engineer will design and specify the pile details, or Contractor will design the piles based on the load details and soil investigation provided by the Engineer, and price the works accordingly. Lack of knowledge with ground improvement technologies and efficient pile design techniques by the Engineer will hinder sustainability and cost effectiveness in piling construction. Lack of awareness on the relation between environmental impacts and sustainable benefits also becomes the barrier for sustainable constructions.

4.5.9.2 Silo thinking by stakeholders

Design phase is fundamentally important in sustainable construction because it is responsible for defining the sources and the constructive technology that will be implemented on the site. Another important role of design is to define the layout conceptualization which will be responsible for most of the non-value added activities on site. There are many benefits that can be attained provided a sustainability focused design is made.

When the Engineer is wholly responsible for design or supervision of construction he will specify the type, width and overall length of the piles based on the ground information. Though the Engineer design may be over conservative, the winning specialist contractor is not allowed to refine the design by the silo thinking of the relevant stakeholders (Engineer, Employer and Authorities), as they feel that the contractor will always look for the cost benefit rather than safe design and also whatever the cost benefit is goes entirely to the contractor if the contract is awarded with fixed price. This silo thinking by the Engineer also becomes the barrier for the minimizing the material usage and related carbon footprint reduction.

4.5.9.3 Financial Considerations:

Despite that sustainable constructions will be cost effective, there are some upfront capital costs to be invested for the procurement of sustainable materials (from new source) and tools, and equipments for energy conservations and efficient production.
This upfront financial burden keeps contractors to retain vested interests in ‘business as usual’ industry practices, and lack of willingness to change.

For example purchase of re-usable anchors, and fuel efficiency devices will help contractors to reduce operational cost, however initial upfront cost is required for the procurement and installation of such items in the process. Contractor thinking only on the financial perspective also hinders the implementation of small energy saving measures which in the long run may make substantial saving in cost and environmental friendliness.

4.5.9.4 Tight build time commitments to contractors

Tight build times can be one of the barriers to innovations, Contractors do not want to try a new system of works (than currently in practice) due to tight commitments for the completion of the projects. Furthermore heavy penalty may be imposed if any delay in completion occurs. The risk attached to introducing / implementing a new method is higher in the construction industry, it can either be positive or negative, and if it is negative then the related remedial works and delay will also be accounted. Also it affects the contractor’s reputation and creditability (Othman, 2010). This results in reluctance to the contractor’s attitude to introduce / implement sustainable construction practices.

4.5.9.5 Non availability of sustainable materials

Sustainable constructions requires a suitable sustainable materials supply chain and availability of their technical details during the design stage in order to incorporate into the design for later construction. Maria Alkinson, GBCA Executive director says that this is one the greatest challenges facing by the construction professionals. Though there are extensive data bases available nowadays, there is limited understanding to use these resources.

Ordinarily, the concrete is readily available and can reach site as soon as ordered, whereas sustainable materials like wood etc sufficient quantity is not readily available always. Non availability of sustainable materials at the same time as readily availability of un-sustainable materials, acts as barrier to use sustainable materials in construction. By planning in advance and procuring at right time and right quantities sustainable materials can be used in constructions.
4.5.9.6 Cheaper Energy Cost.

The relatively low cost of electricity and low energy prices in the GCC countries, is one of the main causes for high electricity consumption (Qader, 2009). Also there is no taxation and subsidies policy (as in the case of industrialized countries) to attain significant saving in energy no measures are being taken to curb energy consumption. The electricity demand in GCC countries by 2015 will exceed 80% of 2005 levels and resulting similar percentage of CO$_2$ emission level increase, if electricity is being produced in the same scenario without finding any new renewable or cleaner sources of power generation (Qader, 2009).

4.5.9.7 Poor Health, Safety and Environmental performance

Health and safety is of major importance in the piling construction, as it involves heavy mechanical equipments. Any ignorance in this will be a huge impact on the production, performance and quality of the works. Build Safe UAE deputy chairman Chris Doyle states that benefits of good health and safety practices affect not only the morale of individual organisations but also directly impacts on the project programme, cost and environmental improvements. Preparing risk assessment for all activities prior to commencement of works and having frequent tool box talks during the execution of works, and training employees, can improve the Heath, Safety and Environmental performance of any company.

4.5.9.8 Non-mandatory Sustainability regulations.

A variety of regulatory and non-regulatory drivers have started to form a new governance paradigm on product sustainability. To address the products social and environmental life-cycle impacts, these drivers are generating attention towards the product function in companies as a focus of sustainability based constructions. These sustainable regulations and policies are to encourage sustainability practice in the construction industry, by awarding incentives and rewards to the organisations that practices sustainability. Said (n.d) asserts that government plays an important role in achieving sustainability through the development and enforcement of the rules and regulations which must be abided by the industries (including construction industry) which play a significant role on the environmental impact.
4.5.9.9 Selection Criteria of Contractors

Gulcan et al (2008) stated that selecting the right contractor for the right job significantly influences the quality of works as well as the construction progress. Singh & Tiong (2005) defined contractor selection as ‘the process of selecting the most appropriate contractor to deliver the project as specified so that the achievement of the best value for money is ensured’. In private construction projects, owners generally develop their own procedures for selecting contractors (Gulcan et al 2008). However, the lowest bid price is the key determinant factor for selecting contractors. Competitive bid price has a critical role in awarding a contract. However, depending on the lowest bid price alone in selecting contractors, especially for specialised / complex construction projects, may result in serious cost and time overrun for the Client (Sonmez et al., 2002). Contractor selection based solely on the lowest bid price is one of the major reasons for project delivery problems Hatush & Skitmore (1998). Selecting a contractor with their past performance in quality, safety and environmental aspects can avoid problems in quality of work, delay in project completion and create additional costs in construction projects. The contractor’s pre-qualification process can be implemented prior to tendering process to select the right contractors for the right job.

4.5.9.10 Skill level

Huovila and Koskela (1998) identified that the lack of skill level is also a challenging barrier for sustainability, as sustainable construction needs skilled workers for the minimization of material wastages and maximizing process efficiency for added value by minimization of resource depletion, minimization of environmental degradation and creating a healthy built environment (Huovila and Koskela, 1998). Lack of co-ordination to manage resources in a more efficient way also acts as a barrier for sustainable construction.

One of the most critical barriers to sustainable construction is the lack of capacity of the construction sector to actually implement sustainable practices. This lack of capacity is a factor both of the number of human resources and the skills levels of these resources (Reffat 2004)
Chapter 5: Research design and methods

5.1 Introduction

The previous chapters provided theoretical information about sustainable practices with piling constructions in the UAE. The literature review presented in depth information about sustainability, its importance in the Built environment, barriers and benefits of sustainable piling constructions. It also explored various options for sustainable piling constructions and their environmental impact level reductions. This chapter emphasises on the research methods, data collection and analysis methods adopted to achieve this research objectives.

5.2 Research Strategy

In pursuing research for proving a hypothesis true or false, various kinds of methods can be applied for successful research. Different research methods can be applied to solve the research problem systematically, these involves gathering data, use of statistical techniques, interpretations, and drawing conclusions about the research data. The research methods are a blue print to complete the research study (Bhojanna, 2007). The research methods can also be applied individually or collectively for the successful research (Shrestha, 2003). Naoum (2007) emphasizes on two types of research methods, namely quantitative research and qualitative research. The quantitative research is ‘objective’ and scientific in nature with more traditional scientific approaches to research in the form of numbers which can be analysed using standard statistical techniques to test the validity. The quantitative can be best suited when to collect factual evidence or to study the relationship between concept, question or an attribute to test a particular theory or hypothesis (Naoum, 2007). Whereas the Qualitative approach is ‘subjective’ in nature, it takes the form of an opinion, view, perception or attitude towards a factor, variable or question. Qualitative data relates to data that cannot be subjected to quantitative or numerical analysis.

Similarly Ghosh and Chopra (2003) define these two types of data as follows:

“Qualitative data is data in the form of descriptive accounts of observations or data which is classified by type”.
“Quantitative data is data which can be expressed numerically or classified by some numerical value”

5.3 Methodology - Data collection

Combinations of quantitative and qualitative methods are used in the research study as these methods complement each other and enables for more thorough analysis. Creswell and Miller (2000) states that collecting, analyzing and mixing both the quantitative and qualitative data at some stage of research process within a single study allow understanding research objectives more completely. On this basis, to perform research study on “Cost-effective and sustainable practices for piling construction in the UAE”, both the Quantitative and Qualitative research methods were adopted in this dissertation. Figure 5.1 illustrates the research methods used in this dissertation.

![Research Methods Diagram](image)

**QUANTITATIVE APPROACH**
- Importance of Sustainability in the construction industry
- Sustainable practices in piling construction
- Barriers for sustainable practices in piling construction

**QUALITATIVE APPROACH**
- CO2 emission levels in a completed piling construction
- Cost and CO2 reduction levels by sustainable practices

Case study of a completed piling construction project

Figure 5.1: Research methods used in this dissertation.

The overall focus of this dissertation is recommending sustainable practices for piling construction and to assess the related cost-effectiveness and carbon footprint reductions. The main objectives defined are

- To explore the importance of sustainability in the UAE construction industry.
- To identify the sustainable practices with piling constructions including benefits and barriers for its adoption in the UAE.
- To assess the cost saving and CO2 emission reductions by the sustainable practices in a completed piling project in the UAE with the help of case study.
The data collection section was divided into 2 parts:

- Questionnaire and survey
- Demonstrative Case study

5.3.1 Questionnaire and survey approach

A descriptive survey was conducted by forwarding the questionnaire through online to individual professionals working in different organisations in the UAE to obtain their views and responses in regard to the knowledge on importance of sustainability, sustainable piling construction practices and its barriers and benefits. The questionnaire was divided into 4 sections in accordance with the research objectives and included with both open type questions to encourage the respondent to provide free responses (Nauom, 2007) and closed type questions in order to get the straightforward analysis (Nachmias and Nachmias, 1996) with quick answers by short responses in the form of yes or no, agree or disagree patterns. Questionnaire sample is attached in appendix.A.

