LEAN AND SUSTAINABILITY MECHANISM FOR INFRASTRUCTURE PROJECTS DELIVERY IN SOUTH AFRICA

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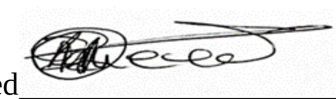
DECLARATION OF ORIGINAL AUTHORSHIP

I, **RASHEED BABATUNDE ISA** on this day 2nd of July 2017 declare that:

- The work in this thesis is my personal effort;
- Sources used or referred to have been acknowledged; and
- The thesis has not been submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognised educational institution previously.

Signed____________________

Rasheed Babatunde ISA

DEDICATION

This study is dedicated to

God Almighty for making this possible.

“And which of your Lord’s favour can you deny” – Alhamdulillah.

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LIST OF PUBLICATIONS

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Isa, R.B., and Emuze, F.A. (2016). Lean Sustainable Indices: A case for South African Public Infrastructure Sector. *Proceedings of the CIB World Building Congress*, Volume IV, Tampere, Finland, 545-557.	**3, 5, 6**
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ABSTRACT

Achieving a resilient and sustainable building infrastructure is essential for continuous economic growth, international competitiveness, public health and overall quality of life, especially in developing countries such as South Africa. Calls for the use of innovative practices for changing the unsustainable, 'Business As Usual' (BAU) model of contemporary building delivery have been on the increase. In its contribution towards resolving this imbroglio, this study aimed at proposing a mechanism for operationalizing the integrated use of lean and sustainability ethos for sustainable infrastructure delivery in South Africa. In this study that was domiciled in a pragmatic paradigm, a case study research design was adopted. Five purposively selected cases within Gauteng province of South Africa were utilized. The perceptions and working experience of government agencies, developer/clients, consultants, project managers, facility managers, users, academia, general contractors and subcontractors in the selected cases were elicited. The quantitative data was statistically analyzed whilst the qualitative data was transcribed, coded and thematically analyzed. The emergent findings were discussed in line with other sources to give insight into the development of the mechanism – the lean-sustainability mechanism for infrastructure (LSMI) delivery. The results of the study suggested that attaining efficiency in energy, material and water resources forms the major features of sustainable construction in the industry. The major drivers for the lean-sustainability paradigm include: drive to gain an industry competitiveness edge, and the market environment that now requires higher efficiency and effectiveness for success, whereas the one significant barrier to the lean-sustainability paradigm remains the sustainability premium in South Africa. An expert survey was used to test the LSMI's robustness. It was discovered that the mechanism possessed adequate robustness to engender transformation in the sector. The evaluation validates the LSMI ability to provide an adaptive form of governance needed for building infrastructure delivery systems, in response to the gradual deterioration of the global socio-ecological stability. The developed mechanism provides a transformational route for achieving building infrastructure sustainability. The mechanism also provides a new way of thinking about building infrastructure delivery from a sustainability perspective.

Keywords – Construction, Developing countries, Infrastructure, Lean, South Africa Sustainability, Transformation.

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ABBREVIATIONS

3Cs	Collaboration, Coordination and Communication
4R + D	Reduce, Recycle, Reuse, Report, and Dispose
ANSI	American National Standards Institute
BAU	Business as Usual
BIM	Building Information Management
BRE	Building Research Establishment
BREEAM	BRE Environmental Assessment Method
CEEQUAL	Civil Engineering Environmental Quality Assessment and Award Scheme
CIB	International Council for Building
Cidb	Construction Industry Development Board
CII	Construction Industry Institute
CIMO	Context-Intervention-Mechanism-Outcome
CIRIA	Construction Industry Research Information Association
CLAW	Construction Lean Awareness Workshop
CP	Clean Production
CPD	Continuous Professional Development
CPM	Construction Project Manager
CSR	Corporate Social Responsibility
D&B	Design and Build
DEFRA	Department for Environment, Food and Rural Affairs
FDI	Foreign Direct Investments
FM	Facility Management
GBCSA	Green Building Councils South Africa
GDP	Gross Domestic Product
GHGs	Greenhouse gases
GRI	Global Reporting Initiative
GSN	Green Supplier Network
GVSM	Green Value Stream Mapping

H&S	Health and Safety
HICs	High-Income Countries
HSE	Health, Safety and Environment
HVAC	Heating, Ventilation and Air Conditioning
ICE	Institution of Civil Engineers
ICIDA	Infrastructure Development in Africa
ICT	Information and Communication Technology
IEA	International Energy Agency
IFOA	Integrated Form of Agreement
IGLC	International Group for Lean Construction
IPD	Integrated Project Delivery/Design
ISO	International Standardization Organization
IUCN	International Union for the Conservation of Nature
JIT	Just-in-time
KIVP	Knowledge Innovation Visible Planning
KPI	Key Performance Indices
LC	Lean Construction
LCA	Life Cycle Assessment
LCI	Lean Construction Institute
LCIA	Life Cycle Impact Assessment
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
LPS	Last Planner System
L-S	Lean-Sustainability
LSC	Lean Sustainable Construction
LSC	Lean-Sustainability Construction
LSMI	Lean-Sustainability Mechanism for Infrastructure
MA	Millennium Ecosystem Assessment
MIS	Mean Item Score
NVAAs	Non-Value Added Activities

ODP	Ozone Depleting Substance
PSR	Pressure-State-Response
QS	Quantity Surveyor
SASBE	Smart and Sustainable Built Environment
SC	Sustainable Construction
SCM	Supply Chain Management
SDGs	Sustainable Development Goals
SM	Sustainability Management
TBL	Triple bottom line
TIMWOOD	Transport, Inventory, Motion, Waiting, Over-Processing, Over-Production and Defects
TMID	Transformation Model for Infrastructure Development
ToC	Theory of Change
TPM	Transformational Process Management
TPS	Toyota Production System
TQC	Total Quality Control
UK	United Kingdom
UN	United Nations
UNCSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environmental program
UNEP	United Nations Environmental Programme
USA	United State of America
USGBC	US Green Building Council
VM	Value Management
VRV	Variable Refrigerant Volume
VSM	Value Stream Mapping
WCED	World Commission on Environment and Development
WECD	World Commission on Environment and Development

DEFINITION OF TERMS

Green building

Green building is "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building" (EPA, 2016: 1).

Lean construction

Lean construction is "the holistic pursuit of continuous improvement with a goal to deliver customer value, while minimizing waste and maximizing value to the customer throughout a project's delivery process and life cycle, and while respecting all stakeholders in the value chain" (Rybkowski, Abdelhamid, & Forbes, 2013: 84).

Lean management

Lean management is "a process improvement methodology built on Toyota Production System (TPS) that focuses on reducing waste and increasing benefits" (Thorhallsdottir, 2016: 326)

Lean production

Lean production is "a method that levers on a complex system of socio-technical practices to enhance manufacturing performance through waste elimination and continuous improvement of production processes" (Boscari, Danese, & Romano, 2016: 53)

Lean thinking

Lean thinking is "a system of learning to deliver exactly what the customer wants, right first time in every respect and doing that and nothing more, or free-perfect-now" (Terry & Smith, 2011: 36).

Public infrastructure

Public infrastructure projects are the products of construction industry (plans, designs, builds, maintain), which enable, support and facilitate production, as well as the social facilities that enhance the quality of life. The quantum of these projects (housing, transportations, communications, power, water, security, education, health, hospitalities and services) in terms of quantity and quality defines the well-being and the standard of living of any nation (Ofori, 2012c: 86).

Sustainable construction

Sustainable construction is the adoption of sustainable thinking, practices and sustainable development principles to the realization of construction sector objectives of delivering sustainable infrastructure (Ogunbiyi, Oladapo, & Goulding, 2013: 82).

Sustainable development

Sustainable development involves creating an infrastructure of material and energy use in communities that meet human needs while maintaining a wide array of metrics of environmental quality, human health, social equity, and economic vitality (Crawford-Brown, 2012: 23).

1.0 DIRECTION OF THE RESEARCH

1.1 Introduction

Stakeholders in the construction sector worldwide are placing a much stronger emphasis on the importance of attaining sustainability within the industry. Environmental concerns that tend to be localised in time past are now a major issue in the global arena. In the last decade, the world has observed repeated signals of serious impending changes in global environment that can and will affect the built environment (Hopwood, Mellor & O'Brien, 2005: 39). These changes have expanded from a question of science to one of global politics, economics, sociology, ethical values, and technological policy issues (Hotta, 2012: 210; Townsend, 2013: 363).

According to Yao (2013: 20), "…. as we head into an uncertain future with resource depletions and energy security issues, striving to achieve sustainable urban environments becomes a prerequisite if mankind is to thrive on Earth". The ever-increasing concentration of greenhouse gases (GHGs) caused by continuous depletion of natural habitats has been in the forefront of national discussions (McMichael *et al*., 2006 as cited in Ghosh *et al*., 2014: 133). The Kyoto Protocol, an international agreement in 1997, was as a result of global environmental concerns that have the obligation of reducing GHG emissions by industrialized countries by the year 2012 (Cheng *et al.*, 2008: 1). The target of the Kyoto Protocol was, however, not realised by 2012 for various reasons. Some of the reasons include: the imbalance in the carbon accounting structure, inadequate framework to operationalize the set goals and lack of adherence to the commitment period by the stakeholders (Schlamadinger, *et al*., 2007: 296).

Du Plessis *et al.* (2002: 14) and Cheng *et al.* (2008: 1) report that an estimated 50% of the world energy need and about 60% of global carbon emissions are due to material processing and usage, maintaining thermal comfort and communication within the built environment. This fact has a strong correlation with global climate change and hinders sustainable development in the built environment. It also has a major dimension for developing countries such as South Africa that is still grappling with urbanization and basic infrastructure development in the face of rapid population growth (Du Plessis *et al*., 2002: 14). In this perspective, achieving sustainable development in developing countries requires organizations to be proactive with a new approach to business. This approach can be new processes, new materials, products, technologies, and new business models so as to ensure that things are done differently (Campos *et al*., 2012: 61; Emuze & Smallwood, 2013: 854).

Sustainable development has been a very controversial but interesting topic, defined in many ways, depending on the field of interest. However, the most frequently quoted definition is from the Brundtland report for the World Commission on Environment and Development (WECD, 1987: 43): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The definition is often described as a triad that attempts to balance environmental, economic and social goals. The needs concept is paramount to South African society that is still grappling with meeting basic infrastructures and rapid urbanization, to which overriding priority should be given – more so, because of the challenges posed by the state of technology and social organization of the regional environment's ability to meet present and future needs (Corfe, 2013: 1; Du Plessis *et al*., 2002: 1).

The construction sector has been probing for answers to the question of how to attain sustainability (Vieira & Cachadinha, 2011: 611). Traditionally, the sector is a massive consumer of raw material and, by nature, a large-scale waste producer (Miller & Ip, 2013: 342). This unsustainable level of waste generation is a concern to the stakeholders in the built environment, as it can hinder the process of creating value. In creating value, a holistic approach must evolve, which will cut out wastes, thereby making the limited resources work effectively, and a more sustainable and a more balanced ecosystem could be achieved.

Lean concept has generally been discussed in the context of waste reduction and waste elimination to create value (Novak, 2012: 51). Terry and Smith (2011: 47) see it as "a way of thinking and delivering value, innovation and growth by: doing more with less – less human effort, less equipment, less materials, less time and less space to align efforts closer to meet customers value expectations." The five principles of lean – value, value stream, flow, pull and perfection – are useful for lean practice in eliminating waste and maximizing efficiency (Corfe, 2013: 3). Huovila and Koskela (1998: 8) opine that the removal of waste (process and material), which leads to value creation in terms of meeting the customer needs, is the major contributions of lean construction to sustainable development.

However, lean and sustainability philosophy have been pursued as separate and parallel initiatives within the construction sector (Ahuja, Sawhney & Arif, 2014: 123). There is therefore a pressing need to integrate the two parallel thinking into one to produce more benefits for the industry. Researchers have examined the paradigm of 'lean sustainable construction' that could leads to sustainable development (Novak, 2012; 51; Campos *et al*., 2012: 61; Emuze & Smallwood, 2013; 853; Corfe, 2013: 1) within the field of construction management. The conclusion shows a significant overlap between the two approaches and seems to have a common goal of 'doing no further harm' to the environment. It on this premise that the United Kingdom (UK) Government highlighted the need for synergy between lean and sustainability in the progress report by HM Government (2009):

> *"… there is growing recognition that 'Lean' thinking, with its focus on delivering real value whilst simultaneously achieving improved competitiveness of the sector and delivering many sustainability objectives, now needs to be considered as a key instrument for the delivery of objectives set out in the Strategy for Sustainable Construction. It follows that Lean thinking should form a central part of organizations' sustainability strategic" (as cited in Corfe, 2013: 2).*

This cannot be truer for developing economies in Sub-Saharan Africa. It is the synergy between these two philosophies that will be beneficial to the attainment of ecosystem equilibrium needed for sustainable development. The methodology for achieving such milestone has not been fully developed, reported or empirically examined (Novak, 2012: 51; Emuze & Smallwood, 2013: 861; Ahuja, Sawhney & Arif, 2014: 123). Therefore, there is an apparent gap regarding the evolution of the mechanism required for promoting sustainable development through the use of lean construction.

1.2 The South African Construction Sector

Construction is a major contributor to the development process in developed and developing countries (Isa, Jimoh, & Achuenu, 2013: 5). Du Plessis *et al*. (2002: 3) see construction as a "… broad mechanism for the realization of human settlements and the creation of infrastructure that supports development. This includes the extraction and beneficiation of raw materials, the manufacturing of construction materials and components, the construction project cycle from feasibility to deconstruction, and the management and operation of the built environment." It is, however, generally regarded as largely a fragmented industry as a result of discrete activities (design and building process) that require different teams of specialists, suppliers, professionals, agencies and firms that are geographically distributed, which have to pull their expertise together and work in unison in bringing it products into fruition in an integrated process approach that presents its own constraints, challenges and opportunities (Sun & Howard, 2004: 148; Ofori, 2012a: 3).

Construction activities globally have been fraught with constraints that require a holistic review. The state of the construction sector in South Africa is not indifferent to the levels of development in the developing economies, where high levels of human resources required for planning, designing, constructing and maintaining of complex projects (such as airports, factories, harbours, hotels, hospitals, ports, power generation and distribution, water purification and distribution installations) conceived by the public sector are insufficient (Mbamali & Okotie, 2012: 144). Ofori (2012b: 4) draws from the work of the United Nations Industrial Development Organization (UNIDO, 1993) that highlighted the following constraints in developing nations construction industries: (i) inability to meet demand as a result of poor organization structure; (ii) lack of stable market for proper risk analysis and capacity building; (iii) low ICT and other advanced technology integration; (iv) skills development that hinders the industry competitiveness in the face of globalization; (v) imported plant and equipment; (vi) limited access to finance; and (vii) poor performance on project indices. These are examples of the state of developing countries' construction industry that are still a major concern.

1.3 Sustainable Development in South Africa

The importance of sustainable development is gaining wider recognition around the globe in the wake of increasing economic, social and environmental demands. Contrary to popular opinion, sustainable development is not merely a 'going concern', but rather, it is a development worth pursuing in order to achieve the state of sustainability, where development is within the limits of a balanced ecosystem. It is not the goal, but the process, subject to continuous improvement, of maintaining a dynamic balance between the demands of people for equity, prosperity and quality of life within what is ecologically possible (Du Plessis *et al.*, 2002: 6). Development should thus be seen in the light of progress through improvement, evolution and the quest for wisdom rather than growth in terms of expansion and acquiring of knowledge (Finch & Zhang, 2013: 306).

Developing economies such as South Africa consider the need for basic developmental challenges such as economic growth, infrastructural development, water scarcity, health and safety, and food security as the context in which sustainable development agenda should be anchored, whilst the developed nations prefer the adjustment of the economic reality in order to maintain balance between social demands and economic growth, while protecting local ecologies and reducing the negative impact of growth on the global environment (Karim, 2011: 1). This lack of parity on the sustainability focus between developed and developing countries led to the inauguration of Agenda 21 for developing nations by the United Nations in the year 2000, with the sole aim of a better understanding of the challenges of sustainable construction in developing countries, in order to formulate a development agenda for research and strategy for construction sectors toward physical development (Du Plessis *et al*., 2002: 1).

Karim (2011: 3) and Du Plessis (2005: 3), however, noted that the attainment of a regional approach to sustainability in Sub-Saharan Africa (particularly South Africa) as a whole is unfortunately limited by factors, which are not limited to:

1) heterogeneous nature of the region: different countries with different challenges at different stages of development;
2) lack of financial incentives;
3) lack of enforceable energy efficiency requirement;
4) lack of sufficient sustainable design knowledge among professionals;
5) varying climatic conditions: hot and arid, to summer and winter, and
6) different economic models: adoption of different concepts and codes to development.

Achieving sustainability can be a common goal in developing economies, although the approach and concept could differ. Challenges notwithstanding, the developing interest in sustainability in South Africa is notable as the country is taking the leading role in the region. South Africa is piloting the inauguration of a national charter for sustainable development and the environment, Ministries of the Environment are being set up, and non-governmental organizations and professional bodies around the region are establishing green building councils (GBCSA). Also, the efforts of the United Nations Environmental Program (UNEP) has always been a significant push for promoting clean production (CP), sustainable consumption, and green industry strategies in developing countries and economies in transition (Yi & Hwa, 2012: 534).

1.4 Lean Construction in South Africa

The industry that is highly labour-intensive and interdisciplinary in nature, mostly relying on a traditional construction approach that is still based on old production systems, which are burdened with non-value added activities (NVAAs) in the supply chain. Such NVAAs include reworks and waiting time, to mention a few. These NVAAs account for construction costs and hinder value creation in developing nations. This problem is particularly crucial for a region that is highly dependent on the developed nations for its supplies in terms of material, expertise and equipment, where minor mistakes in invoicing orders can lead to time overrun and cost impacts (Forbes & Ahmed, 2004: 1).

Davis, Miles, Riley, and Pan (2010: 705) affirm that efforts at improving the construction supply chain management (SCM) have been on-going for some time, with particular focus on making supply chain 'leaner' by maximizing value and delivering customers' satisfaction (lean thinking). Most public projects, especially civil works are *in situ* and their nature make it difficult to identify the generic production steps that are adding value. Also, the mode of their awards by government, under public scrutiny for quick return, tends to divert contractors' focus away from planning and optimizing the on-site construction (Simonsson, Björnfot, Erikshammar & Olofsson, 2012: 36). Lean concept is literarily set out to maximize value, minimize waste and pursue perfection in the construction industry with specific techniques in a project delivery process (Lean Construction Institute (LCI), 2014: 1).

In the context of both construction and manufacturing, Corfe (2013: 6) use the acronym TIMWOOD to represent the seven primary wastes categories: transport, inventory, motion, waiting (delays), over-processing, over-production and defects (errors). Although this concept is still new in African construction, previous studies show that adopting the concept holds a lot of benefits for the region amidst some developmental challenges/resistance (Davis *et al*., 2010: 706; Fernandez-Solis *et al.*, 2013: 356; Emuze & Ungerer, 2014: 1123). Andersen, Belay and Amdahl

Seim (2012: 137) also report positive outcomes through a case study that was conducted in Norway. The positive outcomes pertain to reduced project time and increased schedule adherence despite increase in complexity, reduced costs, improved job quality, better health, safety and environment (HSE) performance and better cooperation among operators in a hospital development project.

Despite all these potential benefits, the penetration of lean in South African construction appears to be rather slow. Limited lean features can be noticed in construction practices, but a further query might even suggest an unconscious act. Emuze and Ungerer (2014) assert in their South African construction study that this resistance is based on uncertainties, which include the lack of awareness; the concept and real value that could come with the change; trust and misunderstanding: when workers are not in agreement with the idea of change; and dated craft.

Emuze and Ungerer (2014: 1129) are further of the opinion that a pathway for lean thinking that focuses on: awareness, need recognition, business strategy, training and education for workers, can have the required changes in "work methods and decision processes" for the good of organizational goal attainment in South Africa. This pathway could be the way to follow for developing nations in order to be able to create value in the global competitive world.

1.5 Problem Formulation

The methods used by most stakeholders for projects procurement makes them struggle to adapt to sustainable requirement and are susceptible to process waste (Lapmski, Horman, & Riley, 2006: 1083). Whilst operational savings can result in quick break-even in high performance projects, additional costs resulting from this process waste hinder the progress of the construction industry toward sustainable development. A lean construction approach is renowned for its ability to reduce material and process waste in complex development and production environments (Vieira & Cachadinha, 2011: 612).

Achieving sustainability-based value – economic, environmental, social, cultural and historic – is much more than just waste reduction, and lean construction needs to identify these as critical variables in sustainable construction (Höök, 2006: 586; Bae & Kim, 2007: 315). Salvatierra-Garrido and Pasquire, (2011: 9) also contend that sustainability is not only about smart use of natural resources or simply "do no further harm to bio-diversity", but can "improve profitability and facilitate the relationship with stakeholders". This interwoven nature of the two philosophies exposes the synergy that can be created within lean construction and sustainable development for greater benefits for the industry.

Researchers such as Koskela and Tommelein (2009: 299), Salvatierra-Garrido and Pasquire (2011: 1), Vieira and Cachadinha (2011: 611), Novak (2012: 51), Corfe (2013: 978), Emuze and Smallwood (2013: 853), and Ahuja, Sawhney and Arif, (2014: 123), have worked on the need to either integrate lean with sustainability or use lean as catalyst for reaching sustainable development. Koskela and Tommelein (2009: 299) argue that sustainability assessment tools currently in use are based on the economic theory of "end is given", which considered only input waste in their evaluation without recourse for process waste as comprehensively looked into in lean theory and therefore, inadequate. Emuze and Smallwood (2013: 853) demonstrated how health and safety (H&S) can be the focus for integrating lean and sustainability. Ahuja *et al*. (2014: 123) used the centrality of building information management (BIM) as a means of integrating the two concepts. However, the seemingly general consensus is that there is need for more comprehensive work on methodologies and frameworks to be scientifically developed and/or empirically verified for this synergy in order to fully harness the benefits therein.

Therefore, there is need for scientifically based mechanisms for the integration of the lean concept as a catalyst for sustainable development. These past studies motivate for asking the central question for this research, which is: How can lean construction inform sustainability in South African building delivery, so that the goals of creating value that meet the requirements of sustainable development can be realised?

1.6 Statement of the Problem

The lack of empirical framework for the integration of the lean construction concept as a catalyst for sustainability hinders the creation of project value and continuous improvement in South Africa. To resolve the aforesaid problem, the principal question has been broken down to the following sub-questions:

1. How is value created with lean in construction?
2. How is value created with sustainability in construction?

3. What are the criteria for enacting synergy between lean and sustainability?
4. What is the mechanism for driving lean and sustainability in construction?
5. How can such mechanism improve construction?

1.7 Aim and Objectives of the Study

The aim of this research work is to propose a mechanism for operationalizing the integration of lean and sustainability in favour of sustainable development in the built environment. This lean-sustainable construction pertains to meeting social, economic, and environmental indices that would bring competiveness and create value in public projects. Based on the above premise, the specific objectives of the study are to:

1. Evaluate the impact of lean on construction through critical examination of its features, processes and drivers.
2. Evaluate the effect of sustainability on construction through critical examination of its features, processes and drivers.
3. Determine the common themes between lean and sustainability in construction to enact synergy between the two concepts.
4. Establish context-specific mechanisms for operationalizing the integration of lean and sustainability in construction.
5. Test the developed lean and sustainability mechanism for infrastructure projects delivery.

1.8 Assumptions Pertaining to the Study

Assumptions are referred to as conditions that are taken for granted without which the research work would not be useful, to be assumed to apply and to be known and accepted widely (Yin, 2009: 25; Fellows & Liu, 2008: 61). Therefore, this research assumed that:

- Construction is a fragmented industry with multiple stakeholders and discrete activities;

- Responses received from the project teams represent the practice for performance in the industry;
- Efficiency and effectiveness are important in a production environment;
- Lean construction is an efficiency-driven philosophy, and
- Sustainability is also an efficiency-driven philosophy.

1.9 Working Hypothesis

The postulated working hypothesis for this research is that: the lack of empirical framework for integrating lean concept as a catalyst for sustainability hinders value creation in building infrastructure in South Africa.

1.10 Rationale for the Study

There is the need to positively alter the approach to sustainable development in the face of growing concerns about the need for adaptation to climate change and negotiated ecosystem services. South Africa – ill-prepared for environmental challenges, while still struggling to meet demands for an improved standard of living, coupled with rapid urbanization and population increase – requires a knowledge-based strategy towards sound decision-making in project planning and execution (Karim, 2011: 2-3). Such informed strategies/policies could engender sustainable development and ensure enhanced human comfort.

The significance of the study is to extend the existing Body of Knowledge in the area of integrative perspective on lean construction and sustainability. Through critical examination and analysis of relevant case studies, the research evolved a mechanism for promoting lean and sustainable construction in South Africa. The evolution of the mechanism focuses on tools that support the elimination of wastes in work processes, work methods, work culture and materials issues.

It is expected that the evaluation of the lean-sustainability concept would contribute to learning, teaching, research and practice in the construction industry. The results of this research effort would also deepen the debate around lean sustainable construction (LSC).

It is also anticipated that the framework from the study would create needed buy-in into the integration of lean and sustainability concepts and tools in projects. The research also promotes sustainable development through:

- energy and resource efficiency;
- industry competitiveness;
- minimization of emissions that impact global warming negatively;
- cost-effectiveness;
- waste reduction;
- improving the health and wellbeing of the populace;
- creating a harmonious working relationship through collaboration between stakeholders, and
- maximization of requirements of clients, contractors and users alike.

1.11 The Scope of the Research

The research centred on the mechanism for lean and sustainability in public sector construction and creating a mechanism for its conceptualization for the benefit of the South African construction industry. The study focused on infrastructure projects. Non-residential building projects were the primary concern of the study. The study was conducted among clients, contractors and subcontractors, professionals, workers and users based in South Africa and experts in the subject area.

1.12 The Outline of the Thesis

Chapter 1: Introduces the background to the study, the problem statement, the research question and sub-questions. Within this chapter, the scope of the study and assumptions for the study have been discussed. The aims and objectives of the study and its justification were also highlighted.

Chapter 2: Presents the lean and sustainability discourse. The focus is on the concepts of lean and sustainability and their features, processes, barriers, drivers, and the need for change towards sustainable development in South Africa.

Chapter 3: The theoretical and conceptual framework of the study are presented in the chapter. An attempt of creating common themes between the two concepts has been made. Specifically, the transformational process model was explored to conceptualize the study.

Chapter 4: Presents the philosophical underpinning of the research, the various paradigm, research methodology, case-based method and case selection, design of interview and survey protocols, and how the data were collected and treated.

Chapter 5: Focuses on presentation of the findings and data analysis of the research study. Answers are offered to research questions in the chapter.

Chapter 6: Illustrates the process towards the development and evaluation of the proposed mechanism and hence presents the route map to the mechanism.

Chapter 7: Conclusions and recommendations pertaining to the study, contribution to knowledge and areas for further research are the focus of this chapter.

1.13 Summary

Based on the aforementioned, the chapter has put the study into context. Chapter 1 has demonstrated the gap that exists in infrastructure project delivery and the needs to contribute towards closing the gap. Literature has also shown that the lean-sustainability paradigm is at its infancy and the dearth of research in the area of operationalizing the concept is evidence. To this end, this chapter set the tone for the literature review that examines the lean-sustainability concept in South Africa as they affect infrastructure delivery towards sustainable built environment in Chapter 2.

