ABSTRACT

SAMANDAR, MOHAMAD SHOAIB. Construction Process Sustainability Index (CPSI): An Integrated Assessment Framework. (Under the direction of Dr. Edward Jaselskis).

The construction industry provides facilities and infrastructure projects to societies across the globe. It also creates up to 7% of job opportunities, accounts for about 1/10th of the world's GDP, and enhances the growth of other industries. However, with all these benefits, it is proven that the construction industry has negative impacts on the environment. The construction industry accounts for 40% of CO$_2$ emissions worldwide, 30% of raw material usage, 40% of energy consumption, and 20% of fresh water consumption. Several countries have achieved different levels of success in implementing sustainability standards in their construction processes, though ranking them based on achievement is still a daunting task due to the lack of clearly defined scales. This thesis presents a design of a construction process sustainability index (CPSI) that assesses sustainability performance of construction processes for specific countries. The focus of the thesis is identifying and integrating indicators in order to develop the CPSI and develop a performance model that assists in evaluating the sustainability of construction processes in a specific country.

The thesis includes the CPSI of each country in terms of its economic, environmental, and social performance. This structure is chosen because it reflects what is currently the most widely accepted approach to defining sustainability. However, this thesis suggests that, to conduct a more accurate sustainability evaluation for the construction industry in a country, sustainability of each of these three aspects must be assessed at the three levels related to the project, company and government. The sustainability characteristics of these three aspects is therefore an average of sustainability for those three levels. After determining the
sustainability of economic, environmental and social, the sustainability level of the whole construction processes in a country can be determined by simply averaging the value of these three pillars. A CPSI is calculated for Afghanistan and description of the findings is provided.
Construction Process Sustainability Index (CPSI): An Integrated Assessment Framework

by
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CHAPTER 1: INTRODUCTION

Population growth, natural resource depletion, water scarcity, global warming, health problems, degraded ecosystems, acid rain, forest destruction and so on are major challenges that have put sustainability in the spotlight for many nations. Sustainability is defined as the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs as per the Brundtland report (WCED, 1987). Sustainability is said to have three major aspects, which are economic, environmental and social. Due to the eminent risks associated with our unsustainable lifestyle, practices and use of natural resources, almost all nations have committed themselves to sustainability by integrating economic health, environmental quality and social welfare. Therefore, there is a strong desire and need for the comprehensive assessment of changes in economic, environmental, and social conditions.

Worldwide, the construction industry is responsible for 40% of CO2 emissions, 30% of raw material usage, 40% of energy consumption, and 20% of fresh water consumption (Wilkinson & Reed, 2006). Therefore, the construction industry and sustainability have long been intertwined, as it is well known that construction influences people’s lives both during building and throughout the life span of the completed product. Construction management can also carry heavy monetary costs with financial decisions influencing the social and environmental aspects of the projects; and contributes significantly to the CO2 emissions and other environmental impacts.

There is a widely recognized need for societies, organizations and individuals to search and find models, metrics and tools to articulate the extent to which, and the ways in
which, current activities and practices are unsustainable (Bebbington et al, 2007).

There are a number of methodologies currently in practice that assess the level of sustainability performance of countries, companies, cities, and governments, used in policy making and public communication to convey information on their performance in fields such as environment, economy, or society. However, as per the literature review, there is no work performed that relates to creating a construction process sustainability index at a country level. Therefore, the main goal of this thesis is to establish and propose a framework for a Construction Process Sustainability Index (CPSI), focusing on determining the sustainability of construction processes in different countries. Construction processes pertain the on-site activities and transportation, where on-site activities include any construction activity from mobilization to close out of the project and transportation is defined from manufacturers’, supplier’s destination to and from the construction site. Sustainable Construction is said to be development that meets the needs of the present without compromising the ability of future generations to meet their own needs. As an ideal, Sustainable Construction Processes takes into consideration minimizing the negative impacts of construction on the environment, society, and economy. The CPSI is composed of sub-indices for social, environmental and economic aspects of sustainability. Within the proposed CPSI system, these three aspects are composed of sub-indices related to three levels: government, company and project. Based on a literature review, discussion with subject matter experts, and relevance and compliance with the definition and goals of sustainable construction processes, fourteen potential indicators of sustainable construction process were identified and a set of questions for each of the three levels (Government, Company, Project) was prepared based on these indicators.
The following questions are posed in this research:

1- What is Construction Sustainability and can a Construction Process Sustainability Index (CPSI) be developed for a country?

2- What are the indicators related to sustainable construction processes?

3- What guideline and method should be used for the development of Construction Process Sustainability Index (CPSI)?

After an extensive literature review the author found that developing a construction process sustainability index is achievable and came up with a set of potential indicators for sustainable construction processes. A Google form containing the indicators, their description, method of measurement and a rating of 1 to 5 was prepared and shared with experts in the field of construction and sustainability for validation. The experts were asked to review and rate the potential indicators for development of a Construction Process Sustainability Index for countries. They were asked to select an importance of 1 (low) to 5 (high) from a drop down list under each indicator. After having the expert’s rating, the author sorted the indicators and set a cut off range of 3.5; any indicators with a mean rating below this value was dropped from the list of possible indicators. A final list of nine indicators for sustainable construction was then selected for the development of construction process sustainability index (CPSI).

As mentioned above the CPSI is composed of sub-indices for social, environmental and economic aspects of sustainability. Within the proposed CPSI system, these three aspects are composed of sub-indices related to three levels: government, company and
Based on the indicators a set of questions was prepared for each of these three levels.

The questionnaires related to project level were sent to project managers and those at the company level were sent to directors of the construction companies. Since it was difficult to get answers from officials in the government, the questionnaire related to this level was answered via materials accessible to the author through public sources (e.g., governmental databases and the internet). After obtaining these responses it was possible to calculate the CPSI for a country.

This introduction to the topic is followed by review of published literature in Chapter 2. A comprehensive review of literature on sustainability, sustainable development, construction sustainability, and assessment methodologies of sustainability has been accomplished in this chapter. Chapter 3 outlines the research methodology conducted in execution of this research, including the principal research questions and proposed hypotheses. Specific steps are described and data collection instruments and methods are listed that were used to collect and analyze data supporting the findings and conclusions of this research.

Chapter 4 explains the application of the CPSI by calculating this index for Afghanistan. Finally Chapter 5 concludes the thesis and proposes further opportunities of research related to this topic.
CHAPTER 2: LITERATURE REVIEW

This research project started with a review of published literature regarding sustainability and thorough targeting of the more narrowly defined subject of developing a construction process sustainability index (CPSI). It became evident after much literature searching that little specific research has been conducted regarding construction process sustainability. The literature review was also performed to identify published industry practices specifically regarding the economic, environmental and social aspects of sustainability, and sustainability assessment methodologies and indices. Again, scarce literature has been published by academia in the narrowly defined area of construction process sustainability.

Chapter 2 provides some background information on defining sustainability as it pertains to the economic, environmental and social aspects. This explanation is followed by the definition of construction process sustainability and finally a review of sustainability assessment methodologies is presented in this chapter.

Sustainability

Sustainability is taken from the word sustinere, which means ‘hold and keep up’. Merriam-Webster dictionary defines sustainability as (Merriam-Webster.com, 2015):

1- Ability to be used without being completely used up or destroyed;

2- Involving methods that do not completely use up or destroy natural resources; or

3- Ability to last or continue for a long time
The concept of sustainability has evolved since the 1970s. Having a wide scope, sustainability has been defined in variety of ways. The most common one being “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” by The World Commission on Environment and Development report of 1987, titled *Our Common Future*.

CERF (Constructing an Efficient and Renewable Future), which is a global non-profit organization established by ASCE (American Society of Civil Engineers), define sustainability as “the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environment quality and the natural resource base essential for future development”.

Building upon these definitions, in 1992 the “Earth Summit” paved the way for globalization of sustainable development. The summit took place in Rio de Janeiro, Brazil, with a goal of raising awareness of a sophisticated problem: achieving a balance on consumption and preservation of natural resources. Nations suffer from increasing poverty and environmental degradation because of thoughtless consumption of wealthy populations in the world.

The term “Triple bottom line” was first used by Elkington, which integrates the economic, environmental and social aspects of sustainability (Elkington, 1998). Since his innovative work, companies include economic and social aspects of their activities in their annual reports (Daub 2007, 78). The “triple-bottom-line” concept is now summarized as people, planet, and profit due to modifications over time (Burgess, 2012).
Sustainability is defined as the connection between the three sectors of economy, environment and society in a conceptual model presented by Du Plessis. She mentions that sustainability happens when these three sectors achieve a reasonable balance (Du Plessis, 2000).

The United Nations General Assembly identified “economic development, social development and environmental protection as interdependent and mutually reinforcing pillars” of sustainability (United Nations, 2005b, p. 12).

Finally, we can say that sustainability is a very wide and applicable topic to all subjects. The three pillars of sustainability are striving to maintain a balance between economy, society and environment.

**Triple Bottom Line:**

From different sources mentioned above, sustainability is said to have three major aspects that are striving to maintain a balance between economy, society and the environment. In this section a detailed review of the literature is conducted on each of these aspects.

**Economic Aspects of Sustainability**

BusinessDictionary.com defines economic sustainability as “The use of various strategies for employing existing resources optimally so that that a responsible and beneficial balance can be achieved over the longer term. Within a business context, economic
sustainability involves using the assorted assets of the company efficiently to allow it to continue functioning profitability over time” (BusinessDictionary.com, 2015).

The economic sustainability often emphasizes the reduction of life-cycle cost of a project. On the other hand, it is the maintenance of the stock’s assets in order to produce a non-decreasing set of benefits (Munasinghe et al., 1995). Particularly, a situation in which an investment produces non-decreasing or constant benefits over-time (Munasinghe et al., 1995).

Because it explains the production, distribution, and consumption of goods and services, the topic of economics is important to the discussion of sustainability. Sustainable economies consists of sub-themes, such as (Sultan et al, 2005):

• Investment in people and equipment for a competitive economy,

• Job opportunities,

• Vibrant local economies,

• Accessible services,

• Creating new markets and opportunities for sales growth,

• Cost reduction through efficiency improvements,

• Reduced energy and raw material inputs, and

• Creating additional added value.

The latest concept of economic sustainability searches for ways to maximize the flow of income that could be generated while decreasing, or at least maintaining, the stock of assets (or capital) which yield this income (Solow, R. 1986). Capital and income are defined
as “a stock of instruments existing at an instant of time”, and “a stream of services flowing from this stock of wealth” respectively (Fisher, 1965).

Uncontrolled economic growth is not sustainable; many argue and point out limitations in applying the economic sustainability rule without additional environmental and social safeguards.

In conclusion, and with reference to the previous review on the term “sustainability”, economic sustainability is the use of natural resources to provide necessary and desirable products and services for the present generation without compromising the ability of future generations to provide for themselves.

Environmental Aspects of Sustainability

Environmental sustainability refers to “the process of maintaining or improving the integrity of the life support system of the earth” (Fuwa, 1995). BusinessDictionary.com defines environmental sustainability as maintaining the factors and practices contributing to the quality of environment on a long-term basis (BusinessDictionary.com, 2015).

In addition, environmental sustainability focuses on health and overall viability of living systems, which can be defined as dynamic, comprehensive, multi-scale, vigor and organization (Costanza, 2000). In summary, the environmental aspect of sustainability considers consumption, recycling and returning of waste to the environment for the current generation in a way that does not jeopardize the ability of future generations fulfill their needs.
Social Aspects of Sustainability

Elkington defined social capital as “measure of the ability of people to work together for common purposes in groups and organizations”. Elkington also suggests social accounting as a process “to assess the impact of an organization or company on people both inside and outside. Issues often covered are community relations, product safety, training and education initiatives, sponsorships, charitable donations of money and time, and employment of disadvantaged groups” (Elkington, 1998).

Since Elkington’s groundbreaking book (Elkington, 1998) the concept of social sustainability has continued to evolve. Sustainability in a social context has been defined as “policies and institutions that have the overall effect of integrating diverse groups and cultural practices in a just and equitable fashion” (Polese & Stren, 2000). The definition of social sustainability is still contestable (Dillard et al. 2009), and adding that the “social aspect of sustainability should be understood as both (a) the processes that generate social health and well-being now and in the future, and (b) those social institutions that facilitate environmental and economic sustainability now and in the future.”

Although the benefits of social sustainability are intangible, they should be considered as strongly as economic and environmental impacts on a society. The benefits of socially sustainable development can be returned in variety of ways, such as improved quality and lifestyle, and creation of job opportunities (Hammer, 2009).

Omann and Spangenberg (2002) mentions that in general, social sustainability relates to personal characteristics, that might include level of education, level of skills and experience, consumption, income, and employment.
Corporate social responsibility is defined by Werna et al. to the World Business Council for Sustainable Development as “the commitment of business to contribute to sustainable economic development, working with employees, their families, the local community and society at large to improve their quality of life” (WBCSD 2000).

Cited by (Valdes-Vasquez et al., 2013) in their paper titled “Social Sustainability Considerations during Planning and Design: Framework of Processes for Construction Projects”, the definition of social sustainability is considered as “a series of processes for improving the health, safety, and well-being of current and future generations” (Mihelcic et al. 2003; Herd-Smith and Fewings 2008; Dillard et al. 2009). They also cite stakeholder satisfaction, noise level, training of disadvantaged people, traffic delays and indoor air quality as indicators related to the above considerations (Kibert 1994; Hill and Bowen 1997; Guy and Kibert 1998; Pearce 1999; Trinius and Chevalier 2005; Gilchrist and Allouche 2005; Surahyo and El-Diraby 2009).

Given the findings in the literature in the context of construction projects, a definition of social sustainability must reflect the different perspectives of the stakeholders of a project. This is described as the engagement and interaction among employees, local communities, clients and supply chain with a goal of meeting the needs of current and future generations and communities (Herd-Smith and Fewings 2008).

Related to construction projects, social sustainability can be divided into four conceptual areas: “community involvement emphasizes public constituencies in governmental and private decisions; corporate social responsibility considers the accountability of an organization in caring for all of the stakeholders affected by its
operations, safety through design ensures worker safety by eliminating potential construction/operation; safety hazards during the design phase, and social design focuses on improving the decision-making process of the design team and the intended use of the project by the final users” (Valdes-Vasquez and Klotz 2010).