5.3.2 Demonstrative case study

Bhojanna, (2007) assets that the case study provide a systematic way of looking at events, collecting data, analyzing information, and reporting the results, accordingly the researcher may gain a sharpened understanding of why the instance happened as it did, and what might become important to look at more extensively in future research. On the other hand, Biggam John (2008) suggests that case study is an empirical inquiry that investigates a phenomenon within its real-life context. It can include quantitative evidence, relies on multiple sources of evidence and benefits from the prior development of theoretical propositions.

In order to validate the hypothesis of this research study, a demonstrative case study was also conducted to compare the impacts in values from the current to the research approaches. Case study of a completed piling construction project in the UAE has been chosen and the related Cost and CO\(_2\) emission levels of the chosen project have been calculated based on actual materials, energy used. Then it has been demonstrated with comparative analysis highlighting the cost and environmental benefits using sustainable practices over the current practices.
5.4 Methodology - Data analysis

Descriptive statistics method used for the data analysis on the basis that the descriptive analysis method is the simplest method of analysis which provides the general overview of the results either in percentages, or actual numbers (Naoum, 2007). Frequency distribution in the form of bar chart, pie chart and graph forms were used in the result analysis part. Under descriptive statistics method of analysis, measurement of dispersion based on the standard deviation (Naoum, 2007) is also carried out and the numerical data analysis provided in the form of tabulation. According to Naoum (2007) this standard deviation method of analysis provides a useful basis for interpreting the data in terms of probability. This method of analysis assigns the numerical value to any given variables (activity etc.) based on their empirical properties. The probability figure, that is calculated using the statistical tests, gives the high level of significance to prove the research hypothesis. The formula used for the standard deviation calculation is as mentioned below (Naoum, 2007).

\[
SD = \sqrt{\frac{\sum(X - \bar{X})^2}{N}}
\]

5.5 Conclusion

Data collection is an important stage in the research as it decides the overall objectives of the research study. This phase provides the in depth information about the study and establishes the facts, views and opinions thus fulfils the validity of the objectives.

The response from the different construction professionals through online questionnaire survey provided their general opinions and views on the research objectives. The case study of the completed project provided the general trend and current practices in the UAE piling construction industry.

The data collection provided detail information about all the chosen objectives highlighting various aspects of the sustainable construction practices in piling construction and its benefits, barriers and impacts on the cost and environment. The data collected from the online survey, case study are analysed and discussed in next chapter and is presented in figures, tables and charts.
Chapter 6: Research Data Analysis and Discussion

6.1 Introduction

As discussed in the previous chapters, a questionnaire based survey approach was used for this research study. This dissertation used www.freeonlinesurveys.com website for the preparing, shaping the questionnaire and distributing to the construction industry professionals. The respondents were asked to choose their answers through the multiple choices and selection of options based on their views and opinions. Since the main objective of this research is related to the piling construction, the questionnaire sent to the piling industry professionals and many other professionals whoever linked with the piling industry directly or indirectly. The responses received from those professionals were analyzed and presented in this chapter. The percentages of the responses received were at satisfactory level and provided their general awareness, views and opinions to enable to conclude this dissertation in a well manner.

6.2 Results: Online survey questionnaire (Refer appendix-A)

6.2.1 Section-1: General information of the respondents.

The questionnaires were sent to approximately 150 individuals working in different organisations in order to obtain their personal views and valuable opinions in regards to the research subject. About 63 responses were received and this enabled quite satisfactory result to conduct this analysis. Results of the question.1 indicate that 94% of the respondents were from the civil construction industry and about 6% respondents from other Mechanical, MEP and HVAC industry. Question no.2 shows that all the respondents were with technical background having various designations from Engineer to Project manager. 28 of the respondents were having more than 15 years experience in the industry and remaining 35 respondents were having up to 15 years of experience. Figure 6.1, 6.2 and 6.3 illustrates the exact percentages and numbers.
Figure 6.1: Type of organisation of the respondents

A) Developer
B) Project Manager
C) Consultants
D) Civil Contractor
E) Piling / Shoring Contractor
F) Other

Figure 6.2: Role of the respondents

A) Project Manager
B) Construction Manager
C) Quantity Surveyor
D) Engineer
E) Other
Section-2: General view on the concepts of sustainability and sustainable construction

The question no.7 was framed in such a way to get general views of the respondents on the aspects and principles of sustainability. The results were satisfactory. Figure 6.4 depicts the general awareness and knowledge of the respondents with regard to the sustainability aspects like Global warming and Climate change, Importance / Benefits of Sustainability, The adverse effects of un-sustainability, CO₂ emissions and its impact, Environmental management systems / ISO 14000, Lean Construction principles etc.
The question no. 4 was prepared to know the respondents involvement / participation in any of the sustainable projects and the question no.8 is to know the construction professionals view on the outcome of the literature reviews that whether sustainable construction can lead to the triple bottom line benefits in terms of as economic, environmental and social aspects. The responses for both the questions were quite positive, majority of the respondents (52 out of 63) were involved in the sustainable projects and about 97% (61 out of 63) respondents were agreed that the sustainable constructions can promote the benefits in terms of Economic, environmental and social aspects. About 3% respondents were neutral on their opinion to this question. No one is disagreed.
Figure 6.5: Trend of respondents (in percentage) on their involvement with sustainable projects

Figure 6.6: Respondents opinions on triple bottom line benefits by sustainable construction

A) Strongly Agree
B) Agree
C) Neutral
D) Disagree
E) Strongly Disagree

Figure 6.6: Respondents opinions on triple bottom line benefits by sustainable construction
6.2.3 Section-3: Importance of sustainable construction practices in the Construction Industry

The literature reviews from previous chapters identified that construction industry has the significant contribution on the environmental impact, accordingly the question no. 12 was formed to know the perspective of the industry professionals in the UAE construction industry’s contribution to the global carbon foot print increase. About 97% (61 out 63) respondents agreed that the UAE construction industry has the significant contribution for the global carbon foot print increase.

Figure 6.7: Respondents views on the contribution of the UAE construction industry for the global carbon foot print level increase.

A) Strongly agree  
B) Agree  
C) Neither/nor  
D) Disagree  
E) Strongly disagree

The results shows in line with the literature reviews, which shows that UAE releases about 170.92 million metric tons of CO₂ in the atmosphere, and holds 29th rank in CO₂ emission world wide. The literature review also identifies that the fast urbanization, increased energy production and usage are the main causes for the UAE’s higher CO₂ emission levels. The population growth in UAE also induces the problem of pollution and waste generation, which results the CO₂ emissions in the atmosphere.
In context of the question-15 “what are the reasons for the UAE’s higher energy consumption in the construction industry?” the top reasons are tight project completion schedule (46 of 63), cheaper cost for fossil fuel (42 of 63), current specification requirements (39 of 63) and low electricity cost (33 of 63) followed by other reasons as mentioned in the figure 6.8 below. The top reasons from the construction professionals are in line with the literature review findings.

Figure 6.8: Respondents views on reasons for the higher energy consumption in the UAE construction industry.

A) Tight project completion schedule
B) Current specification requirements
C) Lack of knowledge
D) Non incorporation of energy conservation measures in the construction industry
E) Availability of Fossil fuel for seawater desalination process
F) Cheaper cost of fossil fuel
G) Adequate Electricity generation to fulfill any demand
H) Fairly low Electricity cost
I) All the above

Figure 6.8: Respondents views on reasons for the higher energy consumption in the UAE construction industry.

The respondents were also requested to provide rating on the following items as mentioned in the question no. 14, based on their contribution for the carbon foot print increase in the construction industry. Among the results obtained the fossil fuel consumption as chosen as the major contributor for the carbon foot print level increase, followed by others elements like construction material use, materials wastage, water usage and electricity consumption as per the ratings mentioned in figure. 6.9 below.
The following question of this section was asked to know whether the current financial downturn in the UAE construction industry provides an opportunity to adopt sustainable construction practices. Most of the respondents were agreed, however very few respondents not agreed since based on the point that it will add additional burden on investors. This is also identified in the literature review as one of the barrier for the sustainable practices. Sustainable constructions will be cost-effective, however there are some upfront capital cost to be invested for the procurement of sustainable materials and tools, equipments for the energy conservations and efficient production but at the prolonged utilisation of the sustainable materials, tools, equipments and services repeatedly, the cost effectiveness can be realised. On this context general awareness on cost and benefits of the sustainable practices may be required at the investor level.
Sengupta Nilanjan (2008) asserts that sustainable construction practices can play a great role in reduction of CO$_2$ emission and thus help in the cost-effectiveness. Accordingly the question no. 10 was framed to investigate whether UAE construction industry can be benefited in terms of cost-effectiveness and competitive advantage by implementing sustainability. About 89% of respondents agreed that the UAE construction can be benefited in terms of cost-effectiveness and competitiveness. Which show that the Sustainable construction not only focuses solely on environmental issues, but also encompasses other benefits like reducing cost of construction by reduction in quantity of materials usage in construction through improved and innovative techniques or use of alternate low-energy consuming materials (Sengupta Nilanjan, 2008). WRI Report (2006) summarizes the number of tangible and intangible benefits of sustainable construction which are listed in the previous chapters.
Also in response to the question no.9 “do you believe that lean construction principles can be an appropriate tool for sustainable construction?” the survey results (Figure 6.12) illustrated that about 82% respondents were in agreement that the lean construction principles can be an appropriate tool for the implementation of the sustainable construction practices. Lean construction principles enable significant cost savings, bring the innovations and enhances competitiveness in the market through efficient implementation of the process, procedures and continuous improvement (CIEF, 2009).
Figure 6.12: Respondents view on adapting lean construction principles as tool for sustainable construction.