2.0 LEAN AND SUSTAINABILITY DISCOURSE IN CONSTRUCTION

2.1 Introduction

This chapter covers related review literature regarding concepts of lean and sustainability, its features, processes, and drivers to include the barriers and success factors. It also discusses the common theme between the two concepts and brought forth the related tools, dimensions, scopes, techniques and practices in the realm of lean and sustainable construction. The priorities and needs of lean-sustainable construction are also highlighted in this chapter.

2.2 Lean Construction: the story and main features

Under the leadership of Engineer Taichi Ohno of the Toyota car manufacturing company in the 1950s, the concept of 'lean' was developed as an industry process of eliminating waste (Howell, 1999: 2; Forbes & Ahmed, 2004: 2). The foundations of lean are rooted in the Toyota Production System (TPS), which stands on two pillars that represent continuous improvement and respect for people (Rybkowski, Abdelhamid, & Forbes, 2013: 84). The company strives for waste reduction and/or practically waste elimination, which resonate with Toyota's vision of attaining optimum value-added works with the lowest amount of waste. Waste is seen as non-value-added activities (NVAAs) that in one way or the other consume resources. Such an activity according to lean construction authors (Forbes & Ahmed, 2011: 47-48; Terry & Smith, 2011: 20) could be over-production of unwanted item, waiting time for next activity, unnecessary movement of material and labour, over-processing waste (waste in the work itself), inventory waste, transporting/conveyance of waste, defective good requiring rectification, or good and service not meeting customers' expectations and skills misuse. Ohno also values meeting the unique requirements of a customer at once as a great step towards waste elimination. Thus, working towards waste elimination, he centred on designing a production process that would deliver the required product right away through massive improvements in the supply chain (Suresh, Bashir & Olomolaiye, 2012: 378; Varghese, 2012: 133). Forbes and Ahmed (2011: 51) illustrate an overview of the Toyota Way as presented in Table 2.1.

Table 2.1: An illustration of the Toyota Way

Toyota foundations	Principles
1. Problem solving (Continuous Improvement and Learning)	Continual organizational learning; views the situation first-hand to thoroughly understand it; make decisions slowly by consensus – consider all options: implement rapidly.
2. People and Partners (Respect, Challenge and Grow Them)	Grow leaders who live the philosophy; respect, develop and challenge people and teams. Respect, challenge and help suppliers.
3. Process (Eliminate Waste)	Create process ‘flow’ to reveal problems; use pulls system to avoid over production. level out workflow; stop when there is a quality problem; standardized tasks for continuous, improvement; use visual control – transparency; use only reliable, tested technology.
4. Philosophy (Long-term Thinking)	Base management decisions on a long-term philosophy even at the expense of short-term financial goals.

Source: Forbes and Ahmed (2011: 51)

The work of Koskela (1992) discussed the possibility of adopting the production process in construction and recommended that the construction industry should consider implementing the production process, as inherent in lean production system, to enhance the industry performance. A new approach not based on technology, but rather on the principles of a production philosophy. This new approach is now known as ‘lean construction’. Koskela (1992: 16) and Forbes and Ahmed (2011: 58) note the lean construction evolution through three stages:

1. Tools: such as Kanban and quality circles.
2. A manufacturing method: prefabrication and modulation, automation, information technology to reduce fragmentation.
3. A management philosophy: just-in-time/total quality control (JIT/TQC).

Several works built on this foundation stress the need for construction-specific tools in order to adopt lean production principles in construction. Forbes and Ahmed (2011: 54) report the effort of Ballard and Koskela in the formation of the International Group for Lean Construction (IGLC) in 1993; later, in 1997, Ballard and Howell co-founded the Lean Construction Institute (LCI) in the USA. Although other researchers and organizations dedicated to the concept of lean construction were formed in other regions of the world, these two separate platforms have been the main vehicles for carrying forward the lean thinking philosophy by abstracting the core concepts of lean production and applying them to the management of construction processes (Salem *et al*., 2005: 2).

The main premise on which researchers (Pasquire & Connolly, 2002: 2; Forbes & Ahmed, 2011: 57; Inokuma *et al*., 2014: 18) anchored the lean construction definition is that of a way of generating maximum possible value for the client through designed production systems that minimize wastes in term of materials, time and effort. This is achieved by critically assessing the 'value stream', putting more effort into 'value-added activities' as against 'non-value-added activities'. Rybkowski, Abdelhamid and Forbes (2013: 84) look at lean construction as:

> "… *the holistic pursuit of continuous improvement with a goal to deliver customer value, while minimizing waste and maximizing value to the customer throughout a project's delivery process and life cycle, and while respecting all stakeholders in the value chain".*

Lean construction sustains continuous improvement throughout the project life cycle in pursuance of client satisfaction, creating a more effective, efficient and profitable industry (Suresh, Bashir & Olomolaiye, 2012: 379). Furthermore, Dulaimi and Tanamas (2001: 2) reiterate it benefits in bringing effective value and risk management into the construction industry and effectively challenges the dated belief that key performance indices (KPI) of cost, time and quality cannot be pursued simultaneously.

Salem and Zimmer (2005: 52) and Forbes and Ahmed (2011: 66) present the work of the Construction Industry Institute (CII), where the authors identified five lean principles that are applicable in the construction industry in their study PT191. These five principles are in the areas of; Customer focus, Culture and people, Workplace organization and standardization, Elimination of waste, and Continuous improvement and built-in quality.

These are achieved by critically exploring three connected opportunities in design and construction projects as a base for lean construction. These opportunities are enumerated (Forbes & Ahmed, 2011: 67) as:

1. Impeccable coordination: lack of coordination results in about 50% promised kept in time. Workflow predictability reduce projects fragmentation, serve as catalyst to project success, when promises are kept between various disciplines and trades involved in a project;
2. Organizing projects as production system: seeking to maximize overall performance by aligning the roles of the parties in a project. Project execution strategies key into technology or best practices such as prefabrication, modularization, and concurrent multi-trade coordination in meeting clients' value proposition; and
3. Projects are a collective enterprise: Aligning rewards with project-wide optimization motivates project team members to practically take ownership of the project success for improve performance. "Team orientation and trust are essential for mobilizing creativity and reducing waste."

2.2.1 Lean thinking

The biggest opportunity for performance improvement is through elimination of time and effort wastage and enabling a greater focus on creating value. In this way, lean thinking represents a path of sustainable performance improvement – and not a quick-fix programme (Pasquire & Connolly, 2002: 8). Terry and Smith (2011: 36) define lean thinking as "a system of learning to deliver exactly what the customer wants, right first time in every respect and doing that and nothing more, or free-perfect-now". The five principles of lean thinking are shown in Figure 2.1. The holistic implementations of these principles would lead to optimum lean construction benefits, as they serve as the main drivers for continuous improvement (Dulaimi & Tanamas, 2001: 12). These principles are further highlighted as:

1) Value identification: understanding the client key performance indices (KPI) in terms of time, cost, H&S and quality.
2) Value stream mapping (VSM): identifying the processes in meeting client KPI, but clarify the steps that truly add value.

3) Value stream flow: assessing the process steps critically, understanding dependencies, balancing resources and planning work to avoid delay and rework particularly at interface.
4) Pull: recognizing the interdependencies of the interface that needs to be delivered at the right time, quantity and quality as 'pull' by the client. And,
5) Perfection: continuously striving to be better by continually removing successive layers of waste.

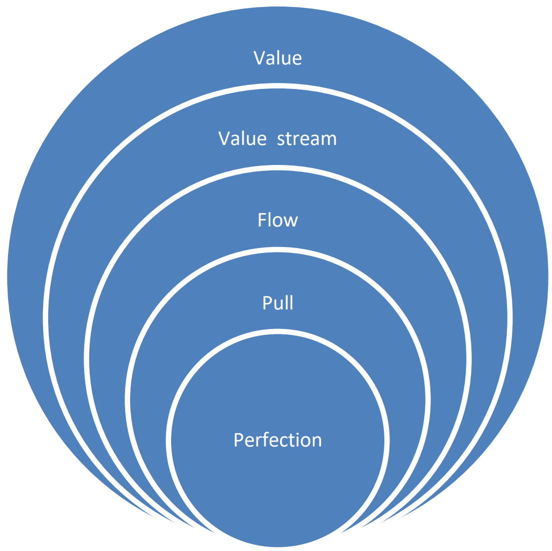


Figure 2. 1: The five principles of lean thinking (Womack and Jones, 1996: 13; Koskela, 2004: 25; Terry & Smith, 2011: 3).

These lean principles are fundamental to the success of lean construction. Koskela (1992: 16) further reinforced this by identifying other key factors that could work in juxtaposition with lean thinking principles. These include reducing variability; reducing cycle times; simplicity; benchmarking; increasing output flexibility; and increasing process transparency. Farrar, AbduRizk and Mao (2004: 2) and Senaratne and Wijesiri (2008: 38) reiterate that elimination of flow obstacles, waste and other NVAAs are the main focus of lean thinking principles. In order to be able to holistically implement these principles, researchers and stakeholders in the construction industry have continued to develop, validate and use several lean construction tools to facilitate progress in the industry.

2.2.2 Tools for Lean construction

The implementation of lean in construction has been evolving overtime. The fundamental differences between manufacturing and construction processes have continue to spring up the necessity for new tools that would be suitable for construction processes and conform to lean principles (Suresh, Bashir, & Olomolaiye, 2012: 380). These tools are developed mainly to implement the lean thinking principles highlighted in 2.1.1 and achieving the key factors, such as: reducing variability, reducing cycle times, simplicity, benchmarking, increasing output flexibility, and increasing process transparency as discussed by Koskela, in construction.

Several researchers (Salem *et al*., 2005: 3; Suresh, Bashir & Olomolaiye, 2012: 381; Sacks *et al*., 2013: 20) have reported the various tools that have been applied in implementing these principles. The tools include: building information modelling (BIM), last planner system (LPS), visualization, the 5S/5C, daily huddle meeting, kaizen, offsite fabrication, failsafe for quality (poka-yoke) and first-run studies, among others. These tools are of different functions and complexity, the cost implications and the level of manpower development required for their adoption/operation are also far apart, as benefits accrued from their usage. Salem *et al*. (2005: 1) report that last planner, increased visualization, daily huddle meetings, and first-run studies achieve more effective outcomes than 5S process and fail safe for quality, contrary to the expectations of the tool champions and the research team. Suresh, Bashir and Olomolaiye (2012: 380), however, emphasize the significance of knowing the right tools for particular projects at a particular time, as there is no requirement to use all of them, but the emphasis should always be on eliminating waste and barriers to work flow.

The adoption of lean tools results in cleaner production (CP), promotes H&S and waste minimization that are of paramount importance to the preservation of the eco-system, the sustainable development of the economy from the environmental, social and economic perspective and the overall welfare of humankind (Yi & Hwa, 2012: 531). The industry must welcome research findings and technological developments to continually optimize efficiency, the quality of their products and services so as to compete in a globalized market (Paton & James, 2008: 3; Senaratne & Sepani, 2011: 4). Cultural adaptation is necessary in the prevailing competitive market if construction industries are to be able to continuously meet clients' needs and respond to the global socio-economic and environmental challenges.

2.2.3 Lean construction practice

Developed and developing countries have made significant inroads in adopting lean thinking into construction practices in the areas of residential, commercial and institutional projects. This implementation of lean construction has helped to create value and enhance continuous improvement in terms of client satisfaction, efficiency, profits and productivity within the industry amidst overcoming constraints (Suresh, Bashir & Olomolaiye, 2012: 385; Aziz & Hafiz, 2013: 679). Several research outputs over the last decade have started to report continuous adoption of lean construction, citing various lean implementation cases and strategies. The large part of these articles focuses on understanding the process, benefits and challenges associated with the implementation of isolated lean practices and tools using individual firms and projects as a case study. Examples of these reports include: Fernandez-Solis *et al*.'s (2013: 355) comprehensive report on the usage of last planner system (LPS) on several projects that result in more reliable planning, better supply chain integration, less firefighting or fewer day-to-day problems and less work flow time among other benefits; Simonsson *et al*., (2012: 35) note the work performance on two bridge projects, where 'increased visualization' of materials, resources and information brought about work flow improvement, increased understanding and ease of measurable lead time, inventory level and reduced production costs. A detailed account of lean construction practices in developing and developed countries that identifies tools, techniques and strategies as adopted within the industry and the benefits accrued were highlighted in the work of Suresh, Bashir, and Olomolaiye (2012: 385). In their account, the practices improve project performance in terms of delivering value to the client and eliminating non-value-adding activities using fewer resources. Other benefits highlighted include reduction in project duration, improved project planning and control, industry productivity and works flow reliability.

Bygballe and Sward (2014: 3) affirm that implementing lean construction has proved to yield significant performance benefits. Nevertheless, implementation challenges continue to intrigue the industry stakeholders and academics alike. Some barriers hindering the full implementation and the maximization of the benefits associated therein were also documented to include resistance to cultural change, inadequate knowledge of lean concepts, unreliable material flow and delay in decision-making. The effects of these barriers are more pronounced in some developing countries where the lean construction practice is yet to be adopted fully (Suresh, Bashir, & Olomolaiye, 2012: 384). These barriers will be discussed in the next section.

2.2.4 Barriers to lean construction practice

Since the emergence of the lean construction concept, adaptation of these production methods, tools, and thinking has been a challenge. The specific characteristics of the construction sector, being fragmented, complex and project-based, are seen as major barriers to the implementation of lean construction (Bygballe & Sward, 2014: 3). Other key barriers to the successful implementation of lean construction have also been indicated, such as: culture, training, leadership, partial implementation and improper conceptualization of lean construction tools within the industry (Wandahl, 2014: 97). Suresh, Bashir, and Olomolaiye, (2012: 382) brought up six categories of barriers, through review of other studies, that hinder the implementation of lean construction especially in the developing countries. These broad categories are:

1) Educational issues: inadequate knowledge and understanding of concept, lack of technical skills, inadequate training, lack of awareness programmes and information sharing.
2) Technical issues: lack of detail and complete designs, specific industry characteristics, lack of agreed implementation methodology, lack of mechanization, and uncertainty of supply chain.
3) Management issues: lack of top management support and commitment, delay in decision-making, poor project definition, lack of equipment, weak administration, lack of supply chain integration, inadequate stakeholders' involvement, inadequate pre-planning, and absence of long-term planning.
4) Human attitudinal issues: cultural change, lack of team spirit, lack of team work, misconceptions about lean practice, lack of self-criticism, over-enthusiasm, and lean being seen as too complex and feared.
5) Governmental issues: inconsistency in policies, government bureaucracy, lack of infrastructure, and inadequate government support.
6) Financial issues**:** inadequate project funding, corruption, inflation, lack of incentives and motivation, poor salaries of professionals, and risk aversion.

The stakeholders need to understand the barriers to that adoption in order to develop strategies to remove them. Naney, Goser, and Azambuja (2012: 292) argue that LC's implementation in the construction industry needs to be accelerated in order to reach a tipping point and attain more acceptability in the industry; they imply that the barriers hindering the LC concept is partly responsible for holding back more rapid adoption. Overcoming these barriers requires a holistic and in-depth evaluation of the industry for adequate and sustainable ‘drivers’ that can bring about change, build trust and establish a new culture of constant learning, improvement and perfection among the stakeholders in the construction industry.

2.2.5 Drivers for change in lean construction in developing countries

For lean to be successfully implemented, certain key theories that can serve as drivers for change and limit the barriers that impede the rapid adoption of the concept must be vigorously pursued. These drivers must be properly synchronized to suit each organizational goal. Such drivers that can mitigate the barriers in 2.1.4 and serve as catalyst for lean construction adoption in developing countries include: awareness and enlightenment campaigns, policy, training and implementation.

1. Awareness and enlightenment campaigns: Lean awareness and enlightenment campaigns are necessary to sensitize the stakeholders, most especially the client, within the construction industry to the goals, opportunities and benefits of lean implementation within the industry. These sensitizations shall be handled by lean construction experts and voluntary organizations within and outside the region with the focus of making known the lean edge over the traditional management approach (Suresh, Bashir & Olomolaiye, 2012: 383). This is vital in eradicating management and human attitudes issues.
2. Policy: The principles that guide decisions, procedure and protocol within the organization must be aligned with the lean sensitization programme (Othman, 2011:179). The policy should establish why the organization supports lean principles and tools; the policy should also show how and what areas can be accommodated within their scope of operations (Simonsen & Koch, 2004: 4; Othman, 2011: 181). Policy plays a central role in solving management and governmental issues.
3. Training: The fundamental step towards the effective implementation of the lean construction process is training (Othman, 2011: 184). Paton and James (2008: 8) are of the opinion that training is central in the implementation of lean as it involves teaching stakeholders and practitioners of the lean tools and techniques available to them, which practically breaks the fear of lack of capacity for new skills and misconceptions towards new concepts. Also, the

Construction Lean Awareness Workshop (CLAW) which is held in most developed countries should be encouraged. CLAW has proven to be vital in helping companies understand the advantages and opportunities of lean construction and they have also been involved in hands-on training on lean tools with operatives, staff and management of companies (BRE, 2011: 4). This will effectively eliminate educational and technical issues.

4. Application: The implementation of lean principles and tools within organizations requires a high level of commitment, willingness and involvement of the organization's management cadre (Alarcon & Seguel, 2002: 3). Thus its implementation calls for a high degree of participation between clients and all the stakeholders in creating conditions and policies that would encourage and support its practical implementation. This can be achieved by engaging more downstream players in upstream processes and vice versa (Howell, 2011: 4). This expected collaboration will serve as incentives and motivation to downstream players and bring about the much-needed transparency.

2.3 Lean Wastes and Associated Sustainability Benefits

Womack and Jones (2003: 15) define waste as "specifically any human activity which absorbs resources but creates no value". Waste impacts negatively on the social, economic and environmental well-being of the society by taking in inputs without beneficial output. Corfe (2013: 5) argues that 'waste' assumes a larger meaning when discussed in a 'lean' context; it has a specific meaning that is wider than material waste alone.

The process of achieving a task or project that we undertake can be seen in three ways:

1) Value: what the customer or end user is prepared to pay for.
2) Non-value (often known as essential non-value-adding): all of the activities that we have to do, under our current conditions to make the value happen, for example, this may be inspections or reporting, or statutory breaks.
3) Waste: every other activities, which are carried out, but add no value to the process and will have an adverse effect on cost, time, quality or sustainability, for example, design rework.

Lean is a process that "eliminates waste through delivering continuous improvement in a collaborative way (Corfe, 2013: 5), where the principles can be directed at sustainability objectives to good effect". These can occur at any stage of the production process/value stream. This waste comes in various dimensions such as: social, economic, and environmental, which includes time, energy, resources, carbon, whole-life cost, physical waste, and poverty, among others. In thinking through this process waste, an acronym, TIMWOOD, has been developed for easy identification of the seven common lean wastes in the construction industry; the associated sustainability benefits of removing them (Corfe, 2013: 6) are highlighted below:

1) Transportation: Excessive movement of physical or virtual things, such as: double-handling of materials on site due to poor planning of deliveries and storage areas, excessive mileage due to non-local suppliers being used, and excessive deliveries to site because of poor planning. The benefits are: reduced cost and emissions of handling equipment, reduced risk of handling damage, reduced physical waste, safer site and lower energy consumption.
2) Inventory: Storing too much or too little of something, poor storage conditions, excessive work in progress, such as ordering too much material and having to dispose of it, lengthy reports where the information needed is hidden in the middle, and using more space than is necessary for a project due to poor design. The benefits are: better cash flow for supply chain, improved safety, reduced material handling and transportation, with associated emission and fuel cost reduction and less risk of damage, excess waste and resource use.
3) Motion: Excessive personal motion or difficult working conditions, such as: static site welfare facilities available at only one point on a large site, site engineer repeatedly driving around a site to sign off permits, and poor ergonomic design of a space. The benefits are: less work-related injuries and absence, safer working environment, improved productivity and reduced fuel use through reducing unnecessary travel.
4) Waiting: People or equipment inactivity, flow of a process stopping because the right information or resource is not available, such as: waiting for the design detail for an air tightness tape around a window, delaying installation; delayed results of an ecology survey; site stoppage due to an accident or incident; and waiting for materials because of late ordering or poor planning. The benefits are: improved productivity, reduced energy use from more efficient working, improved flow of work and less frustration.
5) Over-production: Doing too much too soon, or out of sequence, such as: fully completing a design before considering specialist input, mixing too much mortar for the shift, downgrading insulation, so causing over-specification of the heating system, and excessive packaging material being used. The benefits are: reduced waste rates, reduced transportation of original

and replacement materials, reduced cost associated with excess materials and reduced rework, and potential for damage, reduced resources used.

6) Over-processing: Using an overcomplicated or incorrect process for a task, not having the right resource, equipment or plant breakdown, such as: installing complex maintenance heavy systems, failing an air test through not having adequate quality checks throughout, lengthy pre-construction lead-in, complex deconstruction requirements and exceeding specified requirements for no benefit. The benefits are: reduced resource and energy use in unnecessary processes, improved quality and repeatability, safer working methods and work planned at right time to take into account all ecology impacts.
7) Defects: Having to repeat an activity more than once before it is to the right quality, such as: poor workmanship, completed drainage failing a test, damage to materials or completed work, and re-running energy calculations because of poor air pressure test results late in the build process. The benefits are: improved customer satisfaction, project on time with no faults, lower rates of waste disposal, fewer environmental incidents and reduced transportation of original and replacement materials.

All these are the common process wastes within the industry that have made it a vital ground for continuous improvement. Through the use of various lean tools and concepts – such as cradle-to-grave, Just-In-Time, continuous visualization, last planner, among others – wastes can be eliminated and sustainability benefits accrued in social, economic and environmental dimensions. This lean capability of enhancing the attainment of sustainability objectives and the relatedness between the two concepts – lean and sustainability – explain the viability and the relevance of the synergy under consideration in the study.

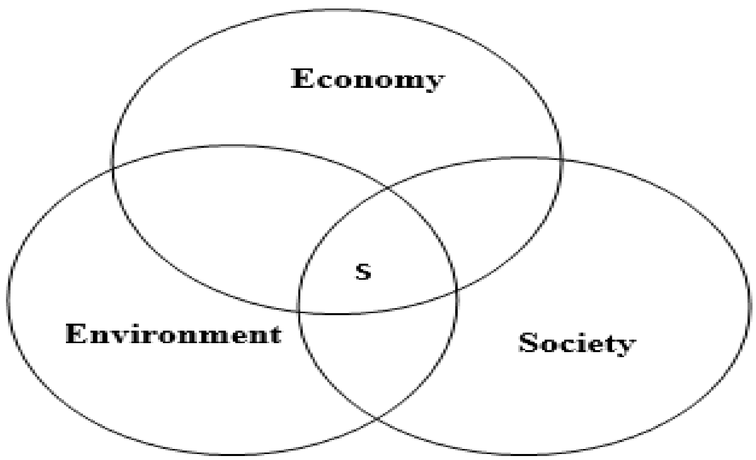
2.4 Sustainable Development: the story and main features

The concept of sustainability development originates from the idea of the sustainable society - the pressure group for energy conservation - and in the management of renewable and non-renewable resources (Brown, 1981 as cited in Yao, 2013: 4). The International Union for the Conservation of Nature (IUCN) promotes this further by introducing the concept in the World Conservation Strategy in 1980. In 1983, the World Commission on Environment and Development (WECD) was established by the *United Nations General Assembly* resolution 38/161 (UN, 1983: 3). This resolution led to a successful pursuit through the concept of 'Sustainable Development' that is primarily based on four interdependent principles related to meeting human needs, maintaining ecological integrity, attaining social sufficiency, and establishing social equity (Shah, 2002: 2). The Brundtland Report for WECD in 1987 is the reference point from which sustainable development has being evolving.

Clear indicators in the later stages of the last century suggest the need to take a second look at how we develop as a group; global climate change, extreme weather events, sea-level rise effects on ecosystem, urban pollution and environmental degradation with its attendant effect on the safety, economy and the global wellbeing have brought forth and continue to be the driver for sustainable development (Wu & Wu, 2012: 65; Yao, 2013: 4). The past two decades have witnessed a growing awareness of the importance of sustainable development around the globe. The 'Agenda 21', the resolution document of the UN 'Earth Summit' in 1992 in Rio de Janeiro (http://users.whsmithnet.co.uk/ispalin/a21/), the Kyoto protocol for reduction in greenhouse gas emissions (http://unfccc.int/resource/convkp.html, the Copenhagen Accord of 2009 related to CO_2 emission (Hirst, 2013: 24), and many other national and international initiatives have shown the growing concern for protecting the environment for the future generations by introducing sustainable development concepts.

WECD (1987: 43) sees development as sustainable if it will not compromise the ability of future generations to meet their needs in the process of meeting the present needs of the people. The Department for Environment, Food and Rural Affairs in the UK (DEFRA, 2005: 2-3) affirms that the goal of sustainable development is to enable people throughout the world to satisfy their basic needs and improve the quality of life, without hindering the quality of life for future generations. Sustainable development involves "creating an infrastructure of material and energy use in communities that meet human needs while maintaining a wide array of metrics of environmental quality, human health, social equity, and economic vitality" (Crawford-Brown, 2012: 23). Opoku and Ahmed (2013:141) went further to include the human angle and define sustainable development as "the adjustment of human behaviour to address the needs of the present, without compromising the ability of future generations to meet their own needs". These definitions, according to Shah (2002: 2), view development as much more than material growth; it associates present with future, human to nature, and material to spiritual; values natural resources as social capital; points out limits to growth, the finite nature of the natural resources, and it emphasizes its proper management and equitable sharing; it puts ecological balance and environmental vulnerability in perspective and emphasizes the link with human activity.

In meeting this goal, the last decades have witnessed ‘sustainable thinking’; an array of visions and executable actions developed featuring the principles of triple bottom line (TBL). TBL (Figure 2.2) features: economic development, environmental protection, and social equity (Madu & Kuei, 2012: 1).



S – Sustainability.

Figure 2.2: The Triple Bottom Line of Sustainability (Wu & Wu, 2012: 68)

Five distinctive stages of adopting Sustainability Management (SM) have been suggested (Nidumolu et al., 2009 as cited in Madu and Kuei (2012: 1): viewing compliance as opportunity, making value chains sustainable, designing sustainable products and services, developing new business models, and creating next-practice platforms. Winkler (2010: 293), on the other hand, suggests that managing sustainability rests on the complete focus on the entire supply chain system. Consequently, proactive companies adopt SM knowing that the outcome in terms of waste reduction, environmental hazards mitigation, favourable social impact and achieving competitiveness lead to long-time economic and social benefits (Madu & Kuei, 2012: 4).

2.4.1 Dimensions of sustainability

Attaining the state of sustainability within the industry requires top management with a clear sustainable ideology, armed with a clear idea for corporate change that must be pursues. These change variables as represented by the TBL are outlined below.

2.4.1.1 Economic dimension

The ultimate goal of the industry is long-time financial performance. Hence, cost-benefit analysis forms a major criterion for any strategy towards sustainability. Sustainable practice must be economically viable in the long run and must also serve as the catalyst to process productivity. This practice adopts integrated whole-life thinking by benchmarking, and assessment/evaluation throughout the whole life of the urban infrastructure (Madu & Kuei, 2012: 5; Wagner, 2012: 225; Yao, 2013: 8). The costs from conception to demolition and the cost of taking corrective actions when ecological problems occur are needed to be itemise as against the potential benefits of implementing sustainability (Epstein, 2010: 52). Sustainability also helps the industries meet the needs of its operating communities in a socially responsible way. Therefore, sustainability practices strengthen the survival of the organization as it reduces costs, increases productivity, increases customer and community goodwill, contributes to both profitability and corporate sustainability, and sustainable development at large (Wagner, 2012: 225).