Although the definition of social sustainability concept can be contestable, it can be said that this aspect of sustainability, as it pertains to the process of construction, is a combination of processes that has the important goal of improving the health, safety and well-being of both current and future generations.

**Sustainable Construction:**

Sustainable construction means “creating construction items using best-practice clean and resource-efficient techniques from the extraction of the raw materials to the demolition and disposal of its components” (Ofori 2000, p. 196). The European Union, in their publication titled *Proposals for a Response to the Challenges of Sustainable Construction*, defines sustainable construction as “the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings), which in turn” (European Commission Enterprise 2001):

- Offer customer satisfaction and enhances the quality of life.

- Offer flexibility and the potential to cater to user changes in the future.

- Provide and support desirable natural and social environments.

- Increase investment in people and equipment for a competitive economy.

- Achieve higher growth whilst reducing pollution and maximizing the efficient use of resources.
• Share the benefits of growth more widely and more fairly.
• Improve towns and protect the quality of the countryside.
• Contribute to sustainable development internationally.

The definition of sustainable construction, which is most widely accepted, is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Bruntland 1987). This consists of three dimensions: economic, environmental and social. In order to achieve these goals, the supply chain of the construction industry is in need of a major change both in material and in production methods perspectives. Current construction methods and practices are not in line with producing truly sustainable buildings and infrastructure; however, moving toward a sustainability goal is possible (Nahmens & Ikuma 2011).

In order to address the important issues in engineering and management domains, sustainable construction will require ingenious solutions based on extensive goals of sustainable development. This field needs a progressive process embedded in the construction supply chain that meets the needs of the present without compromising the ability of future generations to meet their own needs. As per United Kingdom’s DTI (Department of Trade and Industry), sustainability is of increasing importance to the efficient, effective, and responsible operation of business (2004). The following prioritized themes have been benchmarked for action by the construction sector regarding the sustainability at all stages of a project in the UK (UK DTI 2004):

- Design for minimum waste;
- Lean construction and minimize waste;
- Minimize energy in construction and use;
- Eliminate pollution;
- Preserve and enhance biodiversity;
- Conserve water resources;
- Respect people and local environment; and
- Monitor and report (i.e., use benchmarks).

Summarizing the goals of sustainable construction for the UK, we can say that it is to pursue objectives of sustainable development by using knowledge and technology to intensify the sustainability of designs of infrastructure, production processes, operations and practices.

The main intent of sustainable construction is to achieve the goal of sustainable development; which will ultimately meet the needs of both the present and the future generations without compromising living standards. It is important to establish the scope and metrics of sustainable construction to narrow down its directions and definitions. As the boundary of sustainable construction gets broader, it needs to incorporate even broader concepts and practices. The professionals involved in the development of the sustainable construction concepts are often the ones who determine the boundary for it (Chong et al. 2009). The International Council for Research and Innovation in Building and Construction (CIB) anticipated that sustainable construction will lead to healthier built environments and ecological systems, energy conservation, better comfort, waste reduction, resource conservation, and better service life prediction and enhancement. It also recognized the need
to integrate existing technical knowledge and tools with new ideas in order to achieve the sustainable construction visions (CIB 1998).

Kibert (1994) defines the fundamentals and principles of sustainable construction as: resource minimization and reuse, use of renewable and recyclable resources, minimizing environmental footprint, creation of a healthy and nontoxic environment, and the pursuit of better quality built environment. Vanegas and Pearce (2000) define these fundamentals and principles as: resource depletion and degradation, impact on the built environment, and human health.

In order to overcome global environmental and social sustainability challenges, the industry had to move on to establish sustainable construction practices, even though it could not standardize sustainable construction definitions and principles (Chong et al. 2009). There are many green tools and practices that are accepted as sustainable construction practices, even though the benefits need to still be thoroughly investigated. Some of these green tools are listed below (Chong et al. 2009):

- UK’s Building Research Establishment’s Environmental Assessment Method (BREEAM)
- US Green Building Council LEED (Leadership in Energy and Environmental Energy Design)
- Canada’s Green Globe
- Japan’s comprehensive assessment system for building environmental efficiency (CASBEE)
- Singapore’s Greenmark
- China’s Green Olympic Building Assessment System (GOBAS)
- Australia’s building greenhouse rating (ABGR)
- India’s TERI-GRIHA

Most of the above mentioned green tools follow the eight goals of sustainable construction:

1. Reduce carbon footprints,
2. Ecology and environment protection,
3. Healthy indoor and outdoor environment,
4. Water use reduction,
5. Energy efficiency,
6. Eliminating environmentally harmful materials,
7. Improve resource efficiency, and

In summary the term Sustainable Construction is commonly understood to mean development that meets the needs of the present without compromising the ability of future generations to meet their own needs. As an ideal, Sustainable Construction Processes takes into consideration minimizing the negative impacts of construction on the environment, society, and economy. This is done by raising sustainability awareness, having strategic goals for involving sustainability, enforcement of rules and regulations pertaining to sustainability, enhancing safety, increasing use of sustainable materials, local materials, incentives, in the construction industry while minimizing costs, emissions, water usage, use of non-renewable energy.
Sustainability Indices:

Defined by OECD, an index is “a set of aggregated or weighted parameters or indicators” (OECD 2002). Sustainability has become one of the most important issues on the world's policy agenda. Almost all nations have committed themselves to sustainability by combining social harmony, economic wellbeing and environmental quality. Therefore, there is a strong desire for a thorough assessment of changes in the social, economic and environmental aspects of sustainability.

In order to monitor progress towards sustainability, operational indicators that provide information on these aspects of sustainability should be identified. The main objective of sustainability indicators has already been stressed by the United Nations Conference on Environment and Development (UNCED), as previously mentioned, in Rio de Janeiro in 1992. In this conference, the UNCED called on individual countries and both international governmental and non-governmental organizations to “develop and identify indicators of SD in order to improve the information basis for decision-making at all levels” (UNCED, 1992; Agenda 21, Chapter 40). After 1990, a mass of indicators were developed resulting in a multitude of indicator lists. More than 500 versions of sustainable indicators are mentioned by The Compendium of Sustainable Development Indicator Initiatives (Parris and Kates, 2003)--including Atlantic Canada Sustainability Initiatives (ACSI), Social Sustainability Report, and the Sustainable Society Index.

Kates et al. (2001) defines the purpose of sustainability assessment as “providing decision-makers with an evaluation of global to local integrated nature–society systems in short and long-term perspectives in order to assist them to determine which actions should or
should not be taken in an attempt to make society sustainable”. A number of frameworks for the assessment of sustainability exist to evaluate the performance of companies. The World Business Council for Sustainable Development (WBCSD, 1997), the Global Reporting Initiative (GRI, 2002a, b), and Development of Standards (OECD, 2002a, b) are the foundation for sustainability reporting (Singh et al. 2009).

About 140 indicators were published covering economic, environmental, social and institutional aspects of sustainability by the UN Commission on Sustainable Development (CSD) after Agenda 21. This is a non-binding, voluntarily implemented action plan of the United Nations with regard to sustainable development and a product of the UN Conference on Environment and Development (UNCED) held in Brazil, in 1992 (CSD, 2001).

As mentioned above, one of the initiatives for assessment of sustainability performance of companies is the Global Reporting Initiative, which was established in 1997 by the United Nations Environment Program (UNEP), and Coalition for Environmentally Responsible Economics (CERES), a United States nongovernmental organization. The goal of GRI is “enhancing the quality, rigor and utility of sustainability reporting”. The GRI uses a hierarchical framework focusing on three areas: economic, environment, and social. Figure (1) shows the hierarchical structure of the global reporting initiative (GRI).
The United Nations Commission on Sustainable Development (CSD) constructed a sustainability indicator framework consisting of 15 main indicators and 38 sub-indicators, which are in turn divided into four aspects of sustainability: economic, environment, social and institutional. The purpose of this framework is the evaluation of governmental progress towards sustainable development goals (Fig. 2). These sets of indicators are based on consultation with countries, lead agencies within and beyond the UN system that have responsibilities for sustainable development including Agenda 21 implementation, and indicator experts (UNCSD, 1996).

In order to measure the sustainability of operations within the process industry a set of sustainability indicators was published by the Institution of Chemical Engineers (IChemE)
in 2002 (Fig. 3). As per the Institute of Industrial Engineers “the process industries are those industries where the primary production processes are either continuous, or occur on a batch of materials that is indistinguishable” (iienet2.org, 2015).

![Figure 2. UNCSD Theme Indicator Framework](image-url)
Another sustainability rating system named “Envision” was developed by Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure. The main goal of Envision is to provide a comprehensive framework for evaluating and rating the benefits of infrastructure projects in terms of community, environment and economic.

Envision is composed of 60 sustainability criteria, called credits. These credits are divided into five sections of Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. Each Envision credit is described in a 2-page write-up that includes the intent, metric, levels of achievement, description, an explanation of how to advance to a higher achievement level, evaluation criteria and documentation, sources, and related credits.

Infrastructure owners, design teams, community groups, environmental organizations, constructors, regulators, and policy makers can use Envision to:

- Meet their sustainability goals.
- Public recognition for high levels of achievement in sustainability.
- Decision making on investment of scarce resources.
- Include community priorities in civil infrastructure projects.

The Envision tools help the project design team:

- Assess costs and benefits over the project lifecycle.
- Evaluate environmental benefits.
- Use outcome-based objectives.
- Reach higher levels of sustainability achievement.
Since Agenda 21, there has been a significant amount of work at the local, state, national, regional and international levels to identify useful indicators and frameworks for measuring the different aspects of sustainability. A few examples of these initiatives related to different aspects of sustainability are mentioned below.

**Examples of Environmental-Based Indices**

*Environmental Sustainability Index:*

The ESI (Environmental Sustainability Index) measures the overall progress of a country towards environmental sustainability. Professor Daniel C. Esty launched this index in 1999 in cooperation with Columbia University's Center for International Earth Science Information Network (CIESIN) and the World Economic Forum's Global Leaders for Tomorrow Environment Task Force. They have assessed the ESI for 142 countries. This
index has 20 core indicators that are based upon a set of 68 basic indicators. The ESI tracks relative success for each country in five core components. Table 1 shows the five core components, 20 core indicators and sub-indicators of the ESI. In order to calculate the ESI, the values of the 20 indicators are averaged and a standard normal percentile is calculated for each country. For every variable in the data set, a normalized range and measured values from low sustainability (0) to high sustainability (100) is established (WEF, 2002).

*Environmental Vulnerability Index:*

The Environmental Vulnerability Index (EVI) developed by the Pacific Applied Geoscience Commission (SOPAC) in 1999 is based on 50 indicators, which estimates the vulnerability of the environment of a specific country to future shocks. Of the 50 indicators the (EVI) consists of 10 indicators for damage measurement, 32 indicators for hazards, and 8 indicators that estimate the resistance. The 50 indicators are combined by simple arithmetic means and simultaneously reported as a simple and single index. Across the indicators, simple averages are used due to their simplicity in understanding. The index has been designed in a way that reflects the dimensions of a country’s natural environment prone to damage and degradation.

The EVI has a normalization scale of 1 to 7. A value of 1 indicates high resilience/low vulnerability and 7 indicates low resilience/high vulnerability. Equal weights have been given to the 50 indicators and then aggregated by an arithmetic mean.
### Table 1. Components of ESI

<table>
<thead>
<tr>
<th>Component</th>
<th>Indicator</th>
<th>Variable</th>
<th>Year</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Quality</td>
<td>Urban SO2 concentration</td>
<td>MRYA 1990-96</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban NO2 concentration</td>
<td>MRYA 1990-96</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban TSP concentration</td>
<td>MRYA 1990-96</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Water Quantity</td>
<td>Internal renewable water per capita</td>
<td>1995</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water inflow from other countries per capita</td>
<td>1995</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td>Dissolved oxygen concentration</td>
<td>1994-96 or MRYA</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phosphorus concentration</td>
<td>1994-96 or MRYA</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suspended solids</td>
<td>1994-96 or MRYA</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrical conductivity</td>
<td>1994-96 or MRYA</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Percentage of mammals threatened</td>
<td>1996</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of breeding birds threatened</td>
<td>1996</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td>Terrestrial Systems</td>
<td>Severity of human induced soil degradation</td>
<td>1990</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land area affected by human activities as a % of total land area</td>
<td>1992-95</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td><strong>Reducing Stresses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing Air Pollution</td>
<td>NOx emissions per populated land area</td>
<td>1990</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SO2 emissions per populated land area</td>
<td>1990</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOCs emissions per populated land area</td>
<td>1990</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal consumption per populated land area</td>
<td>1998</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vehicles per populated land area</td>
<td>MRYA 1996-98</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Reducing Water Stress</td>
<td>Fertilizer consumption per hectare of arable land</td>
<td>1997</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pesticide use per hectare of crop land</td>
<td>1996</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industrial organic pollutants per available fresh water</td>
<td>1996</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of country's territory under severe water stress</td>
<td>1995</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>Reducing Ecosystem Stress</td>
<td>Percentage change in forest cover 1990-95</td>
<td>1995</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of country's territory in acidification exceedence</td>
<td>1990</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>Reducing Waste &amp;</td>
<td>Consumption pressure per capita</td>
<td>1996</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>Consumption Pressures</td>
<td>Radioactive waste</td>
<td>1996</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Reducing Population</td>
<td>Total fertility rate</td>
<td>2000</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>% change in projected population between 2000 &amp; 2050</td>
<td>2000</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>**Reducing Human</td>
<td>Daily per capita calorie supply as a % of total requirements</td>
<td>MRYA 1988-90</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Vulnerability</td>
<td>% of population with access to improved drinking-water supply</td>
<td>2000</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Environmental Health</td>
<td>Child death rate from respiratory diseases</td>
<td>MRYA 1990-98</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Death rate from intestinal infectious diseases</td>
<td>MRYA 1990-99</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under-5 mortality rate</td>
<td>1998</td>
<td>122</td>
<td></td>
</tr>
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</table>
Table 1. Continued.