A) Strongly Agree
B) Agree
C) Neutral
D) Disagree
E) Strongly Disagree

Figure 6.13: Respondents view on enforcing sustainable construction practices as mandatory requirement in the construction industry.

A) Strongly agree
B) Agree
C) Neither/nor
D) Disagree
E) Strongly disagree
The result of respondents (figure 6.13) with regards to enforcing the regulations for the sustainable construction practices showed that 63% (40 of 63) of the respondents were in favour of enforcing the regulations, 32% of the respondents were neutral on their opinion and 5% of the respondents were disagreed to enforce the regulations. However the Government should take initiatives to encourage the sustainable practices in the construction industry.

6.2.4 Section-4: Feasibility of sustainable construction practices with the piling construction in the UAE.

The survey results (Figure 6.14) for the question no.5 shows that the sustainable practices not being implemented with piling construction in the UAE. Around 79% of the respondents were say that sustainable practices not being implemented with piling construction. Also in response to the question no. 6 on the reason why the sustainable practices are not being practices with piling construction, around 44% (37 of 63) respondents are mentioned that specification requirements as potential reason, and remaining 56% respondents given various reasons such as due to additional cost and unawareness of sustainable practices, Lack of resources, Lack of time etc.

![Figure 6.14: Respondent view on Implementation of on sustainable practices in piling construction in the UAE.](image)

The exact percentages of the various results are illustrated below in figure 6.15. The mixed results on reasons for the non-implementation of the sustainable practices, identifies that there is need for the guidance on the sustainable practices in each activity with the piling construction industry in the UAE. Design consultants and Clients also
should initiate the involvement of the specialist piling contractors at the early design stages in order to incorporate the sustainable practices in the initial tender specification documents prior to release for tender.

![Figure 6.15: Respondents view on reasons for the non-implementation of sustainable practices with piling construction in the UAE.](image)

A) Not aware  
B) Additional cost  
C) Lack of resources  
D) Lack of time  
E) Specification not allowed for sustainable practices  
F) Other  

Figure 6.15: Respondents view on reasons for the non-implementation of sustainable practices with piling construction in the UAE.

Based on the literature reviews it was identified that there are plenty of opportunities in the built environment to attain the benefits in terms of Economic, environmental and social aspects. As the piling construction too affected like other construction industry due to the current financial crisis in the UAE, the following questions were raised with the construction professionals that implementation of sustainable practices with piling constructions in the UAE will have right market opportunity for the cost-effectiveness and the long time survival of the organisations in the industry and what percentage of CO$_2$ emissions reductions can be achieved by the sustainable practices with the piling constructions in the UAE construction industry.

The survey results (figure 6.16) for the question no. 17 shows that 86% of the respondents were in agreement that the fact the sustainable practices with the piling constructions in the UAE will hold the right market opportunity to attain the cost-effectiveness and related benefits for the survival in this competitive and financial crisis
situation. 9.5% of the respondents were neutral with their opinion and 4.5% were disagreed. However the majority of the respondents view is in line with the researcher’s view that adopting sustainable practices with piling constructions will enable the cost-effectiveness and the long time survival in the market at the same time reduce the CO$_2$ emissions in the environment.

![Figure 6.16: Respondents view on the adoption of sustainable practices with piling constructions in the UAE under current condition.](image)

A) Strongly agree
B) Agree
C) Neither nor
D) Disagree
E) Strongly disagree

Figure 6.16: Respondents view on the adoption of sustainable practices with piling constructions in the UAE under current condition.

Accordingly the question no. 16 about what percentage of CO$_2$ emission reduction can be achieved by the sustainable practices with the piling construction on the UAE overall construction industry was raised with industry professionals. 54% of the respondents mentioned 10% and around 21% of the respondents agreed that 20% can be reduced. Remaining responses mentioned on various percentages from 25% to 50%. The results of the respondents are shown below in figure 6.17.
Figure 6.17 Respondents view on percentage of contribution for CO$_2$ emission reduction by sustainable piling construction in the UAE.

6.2.5 Section-5: Sustainable construction practices for piling constructions in the UAE.

6.2.5.1 Aspects of sustainable practices with the piling construction in the UAE.

The figure below (Figure 6.18) shows the respondents selection on various sustainable practices with the piling constructions based on their opinion. Survey result shows that among various sustainable practices, reducing energy consumption, improving resources efficiency, use of sustainable materials, avoiding remedial works or repetitions and reducing waste generation have been chosen as top rated sustainable practices by most of the respondents. In addition improving working environment and reducing pollution, plant and equipments fuel conservation have also chosen. Figure 6.16 below illustrates the results with number of respondents chosen on each aspect of sustainable practice.
Table 6.18: Priorities on aspects sustainable practices with piling construction in the UAE.

6.2.5.2 Key areas to focus for cost-effectiveness and sustainability with piling construction

In response to the question-19 “what are the good practices you make take to improve the cost effectiveness and sustainability in piling constructions? the survey results shows higher responses chosen the aspects such as “select appropriate pile type for construction”, “reduce volume of material usage”, “reduce energy consumption”, “reduce waste generation” and “reduce remedial works”, as highly influenced good practices for the cost-effectiveness followed by other options. The exact percentage of responses on each activity is depicted below in figure 6.19. From the obtained results, it is obvious that the material usage, energy consumption and waste generations can
possibly be reduced from the current construction methods which accounts for more CO₂ emissions and increases the cost of construction at the same time (Chen et al, 2010).

Figure 6.19: Respondents priorities on sustainable practices for cost-effectiveness and sustainability.

The respondents were also requested to rate / prioritise the cost-effective options / measures which they feel is most important to attain cost-effectiveness and sustainability with piling construction. Result of this question (question no-20) is given table 6.1. Pank et al, 2002, asserts that the environmental impacts with the piling constructions are mainly depends on volume of material, energy consumption, waste generation, Soil contamination, noise and vibration, and the air quality, similarly the survey results from the respondents shows that reducing material usage, reducing energy consumption, avoiding remedial works are as the most important cost-effective sustainable practices, along with using water from alternative sources and using alternative technologies for the ground improvements technique are also been chosen as the cost-effective sustainable options by the respondents. This hold true on the statement by Saber (2010); Qader (2009) that desalination plants produces large amount of water for the usage of
construction industry, which increases the CO₂ emissions levels, the production of water by the alternate technologies using renewable energy, reduces the energy consumption for the desalination process and reduces the CO₂ emissions which in turn reduces the cost water too.

<table>
<thead>
<tr>
<th>Cost-effective measures</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Very Low</th>
<th>Responses</th>
<th>Weighted Average</th>
<th>Standard Deviation</th>
<th>Index Value</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing energy consumption through efficient equipment operation</td>
<td>37</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>63</td>
<td>3.59</td>
<td>0.49</td>
<td>10.87</td>
<td>1</td>
</tr>
<tr>
<td>Reducing material usage through efficient pile design</td>
<td>30</td>
<td>31</td>
<td>2</td>
<td>0</td>
<td>63</td>
<td>3.44</td>
<td>0.56</td>
<td>9.63</td>
<td>2</td>
</tr>
<tr>
<td>Using efficient machinery/equipment</td>
<td>17</td>
<td>42</td>
<td>4</td>
<td>0</td>
<td>63</td>
<td>3.21</td>
<td>0.54</td>
<td>9.15</td>
<td>3</td>
</tr>
<tr>
<td>Using reusable materials</td>
<td>20</td>
<td>39</td>
<td>4</td>
<td>0</td>
<td>63</td>
<td>3.25</td>
<td>0.56</td>
<td>9.04</td>
<td>4</td>
</tr>
<tr>
<td>Using sustainable materials for construction</td>
<td>26</td>
<td>33</td>
<td>4</td>
<td>0</td>
<td>63</td>
<td>3.35</td>
<td>0.60</td>
<td>8.98</td>
<td>5</td>
</tr>
<tr>
<td>Using appropriate pile type for construction</td>
<td>18</td>
<td>42</td>
<td>2</td>
<td>1</td>
<td>63</td>
<td>3.22</td>
<td>0.56</td>
<td>8.82</td>
<td>6</td>
</tr>
<tr>
<td>Avoiding post construction remedial works</td>
<td>43</td>
<td>14</td>
<td>5</td>
<td>1</td>
<td>63</td>
<td>3.57</td>
<td>0.71</td>
<td>8.63</td>
<td>7</td>
</tr>
<tr>
<td>Using potable water produced from alternate sources without fossil fuel</td>
<td>39</td>
<td>17</td>
<td>7</td>
<td>0</td>
<td>63</td>
<td>3.51</td>
<td>0.69</td>
<td>8.61</td>
<td>8</td>
</tr>
<tr>
<td>Alternative ground improvement options against pile foundations</td>
<td>37</td>
<td>17</td>
<td>8</td>
<td>1</td>
<td>63</td>
<td>3.43</td>
<td>0.77</td>
<td>7.88</td>
<td>9</td>
</tr>
<tr>
<td>Using fuel saving devices for the vehicles</td>
<td>13</td>
<td>36</td>
<td>14</td>
<td>0</td>
<td>63</td>
<td>2.98</td>
<td>0.65</td>
<td>7.54</td>
<td>10</td>
</tr>
<tr>
<td>Using skilled manpower</td>
<td>13</td>
<td>25</td>
<td>25</td>
<td>0</td>
<td>63</td>
<td>2.81</td>
<td>0.75</td>
<td>6.54</td>
<td>11</td>
</tr>
<tr>
<td>Using timber materials in lieu of concrete piles foreering piles</td>
<td>7</td>
<td>33</td>
<td>20</td>
<td>3</td>
<td>63</td>
<td>2.70</td>
<td>0.73</td>
<td>6.41</td>
<td>12</td>
</tr>
<tr>
<td>Behavioral good practices for efficient energy management</td>
<td>13</td>
<td>19</td>
<td>30</td>
<td>1</td>
<td>63</td>
<td>2.70</td>
<td>0.81</td>
<td>6.03</td>
<td>13</td>
</tr>
<tr>
<td>Use of pile for multi function</td>
<td>13</td>
<td>18</td>
<td>31</td>
<td>1</td>
<td>63</td>
<td>2.68</td>
<td>0.81</td>
<td>5.98</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 6.1: Priority rating on cost-effective and sustainable measures with piling construction.