2.4.1.2 Environmental dimension

The major tasks confronting the global community are those of mitigating the effects of climate changes and preserving the natural resources that provide essential functions for the well-being of society (Winkler, 2010: 293; Corfe, 2013: 1). In meeting these demands, focus on the following areas of improvement in the upstream activities becomes critical:

1) efforts to minimize wastes;
2) developing new and environmentally friendly technology;
3) creating low carbon/pollution supply chain, effectively using renewable/non-renewable resources;
4) using alternative energy sources;
5) fostering harmony between supply chains and nature;
6) offering effective ways of cleaning up the environment, and

7) enforcing extended producer responsibility through principles such as accountability and process change.

In operationalizing this environmental dimension, Madu and Kuei (2012: 6) note the HP concept for achieving sustainability using the "4R + D" system. The acronym "4R + D" stands for *reduce, recycle, reuse, report, and dispose*. The HP concept is still within the "do no further harm" or "builds less, builds smart" sustainability principles. Using visual management techniques to communicate strategy and drive action on projects, adopting sustainable design initiative to encourage designers to eliminate waste, are set out in the sustainability hierarchy diagram (Figure 2.3).

This focus on natural system does not necessarily down-play the importance of economic development. The sustainability concept implies that the method of attaining economic development must resonate with the interests of the future generations and the essential needs of the earth such as green-house gas depletion, biodiversity and ecosystem (Madu & Kuei, 2012: 7). Therefore, efforts towards corporate profitability, competitive positions and strategy should also factor in the issues of earth preservation.

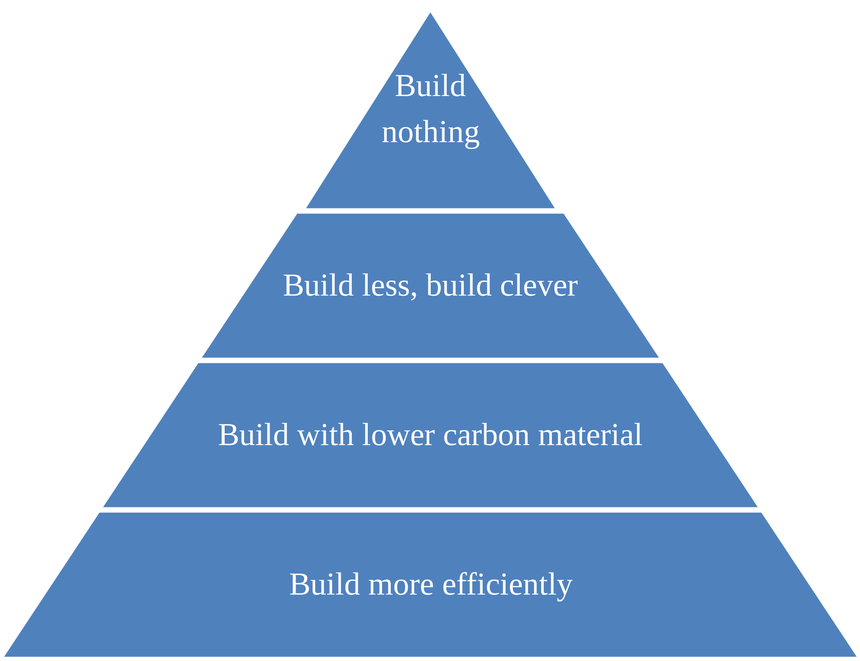


Figure 2. 3: Sustainability hierarchy for design in built environment (Corfe, 2013: 28).

2.4.1.3 Social dimension

Social dimension basically centres on the people and the community well-being of the society where the industry operates. Social responsibility encompasses basic concepts such as corporate citizenship/philanthropy, labour practice indicators, human capital development, social reporting, talent attraction and retention, and industry specific criteria (Madu & Kuei, 2012: 7). It goes beyond the industry-critical mandate and process of providing infrastructure, to reflect an organisation's concern with the social needs of its employees and extended environment, to extending further resources to uplift the community and improve quality of life, improve social civilization, maximize health and comfort, avoid harm and do what is right, be just and fair, and ultimately obey the law of the land (Dong, 2012: 445).

Industries must strive to archive the status of 'corporate social image' by being locally appropriate and utilize locally sourced materials and skills, in efficient and effective ways, to create jobs. Madu and Kuei (1995: 5) emphasize that job creation and expansion is perhaps one of the most important services industries can render to the community. However, for job base expansion to happen, productivity and quality of products and services must be improved simultaneously. This can only be achieved by managing quality along a sustainable supply chain in the industry, thereby enhancing quality, productivity and subsequently an expansion of the market share and job base.

Corfe (2013: 1) is of the opinion that when considering sustainability issues, it is normally a preferred choice to relate the factors to the processes by which they can be influenced. The UK Sustainable Construction Strategy identifies these factors as the 'ends' – climate change mitigation, climate change adaptation, water, biodiversity, waste, and materials – and the processes of achieving the variables as the 'means' – procurement, design, innovation, people, and better regulation – for the built environment industry. Thus, the dimensions of sustainability outlined here have widened the scope of traditional construction. The ultimate aim is the adoption of these dimensions and achieving them simultaneously in order to attain a more sustainable result. This will provide the right platform for the industry to understand the sustainability concept from a strategic and a holistic point of view.

2.4.2 Sustainability perspectives

Unfortunately, the 'concept of needs' has assumed different dimensions and meaning in various regions of the world, based on the level of development, ideological preference, and emphasis on, key dimensions of sustainability, indicators and their linkages have made the balancing and relationship with TBL controversial (Table 2.2). For example, the question often asked is whether economic development can be substituted for a low level of environmental quality (Wu & Wu, 2012: 69). This has now led to a dichotomy that places sustainability efforts on a continuum between 'Weak (false) and Strong (true)' or The 'Brown' and 'Green' sustainability, depending on the willingness of stakeholders to accept and participate in change (Du Plessis *et al*., 2002: 9).

Table 2.2: Major sustainability challenges

	Pollution	**Depletion**	**Poverty**
Developed economies	Greenhouse gases Use of toxic materials Contaminated sites	Scarcity of materials Insufficient reuse and recycling	Urban and minority unemployment
Emerging economies	Industrial emissions Contaminated water Lack of sewage treatment	Overexploitation of renewable resources Overuse of water for irrigation	Migration to cities Lack of skilled workers Income inequality
Survival economies	Dung and wood burning Lack of sanitation Ecosystem Destruction due to development	Deforestation Overgrazing Soil loss	Population growth Low status of women Dislocation

Sources: Hart (1979: 70)

2.4.2.1 The "Weak" and "Strong" sustainability agenda

Wu and Wu (2012: 69) assert that weak sustainability permits mutual sustainability among the three dimensions, whereas strong sustainability does not. The major concern is whether the focus on allowing future generations to meet their basic needs can be met with the current development and consumption patterns. Wu and Wu (2012: 69) simply categorize the resource wealth under consideration into two folds for easy measurement and reference as:

1) Natural capital; natural resources and the services provided to humans by the biophysical environment, and
2) Human-made capital (manufactured and financial); labour, education, skills, intelligence, culture and organisation, buildings, infrastructure, goods, information resources, cash, credit, investments and monetary instruments.

The ideology of weak sustainability is that of 'value for money' where different kinds of capital are fully interchangeable, and natural capital can therefore be used up as long as it is converted into manufactured capital of equal value. This can serve as justification for running down the environment provided the proceeds of environmental degradation were reinvested in other forms of human capital (Du Plessis *et al*., 2002: 10). However, Du Plessis *et al*. (2002: 10) argue that strong sustainability recognizes the essential functions that the natural environment performs for the welfare and survival of the human species and which cannot be replaced by human capitals. These "critical natural capitals", such as the ozone layer, the carbon cycle and the hydrological cycle, cannot be traded for any of the other forms of capital, as their depletion would endanger human survival since the environment provides natural resources and ecosystem services for economic and social development (Figure 2.4). Quoting from a 19th century Cree Indian prophecy, Du Plessis *et al*. (2002: 10) write, "Only when the last tree has died and the last river been poisoned and the last fish been caught will we realize that we cannot eat money."

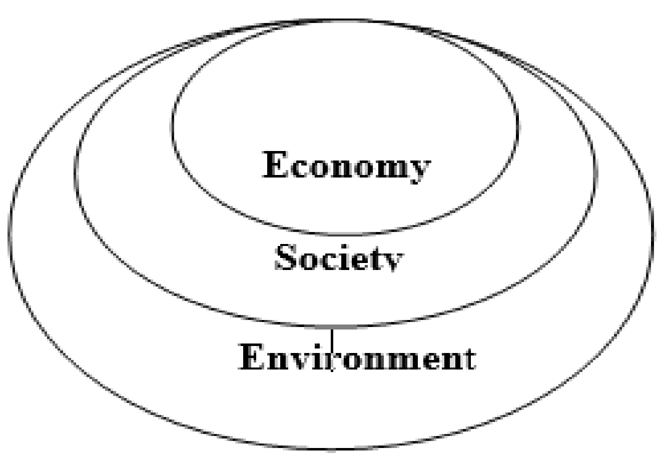


Figure 2.4: Strong Sustainability (Wu and Wu, 2012: 68)

Therefore, adopting a 'weak' sustainability (Figure 2.5) approach will certainly limit the possibility of meeting the future needs if not hampering the means of meeting the present needs. However, Du Plessis *et al*. (2002: 10) is of the opinion that the lore for immediate gratification may seem a perfectly good rationale to trade natural capital of a given value for human-made capital of equal or greater value within a static framework as against a dynamic framework of modelling economic systems through time, thereby protecting our irreplaceable and non-substitutable natural capital.

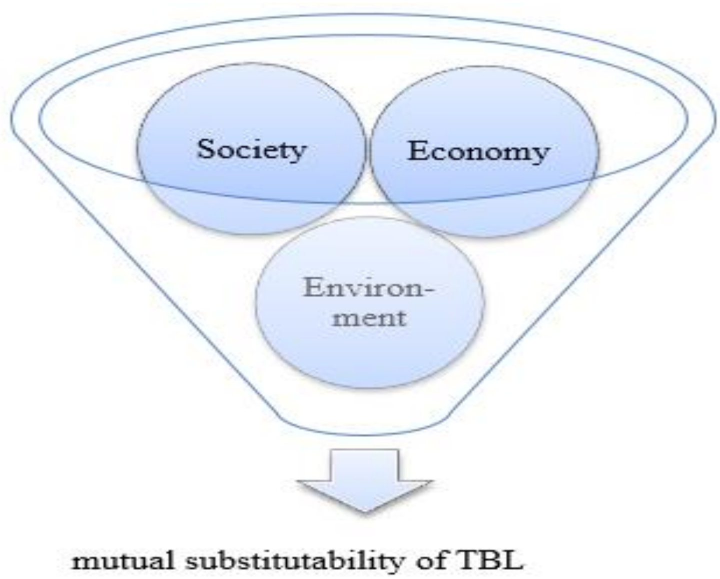


Figure 2. 5: Week Sustainability (adapted from Wu and Wu, 2012: 68).

2.4.2.2 The "Brown" and "Green" Sustainability Agenda

The Green Agenda has a major bias for reducing the environmental impact of urban-based production, consumption and waste-generation on natural resources and ecosystems, and ultimately on the world's life-support systems (Du Plessis *et al*., 2002: 9). On the whole, the life-style of affluence and over-consumption is more pressing in developed societies. In contrast to the Green Agenda, the Brown Agenda focuses on the problems of poverty and underdevelopment, emphasises the need to reduce the environmental threats to health that arise from poor sanitary conditions, crowding, inadequate water provision, hazardous air and water pollution, and local accumulations of solid waste. The Brown Agenda is therefore more related to the emerging and developing economy. Table 2.3 illustrates the difference between the Brown and Green sustainability agendas.

A developing economy, such as South Africa, is at crossroads and in a particularly difficult position, regarding which ideology to adopt in its quest toward sustainability. The interaction between the Brown and Green Agendas is further complicated by the need to address past inequities in service delivery in a manner that is socially acceptable to both the North and South. This will enable the developing world to live within what is ecologically possible, given its small resource base relative to its population growth rates and large infrastructural gap, which minimizes the negative environmental impacts associated with both Green and Brown agendas.

Table 2.3: Difference between the Brown and Green Sustainability Agendas

	Brown	**Green**
Key concern	Human well-being	Eco-systemic well-being
Timeframe	Immediate	Delayed
Scale	Local	Local to global
Concern about	Low-income groups	Future generation
View of nature	Manipulate and use	Protect and work with
Environmental services	Provide more	Use less

Sources: McGranahan and Satterthwaite (2000 cited in Du Plessis *et al*., 2002: 9)

2.4.3 Sustainable construction practice

The construction industry reshapes the built environment by showcasing the engineering products in terms of physical developments that benefit the society, but in the process causes negative impacts on the ecosystem; these attributes make it a key sector in the drive towards the delivery of a sustainable built environment. It is believed that the construction industry accounts for around 40% of all resource consumption and waste produced globally, which includes greenhouse gases. Thus, construction industries have vast potential in actualizing efforts toward the attainment of sustainable development in the world through sustainable construction (Ogunbiyi, Oladapo & Goulding, 2013: 82).

Sustainable construction has been defined in many ways: Ogunbiyi, Oladapo and Goulding (2013: 82) define sustainable construction "as the adoption of sustainable thinking, practices and sustainable development principles to the realisation of construction sector objectives"; Du Plessis *et al*. (2002: 4) see it as "a holistic process aiming to restore and maintain harmony between the natural and built environments, and create settlements that affirm human dignity and encourage economic equity." Sustainable construction concerns itself with three bottom line issues, those of environmental quality, social equity and healthy economic. Environmental protection is important because construction represents a major contribution to climate change, resource depletion and pollution at a global level. Sustainable construction is a subset of sustainable development which focuses on delivering infrastructure that creates value for the customer and enhances the well-being of society. It offers flexibility and the potential for retrofitting in meeting customers' future needs; provides and supports desirable natural and social environments; and maximizes the efficient use of finite resources. It is pertinent to note that all existing definitions of 'sustainable construction' still acknowledge that even if it were attained, construction operations would continue to have environmental impacts, although at a reduced rate (Ogunbiyi, Oladapo, & Goulding, 2013: 82).

The success of traditional design and construction measures through the KPI in terms of cost, time and quality objectives, sustainable design and construction adds to these criteria by looking at minimization of resource depletion, minimization of environmental degradation, and creating a healthy built environment, among other things. The shift to sustainability can be seen as a new paradigm where sustainable objectives are within the building design and construction industry considered for decision-making at all stages of the life cycle of the facility (Houvila & Koskela, 1998: 2) (Figure 2.6). The new paradigm is expected to lead to a state of sustainable development within the global context, where the economy will be healthy, communities will enjoy social equity, cultural heritage, and quality environment.

Sustainable construction as a concept, if successfully practised in the construction industry, will lead to stakeholders' benefit in terms of long-term cost savings, project schedule compliance, reducing environmental risk and uncertainty, ensuring legislative compliance, improving relations with regulators, improving public image, enhancing employee productivity and improving market opportunity. Good construction practice offers both environmental and economic benefits: reduced health and safety impacts on staff and local community, reduced liability costs in connection with waste disposal, minimal rework and reduced construction delays. Contractors for demonstrating environmental responsibility will improve its opportunity to tender, reduce money waste on fines, eliminate fund for restoring environmental damage, experience less money lost through wasted resources, a harmonious relationship with its host community and an improved environmental profile (Madu & Kuei, 2012: 7).

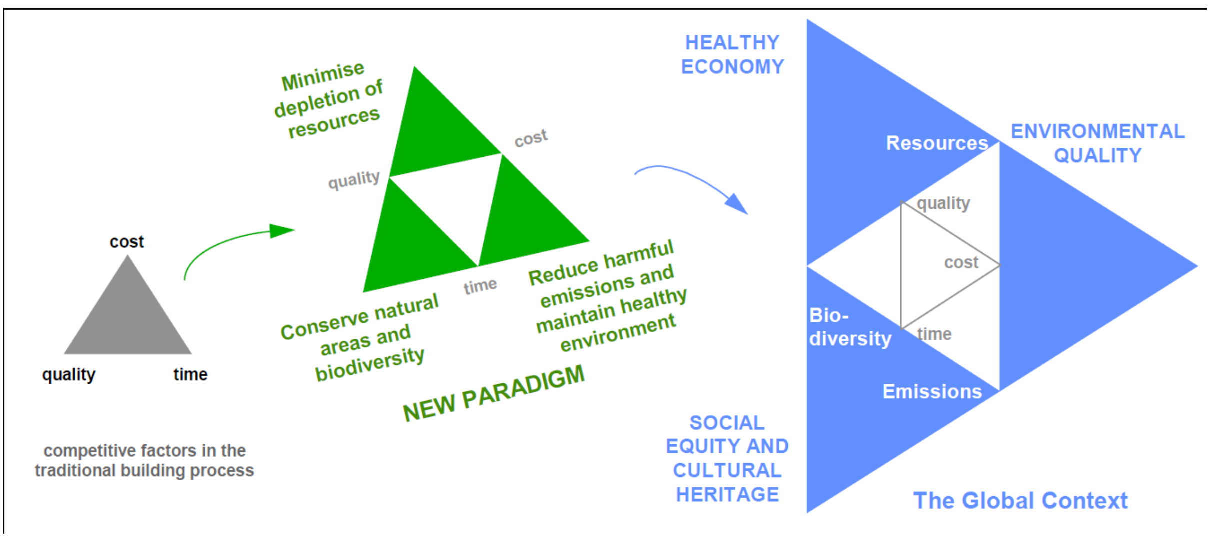


Figure 2. 6: Sustainable construction concepts (Houvila & Koskela, 1998: 3).

In an effort geared towards attaining sustainable construction, there should be changes in culture; thinking, behaving, producing and consuming. Madu and Kuei (2012: 7) suggest that in the journey towards sustainability, the industry must change the culture of creating the built environment by adopting cyclic processes which will promote recycled, renewed and reused resources, and decrease in the use of energy and new mining for natural resources. To attain environmentally responsible construction, all practitioners must make a commitment, change their behaviour, adopt new products, ideas and practices, integrate their environment system with normal work processes, involve close co-operation of all project participants, start as early as possible, and be visible throughout the building’s life cycle.

2.4.4 Drivers and barriers to sustainable construction practice

Sustainable construction practices and/or sustainable procurement encompass some basic principles such as whole-life costing, integrated design, waste management, energy modelling, corporate social responsibility (CSR) and community, and sustainable material resources (Rafindadia, Mikiua, Kovabiub, & Cekiuc, 2014: 459). Any organisation based on these principles will certainly accrue some benefits that drive the process and supply the strength to overcome the barriers associated with such a venture. Various researchers, such as Elmualim *et al*. (2010: 58); Madu and Kuei (2012: 5-7); Wagner (2012: 225) and Finch and Zhang (2013: 318) have reported some barriers and drivers to sustainable practice.

The common barriers reported are: the perception that sustainability costs more, lack of client demand, insufficient policy implementation efforts, contract requirement, lack of skilled trade, lack of management commitment, understanding sustainability, and initial cost increase. In order to overcome these barriers, the following benefits have served as drivers: competitive advantage, legislation and legal requirement, reputation/image, client demand, win more contracts/financial incentive, attract and retain good employees, and good community relations.

2.5 Sustainable Indicators

According to Wu and Wu (2012: 69), 'indicator' can be defined as "... a variable or an aggregate of multiple related variables whose values can provide information about the conditions or trajectories of a system or phenomenon of interest." For an indicator to be valid there must be an established reference that represents a normal state, benchmark, desired behaviour, or goal to be achieved.

Understanding sustainability rests on the ability to successfully determine what aspects of a system to monitor and the variables to use to gauge the state and performance of those aspects are critical. Understanding what should be sustained and developed from the worldviews should form the basic principles and standards that inform general guidelines and specific criteria for indicators, which would in turn provide information on the state, dynamics and underlying drivers of human-environmental systems. Commonly recognized criteria for selecting and evaluating sustainability indicators (Wu & Wu, 2012: 72; Valenzuela, Salgado & Diaz-Alvarado, 2016: 99) include that an indicator should cover the entire range of dimensions of sustainability and their complex interactions; individual indicators should be indicative of the state and changes of the targeted aspect of sustainability; they should be informative, easy to compile from readily available and lasting data sources, understandable to lay people, policy-relevant, predictive or leading, and hierarchical in terms of details and scale; unbiased and transparent methods for weighting and aggregating indicators (Wu & Wu, 2012: 72; Helleno, de Moraes & Simon, 2017: 405).

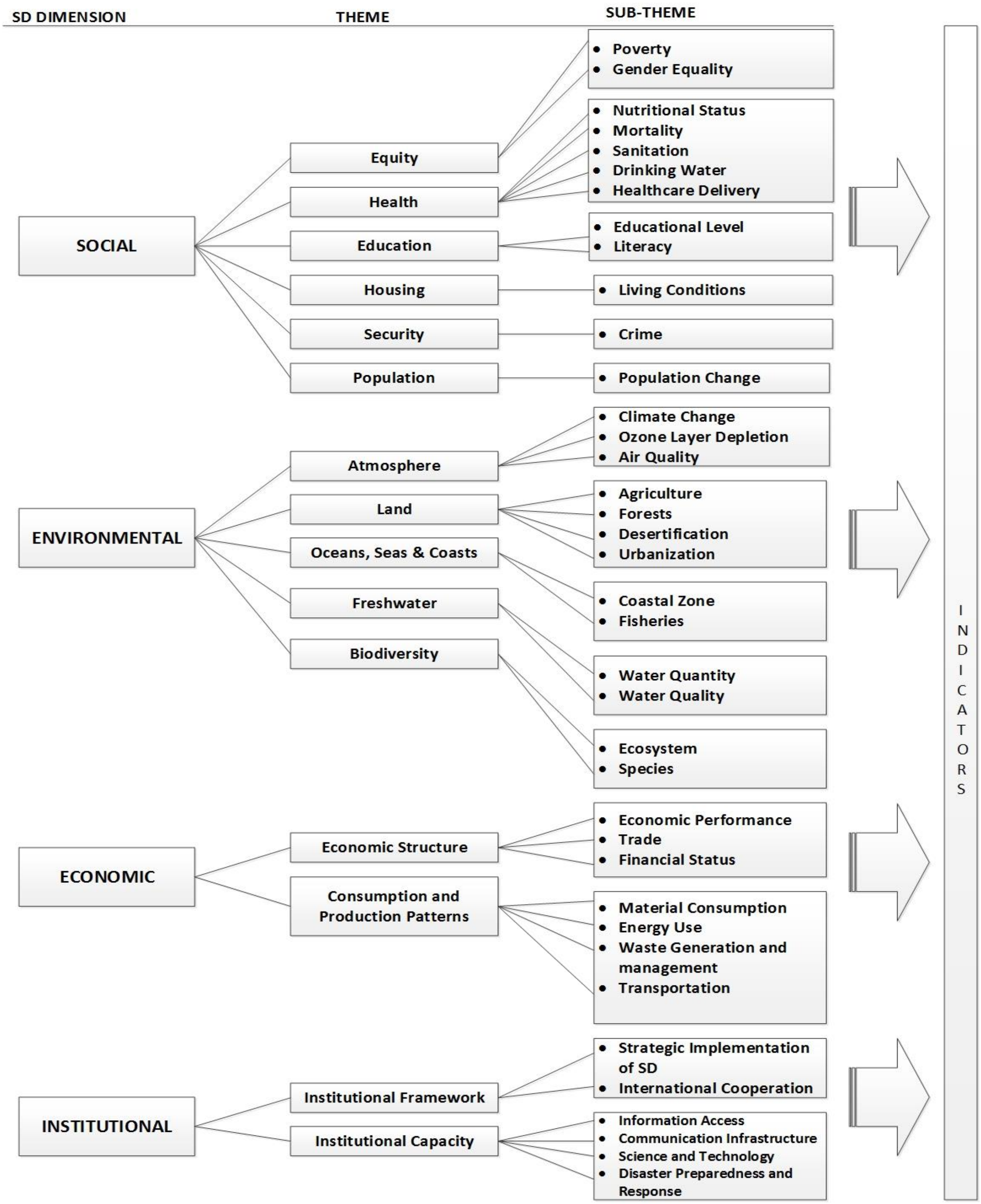


Figure 2.7: Sustainable indicators theme-based framework (adopted from UNCSD, 2001 as cited in Wu & Wu, 2012: 76).

International organizations and other groups of interest based on diverse core values and sustainability theories have developed a number of indicator frameworks for sustainable assessment. These conceptual structures are used to facilitate indicator selection, development, and interpretation (Wu & Wu, 2012: 72). Some of these frameworks that have been widely reported in literatures are pressure-state-response (PSR) frameworks and variance; theme-based frameworks (Figure 2.7); capital-based frameworks; integrated accounting frameworks; and Bossel's orientor framework (Wu & Wu, 2012: 73-78). Different conceptualizations of, and emphases on, key dimensions of sustainable development and their linkages are responsible for variations among these frameworks, as well as various ways of grouping/aggregating them. For the purpose of this study, the theme-based frameworks will be discussed.

Theme- or issue-based frameworks organize indicators around key themes or issues that are characteristically based on policy relevance and provide a flexible conceptual structure. Basically, the United Nations Commission on Sustainable Development (UNCSD) has adopted theme-based frameworks in place of PSR variance because of it flexibility and more explicitly focus on sustainability-related issues. It further emphasizes the multi-dimensional and integrative nature of sustainable development by clearly demarcating the sustainability dimensions and adding crosscutting themes such as poverty, population change and natural hazards that are central to the sustainability debate in developing countries.

2.6 Tools for Measuring Sustainable Construction

In the past decades, the construction industry has experienced the development and usage of many tools and measures to guide its work practices towards sustainable development. Various organizations and councils have for a long time assumed the responsibility of managing schemes and international standards that deal with mandatory and voluntary building and other infrastructure assessments. Building and infrastructure performance can be measured and gauged against a benchmark to improve sustainability (Ding, 2012: 450; Townsend, 2013: 364). Some of the tools that are widely in use are as follows:

2.6.1 BREEAM – BRE Environmental Assessment Method

BREEAM is the world's first and still the leading rating and assessment method for buildings. Developed in 1990 in the UK, it consists of a suite of integrated tools, based on researches, scientific, and market analysis. Its scope on environmental impacts of building are in the areas of: energy; transport; health and wellbeing; water; materials; pollution; land use and site ecology; and management. In the drive to be a vehicle for design support, as well as assessment, across all building life cycle stages and infrastructure, to include master-planning of large-scale development, BREEAM has widened the group of stakeholders involved in its future development, both strategically and at local level.

This development now includes operation and management of broader infrastructure and planning issues through BREEAM communities. Post-construction assessments are now mandatory in the UK for final certification. In order to move forward the ability of builders and designers to innovate and enable lessons learned to be spread across the industry, and innovation credits for an ‘outstanding’ rating, have been introduced to recognise beneficial sustainability aspects within the design that are not covered under the standard criteria.

All other assessment tools are a clone of BREEAM, with modifications to align with a specific goal, needs and peculiar environmental differences; it has been used to develop tools for other regions of the world and sectors of the economy.

2.6.2 LEED – Leadership in Energy and Environmental Design

LEED was USA response to UK BREEAM in 1998 to meet their needs through adaptation. It was developed by the US Green Building Council (USGBC) to enhance the way the construction industry handles sustainability by providing a simple, easy-to-use label. LEED currently has versions covering a wide range of developmental projects, from commercial to neighbourhood development, schools to healthcare (under development), homes to core and shell development. Each version has four ratings: (1) Certified (26-32 points); (2) Silver (33-38 points); (3) Gold (39-51 points); (4) Platinum (52-69 points) – based on the total number of credits that are achieved together with the baseline performance in key areas. A number of mandatory requirements must also be achieved before a rating can be awarded, which are not scored in the method.