<table>
<thead>
<tr>
<th>Component</th>
<th>Indicator</th>
<th>Variable</th>
<th>Year</th>
<th>Count*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social and Institutional Capacity</td>
<td>Science/Technology</td>
<td>R &amp; D scientists and engineers per million population</td>
<td>MRYA 1980-97</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expenditure for R &amp; D as a percentage of GNP</td>
<td>MRYA 1980-1997</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scientific and technical articles per million population</td>
<td>1996</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Capacity for Debate</td>
<td>IUCN member organizations per million population</td>
<td>2000</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Civil and political liberties</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Regulation and Management</td>
<td>Stringency and consistency of environmental regulations</td>
<td>2000</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degree to which environmental regulations promote innovation</td>
<td>2000</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage of land area under protected status</td>
<td>1997</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of sectoral EIA guidelines</td>
<td>1998</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Private Sector Responsiveness</td>
<td>No. of ISO14001 certified companies per million dollars GDP</td>
<td>2000</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dow Jones Sustainability Group Index membership</td>
<td>2000</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average Innovest EcoValue’21 rating of firms</td>
<td>2000</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>World Business Council for Sustainable Development members</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Levels of environmental competitiveness</td>
<td>2000</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Environmental Information</td>
<td>Availability of sustainable development info. at the national level</td>
<td>1997</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental strategies and action plans</td>
<td>1992-1996</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of ESI variables missing from selected data sets</td>
<td>2001</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Eco-Efficiency</td>
<td>Energy efficiency (total energy consumption per unit GDP)</td>
<td>1998</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable energy prod. as a % of total energy consumption</td>
<td>1998</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Reducing Public Choice Distortions</td>
<td>Price of premium gasoline</td>
<td>1998</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subsidies for energy or materials usage</td>
<td>2000</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reducing corruption</td>
<td>2000</td>
<td>117</td>
</tr>
<tr>
<td>Global Stewardship</td>
<td>International Commitment</td>
<td>No. of memberships in environmental intergovernmental orgs.</td>
<td>1998</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage of CITES reporting requirements met</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Levels of participation in the Vienna Convention/Montreal Prot.</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compliance with environmental agreements</td>
<td>2000</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Global-Scale Funding/Participation</td>
<td>Montreal Protocol Multilateral Fund participation</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Global Environmental Facility participation</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Protecting International Commons</td>
<td>FSC accredited forest area as a % of total forest area</td>
<td>2000</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ecological footprint “deficit”</td>
<td>1996</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO2 emissions (total times per capita)</td>
<td>1997</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Historic cumulative CO2 emissions</td>
<td>1997</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CFC consumption (total times per capita)</td>
<td>MRYA 1996-98</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO2 exports</td>
<td>1997-1996</td>
<td>51</td>
</tr>
</tbody>
</table>
Figure 4. EVI Sample Report (Source EVI Report, 2005).
Single page reports are organized for each country’s EVI. The report shows the information of the overall EVI of the country in point totals, key indicators, and percentages of data over which EVI was calculated as well as a classification of the overall vulnerability of the country (Fig. 4). The level of vulnerability of a country’s environment is determined as shown in the EVI levels (Fig. 5).

In summary this index is used to provide insights into the processes that can negatively influence the environmental aspects of sustainability of countries. By assessing and measuring these indicators, this index provides an overall view of a country’s sustainability regarding its environment.

**Examples of Social-based Indices**

*Sustainable Society Index (SSI):*

The Sustainable Society Index (SSI) created by Sustainable Society Foundation (SSF) consists of 22 indicators, which are clustered into five categories. This index is based upon the definition of the Brundtland Commission, while explicitly including the social aspects of human life (Kerk and Manuel, 2008). The SSI has been calculated for 150 countries using...
the data from scientific institutes and international organizations. The five categories with
the 22 indicators are shown in Figure 6.

Data from public sources such as the United Nation’s databases have been used for
the calculation of each indicator of the SSI. If data were missing for an indicator, additional
work was not done on data collection for that indicator. The sustainability value of an
indicator in the SSI framework ranges from 0 to 10. A value of 10 is given to an indicator
which shows 100% sustainability and 0 is given to an indicator if there is no sustainability at
all. The simple data for indicators is transformed to the scale of 0 to 10 (Kerk and Manuel,
2008).

*Well-being Index (WI):*

The well-being index is an index based on the assumption that healthy humans need a
healthy environment (Prescott-Allen, 2001). The well-being index (WI) is the arithmetic
mean of the Human Well-being index (HWI) and Ecosystem Well-Being Index (EWI). Both
the HWI and EWI in turn consist of five sub-indices. Following are the sub-indices of HWI
and EWI, respectively.

**HWI sub-indices**

1- Heath and Population

2- Welfare

3- Knowledge

4- Culture and Society

5- Equity
<table>
<thead>
<tr>
<th>I Personal Development</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Healthy Life</td>
<td></td>
</tr>
<tr>
<td>2 Sufficient Food</td>
<td></td>
</tr>
<tr>
<td>3 Sufficient to Drink</td>
<td></td>
</tr>
<tr>
<td>4 Safe Sanitation</td>
<td></td>
</tr>
<tr>
<td>5 Education Opportunities</td>
<td></td>
</tr>
<tr>
<td>6 Gender Equality</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>II Clean Environment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Air Quality</td>
<td></td>
</tr>
<tr>
<td>8 Surface Water Quality</td>
<td></td>
</tr>
<tr>
<td>9 Land Quality</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>III Well-balanced Society</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Good Governance</td>
<td></td>
</tr>
<tr>
<td>11 Unemployment</td>
<td></td>
</tr>
<tr>
<td>12 Population Growth</td>
<td></td>
</tr>
<tr>
<td>13 Income Distribution</td>
<td></td>
</tr>
<tr>
<td>14 Public Debt</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IV Sustainable Use of Resources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Waste Recycling</td>
<td></td>
</tr>
<tr>
<td>16 Use of Renewable Water Resources</td>
<td></td>
</tr>
<tr>
<td>17 Consumption of Renewable Energy</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V Sustainable World</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18 Forest Area</td>
<td></td>
</tr>
<tr>
<td>19 Preservation of Biodiversity</td>
<td></td>
</tr>
<tr>
<td>20 Emission of Greenhouse Gases</td>
<td></td>
</tr>
<tr>
<td>21 Ecological Footprint</td>
<td></td>
</tr>
<tr>
<td>22 International Cooperation</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** SSI Categories and Indicators (Kerk and Manuel, 2008).

EWI sub-indices

1- Land

2- Water

3- Air

4- Species and genes

5- Resource Deployment
The five sub-indices of Human Welfare Index (HWI) are based on 36 indicators, and the five sub-indices of Ecosystem Welfare Index (EWI) are based on 51 indicators. The method of calculation for the sub-indices is a weighted arithmetic mean of further sub-indices or variables, which in turn are normalized using the proximity-to-target approach and using the specific targets of related indicators.

Based on these indices and many more reviewed by the author, there is a strong emphasize on the social aspects of sustainability and nations are very determined to enhance this aspect of sustainability. The indicators, which are commonly used in these indices, focus on the health, wellbeing and education of the society.

**Examples of Economic-based Indices**

Finally, indices related to the economic aspects of sustainability are investigated. After studying different indices for economic aspects of sustainability, two indices of Internal Market and Genuine Savings are presented below.

*Internal Market Index:*

Developed by the European Commission, the first version of the Internal Market Index was launched in 2001. The Internal Market Strategy attempts to bring to the citizens and companies real world benefits and the goal of this index was to measure whether these benefits are effectively delivered (European Commission, 2001b). The resulting Internal Market Index consisted of twenty variables. Using a statistical method (Principal Components Analysis), the weight and influence of each variable was determined in the final score. The variables include growth in per-capita income, long-term unemployment, price
dispersion, growth in intra-EU trade, prices of utilities services, availability of venture capital, energy intensity, and greenhouse gas emissions. In 2002, the revised version of this index was launched by the European Commission consisting of the following twelve indicators, which were chosen through an extensive review of the economic literature, assessment of available data, and broad-based consultation and analysis:

1. Sectoral and ad hoc State aid
2. Public procurement openly advertised
3. Telecommunication costs
4. Electricity prices
5. Gas prices
6. Relative price levels
7. Intra-EU FDI inward flows
8. Intra-EU trade
9. Active population in member states
10. Pension fund assets
11. Retail lending interest rates/savings interest rates
12. Postal tariffs

The revised index mainly focuses how to measure Internal Market policy impacts. Again the Index is computed as a weighted sum of the twelve base indicators. The relative importance of these indicators was decided by canvassing the members of the Internal Market Advisory Committee (Tarantola et al., 2002).
*Genuine Savings (GS):*

Based on Hicksian concept of income, which states that “the maximum value which he can consume during a week and still expect to be as well off at the end of the week as he was at the beginning”, Pearce and Atkinson (1993) developed an index called the Genuine Savings. The Genuine Savings Index was enhanced by Hamilton using the Hartwick law (Hamilton, et. al, 1997). The Hartwick rule defines the amount of investment in produced capital (buildings, roads, knowledge stocks, etc.) that is needed to exactly offset declining stocks of non-renewable resources (Hartwick, 1997). The Hartwick rule defines the level of re-investment from resource rents that are reinvested to assure the (societal) capital stock will never decline. Since the genuine savings (GS) are based on Hicksian concept of income, they are thus considered an indicator of weak Sustainable Development. Produced capital, human capital (knowledge, skills, etc), and natural capital (resources) are components of the societal capital stock. All values of the components are monetarized, such that aggregation is again achieved by simply adding them up.

The two above mentioned indices: Genuine Savings and Internal Market Indices are examples of economic indices currently being used for measurement of economic aspects of sustainability. The main focus and intention is to have a sustainable economy and to consume economic resources in a sustainable way, so that it fulfills the needs of the current generation without compromising the ability of future generations.
Examples of Sustainability Indices for Cities

*Sustainability Index for Taipei:*

The Sustainability Index for Taipei proposes a Sustainable Development framework specifically for Taipei, which is capable of assessing the sustainability of Taipei. After discussions with experts, exhaustive literature reviews, discussions with government officials and scholars, and considering the characteristics of Taipei, the study selected 51 sustainability indicators that correspond to the socio-economic features of Taipei City. The indicators are divided into four categories of economic, social, environmental and institutional dimensions of sustainability (Lee & Chung, 2007). In addition, the Sustainability Index is calculated for each dimension, as well as the city as a whole. Figure 7 shows the list and framework of sustainability indicators for Taipei City.

The values of indicators are standardized to make the index more comprehensive and easier to calculate. The value for each indicator can fall between 0 to 1 in which, 0 and 1 indicates the lowest and highest levels of sustainability, respectively. Also, this index applies the equal weight method for initial integration and analysis of the overall sustainability trend (Lee & Chung, 2007).

*Compass Index of Sustainability:*

Atkisson Inc. developed the Compass Index of Sustainability, for Orlando, Florida in 1997. This index consists of 28 indicators, which are in turn clustered into four categories of: 1- Nature (N); 2- Economy (E); 3- Society (S); and 4- Well-Being (W) also corresponding to the four points on a compass. Table 3 shows the indicators used in this index and their
relevance to the four mentioned categories. The performance scale of an indicator can be between 0-100 corresponding to unsustainability and sustainability, respectively. The index is further simplified by introducing five quintiles shown in Table 2 below whose values are set using normative judgments. Indicators have equal weights and a simple averaging method is used for calculation of the index for each category of the compass index of sustainability (Atkisson & Hutcher, 2001).

Table 2. System used for coding of the indicators

<table>
<thead>
<tr>
<th>Index Range</th>
<th>Condition Color</th>
<th>Condition Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20</td>
<td>red</td>
<td>very dangerous</td>
</tr>
<tr>
<td>21–40</td>
<td>red/yellow</td>
<td>dangerous</td>
</tr>
<tr>
<td>41–60</td>
<td>yellow</td>
<td>strong caution</td>
</tr>
<tr>
<td>61–80</td>
<td>yellow/green</td>
<td>fair</td>
</tr>
<tr>
<td>81–100</td>
<td>green</td>
<td>sustainable</td>
</tr>
</tbody>
</table>
Figure 7. Sustainability Indicators and Their Framework for Taipei City (Lee & Chung, 2007).
Table 3. Indicators for Compass Index of Sustainability.