The researcher finds that the alternative technologies for the water production without need of either desalination process or electricity will be the best suited to the UAE in order to reduce the CO₂ emissions and to reduce the energy consumption for the water production. In this regards to the question no. 22 “whether the new invention of Airwater well unit / Airwater farm unit will it be best suited to the UAE” The responses from the Industry professionals were quite positive on the suitability of these new technologies to the UAE construction industry. 60% of the respondents agreed that it will be best suited and 17% were said some what suited. 22% of the respondents were un-aware of these new technologies, hence they responded as “don’t know” about its suitability. No one “disagreed”. The results of the respondents are illustrated below in figure 6.20. The “airwaterwell unit” / “Airwaterwell farm unit” produces potable water form the air using solar power and the “desalwave” unit produces water by RO system
producing required energy for this process through sea waves (www.airwatergreen.com). UAE is the hot climate country, the solar power is available in this country and the current potable water production is totally by the traditional fossil fuel burn de-salination process in this country. Based on these grounds, the researcher finds the “Airwaterwell unit and Desalwave units would be best suited to the UAE. The Industry professional too agree with this viewpoint.

![Pie chart]

**Figure 6.20: Respondents view on suitability of producing potable water from alternate technologies in the UAE.**

**6.1.1.1 Benefits Sustainable construction practices with piling construction**

<table>
<thead>
<tr>
<th>Benefits</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Very Low</th>
<th>Responses</th>
<th>Weighted Average</th>
<th>Standard Deviation</th>
<th>Index Value</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings</td>
<td>50</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>62</td>
<td>3.77</td>
<td>0.49</td>
<td>11.49</td>
<td>1</td>
</tr>
<tr>
<td>Increased Productivity</td>
<td>40</td>
<td>19</td>
<td>3</td>
<td>0</td>
<td>62</td>
<td>3.60</td>
<td>0.58</td>
<td>9.79</td>
<td>2</td>
</tr>
<tr>
<td>No/Less remedial works</td>
<td>43</td>
<td>14</td>
<td>5</td>
<td>1</td>
<td>63</td>
<td>3.57</td>
<td>0.71</td>
<td>8.63</td>
<td>3</td>
</tr>
<tr>
<td>Less operating cost</td>
<td>38</td>
<td>19</td>
<td>4</td>
<td>1</td>
<td>62</td>
<td>4.00</td>
<td>1.00</td>
<td>9.00</td>
<td>4</td>
</tr>
<tr>
<td>Employees job satisfaction</td>
<td>10</td>
<td>40</td>
<td>10</td>
<td>2</td>
<td>62</td>
<td>2.94</td>
<td>0.67</td>
<td>7.32</td>
<td>S</td>
</tr>
<tr>
<td>Good market share</td>
<td>28</td>
<td>26</td>
<td>6</td>
<td>3</td>
<td>63</td>
<td>3.25</td>
<td>0.82</td>
<td>7.24</td>
<td>6</td>
</tr>
<tr>
<td>Adds brand name to the organization</td>
<td>12</td>
<td>38</td>
<td>8</td>
<td>4</td>
<td>62</td>
<td>2.94</td>
<td>0.76</td>
<td>6.80</td>
<td>7</td>
</tr>
<tr>
<td>Reduction in water usage</td>
<td>20</td>
<td>17</td>
<td>25</td>
<td>1</td>
<td>63</td>
<td>2.89</td>
<td>0.87</td>
<td>6.19</td>
<td>8</td>
</tr>
<tr>
<td>Client/Owners appreciation</td>
<td>13</td>
<td>23</td>
<td>24</td>
<td>3</td>
<td>63</td>
<td>2.73</td>
<td>0.84</td>
<td>5.98</td>
<td>9</td>
</tr>
</tbody>
</table>

**Table 6.2: Benefits of sustainable practices with piling construction**
The above table (Table 6.2) shows the ranking of the different benefits by sustainable practices with piling construction. The result of the respondents demonstrates that sustainable practices with piling construction not only have the benefit in terms of cost savings but also brings good market share and add visual brand name to the organisation as a whole. Among the various benefits, the “Energy savings” become the top in the list, followed by “increased productivity” and quality work “without any remedial works”, “less operating cost” and “good market share” have also been chosen as some of the benefits of the sustainable practices. It is also argued by Qader, (2009) that the cheaper energy cost and fairly low cost of electricity in UAE as the main causes for the high consumptions. Accordingly most of the respondents believe that due to cheaper energy cost and sufficient availability of the fossil fuel the organisations ignored the opportunity for energy conservation and related triple bottom line benefits, which indeed can be achieved by adopting the sustainable practices.

6.2.5.3 Barriers for the sustainable construction practices with piling construction

Table 6.3 below shows the different barriers for the implementation of sustainable practices with piling constructions in the UAE according to their influence raking.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Very Low</th>
<th>Responses</th>
<th>Weighted Average</th>
<th>Standard Deviation</th>
<th>Index Value</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of time for innovation</td>
<td>39</td>
<td>22</td>
<td>2</td>
<td>0</td>
<td>63</td>
<td>3.99</td>
<td>0.55</td>
<td>10.07</td>
<td>1</td>
</tr>
<tr>
<td>Tight build time commitment to contractors</td>
<td>40</td>
<td>19</td>
<td>4</td>
<td>0</td>
<td>63</td>
<td>3.57</td>
<td>0.61</td>
<td>9.43</td>
<td>2</td>
</tr>
<tr>
<td>Skill level</td>
<td>15</td>
<td>44</td>
<td>3</td>
<td>1</td>
<td>63</td>
<td>3.36</td>
<td>0.57</td>
<td>8.71</td>
<td>3</td>
</tr>
<tr>
<td>Selection criteria of contractors</td>
<td>35</td>
<td>20</td>
<td>7</td>
<td>1</td>
<td>63</td>
<td>3.41</td>
<td>0.75</td>
<td>7.97</td>
<td>4</td>
</tr>
<tr>
<td>Non availability of sustainable materials</td>
<td>35</td>
<td>21</td>
<td>5</td>
<td>2</td>
<td>63</td>
<td>3.41</td>
<td>0.77</td>
<td>7.85</td>
<td>5</td>
</tr>
<tr>
<td>Lack of incentives / motivation</td>
<td>20</td>
<td>35</td>
<td>7</td>
<td>1</td>
<td>63</td>
<td>3.47</td>
<td>0.68</td>
<td>7.85</td>
<td>6</td>
</tr>
<tr>
<td>Cheaper energy costs</td>
<td>35</td>
<td>19</td>
<td>8</td>
<td>1</td>
<td>63</td>
<td>3.40</td>
<td>0.77</td>
<td>7.82</td>
<td>7</td>
</tr>
<tr>
<td>Silo thinking by stake holders</td>
<td>34</td>
<td>20</td>
<td>8</td>
<td>1</td>
<td>63</td>
<td>3.38</td>
<td>0.76</td>
<td>7.80</td>
<td>8</td>
</tr>
<tr>
<td>Financial considerations</td>
<td>14</td>
<td>41</td>
<td>6</td>
<td>2</td>
<td>63</td>
<td>3.06</td>
<td>0.66</td>
<td>7.68</td>
<td>9</td>
</tr>
<tr>
<td>Lack of awareness</td>
<td>10</td>
<td>45</td>
<td>5</td>
<td>3</td>
<td>63</td>
<td>2.98</td>
<td>0.65</td>
<td>7.54</td>
<td>10</td>
</tr>
<tr>
<td>Confusion on cost and benefits</td>
<td>14</td>
<td>26</td>
<td>23</td>
<td>0</td>
<td>63</td>
<td>2.86</td>
<td>0.75</td>
<td>6.65</td>
<td>11</td>
</tr>
<tr>
<td>Lack of knowledge and experienced workforce</td>
<td>12</td>
<td>27</td>
<td>24</td>
<td>0</td>
<td>63</td>
<td>2.81</td>
<td>0.73</td>
<td>6.65</td>
<td>12</td>
</tr>
<tr>
<td>Non-mandatory sustainability regulations</td>
<td>11</td>
<td>22</td>
<td>27</td>
<td>3</td>
<td>63</td>
<td>2.65</td>
<td>0.82</td>
<td>5.89</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 6.3: Barriers of sustainable practices with piling construction
According to the survey results from various respondents, “lack of time for innovation” and “tight build time commitments to the contractors” are become the most influenced barriers for the sustainable practices with the piling construction in the UAE. Apart from those, “selection criteria of contractors” and “skill levels” have also been chosen as barriers for sustainable practices. This is similarly supported by Gulcan et al (2008) who identified that the contractor selection significantly influences the quality of works, completion schedule and the overall cost. Selecting the most appropriate contractor with required skill level and experience to deliver the project provides also best value for money to the client (Singh & Tiong, 2005). Among the various barriers the non-mandatory sustainability regulations are chosen as lowest among all, at the same time the lack of incentives / motivation have been chosen in the higher level (rank 6 in the list). From the results the researcher identifies that the local government should encourage the business organizations with substantial amount of incentives and motivations for the innovations and to adopt sustainable practices, which will highly, influence the industry to transform to the sustainable practices from the conventional practices rather than making the sustainable practices as mandatory.