2.6.3 CEEQUAL – Civil Engineering Environmental Quality Assessment and Award scheme

CEEQUAL complements BREEAM, which focuses on sustainable development of buildings and communities, in providing the generic assessment of the environmental quality of design and construction of major civil engineering projects. CEEQUAL was developed by collaboration of major industry partners under the auspices of the Institution of Civil Engineers (ICE), which came into operation in 2004. The method promotes consideration of sustainable issues throughout the procurement process and covers project management, land use, landscape, ecology and biodiversity, historic environment, water, energy and carbon, use of material, waste, transport, effects on neighbours in civil works.

Unlike BREEAM, it does not allocate points or benchmarks works against specific measured performance levels as projects vary between types, but focuses on the actions undertaken to ensure that environmental quality is built into the design and construction processes. It provides a protocol for assessing, benchmarking, and ‘labelling’ the sustainability performance of projects. Six categories of awards are available to recognize the roles of different stakeholders and stages in the procurement of a project: Whole Project Award (WPA); WPA with an interim client and design award; client and design award; design award; construction award; and design and build award.

2.6.4 UNEP – United Nations Environmental Programme

UNEP is the United Nation’s (UN) arm for addressing environmental issues at the global and regional level and has the power to administer the UN sanctions and enforcement laws. The UNEP has the mandate of coordinating the development of environmental policy consensus by keeping the global environment under review and bringing emerging issues to the attention of governments and the international community for action. UNEP is currently administering a sustainable ‘Buildings and Construction Initiative’. This cluster has a mandate to: promote improved support mechanisms for energy efficiency in buildings under the Kyoto Protocol; (2) identify and support the adoption of policy tools which use a life cycle approach to investment within the building sector; and (3) develop benchmarks for sustainable buildings.

2.6.5 International standards

There are various other international standards specifically to highlight requirements for Environmental Management systems to enable organizations to develop and implement a policy and objectives which also account for the legal and other requirements to which an organization subscribes, and information about main environmental aspects. They also cover assessment of environmental, social, economic, and general frameworks. Such standards are: ISO 14001 – Environmental Management Systems; European Commission Mandate M350 – Integrated Environmental Performance of Building; World GBC – World Green Building Council Movement; GRI – Global Reporting Initiative, and others.

There are new drives towards methodologies which show the environmental performance of our activities, ranging from personal carbon-footprint, to complex sustainability assessments for components, building, infrastructure and the entire built environment. The rush to demonstrate sustainability in our activities has led to more and more standards, guidance, and rating methods (Townsend, 2013: 382). While some of these efforts meet the standards and contribute towards moving the agenda forward, the plethora of ideas breed confusion and conflict in the industry and a lack of consistency in priorities and direction. Developing countries, especially mostly from Sub-Saharan Africa, have not really developed their own tools and rating standards, still adopting mostly BREEAM and other international standards. This also has its own importance because of the peculiar nature of our environment and needs.

2.6.6 GBCSA – Green Star South Africa

The Green Building Council SA has developed the Green Star SA rating tools to provide an objective measurement for green buildings in South Africa and to recognize and reward environmental leadership in the property industry. GBCSA is an adaptation of the Australian BREEAM tailored to the South African context. Each Green Star SA rating tool reflects a different market sector including office, retail, multi-unit residential, public and education buildings, as well as others that are in development such as interiors and existing buildings performance (www.gbcsa.org.za).

The objectives of Green Star SA tools are to:

- establish a common language and standard of measurement for green buildings;
- promote integrated, whole-building design;
- raise awareness of the benefits of green building;
- recognize environmental leadership; and
- reduce the environmental impact of development.

Agreed standards and benchmarks for green building allow us to objectively assess just how 'green' a building is. Rating systems provide a menu of green measures that can be used in the design, construction and management of a building to make it more sustainable. There are several rating systems, including LEED from the US, BREEAM from the UK and Green Star from Australia. The Green Building Council SA uses the Green Star South Africa rating system, based on the Australian system and customized for the South African context. Building owners submit documentation to the Green Building Council SA to achieve a Green Star SA rating. We employ independent assessors to evaluate submissions and allocate points based on the green measures that have been implemented. Certification is awarded for 4-Star, 5-Star or 6-Star Green Star SA ratings.

2.7 Change: the necessary instrument

The stakeholders in the construction industry have been continually seeking to apply better technologies and processes to improve project delivery and derive better value for resources input, but change has come very slowly because of the lack of a unified strategy and little incentive for change. The lean-sustainability construction philosophy views a project as a promise delivered by people working in a network of commitments within the caring capacity of the ecosystem. Smooth work flow is dependent on having the parties to construction make promises to carry out assignments, and keep their promises. Waste is weeded out, work flow becomes more predictable, performance increases and projects can be completed more rapidly and sustainably (Lichtig, 2006: 12).

Change is the necessary instrument if progress is to be made. Heraclitus of Ephesus, realizing this fact 2500 years ago, stated that "change alone is unchanging." In other words, the only thing that is constant is change. In socio-technical systems, Buchannan and Huczynski (2004: 28) aver that organisations respond to change by analyzing the political, economic, social, technological, legislative, ecological factors and modifying their organizational structures and strategies, management styles, working practices, employment patterns and innovative solutions to suit their overall vision and objectives.

Embracing change in an organization requires strategy that may necessitate a change in the beliefs, values, and attitudes of people in the organization and the outsourcing agents – organizational effort runs into some form of employee resistance and it naturally takes time and organization's act of persuasion/assurance to diffuse the need for resistance. Therefore, organization change involves planning, inclusiveness and mind-set for stakeholder's resistance.

2.7.1 Reasons for resistance to change

Smit, Cronje, Brevis and Vrba (2011: 255) state "people will resist change if they think it will cause them to lose something of value". There are various reasons why people feel threatened by their position that will necessitate resistance to change (Figure 2.6). According to Smit *et al*. (2011: 255-256), the following factors are responsible for resistance to change:

1) Uncertainty: People's inherent aversion to change is caused by the uncertainty created by the possibility of losing a job, of having to relocate or of having to undergo further training;
2) Lack of trust and misunderstanding: Even when management processes change that will benefit everyone, people will still resist if they do not fully understand the purpose;
3) Different perceptions: Perceptions of the costs and benefits of a proposed change depend on what individuals think change will mean for themselves and their organisation;
4) Low tolerance for change: People resist change because they fear they will not be able to develop the new competencies necessary to perform well;
5) General reasons: Resistance to change can also be because of inertia (people do not want to change the status quo), timing (change may be resisted because of poor timing), surprise (people do not react favourably to surprises), and peer pressure (work groups sometimes resist new ideas because of anti-management attitudes.

Overcoming resistance to change in lean and sustainability will promote productivity and create value for people in the construction industry. But in doing this, some measures and basic strategies will have to be implemented to help in speeding people through the transition to a sustainable development.

2.7.2 Strategies to overcome resistance to change

Change will often elicit resistance from people any time there is a demand to yield from their comfort zone. Therefore, a holistic approach from the management to lessen the tension and speed up the transition is what is needed to be implemented. Smit *et al*. (2011: 256–257) identify education and communication, participation and involvement, facilitation and support, negotiation and rewards as strategies to overcome resistance to change (Figure 2.8).

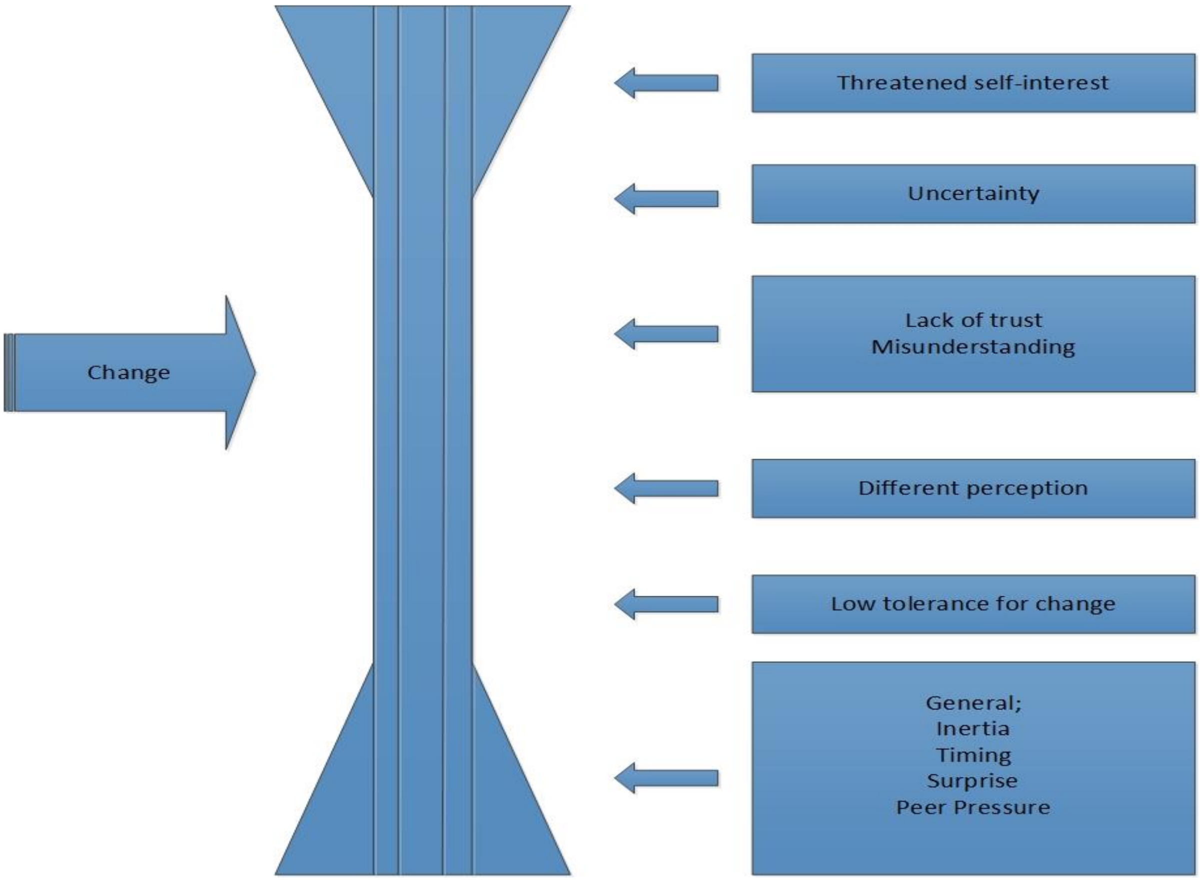


Figure 2.8: Factors for change resistance (Smit et al., 2011: 255).

This will not be an easy process; however, motivation and skills development of construction industry stakeholders will ensure that performance increases by introducing new initiatives, as lean and sustainable constructions are the major initiatives in the industry today.

2.7.3 Understanding the cycle of innovation adoption

For the stakeholders to really understand the best way to go ahead with lean-sustainability transformation there is a need to examine critically the 'lifecycle of change adoption'. The industry has grown accustomed to the idea of 'discontinuous' or 'disruptive' innovations in a variety of aspects of life. Discontinuous or disruptive innovations can be seen as technologies that require a fundamental change to behaviour caused by a new process or technology (Naney, Goser & Azambuja, 2012: 2). Too often, organizations adopt a new management model or new technology based on hopes and expectations for a high return. One of the disruptive technologies that come to mind is the introduction of personal computers and smart phones, which became 'game changers', entirely altering the way business is done. Over the course of the last decade, the construction industry has adopted, even though slowly, many of these 'game-changing' technologies. However, most of the delivery innovations have been continuous or evolutionary, only requiring the upgrading of existing technology or integrating it with existing business practice. All new 'technologies' go through the process of maturation. This life cycle is properly spelt out and described in the Gartner Inc. Hype Cycle model. The Hype Cycle curve (Figure 2.7) compared expectations around an innovation over the time period, which goes beyond general observation and has been used as predictive management decision tool over more than a decade.

The Gartner's Hype Cycle of Innovation demonstrates five distinct phases of innovation adoption over time:

The Innovation Trigger – The cycle begins when an event, product or form of innovation takes place that generates public interest and the hype over its potential triggers some form of interest and early adopters seek a profitable use.

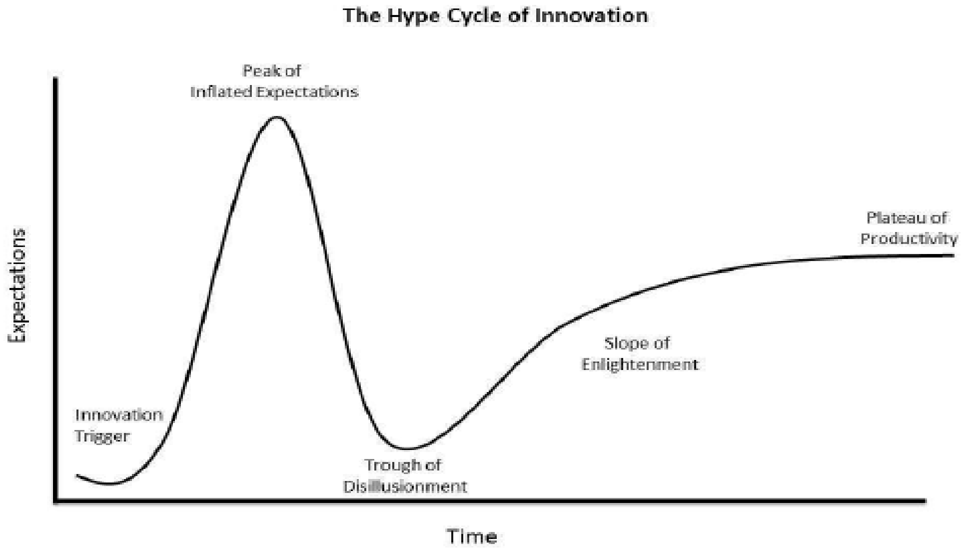


Figure 2. 9: Gartner's Hype Cycle of Innovation (Fenn & Raskino, 2008: 1-4)

The Peak of Inflated Expectations – At this point, firms adopt the innovation in advance of their competitors, claiming benefit and boasting case studies. Competitors try to outsmart each other, adopting the innovation and attempting its use in a variety of settings and to various degrees of success.

The Trough of Disillusionment – As time progresses, excitement fades. Many of the same cases and stories continue, but new adopters begin campaigns for using the innovation without the deep exploration provided by the early adopters. Implementation happens with varying degrees of success and counter-marketing begins as late adopters realize potential benefit is not as easy as hoped. Many leaders and adopters along with media and reporting agencies switch to discussing challenges or obstacles rather than benefits.

The Slope of Enlightenment – The slope of enlightenment is the portion of the curve that happens after the excitement, hope and disappointment take effect. During this phase of the adoption lifecycle, early adopters overcome the initial hurdles, discover the benefits through deeper understanding and exploration and recommit effort and resources to proliferate the widespread usage of the innovation. Over a period of time, the innovation itself matures to a point where best practices are codified successfully through social acceptance.

The Plateau of Productivity – In this last stage, the innovations dynamics are fully understood, real measurable benefit is accepted and greater numbers of organizations feel comfortable with its adoption, having accepted greatly reduced levels of risk. Penetration in industry is accelerated as value is perceived and widespread use is visible.

2.8 Summary

The concepts of Lean and Sustainability have been discussed and the related tools, scopes and practices highlighted. In relation to this study, these philosophies have been described in many ways to capture the common themes as presented in the various definitions and applications. Better understanding of lean concepts by the construction industry can contribute to improvement in all aspects of sustainable construction (green building). The initiative of lean and sustainability seeks to minimize waste during construction, but this common goal is pursued through different approaches and peculiar values. The improvements through the reduction of waste form an important link between lean and sustainability. These two concepts adopt an all-inclusive approach – top to bottom – within organizations.

The lean concept has a positive influence on sustainable building construction in terms of customer values creation and balanced ecosystem. However, the contribution of lean construction to sustainable construction goes beyond the environmental aspect but also extends to the social and economic aspects. Lean-sustainability implementation can exist at two levels – strategic and operational, therefore the implementation issues can be viewed from both perspectives. The lean-sustainability approach has delivered significant economic, social and environmental benefits to companies. Companies are under increasing pressure to create value, deliver profit improvement and to operate their business in a responsible manner, bearing in mind the activities' impact on society and the environment. It is within this context that this research is being undertaken. In Chapter 3 the lean-sustainability approach is conceptualized and theorized towards development of the right mechanism.

3.0 THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1 Introduction

The purpose of this chapter is to review existing process improvement methods and learning frameworks, especially concerning the application of lean and sustainability in construction. This chapter presents the conceptual framework and the theoretical underpinning upon which this study is premised.

3.2 Review of Sustainability Frameworks

For a research work to be meaningful and contribute to the extant knowledge base, it is necessary to review historical studies available within its context. Some of the frameworks developed for achieving sustainability as domiciled in the lean and sustainable development paradigm and necessary for the industry's advancement, especially as related to developing economy, are presented in next sub-sections.

3.2.1 Relational model of sustainable development

The relational sustainable development model is based on the process of delicate balancing of human needs and the ecosystem on which the human species depends for its survival. This relationship is determined by a number of intrinsic factors (Du Plessis, 2007: 67). The first factor consists of those 'needs' that have to be met by society, which is usually dependent on the quality of life available within their domain. This is followed by the mode of technological, political, and economic considerations preferred by the mainstream society. These two factors are significantly linked to the inherent value system of the society. The manner in which constituents of a given society relate with one another vis-à-vis the biophysical environment has a strong correlation with the prevailing value system in the society. The carrying capacity of the environment and the non-renewable nature of the biosphere, in turn, limit the choices available to the society (Figure 3.1).

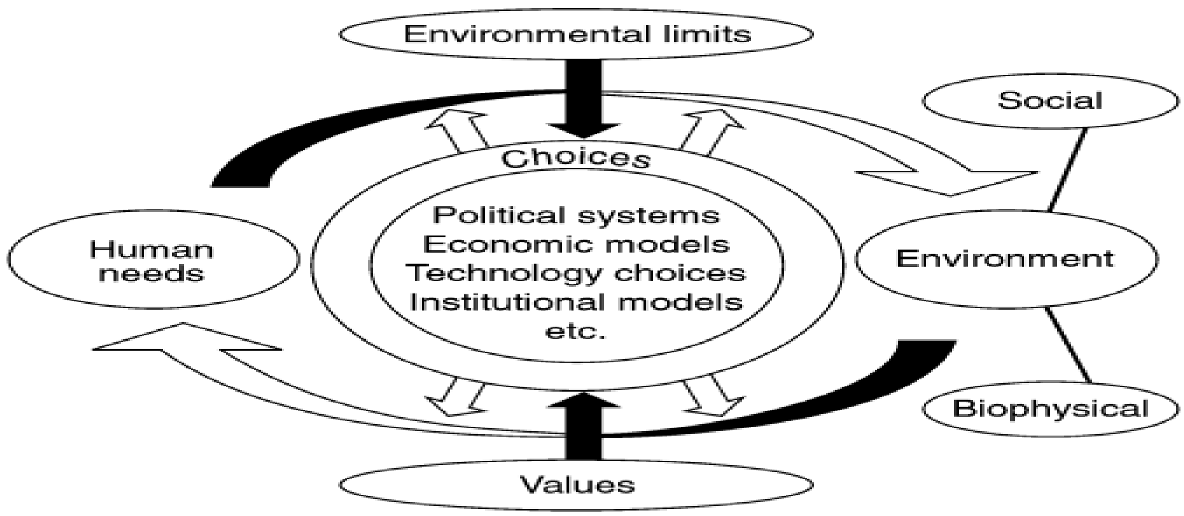


Figure 3.1: A relational model of sustainable development (Source: Du Plessis, 2007: 67)

3.2.2 Life cycle assessment model

Life cycle assessment (LCA) is a green methodology normally used to evaluate the environmental impact of infrastructure projects. It evaluates performance of the building through its useful life to the infrastructure end-of-life. It considers individual elements which, when combined, will effect overall benefits (Pitt *et al*., 2009: 206). LCA examines the entire life cycle of the construction product, process or services by quantifying the environmental impacts, from material extraction and energy used in the production process to acquisition and product-useful life and finally to end-of-life. Over time, LCA has been very useful in the breakeven assessment necessary for green building evaluation, and serves as a driver for sustainable. It enhances decision-making and creates opportunities for improvements within processes, such as construction for better environmental performance and long-time cost minimization (Guggemos & Horvath, 2005; Bilec *et al*., 2006; Sharrard *et al*., 2008; Li *et al*., 2010). Realising its importance, the International Standardization Organization (ISO) and the American National Standards Institute (ANSI) have collaborated to standardize the LCA process. They devised a four-step approach comprising the following: goal and scope definitions, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation (American National Standards Institute 2006; International Organization for Standardization 2006). Other related tools are Eco-quantum, Eco-labels, Ecopoints and Embodies impact study. These tools are enhanced using backcasting methodology in dealing with the complexity involved.

The delay mechanism of the ecosphere, running into decades of time lags, between causes and symptoms of upstream and downstream activities are also very diverse and increase its complication for sound analysis and judgement. Sometimes, this reduces the concept to a matter of trade-offs in triple bottom line. Dealing with this complexity in a comprehensive and systematic way requires an in-depth thinking cause-effect chain of upstream activities by applying 'backcasting' in the planning process (Holmberg & Robèrt, 2000: 94; Cuginotti, Miller & Pluijm, 2008: 29).

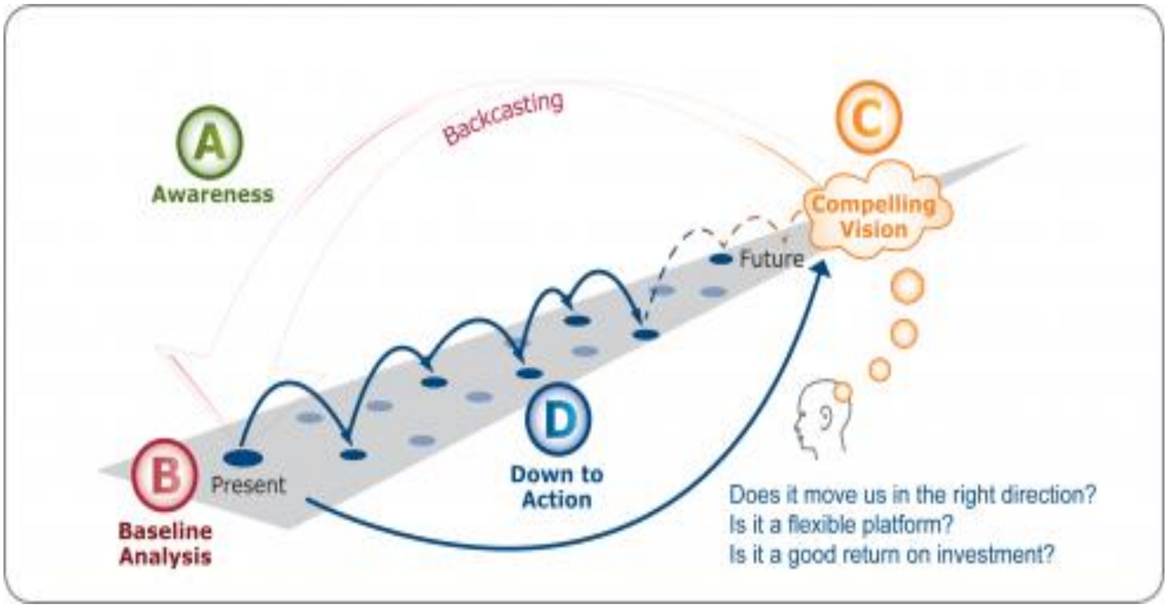


Figure 3.2: Illustration of backcasting methodology (Source: Baxter *et al*., 2009: 11)

Backcasting is different from the traditional forecast (Holmberg & Robert, 2000: 95). The backcasting methodology is premised on the compelling vision of a desirable future condition and a dynamic step is then continuously evaluated to attain those conditions, rather than extrapolating the present continuum into the future. That is, it comprises four basic steps, which are: awareness, baseline analysis of what the condition is, a compelling vision of where to go, and a series of action to get there (Figure 3.2).

Cuginotti, Miller and Pluijm (2008: 29) state that backcasting is particularly useful when applied where the problem to be studied is complex and there is a need for major change, where dominant trends are part of the identified problem, when the problem to a great extent is a matter of externalities, and where the scope is wide enough and the time horizon long enough to leave considerable room for a deliberate choice. These make sustainability a suitable context for backcasting adoption as has been widely used, particularly in Asia.

3.3 Lean and Associated Frameworks

Koskela (2000: 56) states that lean and lean-related tools have been developed either consciously or otherwise over time and are aimed at engendering continuous improvement in the production process. This aims at effort to reduce the share of non-value-adding activities, lead time schedules and supply chain variability, and at the same time increase flexibility and transparency in the production process. These acts result in reduction of process and material wastes, promotion of continuous improvement, and provision of enhanced value for stakeholders, all of which resonate with the lean philosophy. A brief description of some of these frameworks and the list of their common characteristics will be provided in order to determine if the approach can be a template or sufficient for sustainable development.

3.3.1 Lean assessment tool

Various lean assessment tools have been developed to help in establishing efficient processes and practices and/or to improve performance in the construction industry (Salem *et al*., 2006: 18; O'Connor & Swain, 2013: 2). Based on the multi case-study carried out by O'Connor and Swain (2013), Corfe (2013:18) presents a checklist of lean construction tools, principles and practices, as related to achieving the overall vision of sustainability in the construction industry (see Table 3.1). Table 3.1 indicates that lean tools and practices can significantly impact the sustainability and business areas of the construction industry by demonstrating the capacity for problem definition and problem solving, planning and risk management, workplace and process efficiency, and value stream efficiency.

Table 3.1: Lean tools and their relevance to sustainability areas

<table>
<tr><th>Tool type</th><th>Tools</th><th>Impact areas</th></tr>
<tr><td rowspan="2">Problem definition and solving</td><td>Workplace observation</td><td rowspan="9">Sustainability
Resources
Ecology and bio-diversity
Economics
Community
Well-being
Business
Process
Project</td></tr>
<tr><td>Root cause analysis – five whys/fishbone diagram</td></tr>
<tr><td rowspan="2">Planning and risk management</td><td>Collaborative planning</td></tr>
<tr><td>Plan to protect/ FMEA</td></tr>
<tr><td rowspan="3">Workplace and process efficiency</td><td>5S</td></tr>
<tr><td>Standardised work</td></tr>
<tr><td>Visual management</td></tr>
<tr><td rowspan="2">Value stream efficiency</td><td>Process Mapping</td></tr>
<tr><td>Lean design/Design for manufacture and assembly (DfMA)</td></tr>
</table>

Adapted from Corfe (2013: 18)

3.3.2 The framework for lean product life cycle management

The framework for lean product life cycle management is a theoretical model comprising six distinct stages. Stage one of the framework is the understanding of customer needs through to establishment of current product life cycle management status quo. The framework also described some of the fundamental steps required for effective lean overall process management (Hines, Francis & Found, 2006: 866). The approach adopted in the development of this framework outlines how a single project can be managed more effectively from a technical and people-based perspective, respectively. The six stated steps in the framework are: understanding customer needs, value stream mapping, improving end-to-end technical process, improving end-to-end people process, developing the single project standard, and developing the complete process standard (Figure 3.3).