<table>
<thead>
<tr>
<th>Indicator Topic</th>
<th>Indicator Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>N — NATURE</td>
<td></td>
</tr>
<tr>
<td>Tree canopy</td>
<td>Inventory of trees on public lands in the city of Orlando</td>
</tr>
<tr>
<td>Lake quality</td>
<td>Percent of lakes passing water quality standards</td>
</tr>
<tr>
<td>Stream quality</td>
<td>Miles of streams passing State water quality standards</td>
</tr>
<tr>
<td>Air quality</td>
<td>Pollutant Standards Index, US Environmental Protection Agency</td>
</tr>
<tr>
<td>Land use</td>
<td>Acres of land covered by buildings, roads, and other human-built structures</td>
</tr>
<tr>
<td>Control of toxic releases</td>
<td>Toxic release inventory data</td>
</tr>
<tr>
<td>Solid waste recycling</td>
<td>Solid waste per capita, rate of recycling</td>
</tr>
<tr>
<td>Energy sustainability</td>
<td>Total fossil energy use (linked to climate pressure)</td>
</tr>
<tr>
<td>E — ECONOMY</td>
<td></td>
</tr>
<tr>
<td>Economic diversity</td>
<td>Diversity of local job base by sector (resilience measure)</td>
</tr>
<tr>
<td>Economic equity</td>
<td>Income distribution in quintiles</td>
</tr>
<tr>
<td>Home ownership affordability</td>
<td>Affordability index (median home price to media wage)</td>
</tr>
<tr>
<td>Rental housing affordability</td>
<td>Difference between growth rate of average rental unit and growth of median wage</td>
</tr>
<tr>
<td>Transportation and traffic</td>
<td>Vehicle miles traveled</td>
</tr>
<tr>
<td>Child welfare</td>
<td>Child poverty rates (measure of overall societal wealth)</td>
</tr>
<tr>
<td>S — SOCIETY</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>Teacher/student ratios (measure of institutional health)</td>
</tr>
<tr>
<td>Adult learning</td>
<td>Adult literacy rate</td>
</tr>
<tr>
<td>Community stability</td>
<td>Student mobility (rate at which students change schools)</td>
</tr>
<tr>
<td>Public participation</td>
<td>Voting rates</td>
</tr>
<tr>
<td>Public safety</td>
<td>Juvenile crime (measure of current issue and future risk)</td>
</tr>
<tr>
<td>Citizens perception of gov.</td>
<td>Survey data on satisfaction with government performance</td>
</tr>
<tr>
<td>Arts &amp; culture</td>
<td>No data available; indicator included to spur future research</td>
</tr>
<tr>
<td>W — WELL-BEING</td>
<td></td>
</tr>
<tr>
<td>Infant health</td>
<td>Infant mortality and low birth-weight rates</td>
</tr>
<tr>
<td>Child learning</td>
<td>Relevant achievement test scores</td>
</tr>
<tr>
<td>Mental well-being</td>
<td>Arrests for drug violations (proxy for mental health/stability)</td>
</tr>
<tr>
<td>Access to health care</td>
<td>Insurance coverage</td>
</tr>
<tr>
<td>Community connectedness</td>
<td>No data available; indicator included to spur future research</td>
</tr>
<tr>
<td>Optimism</td>
<td>Survey data on perceived quality of life</td>
</tr>
<tr>
<td>Status of elders</td>
<td>No data available; indicator included to spur future research</td>
</tr>
</tbody>
</table>
**Regenerative Concepts:**

Medard Gabel, in his paper titled “Regenerative development: going beyond sustainability” states that “sustainable development is a half-vast approach to vast problems”. Sustainability is not acceptable with its goal of maintaining the devastated status quo. He distinguishes the difference between sustainable development and regenerative development as:

“Sustainable development is the use of resources to improve society’s well-being in a way that does not destroy or undermine the support systems needed for future growth. However, regenerative development is the use of resources to improve society’s well-being in a way that builds the capacity of the support systems needed for future growth.” (Gabel, 2009)

In the context of projects, regenerative development gestates projects as engines of positive or evolutionary change for the systems into which they are built. For instance, instead of looking at how to minimize the adverse impacts on nature, regenerative design looks at how to increase the quality of the nature. In the same manner, regenerative development considers the importance of delivering new capability into the project’s community (Haggard et al. 2006).

Haggard et al. believe that there are four concepts behind regenerative development. They are mentioned below:

1- Flip you paradigm: a regenerative designer cultivates the ability to see the site or project as an energy systems rather than a collection of things.
2- Go to the core: the core organizes all of the dynamics that make up a place, giving it a recognizable character and nature. This core should be understood, without understanding it the complexities of a site can overwhelm us.

3- Learn from the master: the master developer is the nature.

4- Build to Place, Not Formula: infrastructure is usually a product of engineering formulas adopted to specific site conditions. In starting formulas, however, we tend to miss creative opportunities to use natural infrastructure. Regenerative development starts from the belief that we can achieve continuous improvement of living conditions on earth by developing in harmony with nature (Haggard et al. 2006).

In summary regenerative development is not only the use of natural resources for improvement of society well-being in a way that ensures both fulfillment of current and future generations, but also building the capacity of the support systems needed for future growth.

Chapter 2 has provided an extensive review of published literature related to sustainability along with its three major aspects, sustainable construction and indices used for assessment of sustainability. Little research has been completed within the civil engineering domain regarding the assessment of construction process sustainability, providing opportunity to add to this body of knowledge. In order to fill this gap in the literature, development of indicators and an index for construction process sustainability is the primary focus of this thesis. Having presented the precedence work of others in Chapter 2, Chapter 3 outlines the research methodology conducted for this thesis.
CHAPTER 3: DEVELOPMENT OF A CONSTRUCTION PROCESS
SUSTAINABILITY INDEX (CPSI): AN INTEGRATED ASSESSMENT FRAMEWORK

Chapters 1 and 2 introduced the Construction Process Sustainability Index as a relevant and important topic within the context of the construction industry and summarized existing published literature regarding sustainability; its three pillars related to economic, environmental and social aspects; sustainable construction; and sustainability indices. Having established a foundational understanding of CPSI, Chapter 3 outlines in detail the development methodology of CPSI for this investigation.

Overview of Research Methodology

The specific research objectives for developing the CPSI include 11 work tasks within three stages.

Stage 1: Research Planning

- Task 1: Research planning and conducting a comprehensive literature review on the topic of the thesis and other relevant topics.

Stage 2: Development of a Hierarchy Scheme for (CPSI)

- Task 2: Develop a hierarchy scheme for calculation of CPSI.

Stage 3: Development of a Procedure for Calculation of (CPSI) and a Performance Model

- Task 3: Develop the indicators for CPSI.
Task 4: Categorize indicators into economic, environmental and social groups

Task 5: Validate indicators using subject matter experts

Task 6: Develop questions based on indicators for project, company and government levels

Task 7: Develop a rating system for the questions

Task 8: Data collection for establishing a specific country index

Task 9: Calculation of sub-indices using a simple averaging method

Task 10: Aggregation of sub-indices into the CPSI

Task 11: Develop a Performance Model for CPSI

Stage 1: Research Planning and Review of Literature

Task 1: The aim of first stage was related to planning and defining the milestones for each step of the research along with a comprehensive review of the literature. The main goal of the literature review was to help with the answers to the questions of this research, specifically the first and second questions. The first and second questions were stated as follows:

1- What is Construction Sustainability and can a Construction Process Sustainability Index (CPSI) be developed for a country?

2- What are the indicators of sustainable construction processes?

Extensive investigation into published academic work was conducted in the area of sustainability, sustainable development, construction sustainability, and assessment methodologies of sustainability. This review of literature provided answers to the first and
second questions. For the first question, construction process sustainability was defined and based on the literature review it became obvious that an index can be developed for a country to assess the level of construction process sustainability. Having defined the construction process sustainability in question 1 helped with developing the potential indicators for sustainable construction processes. The review of literature focuses on the civil engineering and construction management-related bodies of knowledge and also includes the related areas of sustainability and currently used assessment methodologies. A summary of this review of literature is presented in Chapter 2.

**Stage 2: Development of a Hierarchy Scheme for (CPSI)**

In this stage, a hierarchy scheme is developed showing how the indicators, levels, and sub-indices are combined to establish the CPSI.

**Task 2: Developing a hierarchy scheme for calculation of CPSI**

This thesis presents a design of a composite construction process sustainability index (CPSI) that assesses sustainability performance of construction industry for specific countries. The focus of the thesis is a consideration of how to integrate indicators in order to determine sustainability in a relevant and useful manner for decision-making. It concentrates on construction process sustainability. The construction process in this context is defined as the on-site activities and transportation. The scope for transportation is defined from manufacturers’, suppliers’ destination and pertains to transportation to and from the construction site. It can include worker transportation as well as truck transportation for materials and equipment to and from the site. The scope of on-site activities is bounded by
mobilization and site preparation at project inception to final close out.

The thesis organizes sustainability assessment of each country in terms of economic, environmental, and social performance. This structure has been chosen because it reflects what is currently the most widely accepted approach to defining sustainability (GRI, 2002). However, to conduct a more accurate sustainability evaluation for the construction industry in a country, sustainability of each of these three aspects must be assessed at the three levels related to the project, company and government. It is because these three levels are considered as the major components of the construction industry. In addition, government and construction companies are the two major stakeholders of the industry. The sustainability characteristics of these three aspects (economic, environmental and social) is therefore an average of sustainability for these three levels (project, company and government). After determining the sustainability of economic, environmental, and social aspects, the sustainability level of the entire construction industry in a country can be determined by simply averaging the value of these three pillars of sustainability.

The hierarchy shown in (Figure 8) demonstrates how economic, environmental, and social indicators can be associated into project, company and government levels. Furthermore, it shows how performance of these three levels can be associated into economic, environmental and social sustainability sub-indices and finally how these three sub-indices form the overall CPSI.
Figure 8. Hierarchy Scheme for Calculation of CPSI.
Stage 3: Development of a Procedure for Calculation of (CPSI) and a Performance Model

Assessing progress towards construction sustainability initially requires the identification of construction sustainability indicators that provide manageable units of information on social, economic, and environmental conditions.

The important role of sustainability indicators has already been emphasized by the United Nations Conference on Environment and Development (UNCED). This conference calls on individual countries as well as international governmental and non-governmental organizations to “develop and identify indicators of sustainability in order to improve the information basis for decision making at all levels” (UNCED, 1992; Agenda 21, Chapter 40).

The assessment of sustainability performance for construction processes relies on development of the indicators for economic, environmental, and social aspects of construction process sustainability. These indicators should be studied and measured at the following three levels: project, company, and government. A framework for these indicators should be developed, which integrates these indicators into a composite index and assesses the level of sustainability performance of construction process in a particular country.

The procedure for calculating the CPSI is divided into several steps, which is shown in (Figure 9). The detail of each step is given below:

**Task 3: Development of the indicators for CPSI**

Indicators are proven to be useful tools for policy making and public communication in conveying information on a country’s sustainability performance in areas such as
environment, economy, and society.

“Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)” (Meadows, 1998). Godfrey and Todd believe that the main aspect of indicators is their ability to summarize, focus and condense the enormous complexity of our dynamic environment to a manageable amount of meaningful information (Godfrey and Todd, 2001). Warhurst, in his paper “Sustainability Indicators and Sustainability Performance Management” says that indicators simplify, quantify, analyze and communicate otherwise complex and complicated information by visualizing phenomena and highlighting trends (Warhurst, 2002).

Therefore, in order to be able to assess the level of sustainability performance of the construction process in a country, one must first understand the relevant indicators. A set of (14) potential indicators was identified for CPSI (Table 4). They were chosen based on the previously conducted literature review on the topics previously mentioned in Chapter 2, discussion with subject matter experts and their relevance and compliance with the definition and goals of sustainable construction provided in this thesis.
Figure 9. Procedure for calculating CPSI
**Table 4.** Potential Indicators for CPSI.

<table>
<thead>
<tr>
<th>No.</th>
<th>Economic</th>
<th>Environmental</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use of Local Materials</td>
<td>Use of Sustainable Materials</td>
<td>Sustainability Awareness</td>
</tr>
<tr>
<td>2</td>
<td>Construction as a % of GDP</td>
<td>Renewable Energy</td>
<td>Safety</td>
</tr>
<tr>
<td>3</td>
<td>Incentives</td>
<td>CO₂ Emissions</td>
<td>Life Expectancy of Construction Workers</td>
</tr>
<tr>
<td>4</td>
<td>Careers in Sustainable Construction</td>
<td>Water Usage</td>
<td>Strategic Goals for Sustainability in Construction</td>
</tr>
<tr>
<td>5</td>
<td>New Cons. Certified to Some Standards</td>
<td></td>
<td>Sustainability Enforcement</td>
</tr>
</tbody>
</table>
**Task 4: Grouping of indicators into economic, environmental and social categories**

Once the indicators are developed, the next task is to organize them into the three groups related to economic, environmental and social aspects. The indicators are categorized under their relevant pillars of sustainability as shown in Table 4.

**Task 5: Validation of indicators Using Subject Matter Experts**

A panel of 10-15 experts was formed to validate that a comprehensive and accurate set of indicators representing construction process sustainability was identified. This size was deemed to be sufficient because it consisted of a highly qualified, diverse pool of panelists representing expertise with both sustainability and/or construction.

The expertise of the panel members for the validation of the indicators was evaluated based on their professional accomplishments related to the topic of research. For the purpose of defining an expert, a list of criteria was developed based on discussions with the thesis committee members and literature review and is shown in Table 5. An expert who met at least four of the eight criteria listed were included in the panel.

Using the criteria presented in Table 5, 25 prospective panel members affiliated with sustainability and the construction industry were identified. The potential experts were contacted via email and informed about the research, its objective, and the process of validating the indicators for this study. Sixteen out of the 25 members contacted responded positively to be part of the expert panel. Of the 16 participants, six (37.5%) are academics in the sustainability and/or construction disciplines and ten (62.5%) work for construction firms as sustainability directors. These construction firms are among the list of top 400 contractors determined by ENR in 2014.
Of the 16 experts who initially expressed interest, only fourteen responded to the study. Of the two who did not respond to the study, one was affiliated with academia and one with industry. The panel members are geographically spread across the United States in eight different states, with 30% from North Carolina. Panel members were also from the United Kingdom. The sustainability and construction experience of the panelists ranged from 5 to 51 years (mean = 19.4 years; median = 17 years). The panelists possessed a variety of academic degrees and industrial certifications, and have published papers and given presentations at numerous sustainability and construction industry conferences. Based on the demographics, all of the panelists were judged to be experts in the field of sustainability and/or construction industry.

Table 5. Criteria Used to Distinguish Experts.

<table>
<thead>
<tr>
<th>Faculty Position at an Accredited University</th>
<th>Professional Licensure/ Accredited Professional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Book Authorship (related to construction and/or sustainability)</td>
<td>Sustainability Association Participation/Affiliation</td>
</tr>
<tr>
<td>Sustainability Related Work Experience</td>
<td>Journal/Conference Article Authorship (related to construction and/or sustainability)</td>
</tr>
<tr>
<td>Sustainability Education</td>
<td>Directorate of Sustainability for Construction Firms</td>
</tr>
</tbody>
</table>

A Google form for validation of the indicators was created, in which the indicators were mentioned along with a drop down menu for rating the indicators. The form was sent to the experts who agreed to be part of the expert panel. The form consisted of the potential indicators, a description of the indicators, method of measurement, a dropdown rating system.
for each of the potential indicators, and the addition of two questions at the end of questionnaire:

1- In your expert opinion, which other indicator(s) should be included in development of the Construction Process Sustainability Index (CPSI) of a country? Please let us know which other indicators you feel are important to be included.

2- Please let us know if you have any other comments?

The experts were asked to prioritize the potential indicators using the provided scale of 1-5, where 1 indicates “not important” and 5 indicates “extremely important”.