6.3 Case Study Analysis

6.3.1 Introduction

One of the completed piling projects in the UAE is taken for this research study in order to analyse the method of construction, material usage and the respective CO₂ emission level and the associated cost for the construction. Accordingly the feasible options for sustainable construction practices were identified from the method of construction carried out at the case study project and related cost-effectiveness and CO₂ reduction levels were compared based on the identified sustainable construction practices over the traditional method the project was constructed.

6.3.2 Details of the case study project

The case study project is “2B+G+15 Floor commercial and residential building project” located on plot no. 231-354 at Al Nahda, Dubai. The shoring and foundation piling works were carried out by M/s. Dutco Balfour Beatty LLC. The shoring works was carried out on four sides of the plot to construct two level basements. The shoring piles were designed as contiguous piles. The contiguous piles shoring comprises of 105 nos. 600mm diameter piles with tie-back anchors (33 nos.) supported and 148 nos. 750mm
diameter cantilevered piles. The concrete grade of 40 N/mm², was used for both foundation piles and shoring piles. The GGBS was included in the foundation pile concrete, but for shoring piles concrete GGBS not used. The as-built drawings are attached in the appendix-B.

![Figure 6.21: Architectural image and location of the case study project (Source: Dutco Balfour Beatty LLC)](image)

### 6.3.2.1 Shoring piles

The shoring piles were executed by CFA method construction and foundation piles were executed by rotary drilling method of pile construction.

The shoring scheme was designed to construct from 2m below from the EGL on road sides and on Neighbour plot side from EGL. However since the consultant required the shoring to be constructed for the top 2m height too, kingpost shoring with pre-cast concrete panels were designed and constructed.

Prior to commencement of contiguous pile shoring works, temporary concrete guide wall was constructed on all four sides to enable to construct the contiguous piles in the designed spacing. Approximately 100m³ of 30N/mm² concrete and 230m² of A393 mesh reinforcement used to construct the temporary guide wall.
The shoring pile design was carried out using UK based computerized software “Wallap”. The factor of safety used for the shoring design was 1.9 (The output calculation from Wallap attached in the appendix-B).

![Figure 6.22: Tie-back anchoring work in progress at the case study project (Source: Dutco Balfour Beatty)](image)

**6.3.2.2 Foundation piles**

The piling works comprises of 48 Nos. of 600mm diameter and 162 nos. of 800mm diameter bored-cast in-situ piles. The foundation piles were also designed by the piling contractor. According to the piling contractor’s design, the pile lengths were less than the soil investigation report recommendation. However the piling contractor has been instructed to follow the soil investigation report’s recommended length for construction.

According to the project correspondences, the design consultants have delayed for pile design approval for foundation piles, as they were revising the pile loads in accordance
to changes in the building structural elements. Due to this delay the piling rig and the crew were idle for about 14 days at site.

After completion of the foundation piles, there were some issues on reinforcement bars projection length above cut-off level. Some piles were not having sufficient projection lengths above cut-off level. Hence the piling contractor to employ the manpower to carryout the remedial works for extending the reinforcement bars. The piling contractor purchased rebar-couplers and additional quantity of reinforcement for these remedial works. The piling contractor incurred additional cost on the use of additional manpower, plant, equipments and materials for these remedial works.

6.3.3 Details of the materials, plant and resources usage for the piling project under case study.

**Shoring piles**
- Concrete for shoring piles = 1815 m³
- Concrete over break = 38%
- Steel reinforcement for shoring piles = 275 MT
- Fuel for shoring piles construction = 13546 litres
- Number of shoring piles
  - 600mm diameter = 105 Nos.
  - 750mm diameter = 148 Nos.
- Number of tie-back anchors = 33 Nos.
- No. of days to complete the shoring piles = 30 days
- Average production of shoring piles = 8.43 piles per shift

**Foundation piles**
- Concrete for foundation piles = 2229 m³
- Concrete over break = 23%
- Steel reinforcement for foundation piles = 60 MT
- Fuel for foundation piles construction = 25350 litres
- Number of foundation piles
  - 600mm diameter = 48 Nos.
  - 750mm diameter = 162 Nos
- No. of days to complete the foundation piles = 80 days
- Average production of foundation piles = 3.80 piles per day
**Overall cost per shift**

<table>
<thead>
<tr>
<th>Cost</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of plant and Equipments</td>
<td>Dhs. 11,800 per shift</td>
</tr>
<tr>
<td>Cost of Labour</td>
<td>Dhs. 4,000 per shift</td>
</tr>
<tr>
<td>Cost of fuel</td>
<td>Dhs. 3,500 per shift</td>
</tr>
</tbody>
</table>

**6.3.4 Accessing the options for sustainable practices on the piling construction of the case study project.**

The shoring pile design of the case study project was prepared with a factor of safety of 1.9, to be on more safer side, as the piling contractor’s criteria is on to be more safe design rather than conservative and economic design. BS 8002:1994, states that in practice, there is no advantage in exceeding the pile depth of penetration beyond which the anomalies occur in the value of the factor of safety. CIRIA report 104 (1984) recommends a value of $F_p = 2.0$ for $\phi' > 30^\circ$, $F_p = 1.5$ to 2.0 for $\phi'$ ranging from $20^\circ$ to $30^\circ$ and $F_p = 1.5$ for $\phi' < 20^\circ$. Accordingly the pile can be designed with $F_p = 1.5$ for $\phi'$ ranging from $20^\circ$ to $30^\circ$.

BS 8002:1994 also states that when a wall is very stiff, e.g. reinforced concrete piles, the free earth support condition should be used, since the stiffness of the wall may prevent the rotation of the toe of the wall sufficiently, such that the passive pressure required on the rear face for fixed earth conditions is not allowed to develop. In order that end fixity may develop at the toe of the pile, the embedment should be greater than for the free-earth condition. Providing that the wall section and the props are adequate, there is no failure mechanism which is relevant to an overall stability check. Traditionally, for a retaining wall embedded in sand, a factor of safety of 1 can be used, depending on the confidence that can be placed on the soil parameter values and other various factors which may affect the design. Accordingly if the factor of safety of 1.5 is used for the case study project’s shoring pile design the pile length can be reduced about 1.25m which in turn reduces the concrete, steel quantities and increases the production accordingly (Refer computerized pile design calculation attached in Appendix-B).

If the temporary guide wall is prepared by using structural steel beams (re-useable) instead of concrete guide wall. The concrete, plant and resources usage could be saved, which also reduces the cost and CO$_2$ emissions by avoiding concrete.
The top 2m of the shoring on road sides were designed as kingpost shoring with pre-cast concrete panels. During the tender stage the piling contractor proposed open cut excavation for the top 2 metres, but the consultant insisted for the kingpost shoring with pre-cast panels. Wooden panels can also very well been used in place of pre-cast concrete panels, as the wooden panels are suitable to carry the load for the retaining height of 2m excavation. Usage of wooden panels here not only reduces the cost, time and equipment usage but also reduces the CO\textsubscript{2} emissions.

The foundation piles were constructed with temporary casing method of construction. If these piles were constructed with CFA method, the rate of production could have been increased and fuel, plant and resources usage could have been reduced. Dutco Balfour Beatty LLC, Dubai is using a specialized instrumentation called “SIRIS” (“Stent Integrated Rig Instrumentation System”) fitted in their CFA piling rigs to control the pile concreting and pile diameter, hence the pile quality can be ensured for the CFA piles. The Details of “SIRIS” instrumentation is attached in Appendix-B.

The skill level of the execution staff and supervision staff during execution of the foundation piles should have been improved in this project, so that the concrete over break percentage could have been reduced and the post construction remedial works might have been avoided. The rebar and the concrete top level must be monitored while concreting the piles. Avoidance of post construction remedial works not only reduces the cost and also reduces the wastage of materials, resources and CO\textsubscript{2} emissions.

Even though cost benefit is comparatively less on the usage of potable water obtained from alternate sources, other than traditional fossil fuel burn de-salination plants, this could help to reduce the CO\textsubscript{2} emissions in the atmosphere. The consultant and authorities should encourage the contractors to use the potable water produced from alternate sources.
6.3.5 Assessing the Cost saving and CO₂ level reductions through sustainable practices in the case study project.

6.3.5.1 CO₂ Emissions calculation as per conventional (As usual) method of construction – (Refer Appendix-B)

1. CO₂ EMISSIONS FROM SHORING PILES CONSTRUCTION

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials Used as per current practice (**)</th>
<th>Carbon emission Factor</th>
<th>CO₂ emission (kgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (d0 N/mm²)</td>
<td>1,844.50 m³</td>
<td>0.209 kgCO₂/kg</td>
<td>383,307.10</td>
</tr>
<tr>
<td>Reinforcement Steel</td>
<td>273 MT</td>
<td>1.770 kgCO₂/kg</td>
<td>484,190.00</td>
</tr>
<tr>
<td>Fuel (Diesel) @ 1460 lit /shift / day</td>
<td>43,800 Litres</td>
<td>2.629 kgCO₂/lit</td>
<td>114,756.00</td>
</tr>
<tr>
<td>Manpower</td>
<td>30 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>30 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>1,432,273.10</td>
</tr>
</tbody>
</table>

2. CO₂ EMISSIONS FROM CONCRETE GUIDE WALL CONSTRUCTION

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials Used as per current practice (**)</th>
<th>Carbon emission Factor</th>
<th>CO₂ emission (kgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>100 m³</td>
<td>0.599 kgCO₂/kg</td>
<td>59,990.00</td>
</tr>
<tr>
<td>Steel mesh (A305) @ 6.16 kg/m²</td>
<td>230 m²</td>
<td>1.730 kgCO₂/kg</td>
<td>507.74</td>
</tr>
<tr>
<td>Fuel (Diesel) @ 60 lit / day</td>
<td>10 Days</td>
<td>2.629 kgCO₂/lit</td>
<td>157.20</td>
</tr>
<tr>
<td>Manpower (from Labour supply)</td>
<td>10 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipments</td>
<td>10 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>50,099.74</td>
</tr>
</tbody>
</table>