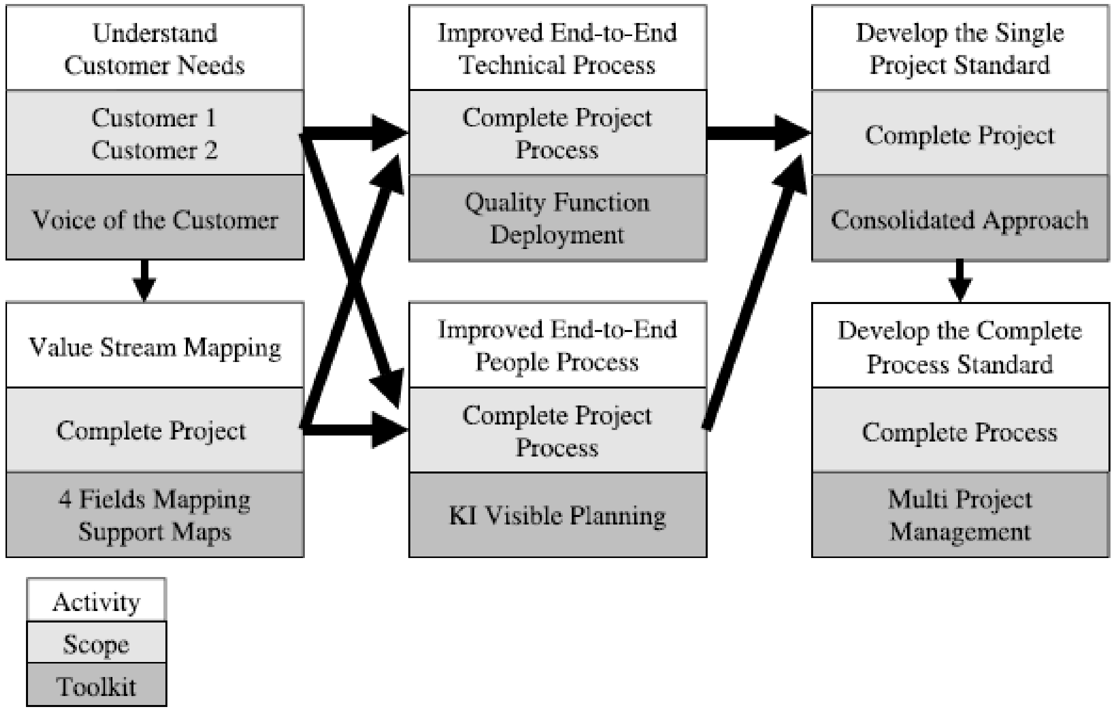


Figure 3.3: Lean Product Lifecycle Management (Source: Hines, Francis & Found, 2006: 875)

- **Understanding Customer Needs**

Hines, Francis and Found (2006: 876) see the concept of customer and customer needs in a broader way than the initial lean pioneering efforts of Womack and Jones (1996: 15). The understanding of the customer's needs was based on the first principle of lean thinking, and the fundamental starting place for any lean process is to focus on customer pull. Hines *et al*. (2006) broadened the customer voice as the first step to include a minimum of two compartments of customer; the external buyer/end-user of the product; and the internal buyer/end user of the process under consideration. This will help create an effective organization that ensures not only satisfied external customers but also an aligned product strategy.

- **Value Stream Mapping**

Lean thinking emphasizes the mapping of the current state of a process and the development of the future state, which is in line with the second step in this developed framework. The step highlighted the appropriateness of four-fields mapping tools as to a number of value stream mapping tools in use. These tools are used to describe a planned or an existing project within four fields, namely: cross-functional participants or stakeholders, various phases (in this case, for a request for quotation), flow chart of the detailed activities within the phases, and the standards by which these processes are performed.

- **Improving End-to-End Technical Process**

The third step of the framework presumes that the Quality Function Deployment (QFD) is a key tool for improving the end-to-end technical part of the process. It draws attention to the interrelationship between the third and the fourth steps in the framework for concurrency, thereby expressing the importance of the technical aspect and people's involvement in a successful project (Hines *et al*., 2006: 875).

- **Improving End-to-End People Process**

The fourth part of the developed framework consists of a people-centred approach, based on the application of knowledge innovation visible planning (KIVP), developed by Japan Management Association Consultants. The focus here is on producing innovative products with the people within the process that will eventually end with the celebration of excellence through concerted efforts (Hines *et al*., 2006: 879).

- **Developing the Single-Project Standard**

Developing single-project standards followed the processes improvements in the developed framework. An attempt to move from a single-project theoretical world environment to one that has repetitive cycles of product development, limiting the barriers of project fragmentation, where any innovation in project management can be incorporated in the future, was considered at this stage (Hines *et al*., 2006: 880).

- **Developing the Complete Process Standard**

The final stage of the developed framework consists of the development of the complete process standard, turning theories into practical applications, in the real world. Products' market performance tends to dominate major texts, with little attention given to the multiplicities of products within a period (Hines et al., 2006: 881). The literature shows that this is exacerbated by the technical product segments of the industry such as the automotive sector that has low varieties and highly innovative products.

As sound as this framework is in relation to this particular study, it appears to be partial or incomplete and originally developed for product development segments of the industry. More so, the framework is yet to be tested in a number of different segments of the industry to ensure its robustness as a framework for the development of competitive advantage.

3.3.3 The 4P Model of Lean

The 4P Model of lean was developed to demonstrate the 'Toyota way' and incorporates 14 key management principles in a pyramid format (Liker, 2004: 27). The main principles are continuous improvement and learning, which sit at the top of the pyramid, followed by development of people and partners, the process orientation and long-term thinking at the base (Table 3.2). Liker (2004: 28) avers that managing the 4P Model can be seen as a prerequisite for sustainable improvements in an organizational set-up. The 14 principles are classified under each of the 4Ps, as shown in Table 3.2.

Table 3.2: The principle of 4P Model of lean

4Ps	**Principles**
Philosophy	- Base management decision on a long-term philosophy, even at the expense of short-term financial goals
Processes	- Create continued process flow to bring problems to the surface - Use pull system to avoid over-production - Level out the workload - Build a culture of stopping to fix problems, to get quality right the first time
People and partners	- Grow leaders who thoroughly understand the work - Live the lean philosophy -Teach the lean philosophy to others - Develop exceptional people and teams who follow the organization's philosophy - Ensure respect for the organization's extended network of partners and suppliers by challenging them and helping them improve
Problem solving	- Go and see for yourself to thoroughly understand the situation - Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly - Become a learning organisation through relentless reflection - Continuous improvement

Adapted from Liker (2004: 27)

3.4. Sustainability and Organizational Learning Approach

Du Plessis *et al.* (2002: 45) posited that for developing countries to embark on a path of sustainable development, the creation of a capable and viable local construction sector is imperative. This can be achieved through an adoption of a sound management culture, learning and adaptation of multi-dimensional enablers such as technological, institutional enablers as well as other enablers related to value systems. This has led to several frameworks for sustainable management and leaning approach developed for continuous improvement in organizations. The ability of these frameworks to be pragmatic in evaluating the impacts of innovative strategies on its business against the expected value-adds is critical (Poksinska, 2010: 320). The need for a qualitative and quantitative impact assessment of improvement and innovative strategies has been argued (Jorgensen & Emmitt, 2009: 236). Assessment and learning tools serve as a roadmap that illustrates the company current status among its important performance parameters and a clear driver for improvement and attainment of sustainability within organizational set goals. Therefore, assessment tools must accurately reflect the nature and complexity of what is being assessed, to permit the right learning protocol for expected outcomes. Jorgensen *et al*. (2007: 372) state that a good assessment tool must include two basic perspectives:

1) A technical perspective, which reflects performance, methods, and tools in relationship to the given organizational strategic 'scope', and

2) Organizational perspective, which reflects management, organizational and human capabilities, culture, and learning.

Several available frameworks, however, address the technical perspective and only a few dwell on the aspects of progressive innovative principles (i.e. organizational perspective). However, a lean-sustainability model can be attainable only with the right technical perspective within continuous organizational learning and practice (Ogunbiyi, 2014: 84). Continuous improvement, respect for people, customer focus, employee empowerment, information sharing and analysis, and participation and teamwork have been suggested to be lean-sustainability values (Corfe, 2013: 30). Continuous improvement requires commitment to learning. Innovations bring about new organization through new ideas, and new ideas usually come from evaluation and learning. Organizational learning and continuous improvement are co-travellers, and the nature of the relationship between organizational learning and continuous improvement is mutual in nature and requires feedback for further innovative opportunities (Madu & Kuei, 2012: 9).

Therefore, the main focus of any organization desirous of continuous improvement and industry competitiveness must be seen as learning, knowing, thinking and understanding organizations. These procedures can only be fully operationalized within organizations embarking on or ready to adopt the sustainable management (SM) concept. SM is holistic in dealing with complex business concepts and is all-inclusive in critically evaluating the parameters for success in a lean-sustainability context.

3.4.1 CIMO Model

According to Madu and Kuei (2012: 11), an innovative vision is a prerequisite for any industry with a set goal of attaining a total sustainability organization. Such vision must be cultivated by the management and shared with all employee and supply chain partners. This vision needs to adopt a strategic option akin to sustainable management (SM) concepts and philosophies. A systems approach with a focus on the context-intervention-mechanism-outcome (CIMO) logic can be adopted (Denyer & Tranfield, 2009: 683). The CIMO model is built around SM in order to adopt a holistic perspective to sustainability (Figure 3.4). Figure 3.4 demonstrates the four components of the CIMO model for SM, namely: Institutional/social/natural setting; intervention, mechanism, and relevant outputs and outcomes.

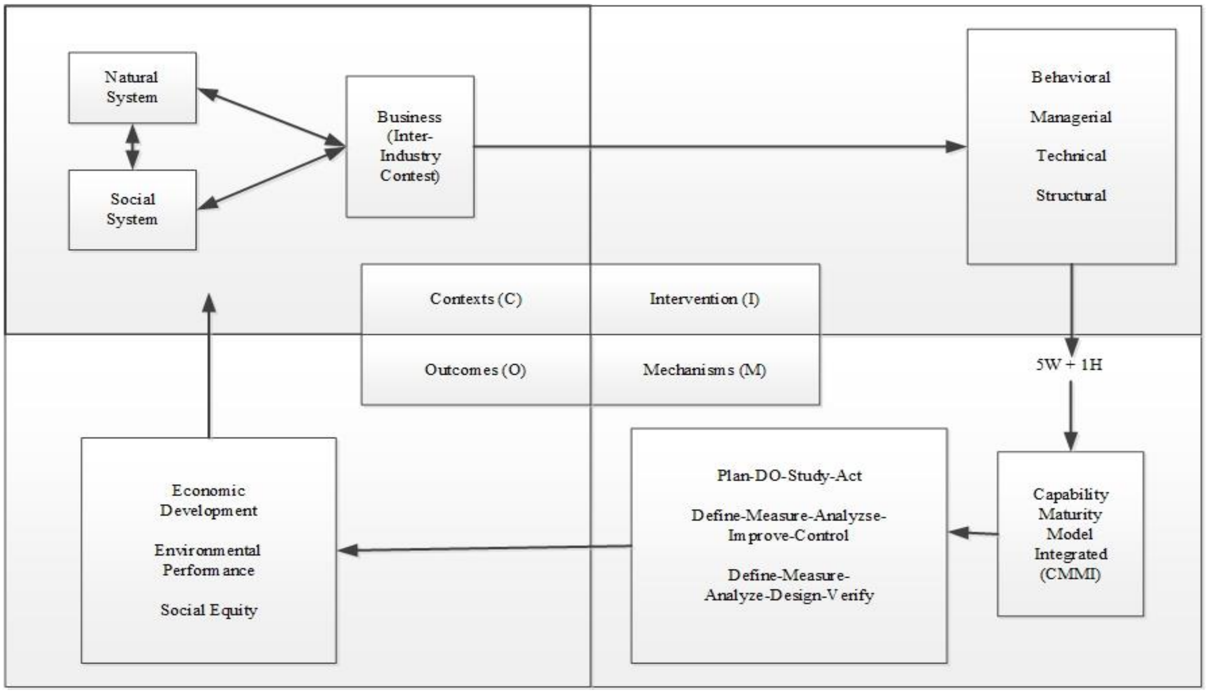


Figure 3.4: The CIMO model (Denyer & Tranfield, 2009: 683)

Context: **-** The successful application of the CIMO model is dependent upon the understanding of the complexity and interrelation of institutional/social/natural systems. The major four constituents of aim, function, appearance, and interacting components represent a screen through which policy makers and sustainability managers may come to see the complexity of organizations fully and effectively (Madu & Kuei, 2012: 12). Therefore, policy and decision makers must be active listeners, facilitators, designers, and communicators, in areas of ethical and legal responsibilities, in order to be successful.

Intervention: **-** Sustainable management (SM) is a holistic driver for sustainability and a strategic approach to achieving compliance, financial robustness, sustainable operations, social development, environmental management, crisis management, and stakeholder relationship management. All these could be classified under four basic components: Behavioural, Managerial, Technical and Structural aspects of SM (Madu & Kuei, 2012: 12).

Mechanism: -

SM relies on applications of proven methods to achieve process improvement and innovation. The mechanism is all- encompassing as it uses the question-and-answer technique in elucidating the sustainability concept, sustainability tools, dimensions and procedure within organizational concepts. And,

Outcome: **-** Sustainability requires that organizations maintain the integrity of social and environmental systems while reconfiguring human resources, management, technical platforms, and structural components to maximize their financial performances. This change induced by sustainability has instigated the development of new types of performance indicators.

The CIMO model is very apt for lean sustainability integration for construction industry development. The model already incorporates most of the lean operating principles in its four main components for sustainable development. However, the model still lacks some basic ingredients of current evaluation necessary for continuous improvement and further innovative opportunities.

3.4.2 Transformation Process Model

The transformation process model (TPM) is an organization-wide SM initiative for stakeholders' interactions between social and natural systems, as a response to the competitive landscape in the new global economy (Madu & Kuei, 2012: 8). Sustainability strategies and capabilities are increasingly important and complex for innovative enterprises in competitive environments around the world. For an organization to simultaneously achieve excellence in sustainable development dimensions of economic, environmental, and social performance respectively, it must undergo a transformation process. Such a process would engender a change from the traditional management approach to SM. The transformational process model (Figure 3.5) is a theoretical framework for sustainability leaders and their value chain partners.

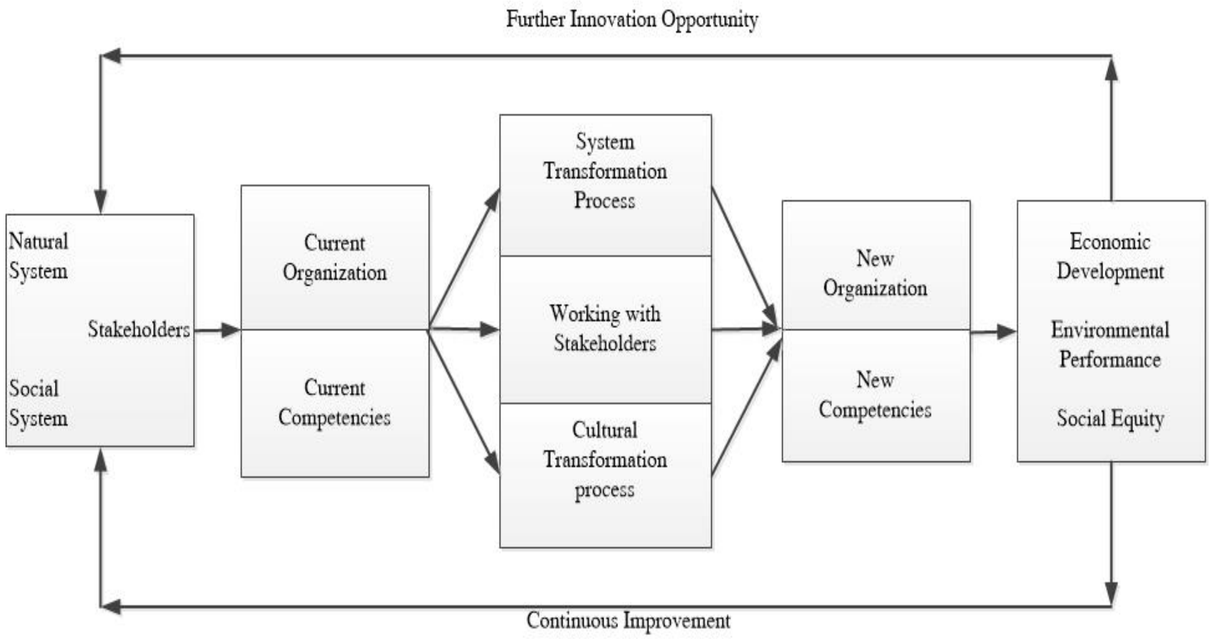


Figure 3.5: The transformation process model (Source: Madu and Kuei, 2012: 8)

As shown in Figure 3.5, stakeholders interact with both natural and social systems. This interaction speaks to the holistic nature of stakeholders' needs and requires a delicate balancing of sustainability requirements. For example, core competencies for sustainability need to be recognized and evaluated for interventions over time. The target here is to move the current situation into a more effective and efficient one. This transformation stage highlights the three main areas where the process of change will impact on a system transformation process, working with stakeholders, and a cultural transformation process. These are the critical principles required to transform the current organization at a point of reflection to a competitive state. Cultural transformation is as a result of the process of emergence – the whole is more than the sum of its parts. It involves using system principles of openness, purposefulness, multi-dimensionality, and emergent property, system dimension; membership, decision system, measurement system, organizational processes and throughput processes, and system methodology. The system transformation is, however, possible due to the influence of relatedness of the parts of a system has on the behaviours of the parts (Luisi & Houshmand, 2009: 101). Therefore, holistic community management involving leadership, employee fulfilment, conflict management, and cultural acceptance thus have economic, environmental, and social impacts (Epstein, 2009: 24).

Organizations must also work with stakeholders on how best to simultaneously achieve excellence in economic development, environmental protection, and social equity in a supply chain. This implies that organizations must take into consideration these concerns throughout the project's whole life cycle and commit the necessary resources to ensure the attainment of sustainability.

Once this transformation is achieved and a process for sustainability is mature, new competencies are attained leading to the birth of a new organization. However, the transformational process assumes a continuous cycle. The organization operates as an open system that evaluates the process maturity for sustainability at a point of reflection, and receives feedback from its internal as well as external environments for further innovation and continuous improvement opportunities. This process involves evaluation of value creation relative to risks and costs.

For the purpose of this study, the approach to industry innovation and learning adopted for the delivery of sustainable public infrastructure will be situated in TPM. The choice of the TPM approach arises as TPM principles resonate with and appear to be the natural background for the lean-sustainability philosophy and both lean and sustainability expectations. Pertaining to this study, the aim is to propose a mechanism for operationalizing the integration of lean and sustainability into the built environment**.** The target case is the infrastructure sector in South Africa. Although none of the SM approaches that have been described above is directly related to the aim of this study, the TPM provides the basics for self-evaluation, cooperation, continuous improvement and opportunities for further innovation in all critical segments of transformation processes of system and culture, and working with stakeholders. Therefore this study adopts the TPM approach to industry innovation and learning for the delivery of sustainable public infrastructure. TPM provides the framework for both internal and external communities to select a set of appropriate metrics for implementation, and specific frameworks in which a company can establish a clear vision of its management processes, focusing on improving its long-term performance for the betterment of the built environment. In other words, TPM provides a basis for sustainable excellence and a holistic framework which covers the whole organization and also provides the capability for continuous evaluations and further improvement. The choice of the TPM approach also arises, as TPM provides the basics for self-evaluation, cooperation, continuous improvement and opportunities for further innovation in all critical segments of transformation processes: system, culture, and working with stakeholders.

3.5 Conceptual Perspective

The contemporary construction environment is greatly characterized by risk aversion, where pressure between KPIs of time, cost and quality hinder optimal value delivery. The emergence of current symptoms from the global environmental, economic and social issues, suggest the fact that the traditional ways of an infrastructure project delivery system are inadequate and not sustainable, calling for a more integrated approach for the world to survive within present environmental limits (Salvatierra-Garrido *et al.,* 2010: 34). The challenges of global environmental issues make desirable a pro-active approach, different from this reductionist, 'scarcity' approach to one of sustainable prosperity through resource renewal and value generation for a smooth transition to ecosystem equilibrium of sustainable prosperity (Novak, 2012: 51).

Infrastructure projects delivery can no longer be viewed in isolation, as it affects all sectors of the economy and accounts for about 50% of energy use. Construction activities have a major impact on physical development, government policies, community activities and welfare programmes. In the USA, buildings alone account for 40% of municipal solid waste, 30% of raw material use, 12% of potable water use, 49% of all energy produced, 77% of electricity produced, and 46.9% of carbon dioxide (CO_2) emission (Floyed & Bilka, 2012: 2). Novak (2012: 51), states that these do not only deplete the earthly physical resources, the transformation from mining raw material into the finished enclosure also requires huge amounts of embodied energy, with a potential contribution to the current planetary adjustment, or sustainable paucity.

This is a call for sustainability 'beyond infrastructure'. The need for innovation within the realm of project performance and value delivery has now been brought to the fore in the construction industry. Lean philosophy stands out as the right concept through which a net enhancement of sustainability ideas in the production process can be facilitated to ensure robust value delivery in infrastructure projects (Corfe, 2013: 10). According to Howell (1999: 3), lean construction is a philosophy and production process that mainly redresses project KPIs' balance by 'increasing value while reducing waste' in the construction industry. This production process is often anchored on waste reduction and normally practised in the segregation of construction process breakdown of the project life-cycle. This potential synergy between lean construction and sustainability initiative is uniquely directed towards the creation of enhanced value and drive towards sustainability (Figure 3.6).

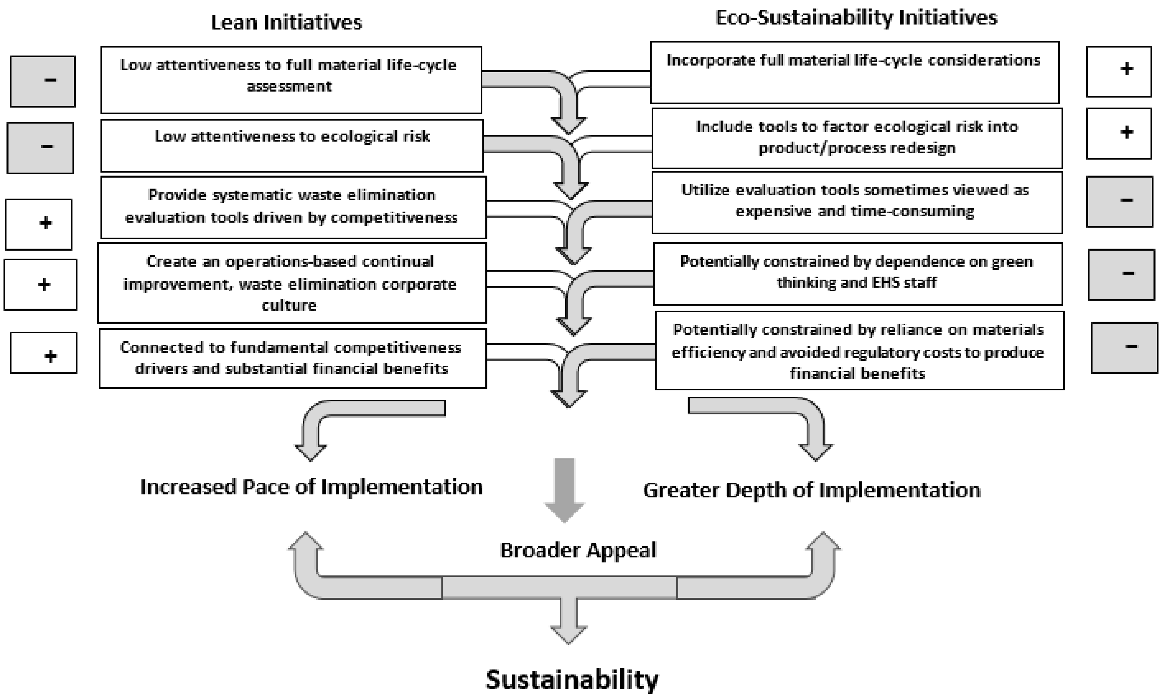


Figure 3.6: Synergies between lean production and eco-sustainability (Source: Larson & Greenwood, 2004: 28)

In order to attain sustainability, activities leading to the creation of goods and services need to be fully understood (Madu & Kuei, 2012: 3). Value stream mapping (VSM) is a reliable tool for understanding this sequence of activities. Green Supplier Network (GSN) has added value to the conventional lean principle of VSM to include both 'lean and green' elements in the traditional mapping principle in an attempt to improve environmental waste (Sarkis, 2012: 89). GVSM enables the construction industry to achieve the elimination of non-value-added time or materials, identification of areas to cut waste, and opportunities to reduce costs and improve performance, and the creation of opportunities for value beyond specification, in areas such as:

- Energy, water, or raw material,
- The level of pollutants and material wastes into the atmosphere, and
- Substances hazardous to health and/or the environment, their use in production process or presence in the product.

Based on this principle, the root causes and major sources of waste, inefficiencies and pollution within the production processes are identified and eliminated through process analyses to create value. The opportunity for value beyond the specifications has emerged as projects with highly developed lean practices have reliably broken through the traditional project tensions and serve as drivers for sustainability and enhanced added value to stakeholders in meeting the tripod of sustainability dimensions (Figure 3.7) (Nahmens & Ikuma, 2009: 2; Novak, 2012: 52).

Accordingly, construction industry stakeholders can leverage the synergy between lean and sustainability to achieve sustainable infrastructure development. The lean philosophy (principles and tools) aligns with the concept of doing more with less – efficiency by doing things right, improve productivity with less human effort, less equipment, less materials, less time and less space to align efforts closer to meet customers' value expectations (Terry & Smith, 2011: 47).

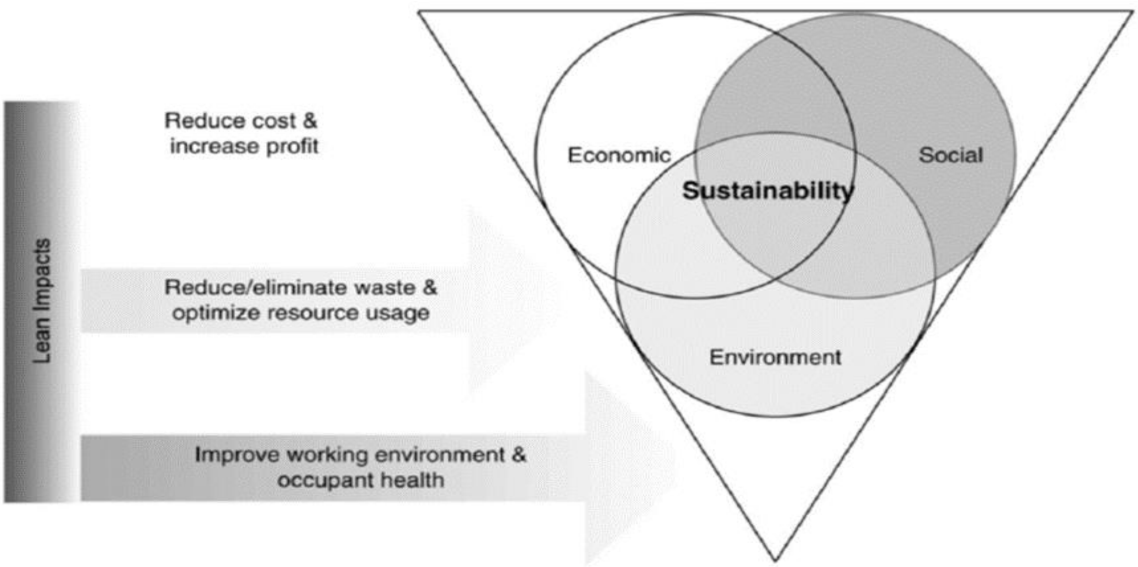


Figure 3.7: Effect of lean on sustainability (Source: Nahmens & Ikuma, 2009: 5)

The sustainability philosophy is based on wastes minimization and prevention of environmental hazards through basic principles of the 4Rs (rethink, reduce, reuse and recycle) to achieve long-time economic and social benefits (Madu & Kuei, 2012: 4). Several works have been produced out on the paradigm of the 'lean sustainable philosophy' that could lead to sustainable development (Novak, 2012; 51; Campos *et al*., 2012: 61; Emuze & Smallwood, 2013: 853; Corfe, 2013: 1) within the field of construction management. The conclusion from these studies is in line with the new proposition of an emerging beneficial synergy for sustainable development. It is the synergy between these two philosophies that will create more value for stakeholders and prove beneficial to continuous improvement and attainment of ecosystem equilibrium in built-environment infrastructure. The integration of lean construction and sustainability practices by the industry's stakeholders will then dovetail into sustainable development necessary for today's industry to create the required value (Figure 3.8).