Fourteen experts responded to the study, while the other two experts were dropped from the study. For the purposes of this study, the following criteria have been used to retain or omit indicators in the CPSI:

- Indicators with a mean rating of ≥ 3.5 were retained and included in the CPSI
- Indicators with a mean rating of < 3.5 were omitted from the CPSI

A mean rating of 3.5, which corresponds to 70% of the total scale of five was chosen as the threshold, because it indicates a strong level of agreement between the experts for inclusion of indicators into the CPSI. The retained indicators were considered to be very important in the calculation of CPSI for a country with agreement from a majority of the experts. Hence, to assess the level of Construction Process Sustainability for a country, one must find a way to measure these indicators.

Based on the ratings of the experts, nine of the fourteen indicators received a mean rating of 3.5 or higher and were retained. Five out of fourteen were omitted due to rating of less than 3.5.
The mean ratings of the retained indicators ranged from 4.7 received by the indicator “Safety” to the lowest mean rating of 3.5 received by the indicator “Renewable Energy”. Table 6 shows the list of the retained validated indicators for the CPSI with their average rating and their method of measurement. Figures 10-18 show the distribution of experts’ rating for the indicators with rating 3.5 or higher, which are included in the assessment of construction process sustainability.
Table 6. Retained Indicators for CPSI including Mean Ratings and Method of Measurement

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Experts’ Mean Rating</th>
<th>Method of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>4.7</td>
<td>Rate of fatalities and injuries</td>
</tr>
<tr>
<td>Strategic Goals</td>
<td>4.5</td>
<td>Existence of long term goals for implementation of sustainability in construction process</td>
</tr>
<tr>
<td>Sustainability Enforcement</td>
<td>4.1</td>
<td>Governmental or non-governmental organizations enforcing sustainability at different levels (project, company and government)</td>
</tr>
<tr>
<td>Sustainable Materials</td>
<td>3.6</td>
<td>Percentage of sustainable materials in construction – by cost</td>
</tr>
<tr>
<td>CO₂ Emission</td>
<td>3.8</td>
<td>Keeping track of CO₂ emissions of construction process and its quantity as a percentage of total CO₂ emission in a country</td>
</tr>
<tr>
<td>Water Usage</td>
<td>3.8</td>
<td>Percentage of non-potable water used in construction process – by volume</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>3.5</td>
<td>Percentage of renewable energy used in construction process – by cost</td>
</tr>
<tr>
<td>Use of Local Materials</td>
<td>4.1</td>
<td>Percentage of local materials used in construction process – by cost</td>
</tr>
<tr>
<td>Incentives</td>
<td>3.7</td>
<td>Existence of incentives as rebate, loans, tax, grants, bond programs, leasing/lease purchase programs, or performance-based incentives</td>
</tr>
</tbody>
</table>
Brief Description of Retained Indicators:

Safety:

Safety is probably the most important indicator of sustainable construction. This was proved by its high ratings received from the panel of experts on the indicators. This indicator measures the rate of construction fatalities and injuries at three levels including the project, company and government level for a country. The injuries and fatalities both include the casualties of all the parties involved in construction (contractors, subcontractors, and owner).

![Safety Chart]

**Figure 10.** Distribution of Expert’s rating for Safety.

Strategic Goals:

Having a clear strategy for implementation of sustainability leads to achievement of these goals with minimum difficulty and effort. Parties that are involved in the construction
industry (e.g., government and construction companies) need to have their own strategies in compliance with their visions. This strategy and its implementation needs to be updated regularly to make sure it suits current threats and opportunities (Kenneth and Brocato, 1995). This indicator looks for the existence of strategic goals of sustainability for the construction industry in a country both at government and company levels.

**Figure 11.** Distribution of Expert’s rating for Strategic Goals in Construction.

**Sustainability Enforcement:**

The purpose of this indicator is to make sure different stakeholders of the construction industry in a country are enforcing sustainability in their construction practices. At the government level it is looking for the existence of organizations established by the government overseeing and enforcing sustainability during construction. Governments need
to establish specialized departments having qualified personnel who are experts in construction and sustainability to control and lead this industry towards sustainability.

At the company level it means having a department dedicated to sustainability. This department will oversee all the construction activities of the firm and strictly enforce sustainability on their projects.

![Bar chart showing the distribution of Expert’s rating for Organizations Enforcing Sustainability](image)

**Figure 12.** Distribution of Expert’s rating for Organizations Enforcing Sustainability

**Sustainable Materials:**

Worldwide around 3 billion tons of raw materials are consumed by buildings and construction activities yearly, which is around 40 percent of worldwide use (Roodman and Lenssen, 1995). Consumption of sustainable construction materials and products enhances the conservation of diminishing nonrenewable resources internationally.
In addition, use of sustainable construction materials can help decrease the environmental impacts that are related to transport, fabrication, reuse, disposal, recycle, installation, processing, and extraction of these construction materials. Therefore, the inclusion of this indicator was felt necessary in the CPSI.

EPA classifies sustainable construction materials as reclaimed and recycled building materials as well as establishing their own Environmentally Preferable Purchasing Program (EPP). EPP regulates the purchasing of the federal government and encourages it to “buy green”, which ultimately stimulates market demand for sustainable materials and services.

The percentage of sustainable construction materials used can take any value between 0 and 100. At the project level this percentage is based on the total cost of materials used.

Figure 13. Distribution of Expert’s rating for Sustainable Materials
**CO₂ Emissions:**

Keeping track of the CO₂ emissions footprint is an important issue that should be considered by the stakeholders of construction industry. It not only provides data on the emissions of CO₂ of the construction process in a country, but also will allow the authorities to take action in case the emission amount is too high and establish a plan to reduce it.

Since the industrial revolution, the concentration of CO₂ has increased by more than 30% and is currently continuing to increase at a rate of 0.4% in a year. The main reason of this increase is deforestation and combustion of fossil fuels (CSD, 2001). This increase has an adverse effect on the environment and causes many other problems such as global warming.

In this context the CO₂ emission is related to the construction processes. This indicator is studied at all three levels (project, company and government). The percentage of CO₂ emissions in a country due to the construction process and keeping track of them at different levels are the two methods by which this indicators is measured. The reason for selecting a 20% cutoff for the percentage of CO₂ emissions in a country is speculated to be the contribution of CO₂ from the construction process. It is assumed that the percentage of CO₂ emissions from the construction process will not go beyond 20% of total CO₂ emissions in a country.
Figure 14. Distribution of Expert’s rating for CO₂ Emissions.

Water Usage:

The United Nations Commission for Sustainable Development warns the world about the long-term sustainability of water in many regions of the world. The use of water has increased twice as fast as the population rate, which has already made several regions chronically short of water. Water stress is governing countries that account for one third of the world’s population. By 2025 as much as two thirds of the world’s population could be living in water-stressed countries (UNEP, 2000).

The amount of work done (research and development) on water sustainability at construction sites has been very scarce. Water is not considered to be a high priority such as carbon footprint and waste reduction. However, the political and environmental agenda is expected to change this because of water scarcity (UK Strategic Forum, 2011). Therefore, the
inclusion of this indicator is deemed necessary in the CPSI. The method of measurement of this indicator is the percentage of non-potable water used in construction processes by volume, and is between 0 to 100 percent.

![Bar chart showing water usage in construction processes](image)

**Figure 15.** Distribution of Expert’s rating for Water Usage.

**Renewable Energy:**

This indicator measures the proportion of energy mix between renewable and non-renewable energy resources used in construction processes. Basically, it is the percentage of construction process’ total energy consumption supplied from renewable energy sources. Renewable resources can supply energy continuously and their use, in general, creates less environmental pressure. In addition, dependence on non-renewable resources can be regarded as unsustainable in the long run (UNCSD, 2011).

The inclusion of this indicator in the CSPI is very important, based on the facts
presented above. The energy used during the construction process primarily represents on-site electricity usage for site office trailers, small equipment and tools, and lighting. As per the EPA, biomass, geothermal, hydroelectric, hydrogen and fuel cells, ocean, solar, and wind are classified as renewable energy sources. It is measured by percentage of renewable energy used in construction processes by cost.

![Renewable Energy Chart](image)

**Figure 16.** Distribution of Expert’s rating for Renewable Energy.

**Use of Local Materials:**

Use of local materials is considered important both for economic development of a region and reducing the adverse effect associated with its transportation on the environment. The definition of local materials is different at project and government levels. At the project level, the definition of local materials adopts the LEED (Leadership in Energy and Environmental Design) rating approach. Per LEED, local materials are those that are
extracted, harvested, and manufactured nationally within 500 miles of a project site. Whereas, at the government level it is those materials that are extracted, harvested, and manufactured nationally within the country borders. This indicator is measured as a percentage of total materials used in construction of a project by cost. Its value ranges between 0 and 100 percent.

![Use of Local Materials](image)

**Figure 17.** Distribution of Expert’s rating for Use of Local Materials.

**Incentives:**

In order to encourage the stakeholders of the construction industry to adopt more sustainable construction process practices, there should be incentives at all the levels. It is essential for the government to reward construction firms that contribute to sustainability and offer them special rewards. In the meantime, the construction firms can play a significant role
in spreading the culture of sustainable building by offering incentives to the owners who build new projects to encourage them to transition from traditional building construction techniques to more sustainable ones.

Potential incentives could include rebates, loans, technical assistance/design assistance, expedited permitting, tax incentives, grants, bond programs, leasing/lease purchase programs, and performance-based incentives.

![Figure 18. Distribution of Expert’s rating for Incentives.](image)

Few experts provided comments or proposed new indicators to be included in the CPSI. The few new indicators proposed were sent to the experts for their rating and the responses for those indicators were recorded. None of the newly proposed indicators by experts were rated equal or greater than 3.5, resulting in their omission from the list of
indicators for the CPSI.

**Task 6: Development of questions based on indicators for project, company and government levels**

As mentioned previously, in order to assess the level of sustainability performance of the construction process in a country, the indicators related to economic, environmental and social aspects of construction process sustainability should be identified and assessed at project, company and government levels.

Having identified and validated the indicators, it is now possible to assess the CPSI for a country based on these validated indicators. For this purpose a set of questions that assess the performance of the indicators are developed for each of the three levels. Questions are a mixture of “Yes”, “No”, percentage, and range responses.

Thus, the performance of each level is assessed by these questions that represent the indicators related to the three aspects of construction sustainability. Table 7 shows these questions, their association with the indicators, levels (project, company and government) and aspects (economic, environmental and social) of sustainability.

**Task 7: Development of a rating system for questions**

Having introduced the questions related to each level, now a numerical method is developed for rating them. The developed numerical system will be used to allocate a score to the questions at each level that will help assign a numerical value to the CPSI of a country. A point based system is developed for questions as follows:

a) Responses to each question are converted to a numerical value varying from zero to
b) There are two different types of questions, and each type has a different way of being converted into point values. The first type of question has two possible answers (Yes or No), where the second type of question has 5 possible answers shown in Table 8.

c) In questions where the answer is either “yes” or “no,” the point value is awarded according to the percentage of “yes” answers. Figure 19 shows an example.

d) In questions such as "Approximately what percentage of local materials is used in this project?" the answer consists of different performance levels, and the points awarded are calculated as follows:

Points awarded = \( \sum (\text{Percentage of responses for a range multiplied by the Point Value associated with the range}) \).

The percentage of responses for a range can be between (0-100) %, and point values associated with the respective range can from 0 to 1 as shown in Table (8). Figure 20 shows an example of these types of questions.
Table 7. Questions for Project, Company, and Government Levels.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Government Level Questions</th>
<th>Company Level Questions</th>
<th>Project Level Questions</th>
</tr>
</thead>
</table>
| Safety           | 1- What is the rate of construction workplace fatalities in your country?  
2- What is the rate of construction workplace injuries in your country?                                                                                     | 1- What is the rate of construction workplace fatalities per year in your firm?  
2- What is the rate of construction workplace injuries per year in your firm?                          | 1- What is the rate of construction workplace fatalities in this project?  
2- What is the rate of construction workplace injuries for this project?                                  |
| Strategic Goals  | 3- Does the government have nationally defined strategic goals for implementing sustainability in construction industry?  
4- How sustainable is the national policy framework?                                                                                                          | 3- Does your firm have defined sustainability goals?                                                            | 3- Are sustainable construction practices enforced by any stakeholder in this project?                     |
| Sustainability   | 4- Has the government established specialized organizations to enforce sustainability practices in construction processes? If the answer is “Yes” how many?              | 4- Does your firm have a sustainability department enforcing sustainable construction practices in your projects? |                                                                                                             |
| Enforcement      |                                                                                                                                                                                                                           |                                                                                                             |                                                                                                             |
| Sustainable      | 5- Approximately what percentage of sustainable construction materials is used in your country?                                                                                                                             | 5- Approximately what percentage of sustainable construction materials is used by your firm annually?      | 4- Approximately what percentage of sustainable construction materials is used in this project?          |
| Materials        |                                                                                                                                                                                                                           |                                                                                                             |                                                                                                             |
| CO₂ Emission     | 6- Does the government measure CO₂ emissions of construction processes in your country?  
7- Approximately what percentage of CO₂ emissions in your country is due to construction processes?                                                    | 6- Does your firm measure CO₂ emissions produced during its construction projects?  
7- Has your firm taken any appropriate measure to reduce the CO₂ emissions produced by its construction projects? | 5- Do you measure CO₂ emissions produced during construction process of this projects?  
6- Does your subcontractor(s) measure their CO₂ emissions produced during construction process of this projects? |
| Water Usage      | 8- Approximately what percentage of water being used in construction processes in your country is non-potable?                                                                                                         | 8- Approximately what percentage of water being used in construction processes of your firm is non-potable | 7- Approximately what percentage of water being used in this project is non-potable?                      |
| Renewable Energy | 9- Approximately what percentage of energy being used during the construction processes in your country is renewable?                                                                                                        | 9- Approximately what percentage of energy being used during the construction processes by your company is renewable? | 8- Approximately what percentage of energy being used during the construction process of this project is renewable? |
| Use of Local     | 10- Approximately what percentage of local construction materials is used in your country?                                                                                                                                   | 10- Approximately what percentage of local construction materials is used by your firm?                      | 9- Approximately what percentage of local construction materials is used in this project?                |
| Materials        |                                                                                                                                                                                                                           |                                                                                                             |                                                                                                             |
| Incentives       | 11- Does the government offer incentives for use of sustainable construction techniques?                                                                                                                                   | 11- Does your firm offer incentives to clients who want to build sustainable projects?                      | 10- Has this project received/will receive any incentives due to implementation of sustainable practices?  |

65
Since the percentage of “Yes” response is 0% for this question the point value awarded is zero, based on the point values found in Table 8.