3. CO₂ EMISSIONS FROM CONSTRUCTION OF FOUNDATION PILES

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials Used as per current practice (**)</th>
<th>Carbon emission Factor</th>
<th>CO₂ emission (kgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>2,228.00 m³</td>
<td>0.309 kgCO₂/kg</td>
<td>670,655.60</td>
</tr>
<tr>
<td>Reinforcement Steel</td>
<td>55,224 MT</td>
<td>1.770 kgCO₂/kg</td>
<td>97,746.48</td>
</tr>
<tr>
<td>Fuel (Diesel) @ 1460 lit /shift / day</td>
<td>55 Days</td>
<td>2.629 kgCO₂/lit</td>
<td>210,386.00</td>
</tr>
<tr>
<td>Manpower</td>
<td>55 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipments</td>
<td>55 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>410,388.08</td>
</tr>
</tbody>
</table>

4. CO₂ EMISSIONS DUE TO POTABLE WATER USE FOR PILING CONSTRUCTIONS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials Used as per current practice (**)</th>
<th>Carbon emission Factor</th>
<th>CO₂ emission (kgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (obtained from DBB Project cost A/C)</td>
<td>159,113 m³</td>
<td>24.30</td>
<td>3,866.45</td>
</tr>
<tr>
<td></td>
<td>(Carbon emission factor obtained from Davis et al. 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>3,866.45</td>
</tr>
</tbody>
</table>

5. CO₂ EMISSIONS DUE TO POST CONSTRUCTION REMEDIAL WORKS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials Used as per current practice (**)</th>
<th>Carbon emission Factor</th>
<th>CO₂ emission (kgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement steel</td>
<td>250 kgs</td>
<td>1.770 kgCO₂/kg</td>
<td>442.50</td>
</tr>
<tr>
<td>Rebar Couplers</td>
<td>375 Nos</td>
<td>1.770 kgCO₂/kg</td>
<td>-</td>
</tr>
<tr>
<td>Fuel (Diesel) @ 30 lit / shift / day</td>
<td>30 Days</td>
<td>2.629 kgCO₂/lit</td>
<td>2,358.00</td>
</tr>
<tr>
<td>Manpower (obtained from DBB Project cost A/C)</td>
<td>30 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipments</td>
<td>30 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>2,800.50</td>
</tr>
</tbody>
</table>
6. CO2 EMISSIONS DUE TO IDLE HOURS (WORK STOPPAGE)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials</th>
<th>Carbon emission Factor</th>
<th>CO2 emission (kgCO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (Diesel) @ 300 lit / shift / day</td>
<td>14 Days</td>
<td>2.630 kgCO2/lit</td>
<td>11,004.00</td>
</tr>
<tr>
<td>Manpower</td>
<td>14 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>14 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>11,004.00</strong></td>
</tr>
</tbody>
</table>

Note:
The idle days are calculated from the concrete supply record (refer appendix-B)

7. CO2 EMISSIONS FROM KING POST SHORING CONSTRUCTION - CONCRETE PANELS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials</th>
<th>Carbon emission Factor</th>
<th>CO2 emission (kgCO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete for Pre-cast concrete panels</td>
<td>34.00 m3</td>
<td>0.509 kgCO2/kg</td>
<td>15,833.20</td>
</tr>
<tr>
<td>Reinforcement for pre-cast panels @ 6.16 kg/m2</td>
<td>1.68 MT</td>
<td>1.770 kgCO2/kg</td>
<td>2,955.90</td>
</tr>
<tr>
<td>Panels casting cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>18,789.10</strong></td>
</tr>
</tbody>
</table>

8. CO2 EMISSIONS DUE TO TIE-BACK ANCHORS FOR SHORING PILES

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials</th>
<th>Carbon emission Factor</th>
<th>CO2 emission (kgCO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel strands (15.24mm @ 1.1kg / m)</td>
<td>1485</td>
<td>1.770 kgCO2/kg</td>
<td>2,801.30</td>
</tr>
<tr>
<td>Cement</td>
<td>8,250 kgs</td>
<td>0.930 kgCO2/kg</td>
<td>7,622.50</td>
</tr>
<tr>
<td>Fuel (Diesel) @ 60 lit / day / shift</td>
<td>8 Days</td>
<td>2.630 kgCO2/lit</td>
<td>1,257.60</td>
</tr>
<tr>
<td>Manpower</td>
<td>8 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>8 Days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>11,821.40</strong></td>
</tr>
</tbody>
</table>

Note:
By using the re-usable tie-back anchors from "CHANCE" the installation can be done 50% faster than traditional anchor installation, hence the 50% installation time is considered as cost saving for installation.

**SUMMARY**

<table>
<thead>
<tr>
<th>Item description</th>
<th>CO2 emission (kgCO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CO2 EMISSIONS FROM SHORING PILES CONSTRUCTION</td>
<td>1,432,273.10</td>
</tr>
<tr>
<td>2. CO2 EMISSIONS FROM CONCRETE GUIDE WALL CONSTRUCTION</td>
<td>50,059.74</td>
</tr>
<tr>
<td>3. CO2 EMISSIONS FROM CONSTRUCTION OF FOUNDATION PILES</td>
<td>410,208.08</td>
</tr>
<tr>
<td>4. CO2 EMISSIONS DUE TO POTABLE WATER USE FOR PILING CONSTRUCTIONS</td>
<td>3,866.45</td>
</tr>
<tr>
<td>5. CO2 EMISSIONS DUE TO POST CONSTRUCTION REMEDIATION WORKS</td>
<td>2,800.50</td>
</tr>
<tr>
<td>6. CO2 EMISSIONS DUE IDLE HOURS (WORK STOPPAGE)</td>
<td>11,004.00</td>
</tr>
<tr>
<td>7. CO2 EMISSIONS FROM KING POST SHORING CONSTRUCTION - CONCRETE PANELS</td>
<td>18,589.10</td>
</tr>
<tr>
<td>8. CO2 EMISSIONS DUE TO TIE-BACK ANCHORS FOR SHORING PILES</td>
<td>11,821.40</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>1,640,622.36</td>
</tr>
</tbody>
</table>

Note:
1. All the data obtained from Ms Dutco Balfour Beatty LLC from their project ref. no. AJ-7628
2. Carbon conversion factors for the materials used for this study are from NHBC (2008), Darwish et. al (2007) and www.concretecentre.com
3. (*) - Refer appendix-B for the Quantity of materials used as per current practices and quantity of materials will be used as per sustainable practices
4. All the unit cost are obtained from Ms Dutco Balfour Beatty LLC from their project ref. no. AJ-7628

Table 6.4: CO2 emissions produced in the case study project.
6.3.5.2 Cost saving and CO₂ Emissions reduction calculation by adopting sustainable practices – (Refer Appendix-B)

### 1. COST SAVING AND CO₂ EMISSION REDUCTION BY THE ECONOMIC DESIGN OF SHOPPING MILLS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (330 MPa)</td>
<td>1,846.30 m³</td>
<td>542.00 m³</td>
<td>20.00 Dhs</td>
<td>39.60 Dhs</td>
<td>1.52</td>
<td>1.52</td>
<td>11,308.12</td>
</tr>
<tr>
<td>Reinforcement Steel</td>
<td>556.90 kg</td>
<td>0</td>
<td>400.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Steel (Galvanized)</td>
<td>52.80 kg/linear meter</td>
<td>0</td>
<td>450.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Material (330 MPa)</td>
<td>542.00 kg</td>
<td>0</td>
<td>38.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>30 Days</td>
<td>21 Days</td>
<td>12.00 Dhs</td>
<td>9.00 Dhs</td>
<td>1.51</td>
<td>1.51</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>534,139.28</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

### 2. COST SAVING AND CO₂ EMISSION REDUCTION BY USING STEEL GUIDE WALL INSTEAD OF CONCRETE GUIDE WALL

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>100 m³</td>
<td>0</td>
<td>200.00 Dhs</td>
<td>200.00 Dhs</td>
<td>1.52</td>
<td>1.52</td>
<td>11,308.12</td>
</tr>
<tr>
<td>bracelet (A380)</td>
<td>10 kg</td>
<td>0</td>
<td>100.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Paint (Galvanized)</td>
<td>10 kg</td>
<td>0</td>
<td>450.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>10 Days</td>
<td>7 Days</td>
<td>12.00 Dhs</td>
<td>5.00 Dhs</td>
<td>1.51</td>
<td>1.51</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>311,100.00</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

### 3. COST SAVING AND CO₂ EMISSION REDUCTION BY USING CFA METHOD OF CONSTRUCTION FOR FOUNDATION PILING

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>24.72 m³</td>
<td>0</td>
<td>2.00 Dhs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reinforcement Steel</td>
<td>112.5 MTR</td>
<td>0</td>
<td>450.00 Dhs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plaster (C30/35)</td>
<td>42 Days</td>
<td>28 Days</td>
<td>12.00 Dhs</td>
<td>10 Days</td>
<td>1.51</td>
<td>1.51</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>544,139.28</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

### 4. COST SAVING AND CO₂ EMISSION REDUCTION BY USING POTABLE WATER FROM ALTERNATIVE SOURCES

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>147 MTR</td>
<td>0</td>
<td>20.00 Dhs</td>
<td>-</td>
<td>1.52</td>
<td>1.52</td>
<td>11,308.12</td>
</tr>
<tr>
<td>obtained from DDB (Refer cost AC)</td>
<td>147 MTR</td>
<td>0</td>
<td>20.00 Dhs</td>
<td>-</td>
<td>1.52</td>
<td>1.52</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>294,139.28</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