Figure 3.8: Lean and sustainability synergy for sustainable development (Researcher, 2016)

Value shares the same characteristic as efficiency, which is based on the preferred desirable's outputs from resource inputs. Value is context-specific, relative and subjective in nature (Salvatierra-Garrido *et al.,* 2010: 34). The measurable qualities (output) of infrastructure components are commensurate to the total cost (input) (Womack & Jones, 1996: 311). Under the lean philosophy, continuous improvement of value has been the main pivot of the production process, thus value-streaming by defining the waste. Similarly, in Koskela's proposed Transformation-Flow-Value model of construction management, a more integrated and balanced approach would aid value-streaming and support the elimination of non-value-adding activities through flow management (Koskela 1999:53; Novak, 2012: 52). Industry stakeholders and shareholders have different perspectives to the concept of value, all of which are embedded within a continuous value chain, and being part of the global system, value must be viewed in the context of both natural and social systems (Salvatierra-Garrido *et al.* 2010: 34; Novak, 2012: 52; Madu & Kuei, 2012: 8). These tensions between value drawers and systems add to the complexity of the construction industry. Hence, the future industry model is of a 'value-enhancing' construction process, which could transform the industry and support a transition to resource revitalization and sustainable value creation in a competitive landscape.

The industry operators need a holistic approach toward driving stakeholder and shareholder values in order to create and sustain competitive advantage, through identification of new opportunities and the associated risks. Creating sustainable value is a way for industry to advance their business priorities, drive innovation, and achieve competitive advantage (Laszlo, 2005: 6). The emergence of sustainable value can occur only through delicate balancing of opportunities and risks and creation of positive value for both shareholders and stakeholders, such as the clients and the communities. Managing the two dimensions is fundamental to industry performance and a sound sustainable model (Laszlo, 2005: 6). Ultimately, stronger engagement and collaboration between shareholders and stakeholders leads to discovery of new sources of value through innovation. These factors are required for the industry to successfully create sustainable value in a competitive environment, and within the current economy, social and environmental paradigm (Figure 3.9). The operators must think and act in new ways, shaping strategies and actions with hearty consideration of their impacts on key stakeholders along the value chains (Laszlo, 2005: 7; Salvatierra-Garrido *et al*., 2010: 32; Novak, 2012: 52). These require new levels of knowledge, competences, and holistic transformation within the industry.

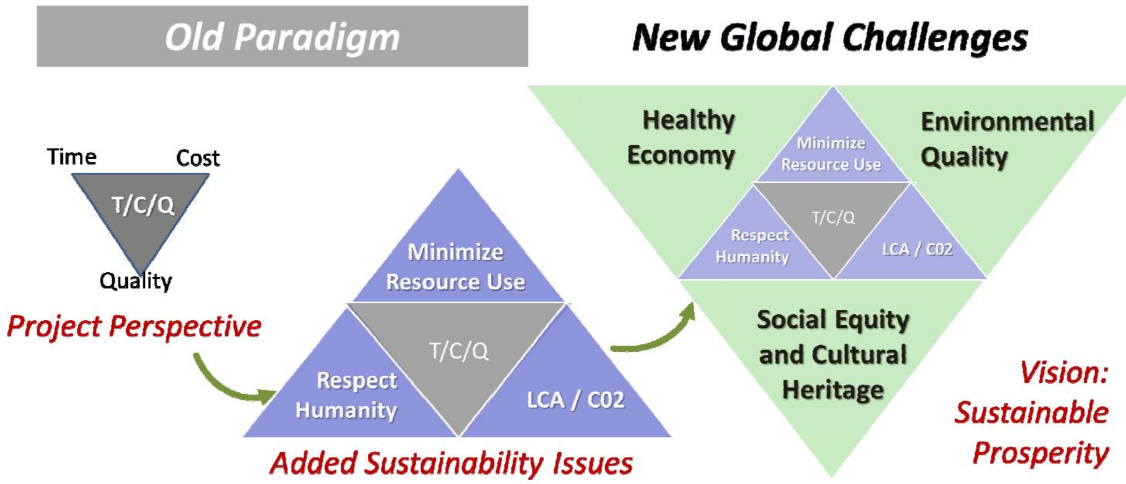


Figure 3.9: The Value paradigm shift (Source: Novak, 2012: 52)

Value can be the template through which stakeholders navigate between natural and social systems to achieve a broader vision of sustainability (Du Plessis, 2006: 74). The challenges of global infrastructural issues can be unravelled, using value as an appropriate construct of change in the context of the construction process improvements (Novak, 2012: 54). However, infrastructure values can only be fully harnessed, if the process of value creation passes through the product life cycle (Bilec *et al.*, 2010: 201). LCA is essential for infrastructure risk aversion – and more so, when considering the generic barriers to infrastructure sustainability uptake of costs and affordability.

One of the pioneering works of Corfe (2013: 31) earlier demonstrated the lean integrated value stream through projects life cycle (Table 3.3). Lean integration created values throughout the project life cycle, and a holistic infrastructure evaluation is best carried out across phases of their life-cycle (Pearce, Ahn & HanmiGlobal, 2012: 164).

Table 3.3: Infrastructure value stream through lean integration

Project life cycle	Lean integration value stream
Brief	Define the 'value' of the project; including performance and sustainability criteria, identify user needs.
Concept	Develop the best concept to meet the value; bring together specialists to define areas for innovation, define systems and set concept design to optimise criteria.
Develop design	Develop construction design; collaborative design and integration of value, develop programme and define key quality and hold points.
Production	Manufacture of offsite elements and components; control of quality and supply, multi-discipline and supply chain integration, to develop optimum systems.
Installation	On site operations; Monitor and improve efficiency and resource use, collaborative working to improve delivery and reduce waste
As constructed	Commission and handover period; integration with client and end users, learning from output performance against as planned.
In-use	Monitoring and efficient use of building and systems; feedback and review of actual performance, learning into future projects.
Deconstruct	Optimise reuse and recycling of components; learning into future projects, efficiency of deconstruction process.

Sources: Adapted from Corfe (2013: 31)

The proposition in TMID is that there can be a synergistic link between lean construction and sustainability, as expressed through the construct of value. Value creation through the lean-sustainability paradigm in infrastructure life cycle could lead to new competences and new organizations for continuous improvement and further innovative opportunities. This proposition is developed through the logical linking of multiple sequential areas of inquiry (Figure 3.10).

The initial phase inquiries into correlation between increased cohesiveness of lean and sustainability with the delivery of project value. The next stage explores the relationship of a case – infrastructure values – with both internal and external communities' sustainability values, and the impact on the project whole life cycle.

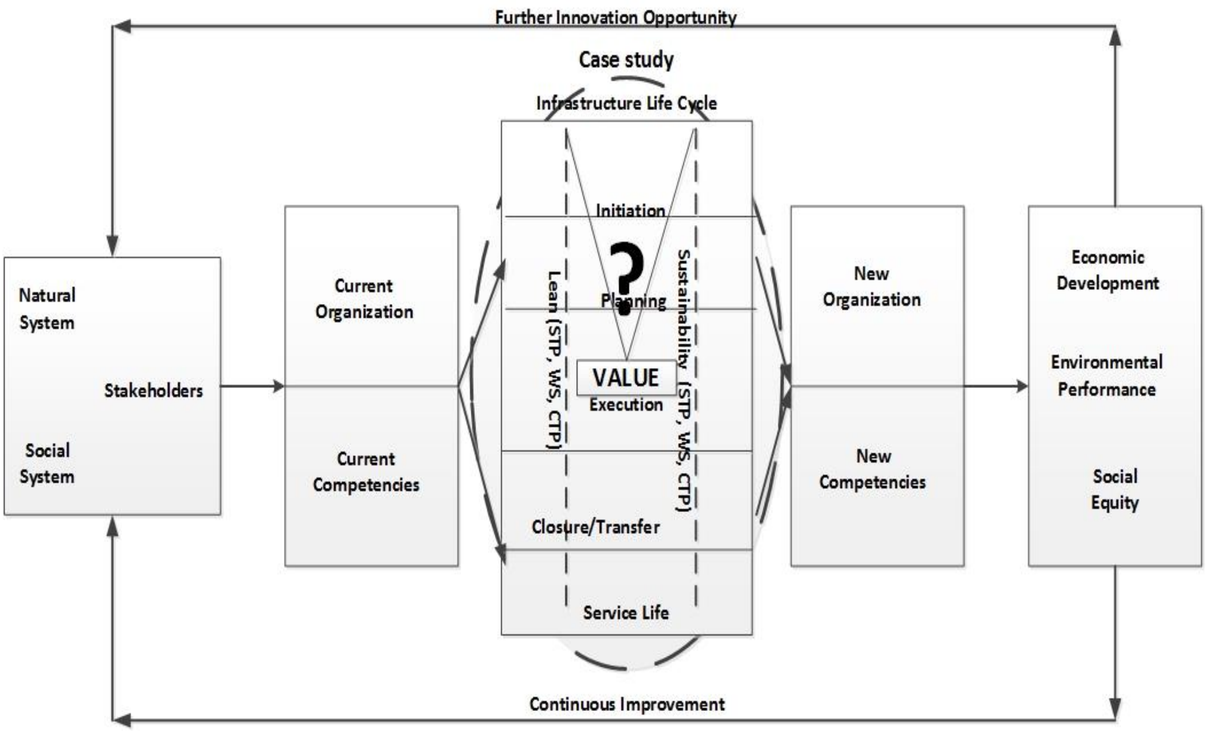


Figure 3.10: Transformation Model for Infrastructure Development – TMID (Adapted from: Madu and Kuei, 2012: 8; Novak, 2012: 54)

The other step explores the impact of lean-sustainability principles on stakeholders' interaction with natural and social systems, and the critical evaluation and development of these core sustainability competences for sustainable development. A final line of inquiry brings the logic of the proposition to a full circle, by examining the opportunity for this broader vision of sustainability to serve as a point of reference for organizations' continuous improvement and further innovation opportunities in infrastructure development. Establishing value as an appropriate construct for industry transformation in the context of the infrastructural development provides a focal point for the built environment sustainable development.

Corfe (2013: 10) claims that lean integration betters the goal of sustainability. Lean practice covers a wide range of infrastructure procurement practices: planning and risk management, collaborative working, problem definition and solving, and value stream efficiency. These approaches include activities and actions to make a difference to the overall infrastructure value delivery, including sustainability performance, and demonstrate the value stream for infrastructure sustainable development. However, it is pertinent to say that major changes delivering high value benefits in terms of cost, time, and sustainability are normally made at the concept or design stages, although opportunities remain throughout the project life cycle (Corfe, 2013: 31). According to Pearce, Ahn and HanmiGlobal (2012: 164), infrastructures are evaluated across phases of their life cycle. These phases (initiation, planning, execution, closure/transfer, service life and end-of-life) are critical constituents of a matrix that must be considered in full or in part, based on the decision support needs of an organization.

The lean-sustainability evaluation of these value streams in the infrastructure life cycle within the socio-technical system perspective would deliver benefits to the end-users. These values in various segment of life cycle must be considered in full or in part based on the decision support needs of an organization to amass benefits. Consequently, one of the limitations of this study is the non-consideration of the end of life phase of the life cycle because of the unavailability of cases for such evaluation.

3.6 Summary

This chapter has presented the context in which sustainable infrastructure is to be discussed. It presents a brief description of some of the process improvement techniques associated with lean and sustainability. However, there is no context specific framework for operationalizing lean and sustainability in South Africa infrastructure development. This lack of efficiency driven mechanism that can guide organizational transformation towards continuous improvement hinders the optimal performance of project's schedules within the sector and slowed the capacity of the stakeholders drive for sustainable infrastructure. An organizational transformation process demands commitment to learning and constant evaluation that results to continuous improvement and opportunity for innovations. An organization cannot improve without new ideas, and new ideas generally come from learning and a shift from traditional system and cultural values into new innovative philosophies, such as lean-sustainability in TPM.

4.0 RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

The aim of this chapter is to describe the study's underlying research design, the philosophical paradigms and applied research techniques. The chapter introduces the research methodology adopted to answer the questions and achieve the aim and objectives of this study. An understanding of the research process is crucial in establishing the epistemological premise on which the scientific presumption is based, in order to give meaning to the research methodology and research methods adopted in carrying out the studies of this nature. This chapter is structured into research process, research philosophy, research methodology, case study research method and justification of the selected method. Also, this chapter will provide an insight into the sampling procedure and units of analysis, data collection methods and data processing procedures as well as the methods of data analysis employed for the study. Furthermore, the methodological framework upon which the entire study is predicated will be highlighted herein. The rationale for the adoption of such a methodological framework will be clearly justified at the end of the chapter.

4.2 The Research Process

The research purpose is to answer questions and attain new knowledge with a science-based tool. Science in this context is used as the method of study and not the object of the study, therefore can be seen as an orderly approach to the acquisition of valid answers and new knowledge. Undertaking research of this nature involves a thorough understanding of various elements of the research process (Gray, 2014: 34). The researcher's ability to determine an appropriate research methodology is considered an important element in a research process. Methodology entails approach to the entire process of a research study, starting from epistemology to theoretical perspective, research approach to methodology, spanning to data collection methods and analysis (see Figure 4.1). As illustrated in Figure 4.1, it is essential to start research work of this nature by considering the related epistemology, as the approach to research and the research methods adopted might be influenced by the belief guiding the measure of the world objective 'truth', or on the contrary, that the real world is too complex to be measured in that way (Gray, 2014: 34).

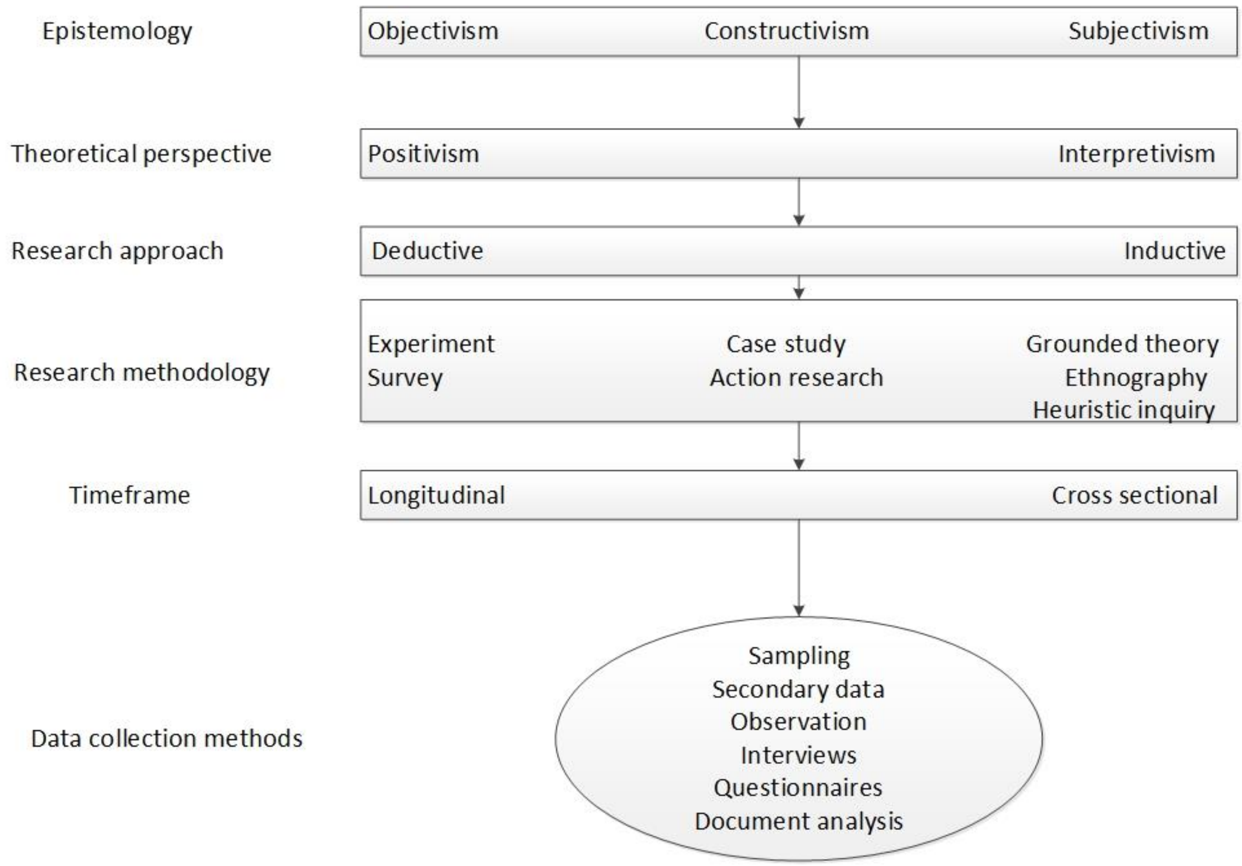


Figure 4.1: Elements of research process (Adapted from Grey, 2014: 35)

This conviction obviously leads to the right theoretical perspective, research approach and data-gathering tools, as embedded in the research methodological framework. Furthermore, it highlights a range of research methodologies and an attempt at some sort of grouping and relational classifications. However, some methodological approaches are quite dynamic in their usage, as the broad tendencies should not be interpreted as a concrete relationship. The best consideration to whatever paradigm is adopted is the need for justification of such stands to research philosophy and research questions (Gray, 2014: 34).

4.3 The Research Philosophy

'Research philosophy' refers to the development and the nature of knowledge (Collins, 2010: 36). The process of creating knowledge can only be presumed and instituted on an acceptable research design. A research design should be based within a specific philosophical paradigm for it to produce valid and credible outcomes. The structure of inquiry and methodological clarity is significant to a landmark discovery of any study. The scientific paradigm accounts for the researcher's moral values relating to the source and nature of knowledge (Morgan, 2007: 50; Collins, 2010: 36). This knowledge base usually guides the researcher's values, assumptions, and techniques in navigating the world order in term of quality output (Willis, 2007: 8). The researcher's belief is shaped by experience and worldviews; such belief often determines the methodological approach that will work within the context of the research endeavour (Easterby-Smith & Lowe, 2002: 27; Creswell, 2009: 6). In other words, a research methodological approach can only be viewed in conjunction with the epistemological and ontological position adopted in the study (Dainty, 2008: 3).

Epistemology has been described by Tracy (2013: 61) as the study of the nature of knowledge and its justification. It examines the origin of knowledge, its limits and how we acquire it, that is, to account for the knowledge in the context of the project. Knight and Turnbull (2008: 65) claim that true belief does not necessarily amount to knowledge, but requires an additional ingredient: justification, which may come from a variety of sources. Knight and Turnbull further stressed that epistemology encompasses the theories of knowledge that proffer answers to questions relating to the nature of knowledge, its acquisition and limitations. Epistemology is, therefore, a conception of reality which places the research assumption into the right perspective, where knowledge could be regarded as acceptable, legitimate and adequate in a discipline (Dainty, 2008: 3; Gill & Johnson, 2010: 191; Gray, 2014: 19). Gray (2014: 19-20) categorized epistemology along three broad divides: objectivism; constructivism; and subjectivism.

Objectivism: "How social entities exist independent of social actors (Saunders, Lewis & Thornhill, 2009: 110)." This depicts the position that social entities exist in reality external to social actors concerned with their existence. Aligning with the positivism, reality consists of what is available to the senses (seen, smelt, and touched), dealing with the facts and not the values (Gray, 2014: 21).

Subjectivism: "Understanding the meanings that individuals attach to social phenomena (Saunders *et al*., 2009: 111)." This depicts the position that social phenomena are created from the perceptions and consequent actions of those social actors concerned with their existence.

Constructivism: "Truth and meaning do not exist in some external world, but are created by the interactions with the world (Gray, 2014: 20)." This depicts the position that "meaning is constructed and not discovered", where a different reality of the same phenomenon is possible – aligning with the position of interpretivism that there is a difference between natural reality and social reality, therefore requiring different kinds of method (Gray, 2014: 23).

Ontology, on the other hand, is concerned with 'existence or being' and whatever we agree to exist must have effects on what we know (Knight & Turnbull, 2008: 66). It is the study of being, of what constitutes reality and of the nature of existence. Ontology, according to Collins (2010: 37), is concerned with the nature of reality which raises assumptions about the way the world works and is perceived by the researchers. Ontology deals with issues of values and ethics of research, that is, it solves the matters relating to ethical concerns of research endeavour (Mertens, 2007: 215; Collins, 2010: 37). "… Ontology embodies understanding *of what is*, epistemology tries to understand *what it means to know"* (Gray, 2014: 19). While the positivists see the world as being independent of our knowledge of it – the process is feeling- and value-free; to relativists, interpretivists and others, there are multiple realities, values and ways of accessing them (Collis & Hussey, 2003: 48; Gray, 2014: 20). Interpretivists, for example, see the world as too complex to be reduced to a set of observable laws – reality behind the workings is much more important than generalization (Gray, 2014: 34). Easterby-Smith and Lowe (2002: 27) suggest that having a theoretical perspective is important to research of this nature; as it helps to clarify issues relating to research design and helps the researcher to recognize which designs will work (for a given set of objectives) and which will not.

This particular research adopts a pragmatic paradigm. The paradigm arises out of actions, situations and their effects as against the worldview of the post-positivism (Creswell, 2009: 9). According to Saunders *et al*., (2012: 109):

"Pragmatism argues that the most important determinant of the epistemology, ontology and axiology you adopt is the research question – one may be more appropriate than the other for answering particular questions."

Essentially, pragmatism is all about what works and finding solutions to problems and the researcher's ability to justify the collective use of both qualitative and quantitative approaches in a research (Bryman, 2006: 116). Tashakkori and Teddlie (1998:30) argue that "study what interests you and is of value to you, study in the different ways in which you deem appropriate, and use the results in ways that can bring about positive consequences within your value system." Thus, the pragmatic paradigm is such that research design resonates with the demand of a particular inquiry and which method is best suited for the researcher. It is more into 'action than philosophy' and better positioned to use quantitative research to throw more light on an aspect of qualitative research, by revealing and/or corroborating certain opinion within the context and vice versa. The truthfulness of any methodological interpretation will only be present when it is practically tested (Tashakkori & Teddlie, 1998: 383; Johnson & Gill, 2010: 206; Creswell, 2013: 4). These features of the pragmatic paradigm make it more suitable for the study, in addition to the aforementioned research philosophy.

4.4 The Research Methodology

Research has been defined as a systematic and organized process of exploring a specific problem for the best solution. It is often about how to solve real problems – the process and the content (Sekaran & Bougie, 2013: 4; Gray, 2014: 3). Methodology is described as a process framework available to an analyst for resolving a given problem (Wilson, 1990: 2). Therefore, research methodology demonstrates the underpinning justifications for the utilisation of particular philosophies, strategies, methods and approaches within a research context. Choosing the research methodology that best suits the research context is important, not only as it will meet the set objectives of a research, but also as it will help in justifying the needed credibility of the work. The research strategy provides the overall direction of the research including the process by which the research is conducted in acquiring knowledge. Research possesses some essential features, which include testing hypotheses, careful observation and measurement, systematic evaluation of data, and drawing valid and reliable conclusions that can be replicated (Fellows & Liu, 2008: 3-5). Methodology is regarded as the general principle that guides the research process in its entirety (Fellows & Liu, 2008: 30). Therefore, research methodology covers all the processes applied in the course of a research activity to achieve its aim and objectives. Leedy and Ormrod (2009: 92) further the argument that relative to the problem and the logic of inquiry, research methodology comprises the technology of data collection, namely tools and methods of research such as interview guides, questionnaires, schedules, case studies, life histories, surveys, participatory observation, and epistemology and anthology of social science guiding the conduct of research.

This research has earlier assumed the relativist perspective, which situates the research within pragmatic paradigms (section 4.2), coupled with the fact that built environment activities are an interaction between natural and social science that warrants a holistic but dynamic approach to inquiry. These peculiar contexts make the case study research method very promising and attractive for this empirical inquiry. Furthermore, case study research (Proverbs & Gameson, 2008: 99) appears to be highly suited for project-based industry with multiple participants.

4.4.1 Case study research methods

Fellows and Liu (2008: 110) describe case study as an in-depth review of a case or a few cases, with the ultimate aim of providing an accurate and comprehensive description of the case. Case study entails a detailed study of one or more organizations with the intention of determining the context and processes of the phenomenon under study (Meyer, 2001: 329). Gummesson (2007: 87) sees case study research as one where conventional cases are used as empirical data for research, especially when knowledge of an area is sparse. Case studies can prove precious when issues of in-depth understanding, increasing conviction and extending the limit of experience about a particular subject are considered (Dooley, 2002: 336). It involves gathering empirical data from the unit of analysis in order to obtain an in-depth knowledge about a problem (Collis & Hussey, 2003: 68). Yin (2014: 14) argues that case study possesses some distinct advantages when a ‘how’ or ‘why’ question is asked about a contemporary set of events, and if the researcher has little or no control over the phenomenon.

According to Yin (2014: 16), case study can be seen as;

> *"…. an empirical inquiry that investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident.*"

In doing this, Rowley (2002: 18) argues

> *"case study research can be based on any mix of quantitative and qualitative approaches. Typically, it uses multiple data sources including two or more of: direct detailed observations, interviews and documents".*

Proverbs and Gameson (2008: 99) affirm that case study research is primarily qualitative in nature, but commonly employs some quantitative data to reinforce the qualitative primary data. It is "qualitative in nature" as it involves complex situations and new areas of development. A qualitative case study design allows for in-depth investigations and rich descriptions of relational phenomena, their dynamics and complexity. Fellows and Liu (2008: 87) suggest quantitative data can be used as a data collection instrument to reveal and corroborate certain opinions within the context of a case study. In a bid to further demonstrate the features of case study method, Yin (2014: 17) further stressed that case study inquiry manages with the technically distinctive situation where many more variables are of interest compared to data points. This situation leads to one result depending on both qualitative and quantitative approaches where the collected data is expected to converge in a triangulating fashion. This triangulation result is subsequently enhanced by the prior development of theoretical propositions in guiding data procedures. In order, therefore, to improve predictability (Harvey, 2013: 18), case-study analysis should be in conjunction with statistical procedure. It is by focusing on cases that a proper and explicit dialectical synthesis can be reached between cause and meaning (interpretation) in order to achieve rationalization (Byrne, 2013: 5). Byrne (2013: 5) further stresses that an attempt at any short of 'generalization' in a case-based method requires classification and comparison.