In questions with 5 possible answers such as "Approximately what percentage of local materials is used in this project?" the points awarded are calculated as follows:

Points awarded = \[ \sum \text{(Percentage of responses for a range multiplied by the Point Value associated with the range)} \]

\[= [(41\% \times 0) + (18\% \times 0.25) + (35\% \times 0.5) + (6\% \times 0.75) + (0\% \times 1)] = 0.265 \]
Figure 20. Percentage of Local Materials Used in a Project.

For this question there were a total of 17 responses. In the above equation the percentages (41, 18, 35, 6 and 0) are the percentage responses for the ranges 0, 1-25, 26-50, 51-75, 76-100%, respectively. Points 0, 0.25, 0.5, 0.75, and 1 from Table 8 correspond to the points associated with those ranges.

The above questions are just samples to show how the responses for these types of questions are calculated. Table 8 shows the definition of ranges used in response to questions and the points allocated to each range. There are a total of 5 ranges used in questions for the project, company and government levels. These different ranges and point allocations take care of normalization requirement. For example the percentage of local materials used and points allocated to the ranges have a direct relation; the higher the percentage of local materials used the higher the points allocated. However, the percentage of CO$_2$ emission and points allocated to its ranges are inversely related; the higher the CO$_2$
emission the lower the allocated point value. Therefore, allocating appropriate points to the related ranges eliminate the need for normalization.

The two right side columns under “ranges” are associated with questions related to safety and represent rates of injuries per 100 construction workers and fatalities per thousands of workers respectively. Per the table the higher the rate of injuries and fatalities the lower the point allocated to that question.

The middle column under “ranges” is associated to the question related to percentage of CO₂ emissions in a country. The higher the percentage of CO₂ emissions in a country due to construction processes the lower the point allocated to it.

The fourth column from right under “ranges” is associated to the questions related to sustainability enforcement. The higher the number of sustainability enforcement organizations in a country the higher the point allocated to that question.

Finally the fifth column from right under “ranges” is associated to the questions related to strategic goals, water usage, use of local materials, incentives, renewable energy, and sustainable materials. There is a direct relation between point allocation and these indicators, meaning that the higher their percentage use the higher the point allocated to them.
Once all of the questions for a level are rated, the level of performance can be found by simply averaging the points awarded to each question. A more detailed explanation of how this formula works can be found in the next chapter. Having developed a rating system for the questions at each level, the following explains in detail the method of data collection.

**Task 8: Data Collection**

In this step, the method of data collection, population of each level, sample size and assumptions associated with the data collection are presented as follows.

1- The method used for data collection is online questionnaire. A set of questions for each level is developed as shown in Table 7. For this purpose Google forms are used, because of their simplicity and user friendliness. The questionnaire is sent

---

**Table 8. Definition of Ranges Associated with Questions and Allocation of Points.**

<table>
<thead>
<tr>
<th>Point Allocated</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.25</td>
<td>1-25 % Yes(1)</td>
</tr>
<tr>
<td>0.5</td>
<td>25-50 % Yes(2-3)</td>
</tr>
<tr>
<td>0.75</td>
<td>51-75 % Yes(4-5)</td>
</tr>
<tr>
<td>1</td>
<td>76-100 % Yes(&gt;5)</td>
</tr>
</tbody>
</table>
out to the participants and their response is collected in a spreadsheet that will be created by Google forms itself.

2- The population is different for each level. The population for the company level is the construction companies in a specific country. Whereas the population for project level is the pool of ongoing construction projects in a country. Getting access to the list of a country’s construction projects and having a comprehensive and complete list of construction projects is a difficult task; therefore, for the purpose of simplicity construction companies are also taken as the population for project level in a country. After a construction company is randomly selected for assessment at the project level, one of the projects among the current projects of that construction company will be randomly chosen and data will be collected on that project.

However, there is not a specific population for the government level to be studied. If the answers are found on the public databases and/or internet, there would be no need to have the surveys answered by governmental organizations/officials. Otherwise, any authority/organization from the government who can answer these questions can be counted as a possible respondent for assessing the government level. For example, the number of fatalities, injuries, and percentage of CO₂ emissions from construction can be found on OSHA’s (Occupational Safety and Health Administration) and EPA’s (Environmental Protection Agency) websites, respectively, for the United States. In case answers are not made publicly available for a country, the questionnaire will be sent to organizations responsible
for overseeing the construction activities in that country. For example answers to questions are not available online for Afghanistan. Therefore, for the purpose of calculating the CPSI for this country, the questionnaires are sent to Kabul Municipality, Ministry of Rural Rehabilitation and Development and three more organizations who are responsible for construction industry in Afghanistan.

3- The sample size can be calculated in several ways. These include use of published tables, imitation of sample size from a similar study, census if the population is small and formulas (Cochran, 1963). The latter one is used for determination of samples in this thesis. In determining the sample size for project and company levels the following assumptions are made:

- The design is assumed to use a simple random sample
- 10% level of precision
- 90% confidence level
- Large population size

Assuming that the population for each of project and company level is large, the sample size for each is determined using the Cochran formula (Cochran, 1963).

\[ n_0 = \frac{z^2pq}{e^2} \]

Where \( n_0 \) is the sample size, \( Z^2 \) is the abscissa of the normal curve that cuts off an area \( \alpha \) at the tails (1 - \( \alpha \) equals the desired confidence level, here, 90%), \( e \) is the desired level of precision, \( p \) is the estimated proportion of an attribute that is present in the population, and \( q \) is \( 1-p \). The value for \( Z \) is found in statistical tables, which contains the area under the
normal curve. Therefore, the required sample size for each of company and project level is:

\[ n_0 = \frac{z^2pq}{e^2} = \frac{1.645^2(0.5)(0.5)}{(0.1)^2} = 68 \]

So, the sample size for each level is 68 assuming there is a large population and that we do not know the variability in the proportion that have sustainable construction processes in place; therefore, we assume \( p=0.5 \) (maximum variability).

If the population is small then the sample size can be reduced slightly. This is because a given sample size provides proportionately more information for a small population than for a large population. The sample size \( n_0 \) can be adjusted using the following equation (Israel, 1992):

\[ n = \frac{n_0}{1 + \left(\frac{n_0 - 1}{N}\right)} \]

Where \( n \) is the sample size and \( N \) is the population size.

**Task 9: Calculation of Sub-Indices**

Once the score of the questions is determined, the performance of a level is obtained by simply averaging the score of the questions related to that level. Since, the questions are scored anywhere from 0-1, the performance of a level will also be within this range, where 0 and 1 represent the lower and upper values of sustainability performance, respectively.

Having the performance of the levels, once again simple averaging is employed to determine the value of the sub-index for the three aspects of CPSI. This value will also be within a range of 0-1.
Task 10: Aggregation of Sub-Indices into CPSI

Having the sub-indices calculated, finally the CPSI of a country is obtained using an average aggregation method of the three values for economic, environmental and social sub-indices.

One may consider different weights for different indicators, questions, levels and sub-indices. However, due to lack of a scientific basis for the attribution of different weights, every indicator, question, level and sub-index has received the same weight for the aggregation into the CPSI. Simple averaging was chosen for two reasons:

1. Transparency: it was important that someone with general education be able to read and understand how the index was constructed. A complicated mathematical approach would violate this principle while not adding much to the basic functionality of the scales.

2. Equal Weighting: Averaging implies that equal weight is being given to each measure.

Task 11: Developing a Performance Model for CPSI

Having calculated the CPSI for a country, one may need to know the performance level of that country and interpret the CPSI from a numerical standpoint to a descriptive and more understandable way of conveying this value. Therefore, a performance model for CPSI is developed consisting of five levels as follows: extremely unsustainable, unsustainable, satisfactory, sustainable, and extremely sustainable (refer to the rating criteria found in Table 9). A description of two of these levels are given below:
I. Extremely Unsustainable: A country’s construction industry is extremely unsustainable. Safety is frequently violated; the number of work-related injuries and fatalities are high. The stakeholders of the construction industry (e.g., government and construction firms) do not have strategic goals for implementation of sustainability in construction. Use of sustainable materials, local materials, renewable energy and non-potable water in construction is very low and limited. On the other hand, the CO$_2$ emissions are very high from construction processes. Sustainability enforcement is weak and there are no incentives offered by the government or other stakeholders of the industry for implementation of sustainable techniques.

Moreover, at this level, the stakeholders are unaware of the importance of adopting sustainability in the construction industry of the country and do not issue any regulations or rules that force its implementation. The government believes that such a step will result in large expenses and extra complications for the construction industry of the country.

II. Extremely Sustainable: The construction industry is extremely sustainable. No safety violations occur; the number of work-related injuries and fatalities are minimized. The stakeholders of the construction industry (e.g., government and construction firms) have strategic goals for implementation of sustainability in construction. Use of sustainable materials, local materials, renewable energy and non-potable water in construction is at its highest levels. On the other hand the CO$_2$ emissions are very low from construction processes. Sustainability enforcement is
very strong and there are incentives offered by the government and other stakeholders of the industry for implementation of sustainable techniques. Moreover, at this level, the stakeholders are completely aware of the importance of adopting sustainability in the construction industry and have strict rules and regulations that enforces its implementation. Dedicated authorities within the government are used to monitor and control the construction industry, and it has well-defined quality control and monitoring methodologies. The government and companies consider sustainability a priority that cannot be compromised.

Table 9. CPSI Value and Related Performance Level.

<table>
<thead>
<tr>
<th>CPSI Value</th>
<th>Performance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.19</td>
<td>Extremely Unsustainable</td>
</tr>
<tr>
<td>0.2-0.39</td>
<td>Unsustainable</td>
</tr>
<tr>
<td>0.4-0.59</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>0.6-0.79</td>
<td>Sustainable</td>
</tr>
<tr>
<td>0.8-1</td>
<td>Extremely Sustainable</td>
</tr>
</tbody>
</table>
Having developed a hierarchy, procedure for calculation of CPSI and a performance model in Chapter 3, for purpose of validation, this index is calculated for Afghanistan and United States of America in Chapter 4.
CHAPTER 4: APPLICATION OF CPSI

In this chapter the effort for calculating the CPSIs for Afghanistan and United States is presented and the CPSI for Afghanistan is calculated. However, the CPSI for United States was not calculated due to the low level of responses received for the surveys for this country. The purpose of this chapter is to demonstrate how to both calculate and use an actual CPSI. The reason for choosing these two countries is that the author is a citizen of Afghanistan and is currently pursuing a master degree in the United States. In addition, these two countries represent two different continents of the world with different economies, environment and cultures. It should be noted that a CPSI can be developed for any country of the world. First, the CPSI for Afghanistan is calculated followed by a description of the process to determine the CPSI for the United States.

Calculating the CPSI for Afghanistan

Afghanistan is a landlocked country located within South Asia and Central Asia. It has a population of approximately 31 million people. During the dark regime of Taliban the construction sector of the country had a zero contribution to the total GDP. It can be argued that no construction work was done during that time. Within the last decade, after the defeat of the Taliban regime, a large amount of money has been dedicated both by the Afghan government and other foreign allies of the Afghan government on the reconstruction of Afghanistan. This amount can be estimated to be within 150-200 billion dollars. The United States as the largest supporter of the Afghan government has already contributed around $104 billion toward the reconstruction efforts (SIGAR, 2014). In a recent article titled, “The
Shocking Cost of Reconstructing Afghanistan,” it is stated that this amount is more than all the money spent on reconstructing Europe after World War II (theweek.com, 2014). This large-scale construction is unprecedented in Afghanistan’s history. In order to determine whether the construction processes in Afghanistan is sustainable, its CPSI is calculated as follows.

**Data Collection**

In this section the method of data collection, population, sampling frame, sample size and assumptions related to data collection are explained in detail for Afghanistan.

The method of data collection for calculation of CPSI for Afghanistan was through the use of e-surveys. For company and project level data, the questions developed in previous chapter were sent to projects and companies in Afghanistan via email. Follow-up phone calls were conducted by the researcher to the participants to inform them about the research, its objective, and the process of answering the questions for this study. The researcher provided information and explained the objective of the research and provided them with his contact addresses to reach him in case there were any questions.

The population for the sample size included all construction companies and projects in Afghanistan. Since, obtaining a comprehensive list of ongoing construction projects in Afghanistan is very difficult, the construction companies were chosen to be the population for both the company and project levels. After a construction firm was chosen to answer the questions at the company level, the questionnaire was sent to the firm for answers. The construction firms that were randomly selected to answer questions at project level were asked to present the list of their projects. Having the list of construction projects for a firm
the researcher then randomly selected a project from the list and asked the firm to answer the questionnaire based on that project.

After several attempts, the researcher was able to obtain a list of 450 construction companies conducting business in Afghanistan and registered with both ABA (Afghan Builders Association) and AISA (Afghanistan Investment Support Agency). In order to operate a business legally in Afghanistan it needs to obtain a business license and register with AISA. According to a 2009 report of AISA, the number of construction firms registered with this organization is around 8500 construction companies.

Sample size was calculated using the Cochran formula and established that 68 companies and 68 projects would need to be sampled. The calculation of sample size and related assumptions are given below:

- The sampling design is assumed to be simple random sampling
- 10% level of precision
- 90% confidence level
- Large population size

\[
 n_0 = \frac{z^2pq}{e^2} = \frac{1.645^2 (0.5)(0.5)}{(0.1)^2} = 68
\]

The sample size for each of company and project levels is 68. Using Microsoft Excel and the list of 450 construction companies obtained, seventy (70) construction companies were randomly selected for the company level and 70 construction companies were randomly selected to answer the questionnaire at the project level. The first group was contacted and
asked to answer questions related to the company level and the second group was contacted and asked to send their ongoing project list to the researcher who then randomly selected the projects that data needed to be collected on.

**Project Level**

The questionnaire related to project level was sent out to project managers responsible for each of the 70 projects. Of the 70 project managers contacted only 37 (53%) responded. Projects ranged in size from $5 M - $150 M. These projects are geographically spread across Afghanistan, representing fifteen different provinces, with a majority in Kabul province. The following figure shows the percentage of different types of projects included in this study.