### 5. COST SAVING AND CO₂ EMISSION REDUCTION FOR AVOIDING ANY REMOVAL WORK

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement steel</td>
<td>500 kg</td>
<td>0</td>
<td>400.00 Dhs</td>
<td>-</td>
<td>1.04</td>
<td>1.04</td>
<td>2,205.00</td>
</tr>
<tr>
<td>Plaster (C30/35)</td>
<td>10 Days</td>
<td>7 Days</td>
<td>12.00 Dhs</td>
<td>5.00 Dhs</td>
<td>1.51</td>
<td>1.51</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>554,139.28</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

### 6. COST SAVING AND CO₂ EMISSION REDUCTION FOR AVOIDING ANY FOUR HOURS WORK STOPPAGE

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity of materials (as per current practices)</th>
<th>Quantity saving (as per sustainable practices)</th>
<th>Unit cost (Refer Note-4)</th>
<th>Cost saving (Dhs)</th>
<th>Density</th>
<th>Carbon emissions factor</th>
<th>CO₂ emission reduction (kg/CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>380 m³</td>
<td>0</td>
<td>200.00 Dhs</td>
<td>-</td>
<td>1.52</td>
<td>1.52</td>
<td>11,308.12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>114,139.28</td>
<td></td>
<td></td>
<td>11,308.12</td>
</tr>
</tbody>
</table>

Note:
The table data are calculated from the concrete supply record (refer Appendix-B)
Table 6.5: Cost saving and CO\textsubscript{2} emission reductions in the case study project.

<table>
<thead>
<tr>
<th>Item</th>
<th>Used as per current practice (kg)</th>
<th>As per sustainable practice (%)</th>
<th>Quantity saving</th>
<th>Unit cost (Rs/ton)</th>
<th>Cost saving (Rs)</th>
<th>Density</th>
<th>Carbon emission Factor</th>
<th>CO\textsubscript{2} emission reduction (kg/1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete for pre-cast concrete</td>
<td>34.00 m\textsuperscript{3}</td>
<td>34.00 m\textsuperscript{3}</td>
<td></td>
<td>2,500.00</td>
<td>1,129 kg/CO\textsubscript{2}</td>
<td>15.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforcement for pre-cast panels</td>
<td>1.68 M\textsuperscript{3}</td>
<td>1.68 M\textsuperscript{3}</td>
<td></td>
<td>44,000.00</td>
<td>1,715 kg/CO\textsubscript{2}</td>
<td>20.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pile driving cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel cost for service piles</td>
<td>22,315.00</td>
<td>79.00</td>
<td>28,000.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>16,599.00</strong></td>
</tr>
</tbody>
</table>

Note:
The pre-cast panels need to be cast, cured and transported to site in many trips, however, using sustainable practices is less than the pre-cast concrete panels which also reduce the fuel consumption for transportation and CO\textsubscript{2} emissions.

8. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING REUSABLE ANCHORS FOR SHORING PILES

<table>
<thead>
<tr>
<th>Item</th>
<th>Used as per current practice (kg)</th>
<th>As per sustainable practice (%)</th>
<th>Quantity saving</th>
<th>Unit cost (Rs/ton)</th>
<th>Cost saving (Rs)</th>
<th>Density</th>
<th>Carbon emission Factor</th>
<th>CO\textsubscript{2} emission reduction (kg/1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel strands - 41.6 M\textsuperscript{3} (1 kg/m)</td>
<td>41.6 M\textsuperscript{3}</td>
<td>1.63 M\textsuperscript{3}</td>
<td>0.00</td>
<td>9,000.00</td>
<td>1,730 kg/CO\textsubscript{2}</td>
<td>3.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor</td>
<td>15.00 kg</td>
<td>15.00 kg</td>
<td>0.00</td>
<td>7,000.00</td>
<td>1,850 kg/CO\textsubscript{2}</td>
<td>5.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pile (Dead) @ 66 Hz / day / drill</td>
<td>12 Days</td>
<td>12 Days</td>
<td>0.00</td>
<td>5,600.00</td>
<td>2,530 kg/CO\textsubscript{2}</td>
<td>20.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recipe</td>
<td>15.00 kg</td>
<td>15.00 kg</td>
<td>0.00</td>
<td>7,000.00</td>
<td>8,000 kg/CO\textsubscript{2}</td>
<td>1.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>12 Days</td>
<td>12 Days</td>
<td>0.00</td>
<td>1,180.00</td>
<td>3,000 kg/CO\textsubscript{2}</td>
<td>2.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>26,977.00</strong></td>
</tr>
</tbody>
</table>

Note:
By using the reusable base anchors from "CHANCE" the insulation can be done 50% faster than traditional anchor installation, hence the 50% insulation time is considered as cost saving for installation.

**SUMMARY**

<table>
<thead>
<tr>
<th>Item description</th>
<th>Total cost saving (Rs)</th>
<th>CO\textsubscript{2} emission reduction (kg/1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY THE ECONOMIC DESIGN OF SHORING PILES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING STEEL GUIDE WALL INSTEAD OF CONCRETE GUIDE WALL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING CO\textsubscript{2} METHOD OF CONSTRUCTION FOR FOUNDATION PLILLS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING POTABLE WATER FROM ALTERNATIVE SOURCES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION FOR AVOIDING ANY REMEDIAL WORKS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION FOR AVOIDING ANY BLIME HOURS (POOL DUMPAGE)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>7. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING WOODEN PANELS FOR KING POST SHORING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>8. COST SAVING AND CO\textsubscript{2} EMISSION REDUCTION BY USING REUSABLE ANCHORS FOR SHORING PILES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26,977.00</strong></td>
<td><strong>11,957.00</strong></td>
</tr>
</tbody>
</table>

Note:
1. All the data obtained from MS Dato Balbir Sats Ltd from the project ref. no. AJ 763
2. Carbon conversion factors for the materials used for this study are from NHB (2010), www.ehia.org (2007)
3. (%) - Refer appendix B for the Quantity of materials used as per current practices and quantity of materials will be used as per sustainable practices
4. All the cost are obtained from MS Dato Balbir Sats Ltd from the project ref. no. AJ 763

**FINDINGS FROM CASE STUDY**

**COST SAVING (%) BY ADOPTING SUSTAINABLE PRACTICES**

- Contract Value (including variations) (AED) | 6,480,000.00
- Cost saving by adopting sustainable construction practices (AED) | 972,321.01
- Amount carried from Cost saving Table | | |
- % of Cost saving due to sustainable practices | 19.06%

**CO\textsubscript{2} EMISSION REDUCTION (% ) BY ADOPTING SUSTAINABLE PRACTICES**

- CO\textsubscript{2} emission from conventional method of construction (kg/CO\textsubscript{2}) | 1,940,622.36
- CO\textsubscript{2} reduction by adopting sustainable construction practices (CO\textsubscript{2} emissions saving carried from Cost saving Table) | 561,080.70
- % of CO\textsubscript{2} emission reduction due to sustainable practices | 18.43%

6.3.6 Comments and discussions on case study

The case study of the chosen project is given insight view on the cost and environmental benefits of sustainable practices with the piling construction. It is demonstrated that the sustainable practices could able to reduce the cost of construction about 15%, which will
result in increase the contractor’s competitiveness in the market, during tendering for future project and increase the profit to the organisation, if implemented in the current projects. In addition to the cost saving, the project consumes low embodied energy materials, and reducing the wastages through sustainable practices, the organisation can able to draw the attention of the Industry towards them being more sustainable in the current market. This also influences towards the brand name to the organisation (CIEF, 2009). The case study also demonstrated that by adopting sustainable practices about 18.61% of CO$_2$ emission can be reduced.

It is evidently proves that by promoting the new system (innovation) for the execution of piling construction, cost saving and environmental protection can be achieved. In some cases implementation of new systems and technologies as part of sustainable practices, may require some initial investment for the additional resources and for the procurement of materials which are more sustainable than the current materials in use, but at the prolonged utilisation of the sustainable materials / services repeatedly, the cost effectiveness can be realised.

It is also noticed from the case study that the majority of the cost savings and the carbon emission reduction were arrived by improving the design efficiency and changing the method of construction which are some how linked with the ground conditions and the geotechnical parameters. The adequate soil investigation data and the skill level of the geotechnical engineer can play a major role in achieving these sustainable benefits as asserted by various researchers (Khawaja, 2008; Gannon et al, 1999; Huovila and Koskela, 1998).

### 6.4 Conclusion

The results of the online questionnaire survey from the industry professionals and the case study of a previous project presented an insight view on sustainability and its impacts to the environment. The responses of the construction professionals showed their interest to adopt the sustainable practices in the piling constructions in the UAE and consequently they have expressed their general awareness, views and opinions on the chosen topic. They have also agreed on various aspects of sustainable practices and their needs, benefits. Among the various benefits “Energy saving” and “increased productivity” were rated as the top 2 ranked benefits. These benefits of sustainable practices not only limited to cost saving but also quicker construction completion and
CO₂ emissions reduction benefits also achieved. There are some barriers for the implementation of sustainable practices were identified from the literature reviews and rated them based on their influence level. The lack of time for innovation was selected as the top rated barrier for sustainable practices. In this context Othman (2010) demonstrates that the innovation in the construction industry bring the sustainability through the new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software and the process which in turn reduces the production costs, expedites the delivery or increases quality.

The “Airwaterwell / desalwave” are the new technologies for the production of potable water without the traditional fuel burn de-salination process, which are currently used in the overseas countries, but it is not introduced in the UAE. The local government and authorities should encourage the organisations to establish these types of sustainable alternatives technologies and adopt the sustainable practices in all construction sectors including piling constructions.