4.4.2 Justification for case study strategy

The decision to choose case study research as opposed to other types of research in this work was influenced by the widely held consensus on the ability of the design to produce an in-depth understanding of particular phenomena (Fellows and Liu, 2008: 110; Yin, 2014: 11). Saunders *et al.* (2009: 603) claim that an appropriate research strategy has to be selected based on some factors that include the types of research questions and objectives, the extent of existing knowledge on the subject area to be researched, the amount of time and resources available, and the philosophical underpinnings of the researcher.

The peculiarities of case study elicit an informed decision to prefer the research strategy, when its strengths and limitations are compared to other forms of research methodology. For a research strategy to be viable for selection, it must satisfy three basic conditions within the context of the study (Yin, 2014: 9). These conditions consist of the type of research question posed, the extent of control a researcher has over actual behavioural events, and the degree of focus on contemporary as opposed to entirely historical events (Table 4.1). Table 4.1 illustrates these conditions as it relates to five major research methods. Accordingly, case study was preferred when the research questions take the form of ‘how’ and ‘why’. As stated in Chapter 1, the research work was meant to proffer answers to the following questions: (1) how value is created with lean in construction, (2) how value is created with sustainability in construction, (3) what criteria exist for enacting a synergy between lean and sustainability, (4) what the mechanism is for driving lean and sustainability in construction, and (5) how such mechanism can improve construction. It can be noted that the research questions predominantly consist of ‘how’ type of research questions, favouring case study research.

Table 4.1: Relevant situations for different methods

Method	**Form of Research Question**	**Requires Control of Behavioural Events?**	**Focus on Contemporary Events**
Experiment	how, why?	Yes	Yes
Survey	who, what, where, how many, how much?	No	Yes
Archival Analysis	who, what, where, how many, how much?	No	Yes / No
History	how, why?	No	No
Case Study	how, why?	No	Yes

(Source: Yin, 2014: 9)

This is followed by the fact that the researcher has no control over the behaviour of project stakeholders involved in lean-sustainable buildings or the possibility of manipulating variables leading to their actualization. More so, the issues under investigation were contemporary, as the context of this research is about how lean and sustainability practices can be synchronized within the construction industry for sustainable building infrastructure delivery, meeting the three main conditions for case-based method in research.

The method is aligned with the philosophical viewpoint. This research was earlier situated within the philosophical viewpoint of a pragmatist. Pragmatism is based on the argument that "the most important determinant of the epistemology, ontology, and axiology you adopt is the research question" (Saunders *et al*., 2009: 109). Although the research questions show the bias towards interpretivism, subjectivism and value-laden research on the philosophical spectrums, previous research studies have shown the possibility of adopting a positivist approach to case study research (Rezgui and Miles, 2010: 560; Ribeiro & Fernandes, 2010: 162). Hence, case-based approach is often placed in between the two extremes of a continuum: positivism and interpretivism. What available evidences suggest, though, is the predominance of interpretivism territory, that it is common for case study researchers to adopt a constructivism philosophical positioning (Gray, 2014: 35). It can then be said that case study research is compatible with pragmatic philosophical ideals.

Last is the appropriateness and the suitability of the research method. The study context is premised on the applicability of a juxtaposition of lean-sustainability construction principles towards the attainment of sustainable building infrastructure. Although the claim of the dominance of quantitative methods as a research paradigm within the construction management research persists, other forms of research strategies are now being deployed within the industry (Dainty, 2008: 3). Proverbs and Gameson (2008: 99) mentioned that case study appears to be highly suited for project-based industry with multiple participants. This new belief has been further demonstrated by some works in the construction management domain such as lean and sustainability (Panas & Pantouvakis, 2010: 66; Jacobs, 2011: 9; Novak, 2012: 51), which shows a growing acceptance within the industry that has hitherto been lacking. Also, other research strategies such as experiment and survey were considered less applicable to this study as the researcher did not have control over the phenomenon being studied. The generally held positivist positioning of experimental studies is to manipulate independent variables to observe the response of the dependent variables (Gray, 2014: 137). Hence, case study is deemed more appropriate and suitable for the research under consideration. A case study methodology was chosen to best address the exploratory nature of the proposition by investigating exemplary events in the field of lean-sustainable construction. The contemporary nature of the phenomenon also offers an opportunity for rich data presented in mixed methods (Novak, 2012: 56).

4.4.3 The Case Study design

The significance of research design is primarily to ensure coherence within the research process. Rowley (2002: 18) sees research design as "… the logic that links the data to be collected and the conclusions to be drawn to the initial questions of a study". It is an action plan for meeting the study objectives through the questions to conclusions. That is, case-based research design should demonstrate a clear view of the research aim and objectives on which the themes and prepositions to be tested are based. The study under consideration is descriptive and comprises exploratory studies that need propositions (themes), and is generalizable to theory development. The research has to make an informed speculation, on the basis of the literature and any other earlier evidence regarding the expected research outcomes. It is in line with the questions stated earlier that prepositions will be formulated and tested in order to contribute to the theory within the context of the study. The research is pragmatic in nature – as such, a mix of the deductive and inductive approaches is adopted. However, it urges the definition of questions in advance of data collection. Hence, the study provides a two-way approach to issues of validity and reliability, and data collection and analysis.

Gray (2014: 247) suggests that however accurate the case study design adopted, it is pertinent for the researcher to demonstrate a holistic and comprehensive grasp of the cases, dimensions, variable and categories woven together in a specific outline (Patton, 1990: 387). Case study strategies are usually categorised along two distinct lines: (a) the number of case studies used (single/multiple), (b) the proportion of the case that reflects the unit of analysis (holistic/ embedded) (Figure 4.2). As illustrated in Figure 4.2, single-case study research can be justified for study when the following situations avail: when the single case represents the critical case in testing a well-formulated theory; when the single case represents an extreme or unique case; and when the single case is a critical, unusual, common, revelatory or longitudinal one (Yin, 2014: 51). Multiple-case studies, according to Yin (2009: 54; 59), are the selection of two or more cases that are assumed to be similar to predict analogous results in order to give rise to literal replications. Multiple-case study involves selection of case samples in a population from which the cases are drawn that share a commonality, or there exists a basis for comparison and enhanced generalization. It is when a number of cases are studied jointly to investigate a phenomenon (Gray, 2014: 274). The use of multiple cases to test a range of cross-case propositions also boosts the external validity and enhances replicability (Hesse-Biber & Leavy, 2011: 274; Yin, 2014: 55; Gray, 2014: 276). The distinction between holistic cases, and embedded cases is the number of units of analysis. The entire case forms the unit of analysis in holistic case or cases, while embedded cases consist of several units of analysis within the case or cases (Yin, 2014: 50). The difficulties of holistic case studies can be mitigated if multiple units of analysis were used, as it allows for more sensitivity and enhanced earlier notification of potential slippage between research questions and the direction of the study (Gray, 2014: 276). Hence, this study employed the multiple-case/embedded (multiple units of analysis) designs, where the various role players (units) selected are embedded within cases in the South African context.

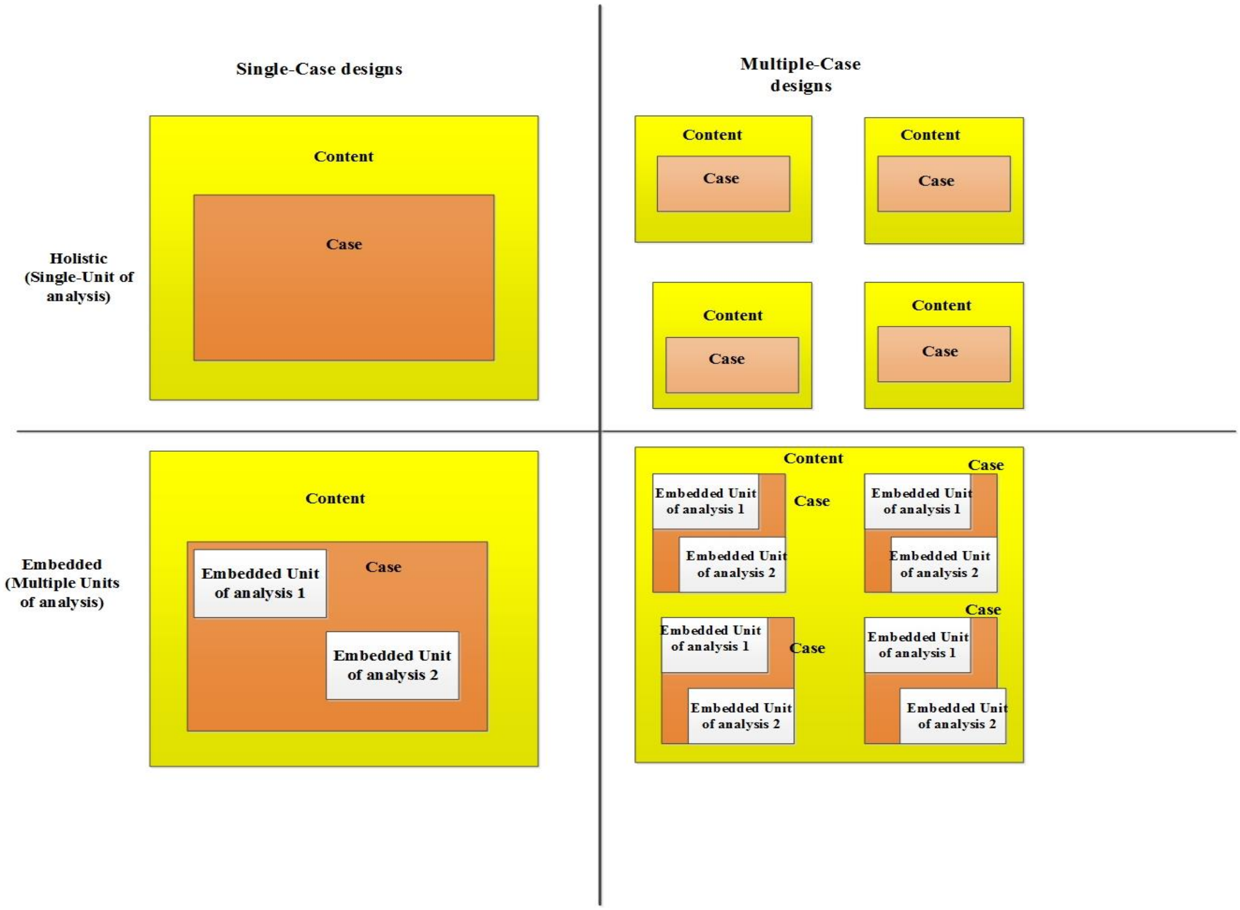


Figure 4.2: Basic Types of Case Study Designs (Source: Yin, 2014: 50)

Case study research employs theoretical sampling as opposed to the conventional quantitative sampling in the selection of cases for the study proper. Theoretical sampling is based on the need to select cases that support replication or extension of the existing or developing theory, so as to provide divergent types of examples (Eisenhardt, 1989: 533). This type of research design requires careful craftwork, as a comprehensive and standard catalogue for case study designs has yet to emerge (Yin, 2014: 27). This 'primitive state' was reinforced by the work of Eisenhardt and Graebner (2007: 26) that alludes to the fact that the selection of cases for the purpose of case study research has posed a great challenge to an attempts to build theory from cases. Eisenhardt and Graebner (2007: 27) then advocate for the correctness of theoretical sampling; a situation where

> *"...cases are selected because they are particularly suitable for illuminating and extending relationships and logic among constructs."*

They further argued that this is proper for the development of theory and not theory testing. This, they maintain, is the answer to questions posed on the representative nature of cases for the purposes of analytical generalization. It is in line with this, that the selection of cases in this particular study was made to ensure that those selected cases not only allow logic among constructs for analytic generalization towards theory development, but also assist in the testing of the propositions with the findings.

4.4.3.1 Selection of Cases

The purpose of this research is to develop a mechanism for the integration of lean and sustainability in building infrastructure development within the South African built environment; by highlighting the best practices (principles/tools/techniques) that work, so as to serve as a roadmap for industry stakeholders' in the attainment of sustainable development. Consequently, the selection of cases was based on one hand, on the criterion of the Green Building Council of South Africa (GBCSA) and on the other hand, the evidence of integration of lean principles on the building infrastructure development in the built environment. These are to extend the needed relationship and logic among lean-sustainability constructs. Succinctly put, the selected cases were based on the information available on the Green Building Council data base (https://www.gbcsa.org.za/projects/case-studies/) of certified buildings.

While the adoption of the lean principle was verified through pilot survey data and documents review of three prototype projects in the USA (Table 4.2). This is due to the dearth of lean- certified projects and the infancy of the Lean Council within the study area. Table 4.2 illustrates the summary of the prototypes and their characteristics as it relates to the lean-sustainability construct. These prototypes serve as a vignette to demonstrate L-S integration best practice, in understanding what works in the L-S concept. The major deductions in these projects are that traditional project delivery inadequately equipped to deliver L-S integration, an Integrated Form of Agreement (IFOA) contract is required for successful implementation of the construct, earlier involvement of core project teams, multidisciplinary collaboration, change agent (L-S champion) and making the project's overall success the primary goal. Moreover, lean and sustainability practices are of similar implementation strategies, but distinctly different in evaluation perspectives (Miller, Pawloski & Standridge, 2010: 12; Seed, 2014: 1147).

Table 4.2: Lean-Sustainability Prototypes Projects in USA

Cases	Description	L-S integration best practices	Outcomes
Sutter Medical Center Castro Valley, CA by Universal Health Services, Inc. (UHS).	A 230,000 square feet and seven-storey tall Sutter Health hospital. The $320 billion healthcare facility project was funded (without public dollars) by Sutter Health, a not-for-profit health system in Northern California. Opened to patients in 2012.	- Integrated project delivery (IPD), a common value and culture in lean and sustainability practices. - The desire for early involvement from the constructors and specialty trades and strong multi-disciplinary collaboration demands - A new kind of leadership - High degree of collaboration - Self-learning on numerous projects through Study Action - Engagement of lean and green consultants to provide formal training in personal assessment and team building.	- Delivered at or better than predictions for cost, time and other schedules to include sustainability. – Out-performed similar project cost targets by between 10% and 30%. - Reduced project wastes and conflicts - More leaders created (integrated project managers).
Seattle Children's Bellevue Clinic, Bellevue, WA	A two-storey hospital with a total of 80,000 gross square feet that cost approximately $75 million dollars to construct in 2010.	- An Integrated Form of Agreement (IFOA) contract - The owner, design team, and general contractor all entered into a single contract - The mechanical and electrical sub-contractors were involved early and	- More ownership of work process. - The project was delivered three months ahead of schedule, $30 million was saved from initial estimates, the square footage was reduced 27%, and the

		contributed during the design phase. - Due to the shared risks and rewards of the IFOA, the project participants changed their typical approach by making the project's overall success the primary goal.	green building goal was exceeded due to the IPD method - Eliminates re-work -Exceeded the LEED target.
Michigan State University Shaw Hall	The Vista at Shaw Hall is a dining facility on the Michigan State University campus. The first IPD project on a US public university campus.	- Adopted IDP and collaborated on design. - Shared the risks and rewards of the project - A change agent (champion) - Earlier involvement of project teams.	- Achieving LEED Gold in 2014 instead of the original goal of LEED Silver - Effective and efficient project delivery - Exceeded budget and create extra value

Sources: Kim and Dossick (2011: 53); Aliaari and Najarian (2013: 32); Neumann and Smith Architecture (2014:1); USGBC (2015:1).

Adequate care was taken in selecting similar infrastructures that exhibit a similar projects characteristic in the selection of the cases. These are those building projects that can be used as a standard of judgement by which lean and sustainable traits were inherent. These values encompass the natural and socio-economic aspects of infrastructure development as it relates to various stakeholders in the industry (Edum-Fotwe & Price, 2009: 313; Emuze, 2015: 19).

As illustrated earlier, the research design is an embedded type of case study, with multiple cases and multiple units of analysis. Yin (2014: 57) and Eisenhardt (1989: 535) suggest that two or three cases could be selected for literal replication whereas four to six cases can be used to study theoretical replication (predicting contrasting results). In particular, 11 cases were initially identified out for selection out of the 25 cases from the GBCSA database through a mix of purposive and convenience sampling (Flick, 2009: 3). The selected cases have a unique geography and similar delivery patterns that is also united by the common market of public/private working places in Gauteng Province. This was done with the thought to achieve a compelling argument and the needed repetitiveness within the context of the study. The basis for such an argument stemmed from the generally held notion that lean-sustainable facilities hold some benefits for stakeholders compared to traditional types. The final five rated selected facilities attained GBCSA ratings of 5- to 6-star ratings from 2012 to 2016. These can be inferred to range between 5 (good) to 6 (excellent), in order to throw more light on procurement strategies, toward attaining lean-sustainable building in a South African context. The five facilities employed sustainability consultants to properly conceptualize the projects in meeting the GBCSA certification that is the explicit regulatory framework in South Africa. All these are geared towards modifications to allow for analytical generalization of information from the unit of analysis.

4.4.3.2 Determining the unit of analysis

Gray (2014: 271) avers that proper identification of the unit of analysis is critical to design issues in a case-based method and the overall success is dependent on its conformity with the research objectives of the study. A unit of analysis, according to Collis and Hussey (2003: 68), refers to the phenomenon under study, about which data is collected and analysed. Case-based research is practically based on gathering information about the unit of analysis in order to obtain an in-depth knowledge about the research area (Collis & Hussey, 2003: 68). The unit of analysis is the basis for the case, as it identifies what the researcher wants to study within the case study. Fellows and Liu (2015: 25) argued that case studies commonly extract information from key 'actors' (informants) in the subject area. In this study, the interplay between natural and social edifice that leads to sustainable building infrastructure is demonstrated by the industry stakeholders. The project teams, facility managers and users are the main players in the procurement and the subsequent management of the life cycle of a particular infrastructure asset.

4.4.4 Generalisation, validity and reliability of case-based method

Generalization, validity and reliability are the concepts that determine the quality of research strategy. The quality of work demonstrated by a researcher is the basis on which other researchers should regard a piece of research as knowledge that can be assimilated into the knowledge base of a field of study (Rowley, 2002: 20; Yin, 2014: 45). It is essential to demonstrate that these concerns have been fully considered for a research to be worthwhile. As case study research is often subjected to criticism for lack of quality when compared to other forms of research strategy, it is imperative to establish the validity and reliability of the strategy by following design tests of construct validity, internal validity, external validity and reliability (Table 4.3).

Table 4.3: Case study tactics for four design tests

TESTS	*Case Study Tactic*	*Phase of Research in which tactic occurs*
Construct validity	• Use multiple source of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection Composition
Internal validity	• Do pattern matching • Do explanation building • Address rival explanations • Use logic models	Data analysis Data analysis Data analysis Data analysis
External validity	• Use theory in single-case studies • Use replica logic in multiple-case studies	Research design Research design
Reliability	• Use case study protocol • Develop case study database	Data collection Data collection

Source: Yin (2014: 45).

Table 4.3 highlights the different tactics used in this research to satisfy the quality tests, thereby ensuring the validity and reliability of the research strategy used. Data must firmly demonstrate its consistency to be admissible in research. The consistency of a measure determines the validity and reliability of research. Validity is a measure of the candour of a measuring instrument. It indicates whether the instrument measures what it purports to measure. On the other hand reliability is a measure of consistency not truthfulness of the outcome (Yin, 2009: 54). Thus, validity and reliability are not mutually exclusive, but an outcome must be valid in order to be consistent. Yin (2009: 54) maintains that reliability seeks to prove that research can be replicated and reach the same conclusion if everything remains equal.

However, Leedy and Ormrod (2009: 29) contend that in each case, event of observations and interviews are unique. The uniqueness of the moment requires that each occasion be validated on its own merit and only discarded upon superior evidence. However, generalization is more likely when case study design has been appropriately informed by theory, and can therefore be seen to contribute to the established theory (Rowley, 2002: 18). This form of case study analytical generalization differs from the statistical generalization, as previously developed theory is used as a template with which to compare the empirical results of the case study. If two or more cases are shown to support the same preposition leading to theory, replication can be claimed. All these can be achieved through thorough documentation of procedures and appropriate record-keeping. Many of the approaches for ensuring generalization, validity and reliability are discussed further in the sections on data collection and analysis.

4.5 Ethical Considerations Pertaining to the Study

One of the most important aspects in the field of research is the consideration for ethical issues as a sound designs and carefully constructed data gathering tools can be jeopardised by unethical reporting (Gray, 2014: 90). The ethical consideration was necessary in order to promote the research quality and guard against impropriety, and also to protect the participants and their organizations, as mentioned by Creswell (2014: 92). The research accorded due consideration to ethical issues governing research and publishing in the study. The researcher is also mindful of the established codes of conduct and regulations guiding research work of this nature. According to Fellows and Liu (2008: 250-252) and Mitchell and Jolley (2010: 52), for ethical reasons, consideration must be given to the following:

- Openness: full disclosure of purpose, methods and intended possible uses of research to research staff and subjects, and participation must be voluntary;
- Privacy: the right not to participate; the right to be contacted at the right time and to withdraw at any time;
- Confidentiality: responses/data generated from the questionnaires will be used purely for academic purposes and secrecy it required; and
- Truthfulness: research findings will be presented in an honest manner without any misrepresentation.

"Your reputation rests not only with what you produce, but also with how well you seem to respect other people's intellectual property rights." (Becker & Denicolo, 2012: 132).

4.6 Research Methodological Framework

Research methodological framework can be used to depict the research process used in a study (Figure 4.3). As illustrated in Figure 4.3, the framework shows the various stages in the research process that are discussed and presented in the next sub-sections.

4.6.1 Initial literature review

An essential early stage of virtually all research study is to search for and to examine potentially relevant theory and literature, which resulted from the previous research study (Fellows & Liu, 2015: 61). For the purpose of this research, an initial review of literature was extensively and critically undertaken and the process follows throughout the research in order to build up a robust theoretical base for the research area and serves as a foundation for addressing the problems and meeting the purpose of the study.

Gray (2014: 41) and Fellows and Liu (2015: 39) agree that most research activities often evolve from interest-driven themes arising from past experiential knowledge or from an extensive review of literature. Creswell (2014: 28) sees literature review as a systematic method which allows the identification, evaluation, integration, bridging and interpretation of the existing body of knowledge. It ultimately helps in establishing the context of the research area by identifying the gaps in knowledge, building bridges between related topics, as well as identifying the main methodologies and research techniques that are consistent with the assumptions of the study.

The literature review undertaken in this research study covered the fields of lean and sustainable construction and their applicability within construction organisations for sustainable infrastructure development in South Africa. The review helps to contextualize the study area through exploration of the impact of lean-sustainability concepts on building infrastructure construction through critical examination of its features, processes, barriers and drivers.

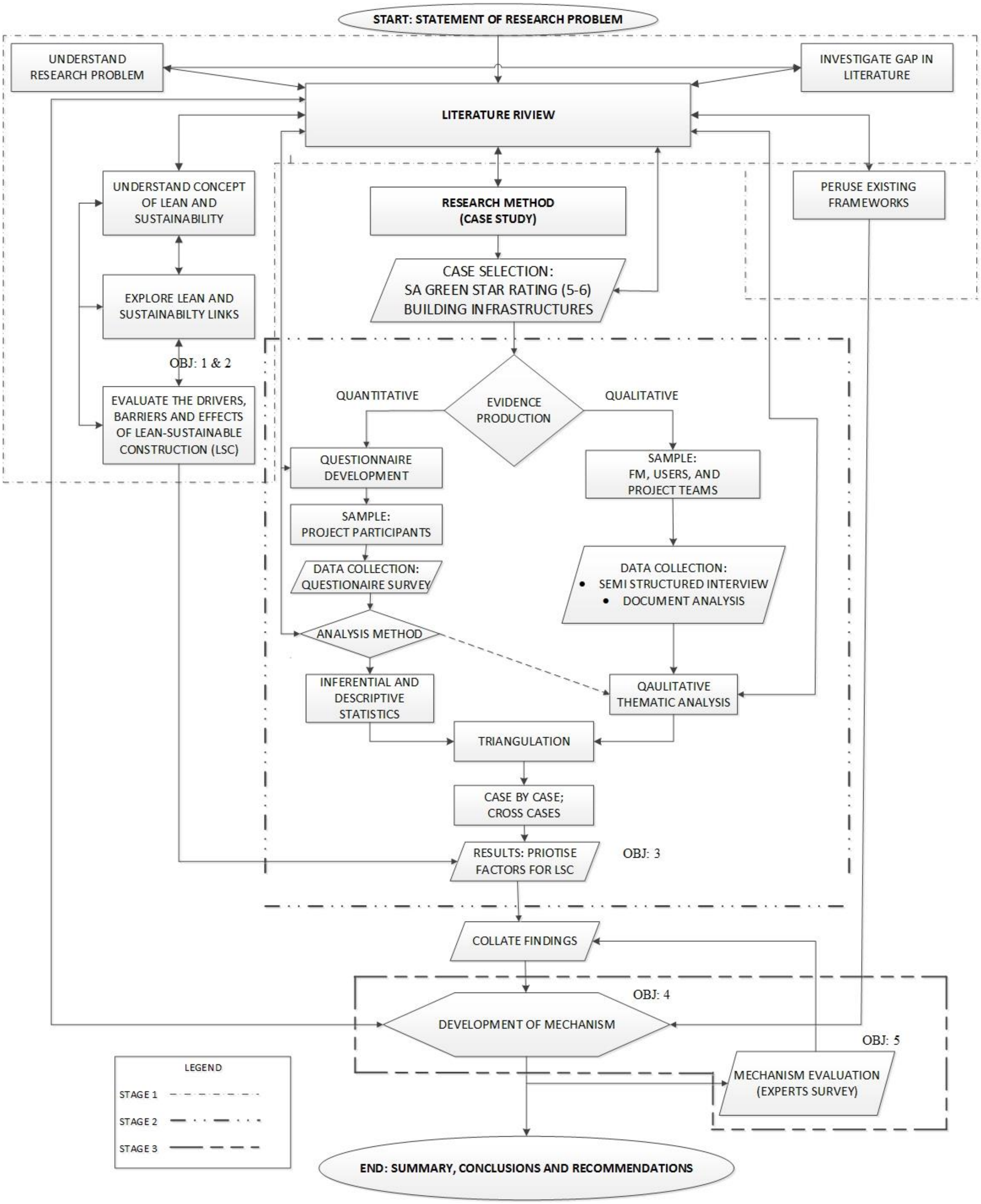


Figure 4.3: Research methodological framework for the study (Researchers fieldwork, 2016)

The outcomes of the literature review led to understanding of the research problem and the derivatives responded partly to the research questions and also helped in the formulation and refining of the research instruments. In addition, the literature review exercise perused the relevant sustainable frameworks in the industry to situate the research within a concept in order to further the limits of knowledge. This was necessary in that it allowed the study to select the most appropriate approach for assessing the benefits of the lean approach in sustainable construction within infrastructure development.

4.6.2 Data collection procedures

Data are pieces of information in an unorganized manner. Data contains finite set of information that must be shorted, processed and presented in a recognized research format in order to draw a valid conclusion (Leedy & Ormrod, 2009: 93). According to Yin (2014: 106), there are six sources of data commonly used in case study research (Table 4.4). Table 4.4 illustrates the strengths and weaknesses of the various sources of data available for used in case study research. These sources of data collection can be more beneficial by adopting the four data collection principles (Yin, 2014: 118-129). These principles are the use of multiple sources of evidence, creating a case study database, maintaining a chain of evidence, and exercising care when using data from electronic sources.