![Project Type Percentages](figure21.png)

**Figure 21. Project Type Percentages (n=37)**
Rating the Project Level Questions

In this section the questions related to project level are rated.

1. What is the rate of construction workplace related fatalities in this project?

   The number of fatalities includes those of the subcontractor(s) as well. The values on the x axes of the following figure show the rate of fatalities at project level. It shows fatality rate per thousands of construction workers. Figure 22 shows the responses to this question and uses the formula presented in Chapter 3 to calculate the score for it as follows:

   Point awarded = \[ \sum (\text{Percentage of responses for a range } \times \text{Point associated with the range}) = [(81\%)X1] + [(3\%)X0.75] + [(5\%)X0.5] + [(8\%)X0.25] + [(3\%)X0] \] = 0.88.

![Construction Workplace Fatalities](image)

**Figure 22.** Construction Workplace Fatalities at Project Level

2. What is the number of construction workplace related injuries on this project?

   This includes the number of injuries of the subcontractor(s) as well. Figure 23 shows
the responses to this question; using the formula presented in Chapter 3, the score for this question is calculated as follows:

Point awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = [(24\%) \times 1] + [(30\%) \times 0.75] + [(24\%) \times 0.5] + [(14\%) \times 0.25] + [(8\%) \times 0] \)

= 0.62.

![Construction Workplace Injuries](image)

**Figure 23.** Construction Workplace Injuries at Project Level.

3. Approximately what percentage of sustainable construction materials is used on this project?

Figure 24 shows the responses to this question and using the formula presented in chapter 3, the score for this question is calculated as follows:

Point awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = [(84\%) \times 0] + [(16\%) \times 0.25] + [(0\%) \times 0.5] + [(0\%) \times 0.75] + [(0\%) \times 1] \)

= 0.04.
4. Do you measure CO\textsubscript{2} emissions produced on this project during the construction phase?

Figure 25 shows that none of the projects measured their CO\textsubscript{2} emission at the project level. The percentage of “Yes” response is zero. Therefore, the score for this question is zero as found in Table 8.

5. Do your subcontractors measure their CO\textsubscript{2} emissions produced during construction process of this projects?

The percentage of “Yes” was zero for this question too. Using Table 8, the score for this question is calculated to be zero. The following figure can be used for both questions (4 and 5) because they have the same answers.
6. Approximately what percentage of local construction materials is used on this project?

Figure 26 shows the responses to this question; using the formula presented in chapter 3, the score for this question is calculated as follows:

Points awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = [(0\%) \times 0] + [(35\%) \times 0.25] + [(46\%) \times 0.5] + [(14\%) \times 0.75] + [(5\%) \times 1] = 0.47 \)

7. Approximately what percentage of water being used in this project is non-potable?

Figure 27 shows the responses for this question. The score for this question is calculated as follows:

Points awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = [(19\%) \times 0] + [(24\%) \times 0.25] + [(27\%) \times 0.5] + [(16\%) \times 0.75] + [(14\%) \times 1] = 0.45 \)
Figure 26. Use of Local Construction Materials at Project Level

Figure 27. Non-Potable Water Usage at Project Level
8. Approximately what percentage of energy being used during the construction process of this project comes from renewable energy sources?

Figure 28 shows the responses to this question using the formula presented in Chapter 3, the score for this question is calculated as follows:

\[
\text{Points awarded} = \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = \{(41\%) \times 0 + (30\%) \times 0.25 + (19\%) \times 0.5 + (11\%) \times 0.75 + (0\%) \times 1\} = 0.25
\]

![Renewable Energy Used at Project Level](image)

**Figure 28.** Percentage of Renewable Energy Used at Project Level.

9. Has this project received/will receive any incentives due to implementation of sustainable practices?

Sustainable construction practices are those practices that enhance the performance level of indicators of construction sustainability. For example, use of non-potable water, use
of renewable energy, practices that decrease the construction work-related fatalities and injuries and so on are said to be sustainable construction practices.

Potential incentives could be rebate, loans, tax incentives, grants, bond programs, leasing/lease purchase programs, and performance-based incentives. Figure 29 shows the responses for this question. The percentage of “Yes” is zero for this question. Referring to Table 8 the related score for this question is zero.

![Incentives](image)

**Figure 29.** Incentives at the Project Level

10. Are sustainable construction practices enforced by any stakeholder in this project?

The enforcing stakeholders at the project level can be owners, contractors and government officials. As one can see in Figure 30, the percentage of “Yes” responses for this question is zero. It shows that not only incentives are not provided for implementation of sustainable construction practices, but also that there is no organization enforcing them.
Figure 30. Enforcing Sustainable Construction Practices at Project Level

Figure 31 shows the average rating of indicators at project level for Afghanistan. Safety has the highest rating followed by water usage, use of local materials and renewable energy. However, several questions related to incentives, CO₂ emissions, and sustainability enforcement scored zero at project level for Afghanistan.
Figure 31. Rating of Questions at Project Level

Company Level

After randomly choosing 70 construction companies in Afghanistan using Microsoft Excel, the questionnaire related to company level was sent to these firms via email. Of the construction companies contacted, 33 (47%) responded to the questionnaire. The construction companies are geographically spread across Afghanistan, representing ten different provinces of Afghanistan, with a majority in Kabul province.

Rating the Company Level Questions

Questions related to the company level are provided as follows:

1. What is the rate of construction workplace related fatalities per year in your firm?
The number of construction fatalities in this question contains both the fatalities of the contractor and any sub-contractor(s) working for the firm. Figure 32 shows the distribution of answers related to construction work fatalities by these firms. The score given to this question is calculated using the following formula.

Points awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) \)

\[ = [(9\%)X0] + [(6\%)X0.25] + [(15\%)X0.5] + [(24\%)X0.75] + [(45\%)X1] = 0.73 \]

2. What is the rate of construction workplace injuries per year in your firm?

The number of construction injuries in this question contains both the injuries of the contractor and any sub-contractor working for the firm. Figure 33 shows the number of construction work-related injuries per 100-construction workers on the “X” axis and number of responses on the “Y” axis. The score given to this question is calculated using the following formula:

Points awarded = \( \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) \)

\[ = [(21\%)X0] + [(30\%)X0.25] + [(24\%)X0.5] + [(15\%)X0.75] + [(9\%)X1] = 0.6 \]
Figure 32. Construction Workplace Fatalities at Company Level

Figure 33. Construction Workplace Injuries at Company Level
3. Does your firm have defined strategic goals regarding how to involve sustainability in its construction process?

As shown in Figure 34 all the construction companies that responded to this questionnaire do not have any goal for implementation of sustainability in their construction processes. Per Table 8 this question receives a score of zero.

Figure 34. Existence of Strategic Goals for Implementation of Sustainability in Construction Processes at Company Level

4. Approximately what percentage of sustainable construction materials does your firm use annually?

Figure 35 shows the responses received for this question and using the formula presented in chapter 3, the score for this question is calculated as following:
Points awarded $= \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range}) = 
\{[(82\%) \times 0] + [(12\%) \times 0.25] + [(6\%) \times 0.5] + [(0\%) \times 0.75] + [(0\%) \times 1]\} = 0.06$

![Sustainable Construction Materials](image)

**Figure 35.** Use of Sustainable Construction Materials at Company Level

5. Does your firm measure CO$_2$ emissions produced by its construction projects?

The construction firms that filled out this questionnaire do not measure their CO$_2$ emissions. The percentage of “Yes” responses for this question is zero; referring to Table 8 the score for this question is calculated to be zero. Figure 36 shows the distribution of answers.
6. Has your firm taken any appropriate measures to reduce the CO\textsubscript{2} emissions produced by its construction projects?

Construction firms should develop means and methods to minimize their CO\textsubscript{2} emissions on their construction projects. Taking necessary measures such as; a) energy efficient site accommodation b) Reducing the transport of waste c) Fuel efficient driving and d) Efficient use of construction plant, can play role in decreasing these emissions. Unfortunately, the firms that responded to this questionnaire do not have any methods and measures to minimize the CO\textsubscript{2} emissions of their construction activities. The percentage of “Yes” responses for this question is zero, therefore this question receives a score of zero.

7. Approximately what percentage of local construction materials does your firm use?

Figure 37 shows the distribution of responses to this question and point allocated to this question is calculated as follows:
Point awarded = \[ \sum \text{(Percentage of responses for a range X Point associated with the range)} = \{(0\%)X0\}+(21\%)X0.25\}+(52\%)X0.5\}+(27\%)X0.75\}+(0\%)X1\} = 0.52 \]

**Figure 37.** Use of Local Construction Materials at Company Level.

8. Approximately what percentage of water being used in construction processes of your firm is non-potable?

Figure 38 shows the responses of the firms to this question. The point value awarded to this question is calculated as follows:

Point awarded = \[ \sum \text{(Percentage of responses for a range X Point associated with the range)} = \{(0\%)X0\}+(45\%)X0.25\}+(30\%)X0.5\}+(15\%)X0.75\}+(9\%)X1\} = 0.38 \]

9. Approximately what percentage of energy being used by your firm during the construction process is renewable?
The distribution of responses for this question is shown in Figure 39 and the point value awarded to this question is calculated as follows:

**Figure 38. Percentage of Non-Potable Water Used at Company Level**

Points awarded = \( \sum \) (Percentage of responses for a range X Point associated with the range) = 
\[ [(48\%) \times 0] + [(30\%) \times 0.25] + [(12\%) \times 0.5] + [(9\%) \times 0.75] + [(0\%) \times 1] = 0.2 \]
10. Does your firm offer incentives to clients who want to build sustainable projects?

The percentage of “Yes” response for this question is zero referring to Table 8, the related score for this question is calculated to be zero.

11. Does your firm have a sustainability department enforcing sustainable construction practices in your projects?

Having a department dedicated to sustainability indicates the commitment of a firm to sustainability and makes sure that sustainable construction practices are implemented in the construction process of the firm. Unfortunately, the construction companies that answered this questionnaire from Afghanistan do not have any department dedicated to sustainability. The percentage of “Yes” responses to this question was zero. Therefore, the score for this question as per Table 8 is zero. Figure 40 shows the distribution of answers to this question.
Figure 40. Enforcing Sustainable Construction Practices at Company Level

Figure 41 shows the rating of indicators at the company level for Afghanistan. One can see that safety has the highest rating followed by use of local materials and use of non-potable water. However, several indicators related to incentives, CO₂ emissions, sustainability strategic goals, and sustainability enforcement have scored zero at the company level for Afghanistan.
Questions related to construction sustainability at the government level are addressed in this section. Most of the questions related at the government level can be answered by searching the public records and government-related websites for countries; but unfortunately Afghanistan does not have such information disclosed publicly. After a rigorous search for answers to the government level questions, the researcher was not able to find these data on public records and the Internet. It is assumed that data such as construction fatalities, injuries, CO₂ emissions, renewable energy, and other related data necessary to this research are not collected by the government and there is no public record available. The only way to be able to measure the sustainability performance of government was to contact the

![Rating of Questions at Company Level](image)

**Figure 41.** Rating of Indicators at Company Level for Afghanistan

**Government Level**

...
governmental organizations responsible for construction in Afghanistan and ask them to fill out the questionnaires. The following organizations were contacted and informed about the research, its objective, and the process of developing the CPSI.

5- Ministry of Rural Rehabilitation and Development (MRRD)
6- Kabul Municipality
7- Ministry of Public Works
8- Central Statistics Organization (CSO)
9- Afghanistan Investment Support Agency (AISA)

These organizations are said to be in charge of construction activities in Afghanistan.

From the five organizations contacted only three of them answered the questionnaires.

Following are the answers provided to the questionnaires by these organizations.

**Rating the Government Level Questions**

Having received the answers of the three governmental organizations the questions related to the government level for Afghanistan’s CPSI are rated as follows:

1. What is the rate of construction workplace related fatalities in your country annually?

   Figure 42 shows the distribution of answers related to construction workplace fatalities. The score given to this question is calculated using the following formula:

   \[
   \text{Points awarded} = \sum \text{(Percentage of responses for a range} \times \text{Point associated with the range)}
   \]

   \[
   = \left\{ \left[ \text{(0\%)} \times 0 \right] + \left[ \text{(100\%)} \times 0.25 \right] + \left[ \text{(0\%)} \times 0.5 \right] + \left[ \text{(0\%)} \times 0.75 \right] + \left[ \text{(0\%)} \times 1 \right] \right\} = 0.25
   \]
2. What is the rate of construction workplace injuries in your country?

Figure 43 shows the distribution of responses for this question. The score for this question is calculated as follows:

\[
\text{Points awarded} = \sum (\text{Percentage of responses for a range} \times \text{Point associated with the range})
\]

\[
= [(67\%) \times 0] + [(33\%) \times 0.25] + [(0\%) \times 0.5] + [(0\%) \times 0.75] + [(0\%) \times 1] = 0.08
\]
3. Does the government have nationally defined strategic goals for implementing sustainability in construction industry?

According to the organizations, currently the government of Afghanistan does not have strategic goals to implement sustainability in its construction industry. Therefore, the score for this question is calculated to be zero.

4. Approximately what percentage of sustainable construction materials is used in your country?

The distribution of responses for this question is presented in Figure 44. The score for this question is calculated as follows:

Points awarded = \( \sum \) (Percentage of responses for a range X Point associated with the range)

\[
= \{(0\%)X0\} + \{(100\%)X0.25\} + \{(0\%)X0.5\} + \{(0\%)X0.75\} + \{(0\%)X1\} = 0.25
\]
5. Does the government measure CO$_2$ emissions of construction processes in your country?

Once again the responses for this question were no. The percentage of “Yes” response was zero. Thus, the rating of the question is calculated to be zero.