The Alternative ground improvement techniques against the conventions pile foundations have been chosen as one of the major the cost-effective option. However as identified from the survey results either the current specification not includes these specialised ground improvement techniques or does not allow using it. It is also known from survey results that there is lack of awareness about these ground improvement techniques.

The case study on a completed piling project in the UAE compared the sustainable practices with current practices on piling constructions in the UAE and thus highlighted the benefits in terms of cost saving and the environmental benefits by reducing the CO₂ emissions over the conventional type of construction practices. The case study demonstrates that the sustainable practices could able to reduce the cost of construction about 15%, and accordingly the CO₂ emission can also be reduced by 18.61% which imprint a high level significance to the hypothesis.
Chapter 7: Conclusions and Recommendations

7.1 Introduction

This chapter presents the outcome of research study, which has been conducted through various literature reviews, an industry survey and a case study to attain the aims and objectives. The aim of the research was to identify good practices for cost-effective and sustainable piling construction in the UAE. In this regard, the importance of sustainability and its impact to the Economy, the Environment and Society were identified, and various sustainable practices explored in order to achieve cost-effectiveness and sustainability in piling construction sector in the UAE. The industry survey result findings, and the case study of an existing project, are summarized in this chapter to assess the practicality and applicability reality of the aim and objectives of this research.

Recommendations with regards to the research topic to various participants of the industry including Investors, Developers, Authorities and Contractors, followed by limitations and further research recommendations are also provided in this chapter.

7.2 Conclusions

This section concludes the research study and provides details and various findings in relation to the research objectives.

Research objectives and the various findings

- To explore the importance of sustainability in the UAE construction industry.

This research study identifies that there are sustainability issues linked with many countries economic development. Global warming, Ozone depletion, Natural disasters, Health problems, Pollution, Poverty, Un-employment and Economic downturn were identified as some of the consequences of un-sustainability. According to the survey, construction professionals strongly agree that the UAE construction industry has the significant role in the global carbon foot print increase. Most of the results show that Fossil fuel consumption, Construction material use and Materials wastage are the main reasons for the carbon foot print increase (Current level of 170.92 million metric tonnes of CO₂ per annum) in the UAE construction industry.
Though the results show the respondents have sufficient knowledge on general awareness of sustainability aspects, there are some influencing factors to the higher energy consumption in the UAE construction industry. Tight project completion commitments to contractors, current specification requirements, cheaper fossil fuel and low electricity cost have been chosen as the main causes for the higher energy consumption in the UAE construction industry.

The UAE construction professionals believe that by changing current construction practices to sustainable practices, the construction industry can benefit in terms of cost-effectiveness and carbon emission reductions from the current level. They also agree that the current financial downturn in the UAE construction industry will provide a good opportunity to adopt sustainable practices in all sectors of the construction industry based on the grounds that sustainable construction practices may bring a competitive price advantage to the contractor (to win more projects), and also reduce the overall cost of the project, which will provide a competitive advantage for the client to enable them to achieve value for money.

- To identify sustainable practices with piling construction including benefits and barriers to its adoption in the UAE.

The research identifies that, currently in piling construction, sustainable practices are not being implemented in the UAE due to various reasons including lack of awareness, current specifications requirements, lack of time etc. According to industry professionals opinions, current financial downturn and depressed market provides the right opportunity to implement sustainable practices with piling construction, in order for organisations to enhance cost-effectiveness and ensure long-time survival in the UAE market.

This research identified and focused on various principles of sustainable practices with piling constructions in the UAE, which includes economic / efficient pile design, appropriate pile type selection, reduced energy consumption, plant, equipment and resources efficiency improvement, pollution reduction, avoiding repetitions and remedial works, use of sustainable materials, and noise and vibration reductions to achieve cost-effectiveness and carbon emission reductions.

Among various options on sustainable practices, efficient pile design for reducing materials use, efficient equipment operations for energy conservation, quality of works to
avoid post construction remedial works, use of water from alternate sources (other than from the de-salination process) and ground improvement options as opposed to pile foundations, were chosen as influencing options for cost-effectiveness and carbon emission reductions.

In regard to the benefits of sustainable construction practices with piling construction many tangible benefits like increased productivity, less operating cost, energy savings, and less or no remedial works were identified, which directly influence cost-effectiveness (cost saving), and carbon emission reductions. There are also various intangible benefits. Good market share, brand name to the organisation, client / owners appreciations, employee job satisfaction are also achieved due to sustainable practices.

The research and the results show that lack of time for innovation, tight build time commitments to the piling contractors, and silo thinking by the stake holders are the main barriers for the implementation of sustainable practices with piling constructions in the UAE. Also, cheaper cost of fuel and energy in the UAE become a prominent barrier as the organisations neglect opportunities for the fuel and energy conservation.

The study finds that the selection criterion for the contractors is also part of the barriers to sustainable practices with piling construction. The selection of inefficient contractors results in poor quality of work, which not only creates remedial works, but also delays the whole project completion. The selection of efficient and capable contractors though the proper pre-qualification process, enables hassle free completion of the project to the stake holders and, at the same time minimises remedial works, and increases the quality and efficiency of the works, resulting in cost savings and environmental pollution reductions. Client and Owners are recommended to include a well structured contractor pre-qualification process in all their projects.

In addition, financial considerations and skill levels also form barriers. However, financial considerations for sustainable materials / plants purchase can be justified by the prolonged / repeated use of these materials or equipments. In the same way highly skilled resources can attain cost-effectiveness in the works and related benefits by the execution of improved methods / procedures.

- To assess cost savings and CO₂ emission reductions by sustainable practices in a completed piling project in the UAE with the help of case study.
The case study of a chosen project in the UAE, provided a clear view on current practices for the completion of the project, and the key areas where sustainable practices can be implemented. The case study also showed the quantity of materials used under the current way of execution and compared these with the saving in materials / services by sustainable practices. Not limited to this, the case study also depicts the related CO₂ emission reductions due to saving in materials / services by sustainable practices with the chosen piling project in the UAE. The outcome of the case study findings shows that the cost construction could have been reduced to 15% by adopting sustainable practices and accordingly 18.61% of CO₂ emission could have been reduced by the sustainable practices. This provides and strong and significant value to the hypothesis and proves that the hypothesis hold true and the piling companies can attain cost effectiveness in a sustainable way by adopting the recommended sustainable practices.

As a whole the case study demonstrated in quantitative perspective that sustainable practices with piling construction can attain cost-effectiveness and carbon foot print reductions, which concludes the objectives of this research study in an effective way.

7.3 Recommendations

The following are some of the recommendations that can be documented from this research.

Though the industry professionals in the UAE are aware of the general perspectives of sustainability, there is still a need to enhance the level of understanding and the knowledge to the Clients, Investors, Developers, and Engineering consultants involved in the construction industry, to enable the implementation of sustainable practices in all disciplines of the construction industry.

Design consultants and Project Managers should involve specialized contractors to advise on realistic time frames and economic solutions for piling and ground improvement works, and to incorporate sustainable construction specifications for these works. The pioneers in Ground Improvement technology M/s. Pennine (A Division of Balfour Beatty Ground Engineering) have a local office (in Dubai) to consult for ground improvement design and foundation construction solutions.

Local government can create incentives that will encourage local contractors who perform works in a sustainable way, to further increase their own environmental
protection goals. Depending on local building and development conditions and the resources of the local government, the incentives can be set up as large monetary rewards.

Governments can reduce / stop subsidies being issued for fossil fuel use. Instead they can subsidise renewable energy technologies. A good example is Spain. Spain has been giving huge subsidies for wind energy, to encourage this renewable energy sector to produce more energy for the local use.

Local government should provide subsidies for the import of sustainable materials so that sustainable materials can be readily available in the local market at affordable prices in sufficient quantity for use without any shortage. Government should also encourage establishments to manufacture and market fuel saving devices so that both organizations and people will benefit (cost benefits) by using such devices in their vehicles. At the same time the carbon emission will also be reduced due to reduced fuel consumption.

Local Banks should be encouraged to provide loans for business organizations to establish plants to produce water through innovative alternative technologies (without conventional de-salination process using fossil fuel), and Energy from only renewable sources. This study recommends the “Airwaterwell Unit / Airwaterwell water farm”, which produces potable water (small to bulk quantity) from atmospheric air using solar power (without the need of fossil fuel or gird electricity), and the “Desalwave unit” which produces potable water from a new desalination technology for large-scale production of clean drinking water from sea water without the need of grid electricity. Both technologies are recommended for the production of potable water for construction and industrial use in order to attain cost savings and carbon emission reduction in the UAE.

Client / Developers should make appropriate contractors pre-qualification criteria as prime requirements in any project, which will steer the contractors to improve the quality of works in a sustainable way and to obtain certifications in order to add to their credentials to become pre-qualified for tendering projects.

Specialist contractors like piling / ground improvement specialist contractors, should be invited at the early stages of any project for their advice on cost effective and sustainable solutions to add in the specifications for implementation in the project.
Construction contractors should invest certain funds for innovation and improvements in present methods and procedures, for high production and cost savings through a sustainable way.

7.4 Limitations

This study was conducted on the sustainable construction practices for the piling construction in the UAE. Piling construction covers one sector of the construction industry and the projects adopting sustainable practices in piling construction are limitations to the research. The non-availability of common data matrices in UAE to conduct the demonstrative case study, are also deemed as the limitation to this research.

7.5 Future research recommendations

Further research on the following is recommended.

- Comprehensive research shall be done for a project which includes all sectors of the construction industry. Accordingly, CO₂ emissions for all activities can be assessed and analyzed.

- Sustainable practices for activities in all sectors of the construction industry should be drawn up and the outcome benefits explored.

- Case studies should be conducted on completed sustainable projects throughout the country and data matrices should be maintained.

- Detailed research on establishing the “Airwaterwell” farm units or Desalwave units in the UAE for the production of potable water for the use of the whole industry and not only limited to piling construction is also recommended.
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