6. Approximately what percentage of CO$_2$ emissions in your country is due to construction processes?

Since the government does not measure the CO$_2$ emissions from construction activities in Afghanistan the exact percentage of this amount is therefore unknown, but the organizations measured it to be (1-5 %) of total CO$_2$ emissions in Afghanistan. They provided a comment with their responses stating that this response is an approximation and not an exact number. Figure 45 shows the distribution of responses for this question. The rating of this question is calculated as follow:
Points awarded = \( \sum \) (Percentage of responses for a range \( \times \) Point associated with the range)  
= \{[(0\%)X0]+[(0\%)X0.25]+[(0\%)X0.5]+[(100\%)X0.75]+[(0\%)X1]\} = 0.75

**Figure 45.** Percentage of CO\(_2\) Emissions from Construction Processes in Afghanistan

7. Approximately what percentage of local construction materials is used in your country?

From the government’s perspective, the local construction materials are those that are extracted, harvested, and manufactured nationally within a country. The distribution of responses to this question from governmental organizations is shown in Figure 46. The point value allocated to this question is calculated as follows:

Point awarded = \( \sum \) (Percentage of responses for a range \( \times \) Point associated with the range)  
= \{[(0\%)X0]+[(0\%)X0.25]+[(67\%)X0.5]+[(33\%)X0.75]+[(0\%)X1]\} = 0.58
8. Approximately what percentage of water being used in construction processes in your country is non-potable?

Figure 47 shows the distribution of responses to this question. The allocated point value to this question is calculated as follows:

\[
\text{Point awarded} = \sum \text{(Percentage of responses for a range} \times \text{Point associated with the range)} = \{(0\%) \times 0 + (0\%) \times 0.25 + (67\%) \times 0.5 + (33\%) \times 0.75 + (0\%) \times 1\} = 0.58
\]

9. Approximately what percentage of energy being used by construction processes in your country is renewable?

The responses from the three governmental organizations to this question are shown in Figure 48. The point value awarded to this question is as follows:
Point awarded = \( \sum \text{ (Percentage of responses for a range X Point associated with the range)} \)

\[
= \{(0\%)X0\} + \{(0\%)X0.25\} + \{(100\%)X0.5\} + \{(0\%)X0.75\} + \{(0\%)X1\} = 0.5
\]

**Figure 47.** Distribution of Answers at Government Level for Percentage of Potable Water Used in Construction Processes
10. Does the government offer incentives for use of sustainable construction techniques?

As per the responses to this question the percentage of “Yes” is zero. Therefore, the point value allocated to this question is also calculated as zero as per Table 8.

11. Has the government established specialized organizations to enforce sustainability practices in construction process? If the answer is "Yes", how many?

Based on the responses received, the government of Afghanistan does not have any organization to enforce sustainable practices in construction industry. The distribution of responses is shown in Figure 49. The point value awarded to this question is calculated as follows:

Point awarded = Σ (Percentage of responses for a range X Point associated with the range) = {[(100%)X0]+[(0%)X0.25]+[(0%)X0.5]+[(0%)X0.75]+[(0%)X1]}=0

Figure 48. Distribution of Responses on Use of Renewable Energy by Government Organizations
Figure 49. Distribution of Responses for Sustainability Enforcement Question

Figure 50 shows the rating of indicators related to sustainability at the government level for Afghanistan. In this rating, the highest rated indicator was use of local materials followed by non-potable water usage. Safety is rated considerably lower at the government level than in project and company levels and two of the indicators related to sustainability goals and enforcement received scores of zero.
Figure 50. Rating of Questions Related to the Government Level for Afghanistan

Calculation of the Sub-Indices of CPSI for Afghanistan

In previous sections, the questions related to project, company and government levels were rated and presented. Having analyzed those questions, in this section the three sub-indices of CPSI for Afghanistan are calculated.

The sub-indices are calculated in Table 10. The method of calculation was explained in detail in chapter 3. In this table the scores of questions are used to obtain the mean rating of indicators at three levels of Project, Company and Government. Furthermore, these values are averaged to obtain the mean rating of each indicator. Finally, the values of the sub-indices are obtained by simply averaging the ratings of indicators. For further detail please refer to following table.
Table 10. Values of Sub-Indices and Rating of Indicators at Three Levels.

<table>
<thead>
<tr>
<th>Sub-Index</th>
<th>Indicators</th>
<th>Mean Rating of Indicator= (Project+Company+Government)/3</th>
<th>Rating of Indicators at</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Safety</td>
<td>0.53</td>
<td>Project Level 0.75</td>
</tr>
<tr>
<td></td>
<td>Strategic Goals</td>
<td>0.00</td>
<td>Company Level 0.67</td>
</tr>
<tr>
<td></td>
<td>Sustainability Enforcement</td>
<td>0.00</td>
<td>Government Level 0.17</td>
</tr>
<tr>
<td>Environmental</td>
<td>Sustainable Materials</td>
<td>0.12</td>
<td>Project Level 0.04</td>
</tr>
<tr>
<td></td>
<td>CO2 Emissions</td>
<td>0.13</td>
<td>Company Level 0.06</td>
</tr>
<tr>
<td></td>
<td>Water Usage</td>
<td>0.44</td>
<td>Government Level 0.25</td>
</tr>
<tr>
<td></td>
<td>Renewable Energy</td>
<td>0.29</td>
<td>Project Level 0.25</td>
</tr>
<tr>
<td></td>
<td>Use of Local Materials</td>
<td>0.52</td>
<td>Company Level 0.47</td>
</tr>
<tr>
<td></td>
<td>Incentives</td>
<td>0.00</td>
<td>Government Level 0.52</td>
</tr>
</tbody>
</table>

Table 10 shows the values of economic, environmental and social sub-indices. It also includes the mean rating of indicators obtained by answering the questions at project, company and government levels for Afghanistan.

Safety is the indicator with the highest rating followed by use of local materials and water usage in construction. Strategic goals and sustainability enforcement are the indicators with mean ratings of zero, indicating that the stakeholders of construction industry in Afghanistan does not have any strategic goals to involve sustainability in construction processes and that sustainable construction practices are not enforced by any organizations in the country.

The values for incentives is also zero, indicating that there are no incentives and motivations provided for stakeholders of a construction project to implement sustainable construction techniques during the construction process.
As shown in Table 10 the values of social, environmental and economic sub-indices are 0.18, 0.24 and 0.26, respectively. A graphical presentation of the rating of the indicators is shown below. In this Figure 51, the mean values of the indicators are illustrated and their distance from being extremely sustainable is shown.

![Graphical Representation of Indicator's Value](image)

**Figure 51.** A Graphical Representation of Indicators’ Values for Afghanistan CPSI.

**Aggregation of the Sub-Indices into CPSI**

In the previous section, the values of economic, environmental and social sub-indices were calculated. In this section they are aggregated to give the overall value of Afghanistan’s CPSI. The value of CPSI for Afghanistan is obtained by simply averaging the values of the three sub-indices calculated in previous section.
Afghanistan’s CPSI = average of economic, environmental and social sub-indices = 
\[(0.18+0.24+0.26)/3 = 0.23\].

According to Table 9, the construction industry of Afghanistan belongs to the second level of CPSI performance model, which is unsustainable. It indicates that overall the construction process in Afghanistan is not sustainable. Safety can be much improved as the number of work-related injuries and fatalities are high. The stakeholders of the construction industry (government and construction firms) do not have strategic goals for implementation of sustainability in construction. Use of sustainable materials, local materials, renewable energy and non-potable water in construction is low. Sustainability enforcement is very weak and there are no incentives offered by the government or other stakeholders of the industry for implementation of sustainable techniques.

In addition, the stakeholders of Afghanistan’s construction are unaware of the importance of adopting sustainability in the construction industry of the country and do not issue any regulations or rules that force its implementation.

**Calculating the CPSI for United States**

The market share of United States construction industry is around 10 percent, which makes it the second largest construction market in the world. Based on the bureau of labor statistics of the United States, the construction industry in this country had an average employment of 6.14 million in year 2014. According to the United States census bureau the value of construction in 2014 was around one trillion dollars. This organization also gives the number of construction companies in this country to be around 729,345 construction firms.
This section focuses on calculation of the CPSI for United States in order to measure the level of its sustainability.

**Data Collection**

In this section the method of data collection, population, sampling frame, sample size and assumptions related to data collection are explained in detail.

The method of data collection for calculation of CPSI for United States was the same as Afghanistan; e-surveys. For company and project levels data, the questionnaires developed in previous chapter were sent to projects and companies in United States via email. Follow up phone calls were conducted by the researcher to the participants to inform them about the research, its objective, and the process of answering the questions for this study.

The populations for company and project levels are construction companies and construction projects in United States, respectively. Since, getting a comprehensive list of construction projects for United States is almost impossible, the construction companies were chosen to be the population for both of the levels. Same procedure used for Afghanistan was employed for selection of project level data for United States too. After a construction firm was chosen to answer the questions for project level, the firm was asked to present the list of their projects. Having the list of construction projects for a firm one project was randomly chosen from the list and the firm was asked to answer the questionnaire on that project.

The 2014 list of top 400 contractors by ENR (Engineering News-Record) was used as the sampling frame for company and project levels. Because having the list of 729,345 construction companies and randomly selecting construction firms out of it was a tremendously difficult task to do, therefore this list was accepted as the sampling frame for
this study.

Sample size was calculated using the Cochran formula with the following assumptions:

- The sampling design is assumed to be simple random sampling
- 10% level of precision
- 90% confidence level
- Large population size

\[
n_0 = \frac{z^2 pq}{e^2} = \frac{1.645^2 (0.5)(0.5)}{(0.1)^2} = 68
\]

The sample size for each of company and project levels is 68. Seventy (70) construction companies were randomly selected from the list of 400 top contractors to participate in this study for the company level and 70 construction companies were randomly selected for project level. The first group was contacted and asked to answer the questions related to the company level and the second group was contacted and asked to send their ongoing project lists to the researcher, so that he randomly select a project from the list for data collection.

**Project and Company Levels**

The questionnaires related to project and company levels were sent out to 140 construction firms. Of the 70 construction companies contacted for project level questionnaire only 5 (7 %) answered to the questionnaires and of the 70 construction companies contacted for company level questionnaire only 2 (3 %) answered to the questionnaire.
The CPSI was not calculated for the United States, because the level of responses received was very low. The small number of responses received does not represent the project and company levels of construction industry in United States; therefore the index was not calculated for this country.

In Chapter 4 the CPSI of Afghanistan is calculated with an effort on calculating the CPSI for United States was also mentioned. In chapter 5 a brief conclusion of the thesis along with the limitations and future research opportunities are presented.
CHAPTER 5: CONCLUSION

This last chapter presents a summary of the research study, a review of the research objectives, and research outputs and conclusions. Finally, the chapter concludes with the recommendations for future research.

The aim of this research has been to define construction process sustainability, determine the indicators that can be used in a Construction Process Sustainability Index (CPSI), and develop a framework for the CPSI, which will help with the assessment of construction sustainability in a country.

Based on a rigorous review of literature, sustainable construction process was defined to mean development meeting the needs of the present without compromising the ability of future generations to meet their own. It takes into consideration minimizing the negative impacts of construction on the environment, society, and economy by raising sustainability awareness, having strategic goals for involving sustainability in the industry, enforcement of rules and regulations pertaining to sustainability, enhancing safety, increasing use of sustainable materials, local materials, incentives, in the construction industry while minimizing costs, emissions, water usage, and use of non-renewable energy.

Potential indicators were identified based on their suitability for such an index and a panel of experts was established for validation of the indicators. Nine indicators were chosen out of fourteen and used in the development and calculation of the CPSI. These indicators pertain to safety, sustainability strategic goals, sustainability enforcement, water usage, renewable energy, sustainable materials, CO\(_2\) emissions, local materials and incentives. In
addition, a hierarchy scheme, framework and performance model were developed for this index.

The hierarchy scheme shows that the CPSI includes three sub-indices related to economic, environmental and social aspects for the government, company and project levels. The framework defines several steps to be taken in order to calculate the CPSI for a country. The performance model was developed to help with the interpretation of the value received from the CPSI and can be used as a benchmark to assess a country’s construction sustainability. It is divided into five descriptive categories consisting of extremely sustainable, sustainable, satisfactory, unsustainable and extremely unsustainable.

Furthermore, a real application of the framework for calculation of CPSI, and performance model is conducted to show how they can be implemented. The CPSI of Afghanistan is calculated and an effort was made to calculate the CPSI for United States too, but was not successful due to the low number of responses received at the project and company levels. The input data used in the calculation of Afghanistan’s CPSI was gathered by conducting surveys on the construction companies, the government, and the projects in Afghanistan. The study found that the CPSI of Afghanistan is equal to 0.23, which means that Afghanistan can be categorized as “Unsustainable”. The best sustainability performance is exhibited by the economical sub-index, then by the environmental, and the social sub-index was determined to be the least effective.

The CPSI value of Afghanistan indicated that the stakeholders of construction (government and construction companies) in Afghanistan need to define proper strategic goals to involve sustainability in their operations, and establish organizations enforcing
sustainability in the construction processes. In addition, incentives should be offered at different stages of the construction process to encourage stakeholders to implement sustainable practices and techniques. Furthermore, use of local materials, renewable energy, sustainable materials and non-potable water should be increased.

**Research Contributions**

In this research, indicators of sustainable construction processes, a sustainability performance model and a comprehensive framework for calculation of a construction process sustainability index has been developed which assists construction industry stakeholders (government, construction firms, and other related organizations) in quantifying the level of their construction process sustainability and accordingly take actions for improving it, if necessary.

Moreover it can be used to increase the awareness of government and construction firm employees about the extent of sustainability of their own construction processes. The CPSI for a country can also be used as a policy instrument for all government levels. For instance, indicators can be assigned to a specific organization within the government for development of it towards sustainability. Regular monitoring of progress will help to reach the goals set by the government.

Another important use of the CPSI can be a relative comparison of the scores of different countries for the purpose of learning from each other and to inspire each other to make progress on the road toward more sustainable construction processes.
**Future Research and Recommendations**

The research framework could be expanded in the future to provide more detail to the CPSI. Simple averaging was used in calculation of CPSI, but in future research, different weights can be assigned to different questions, indicators, levels and sub-indices based on their importance and relevance.

In addition, questions used at the different levels (project, company and government) can be validated using the same method that was used for validation of indicators. Therefore, validation of questions is recommended in future research. Moreover, the method of measurement for indicators can be expanded by taking into consideration the different aspects of each indicator. The research only considered certain important aspects of each indicator but could have used other measures as well. For example safety was measured by the number of fatalities and injuries. However, considering lost time and near miss incidents could have improved the accuracy of the CPSI.
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