Table 4.4: The strength and weaknesses of sources of data

Sources of evidence	**Strengths**	**Weaknesses**
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of case study • Specific – can contain the exact names, reference, and details • Broad – can cover a long span of time and many events	• Irretrievability – can be difficult to find • Biased selectivity, if collection is incomplete • Reporting bias – reflects • Access – deliberately withheld
Archival records	• [Same as in documentation] • Precise and usually quantitative	• [Same as in documentation] • Accessibility due to privacy reasons

Interviews	• Targeted – focuses directly on case study topics • Insightful – provides explanations as well as personal view (e.g., perceptions, attitudes)	• Bias due to poorly articulated questions • Response bias • Inaccuracies due to poor recall • Reflexivity – interviewee gives what interviewer wants to hear
Direct observations	• Immediacy – covers actions in real time • Contextual – can cover the case's context	• Time-consuming • Selectivity – broad coverage difficult without a team of observers • Reflexivity – actions may proceed differently because they are being observed • Cost – hours needed by human observe
Participant-observation	• [Same as in direct observations] • Insightful into interpersonal behaviour and motives	• [Same as in direct observations] • Bias due to observer's manipulation of events
Physical artifacts	• Insightful into cultural features • Insightful into technical operation	• Selectivity • Availability

Source: Yin (2014: 106).

The researcher was mindful of the aforementioned strengths and weaknesses of the various tools in the adoption process. Furthermore, most of the weaknesses were limited by the adoption of the multiple cases selected.

This research is aimed at proposing a mechanism for operationalizing lean sustainable construction in the built environment: the case of the building infrastructure sector in South Africa. This lean sustainable construction pertains to meeting social, economic, and environmental indices that will bring competiveness and create value in public projects. It involves both the internal and external stakeholders to the exploration of the interaction between the natural and social systems in the built environment. The research is pragmatic in nature, adopting both qualitative and quantitative designs to data collection in the case study.

The case study approach has earlier been justified for the work because of the peculiarity of the research area (section 4.4); sustainable infrastructure (green building) is still developing and the numbers of prime actors' minimal in the South African context. These peculiarities tend to limit the sampling methods to theoretical sampling (purposeful sampling) in the research within the selected cases.

Purposive sampling means that participants are selected according to a defining characteristic that makes them role players of the data needed for the study (Nieuwenhuis, 2007: 82). This logic of the sampling is different from statistical sampling because the idea is to select cases that are replicable or will be able to further the emergent theory. The sampling methods used were, however, independent of each other in that, for the quantitative design, the purposeful sampling of the projects team were used, while purposive sampling of the facility managers and users were used for the qualitative design (Teddlie & Yu, 2007: 92). Creswell and Clark (2011: 183) state that it is beneficial for the two strategies of data collections to have different sample sizes for the two data procedures as this helps the researcher to obtain an in-depth qualitative exploration and robust quantitative examination of the research problem.

4.6.3 Qualitative data collection

The research techniques used under the qualitative collection seek to gain in-depth understanding of the research problem. The qualitative strategy gathered unstructured data that tends to be detailed and rich in both the content and scope (Fellows & Liu, 2015: 29). These data were systematically gathered, keeping in mind the analytical procedure that would reveal patterns, insights, or concepts that seemed promising (Yin, 2014: 135). These promising concepts emerged through various forms of data manipulation. Yin (2014: 136–140) suggested four basic data collection strategic guides to data collection for analytical ease. These data strategies are briefly highlighted below:

- *Relying on theoretical propositions*: to follow the theoretical prepositions that led to the case study; the proposition would have shaped the data collection plan to yield analytical priorities
- *Working your data from the 'ground up'*: to pour through the data; finding out that some part of the data suggests a useful concept or two

- *Developing a case description*: to organize case studies according to some descriptive framework; serve as alternative to working from questions and prepositions, and
- *Examination of plausible rival explanations*: to define and test plausible rival explanations; awareness of rival explanation can influence the data from onset.

It was based on the aforementioned that guides the data collection for this research, and on the primary theoretical proposition that other propositions were derived. The research tools deployed in the data collection under this design are interviews and unobtrusive measures (documentation and direct observation). These tools and how they were deployed are briefly highlighted below:

4.6.3.1 Interview and interview sessions

According to Hesse-Biber and Leavy (2011: 94), interviews can be seen as a conversation between an interviewer (researcher) and the interviewee (respondent) which requires the act of asking questions and listening for answers. The researcher mode of data collection is the verbal information from the case participants – typically, conversation in nature and normally guided by the researcher's mental agenda (Yin, 2014: 239). Interviewing is used to elicit interviewee experiences, opinions, attitudes, values and processes. Essentially, the interview is the favoured approach where there is a need to achieve highly personalized data, opportunities for probing are required and a good return rate is important. The three categories of interviews identified by Hesse-Biber and Leavy (2011: 102-103) include:

- Structured interviews;
- Semi structured interviews, and
- Open ended interviews.

The semi-structured interview variants were deployed for the interview sessions in this stage of the research, with the adoption of both closed and open-ended predetermined questions (see Appendix 2). The structured interviews approach enhances research reliability through process standardisation and replicability (Hesse-Biber & Leavy, 2011: 102). The predetermined questions were answered by the selected role players in the project teams. Purposive sampling was used to determine the facility manager (FM) and users in the group selected to be interviewed. This sampling technique is a non-probability sampling procedure normally associated with qualitative research that has to do with selecting the stakeholders to be interviewed based on the interviewer's knowledge on the characteristics of the population (Teddlie & Yu, 2007: 77). Prior to the main interview session, a pilot study (interview) was carried out among academics and experienced role players in the construction industry to test and refine the interview protocol. This refinement was necessary in order to obtain the input of the expert in the research instrument. This protocol was then sent to the FM and the users of the infrastructures of the selected cases before obtaining invitations for the interview session.

The interviews lasted an average of 30 minutes and were recorded and notes taken. The permission of the interviewees was sought and obtained for recording before the commencement of the interviews.

4.6.3.2 Documentation (unobtrusive measure)

Although the use of semi-structured interviews enabled the collection of data pertaining to the stakeholders' views within the bounded context of the case study (Star-rated building) (Kvale, 2006: 21); the use of archival records provided information which helped in drafting the interview guide as well as resolving any biases established from the interviews (Sauders *et al*., 2012: 155). The Green Building Council South Africa (GBCSA), a body responsible for the rating and promotion of sustainable building in South Africa, archives all the certified completed projects within the region, was reviewed for the selected cases (https://www.gbcsa.org.za/projects/case-studies/).

4.6.3.3 Physical evidence (unobtrusive measure)

The selected cases were physically observed through a tour of the facilities. The purpose was to help confirm the various claims made about the facility using the observation protocol developed based on the claims on the archival records. The physical observation allows the researcher the ability to physically see the sustainability features, design concepts, and ask some relevant questions about the effectiveness of the deployed technologies. These qualitative evidences would be deployed to make sense of the thread of narratives observed in the mixed data sources emanating from the five selected cases in this study (Gray, 2014: 9).

4.6.4 Quantitative data collection

The quantitative data collection (survey) is one of the best strategies often adopted in the collection of data where the objective is to reach a larger portion of the society which would have been difficult to attain using other strategies. The research technique used under the quantitative data procedure is the administration of questionnaires attained through survey design. Survey design, according to Creswell (2009: 145) and Collis and Hussey (2003: 66), collects numerical descriptions of phenomena such as trends, attitudes, or opinions of selected samples that can be generalized to the population. The common sampling method under questionnaire survey is the statistical probability method; no matter how small the population is, sampling errors can be eliminated by adopting the whole population for the survey (Collis and Hussey, 2003: 66; Adinyira, Fugar & Osei-Asibey, 2011: 28).

After selection of the cases as earlier discussed, the project teams were identified from the GBCSA database and the Google search for the addresses followed. The cases selected have an average of seven categories of role players (clients, sustainability consultants, contractors, quantity surveyor, architect, mechanical and electrical (M&E) engineer, and project manager (PM) in the project teams). The mail survey was used through the administration of questionnaires to the project teams of the six selected cases. The above scenario led to a target sample of 42 respondents for the questionnaire. The instruments were reviewed with the Promoter several times prior to the pilot study and with two other people – a post-doctoral fellow, and a senior academic with prior experience in the sustainability field. Furthermore, part of the outcome is a peer review conference paper to further fine-tune the variables of the instrument. The research instruments (questionnaire for the role player) were pilot-tested in accordance to suggestions by Leedy and Ormrod (2005: 152 & 192), Hoxley (2008: 125), and Gill and Johnson (2010: 144). The suggestions of these experts were incorporated in the final instruments before the first set of questionnaires was ready for distribution.

4.6.5 Data Analysis

Yin (2014: 168) suggests, irrespective of specific analytic strategy, four principles to underlie high-quality data analysis in good social science research to include: attend to all evidence, address all plausible rival interpretation if possible, address the most significant aspect of case study, and adopt prior expert knowledge.

4.6.5.1 Analysis of qualitative data

Qualitative analysis involves the process of data reduction to reveal its characteristic elements and structure by gaining new insights into the data. There are various analytical strategies to qualitative data with different data mechanics, such as: content analysis, grounded theory, narrative analysis, and thematic analysis, among others (Gray, 2014: 607–622). This research adopts the thematic approach to data analysis. Braun and Clarke (2006: 77) identify six practical stages to thematic analysis:

- Stage 1: Familiarity with the data. Transcribe the data if necessary, noting down initial ideas.
- Stage 2: Generate initial codes; code interesting features of the data systematically across the entire data set.
- Stage 3: Search for themes; collate codes into potential themes, gathering together all data relevant to each theme.
- Stage 4: Review themes; check if the themes selected are valid in relation to the coded extracts and the data set.
- Stage 5: Define and name the themes; refine each theme, generating clear definitions and names for each theme and identify the 'story' that each tells.
- Stage 6: Produce the report; select clear and compelling extracts relating back to the original research questions and the literature.

4.6.5.2 Quantitative data analysis

The quantitative analysis was analyzed statistically, adopting both descriptive and inferential analytical tools. The study deployed a statistical package for the social sciences (SPSS) version 20, to analyze various statistical tests such as: mean item score (MIS), t-test, and Kruskal-Wallis test to reduce the data to reasonable units for gaining meaningful insight. The MIS was used to rank the variables according to the participants' perception within the cases. The t-test and Kruskal-Wallis test were used to test for any significant difference of outcomes.

- *Mean item score*

According to Audu and Kolo (2007: 47), mean item score is the process of assigning numerical values to respondents' ratings of variable's importance, for example very high influence (5 points), high influence (4 points), in this order. The mean score (MIS) of every importance was computed using equation (2)

$$\mathrm{MS} = \sum \frac{(\mathrm{fxS})}{\mathrm{N}} \quad 1 \leq MS \leq 5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where:

S= the score assigned to each factor by the respondents, it ranges in dependent on the ordinal scale in use (in this case 1-5)

f= frequency of responses to each rating (1-5)

N= total number of responses in the respective score.

4.6.5.3 Data triangulation

Whereas the qualitative analysis adopted thematic approach to data analysis, the triangulation process was aligned with this approach for mixing qualitative and quantitative dataset. Pre-set themes derived from the research questions and the emerging themes from the qualitative analysed data were adopted for presentation. As such, the data was thematically presented based on seven pre-set themes in Chapter 5.

4.7 Profile of Selected Cases

The profile of the five selected cases is presented in Table 4.5. Table 4.5 shows a brief overview of selected cases by providing information such as location, GBCSA rating, description of the projects, major sustainability features and the acronyms.

Table 4. 5: A brief overview of selected case studies.

Cases/ Star (*)	Location	Description	Major sustainability features

C_1/ 5 *	129 Patricia Road, Sandton, 2196	The building comprises seven floors (including a ground floor) of lettable A-Grade office space above five basement levels and open parking. It includes a frameless glass, full-height facade including silicone-based self-cleaning finishes, low-maintenance tile/aluminium cladding and insulated spandrel panels. It features contemporary linear layering of horizontal and vertical structural elements. Its composition is derived through a layered orthogonal articulation from a series of rhythmic interactions of solid and void which embraces the deep and narrow building site.	• HVAC system is a low-energy air-cooled direct expansion variable refrigerant volume (VRV) system with inverter heat recovery. Its power consumption is $\leq$ 45W/m^2 and provides fresh air at a rate of 12.5ℓ/s per person. • Energy-efficient T5 fluorescent lighting and LED lighting are installed and lighting is controlled via light sensors. • The domestic hot water system utilises heat recovery from the VRV system to heat water in the hydro-box units located on the roof. Reduction in potable water consumption is achieved through the water efficient sanitary fittings and rain harvesting. Treated water is used for flushing toilets and irrigation.
C_2/ 6*	B2 House, 8 Tyrwhitt Ave, Rosebank, Johannes-burg, SA	A 6-Star Green Star SA Interiors v1 As Built Rating, demonstrating 'World Leadership'. The building is located within the centre of Rosebank, within walking distance of the Gautrain, Rosebank Mall, Taxi rank and bus stop providing alternative methods for staff and visitors to commute to the office building. Alternative transport methods include a branded electric vehicle with charging facilities and electric bicycles. An Occupancy Users Guide and Comprehensive Transport Plan have been developed for the Solid Green. Interior fit-out to enlighten staff with regards to transport facilities, incentives and local amenities available in the area, as well as how to use building services to the optimum potential. A green lease has been	• Provision of tuning and enhanced commissioning for all services and installations to ensure they operate to their optimal design potential. • An ergonomic assessment has been carried out on the office furniture (new or reused) and workstations by a registered ergonomist with future recommendations • Water and energy sub-meters provide live metering results which are continuously displayed in the foyer via Solid Insight • General Illuminance requirements have been met by providing sufficient lighting levels appropriate to the tasks performed throughout the fit-out. • Energy Star ® rated appliance

		implemented for the Solid Green Office to monitor and report on energy usage, water consumption and waste generation by staff and building visitors. The results are continuously displayed in the foyers via Solid Insight making building users aware of their environmental footprint. Solid Green Consulting has made an effort to reduce their waste generation by developing and implementing an Operational Waste Management Plan and providing separation bins, food waste recycling 'Bokashi', worm farm and recycling waste storage areas within the tenancy. Enhanced ASHRAE Commissioning process was implemented for the fit-out as a prerequisite for the LEED Commercial Interiors v3 Rating achieved. Radiant Cooling was implemented for efficient space cooling as well as Renewable energy to offset the peak demand.	• All printers and photocopy equipment are certified as having low emissions. • Low volatile organic compounds paint, adhesives, sealants and carpets reducing the internal air pollutant levels. • Materials and furniture mostly reused and locally sourced
C3/ 5*	Anderson, Main & Marshall Streets, Johannes-burg, SA	A multi-building development that forms part of the Firm Campus in the Central Business District of Johannesburg. The project comprises of Block A and Block B, which are separate office buildings linked together with an eight-level atrium bridge structure over Marshall Street, and Block C which is a car park and houses the gas-powered Energy Centre on its ground and mezzanine levels. These new buildings extend and expand the existing Campus in a westerly direction and are an expression of the firm faith in the regeneration of the City of Johannesburg and the commitment to sustainability.	• One of the largest grey water plant to ever be installed in any office building in South Africa, with the capacity to recycle 45m³ of grey water. • Towers West has a post-consumer recycled contents of over 90%, this greatly reduces the embodied energy of the steel. • Daylight and motion sensors have been installed to further enhance the efficiency and power saving of the building. • With the building being located in the Johannesburg CBD, the building occupants' overall travel footprint has been decreased due to

		The three buildings are linked through their basement parking. Block A links to Block B under Marshall Street on one level and Block B links to Block C under Delvers Street on all levels. The commercial office space allows for 3800 occupancy for staff. These buildings form part of the Firm's Urban Campus Regeneration Proposal which plans to narrow the precinct's streets to introduce various types of trees to define the urban edge, to reintroduce outdoor artwork, and to improve pedestrian links around the campus to facilitate movement between buildings retail shops and public transportation nodes.	accessibility of various amenities in close proximity
C_4/ 6*	ERF -1563, Arcadia Extension 6, 473 Steve Biko Rd, Pretoria, SA	This is the first government building in South Africa to achieve a 6-Star Green Star SA rating, and the first 6 Star rated building in the City of Tshwane. The project also achieved the highest score for a large commercial office space of this magnitude awarded by the GBCSA to date. The new head office is likely to be a catalyst in the South African built environment, spurring momentum of the adoption of sustainable building practices.	• Optimal building orientation and intense modelling and efficiencies were undertaken to meet the lofty energy consumption goal – not to exceed 115kWh/m2/annum. • The roof is almost entirely covered with solar photovoltaic panels to supply almost 20% of the building's energy needs. • The parking area features a concentrated photovoltaic panel (CPV) which tracks the sun, and supplies power to the electric vehicle (EV) charging station. • Water efficiency measures are expected to consume 30% less water and include rainwater harvesting system, water-wise indigenous plants and efficient irrigation systems. • The Facilities Management (FM) team was involved from the start, and will be trained as

			Accredited Professionals to equip them to operate and keep the building performing optimally.
C5/ 5*	Cnr Aramist & Southern Cross St, Waterkloof Glen, Pretoria, SA	This is the regional campus for the firm in Tshwane with over 1000 staff moved into the building, consolidating 16 premises. In line with their commitment to environmental sustainability. The Firm wanted to assess the impact that a green building has on their staff so they implemented a work place assessment of staff prior to moving to the new building , at the time of the move and then repeated the study for a third time after 12 months. The research will serve as valuable insight into assessing the employee benefits as occupants of green buildings.	• Best practice design for lights and HVAC. • A thermal storage system installed to remove the HVAC peak energy from the national grid. • The building has also focused on reducing the reliance on potable water supplies by capturing rainwater and using it to irrigate the landscape and flush toilets.

4.8 Summary

In this chapter, various components of research philosophy in the context of epistemology and ontology were explained. The research adopted a pragmatic paradigm leading to the selection of case study method to problem solving. The various approaches to the selection of the multi-case study and the data collection instruments were described. The explanations serve as a guide to data collection and analysis in the further chapters.

5.0 DATA ANALYSIS

5.1 Introduction

The purpose of this chapter is to report the data emanating from the application of the previously selected research instruments deployed in answering the research questions. The two stages of the case design earlier presented in section 4.6 is presented and analyzed to elicit findings towards meeting the research objectives. The outcomes of these stages were triangulated during data analysis to provide insight into research questions. The findings are related to the practices of the lean-sustainability construct within the South African built environment space. The links between lean and sustainability practices, drivers and barriers, the lean-sustainability indicators within the selected cases are presented. Specifically, this chapter fulfils objectives 1-3 and serves as part of the template for the development of the mechanism in Chapter 6.

5.2 Presentation of the Cases

As described earlier in section 4.9, the selected cases comprise two 6-star and three 5-star buildings rated by the GBCSA. Table 5.1 illustrates the ephemeral description of the selected cases. The homogeneity of cases needed in sustainability standards for best industry practices were made possible by attempting to select the best available cases within the Gauteng Province. Gauteng Province hosts the highest numbers of GBCSA-rated buildings. The selected building type comprises private and public office spaces. The standards for the lean component of this construct were derived from the illustration of similar cases (see section 4.4.3) to build a vignette depicting best lean practices.

Table 5.1: Ephemeral description of selected case studies

Cases	Location	Star rating (points)	Usage / ownership type
Case 1 (C_1)	129 Patricia road, Sandton, 2196	5-star (60)	Office space/private
Case 2 (C_2)	B2 House, 8 Tyrwhitt Ave, Rosebank, Johannesburg, South Africa, SA	6-star (83)	Office space/private
Case 3 (C_3)	Anderson, Main & Marshall Streets, Johannesburg, SA	5-star (66)	Office space/private
Case 4 (C_4)	ERF -1563, Arcadia Extension 6, 473 Steve Biko Rd, Pretoria, SA	6-star (82)	Office space/public
Case 5 (C_5)	Cnr Aramist & Southern Cross St, Waterkloof Glen, Pretoria, SA	5-star (62)	Office space/private

Moving forward, the cases shall be referred to as: Case 1(C_1), Case 2 (C_2), Case 3 (C_3), Case 4 (C_4), and Case 5 (C_5) in this work to provide for utmost confidentiality as dictated by research ethics. This is to provide for the needed identity secrecy in research ethics. The five cases (C_1 to C_5) exhibit the lean-sustainability construct guiding the study, within which the research questions were analyzed thematically through pre-set themes. The set pre-set themes help to achieve research objectives and coding reliability of the data (King, 2012: 256). These seven (7) pre-set themes that were adapted from the research questions (I – III) are as stated below:

Theme #1: Sustainable construction practices

Theme #2: Lean construction practices

Theme #3: Synergy between lean construction and sustainability in rated green projects

Theme #4: Barriers to lean-sustainability concept

Theme #5: Drivers for lean-sustainability concept

Theme #6: Benefits (indicators) of lean-sustainability on project performance

Theme #7: Stakeholders' role in engendering lean-sustainability paradigm

The themes help to compare the perspectives from the different cases within the context. Data were collected to provide insights into these themes through a mixed methods research design (see Chapter 4).

5.3 Data Collection Procedure

The quantitative and qualitative approaches were deployed sequentially to collect data from the units of analysis within the selected cases. Quantitative data collection adopts questionnaire survey as research instrument, whilst qualitative approach adopts a mixture of semi-structured interviews, archival records, documents review and physical observation. However, the data from these sequential case studies were analyzed to converge with the data from the pilot survey. This convergence helped to improve the internal validity of the research findings (Xiao, 2002: 103).

5.3.1 Quantitative data collection and analysis techniques

5.3.1.1 Questionnaire survey

In this stage of data collection, an initial 76 mails were electronically sent to the respondents (project teams) on 8 and 9 February 2016. The project team included the initial 11 identified case studies. By 12 April 2016, only six of the questionnaires had been filled in and mailed. This was then followed by the visit to the target respondent offices (especially the sustainable building consultants) by the researcher between 18 May and 22 May 2016, with another round of questionnaires consisting of the same questions as previously mailed. This single act increased the numbers of responses to 22 and facilitated the later adopted snowballing technique. The responses were sorted case by case to identify the cases where reasonable progress was made for selection (as target cases). The snowballing technique was then adopted to improve the number of respondents to 32 of the total of 66 administered questionnaires within the selected cases (C_1 – C_5). These responses represent an average of six respondents per case, at 49% response rate as at 24 August 2016 (Table 5.2). After six months of data collection (8 February to 24 August 2016), the data from the five selected cases were analyzed. The structured data from the survey were statistically analyzed, whilst the semi-structured data in the survey were analyzed using content analysis. The analytic outcomes were aligned and discussed along the pre-set themes.

Table 5.2: Questionnaire administered and response rate within the selected cases

Cases	Questionnaire administered	Number returned	Response rate (%)
C_1	14	8	57
C_2	13	8	61
C_3	15	5	33
C_4	13	6	46
C_5	11	5	46
Summary	66	32	49

The satisfactory response rate of 49% within the selected cases may be connected with the targeted approach adduced above. This response rate is considered adequate in social science research. It is on this premise the response rate is assumed to be adequate for the analyses that were carried out.

5.3.1.2 Demographics of respondents

As previously discussed in section 4.4.3.2, the unit of analysis adopted for this study comprised the project teams for the selected cases. Each project team consisted of project stakeholders such as the Client/Client representative, Government/Regulator, Developer, Consultants, Construction Project Manager (CPM), Engineers, and Sustainability Consultant. Table 5.1 illustrates the demographics of the respondents per case and shows information such as: the academic qualification, professional affiliation, years of experience, and capacity on the project. The academic qualification of respondents ranged from B.Tech to PhD, with most respondents holding an Honours degree, with only one PhD. This level of education demonstrates that the respondents had the right knowledge to properly respond to the questionnaire survey. The major professionals in the construction industry were well represented on the affiliations of the respondents with architects being most prominent, followed by the engineers. This scenario represents prominent members of these two professional practices as consultants in different capacities on a project. Most respondents' years of experience were situated within the range of 6-10 years and 11-15 years, whilst none of the respondents had above 20 years in industry experience. These totals of years on the job is an indication that on average, the respondents were experienced enough to give reasonable and reliable responses.

Table 5.3: Respondents demographics

Cases	S/N	Academic Qualification	Professional affiliation	Experience (years)	Capacity on project
Case 1	1	B.Tech	Engineer	0-5	Engineer
	2	Honours	QS	6-10	Consultant
	3	Masters	Architect	16-20	Designer
	4	Honours	CPM	6-10	Client/client rep.
	5	Honours	Architect	6-10	Regulator
	6	Honours	Engineer	11-15	Contractor
	7	Honours	CPM	6-10	CPM
	8	Masters	Others	0-5	Sust. Consultant
Case 2	1	B.Tech	Engineer	0-5	Engineer
	2	Honours	QS	6-10	Consultant
	3	Masters	Architect	16-20	Designer
	4	Honours	CPM	6-10	Client/client rep.
	5	Honours	Architect	6-10	Regulator
	6	Masters	Engineer	11-15	Contractor
	7	Honours	CPM	6-10	CPM
	8	Masters	Architect	0-5	Sust. Consultant
Case 3	1	B.Tech	Engineer	16-20	Engineer
	2	Honours	QS	6-10	Consultant
	3	Honours	Architect	16-20	Consultant
	4	Honours	CPM	0-5	CPM
	5	Honours	Architect	6-10	Sust. consultant
Case 4	1	B.Tech	Engineer	11-15	Consultant
	2	Honours	QS	6-10	Consultant
	3	Honours	Engineer	6-10	Client/client rep.
	4	Honours	Architect	6-10	Regulator
	5	PhD	CPM	0-5	Client/client rep.
	6	Honours	Other	6-10	Sust. consultant
Case 5	1	B.Tech	Engineers	16-20	Engineer
	2	Honours	QS	6-10	Consultant
	3	Honours	Architect	16-20	Sust. consultant
	4	Honours	CPM	6-10	CPM
	5	Masters	Others	0-5	Contractor

Summary:	**Cases:**	5
	Total respondents:	32 (8, 8, 5, 6, 5)
	Academic qualifications:	B.Tech (5), Honours (20), Masters (6), PhD (1)
	Professional affiliation:	CPM (7), Engineer (8), Architect (9), QS (5), Others (3)
	Years of experience:	0-5 (7), 6-10 (16), 11-15 (3), 16-20 (6)
	Capacity on the projects:	Client/rep. (4), Designer (2), Consultant (7)

	Engineer (4), CPM (4), Contractor (3), Regulator (3), Sustainability Consultant (5)

5.3.2 Qualitative data collection and analysis techniques

5.3.2.1 Semi-structured interview

The semi-structured interview was carried out in two stages:

Stage 1

The first stage was carried out during the pilot study to refine the research instruments, and to get insights into the lean-sustainable construct from the construction industry practitioners. The researcher found the outcomes of this stage worth reporting as these corroborated and enriched the evidence from the survey findings during the discussion section of the cross-case as opposed to the intra-case of stage 2. This stage also helped in its initial set purpose of refining the questionnaires for the survey. Four (4) interviews sessions were carried out at this pilot stage. The sessions also created a clearer understanding of the study for an unbiased analysis (Stringer, 2014: 113). The interviewees comprised two (2) senior project managers, a consultant and a senior policy administrator, with an average age and experience of 43 and 19 years respectively. The interviewees hold a minimum of an Honours degree. These sets of interviewees are subsequently referred to as PS1, PS2, PS3 and PS4 in the data analysis section.

Stage 2

The second stage consisted of various interview sessions within the selected cases. The session was held during the week-long visit by the researcher between 18 May and 22 May 2016. The researcher had previously identified a total of ten (10) interviewees. The interviewees were intended to cover the occupants and the facility management (FM) of the selected infrastructures (C_1 – C_5). Interview protocols were mailed to target respondents beforehand and calls were made to confirm the dates. Care was taken to ensure that the selected interviewees had the right understanding of the phenomena. In order to select best interviewees that could provide the in-depth knowledge of the operational workings of the projects. Initially six (6) individuals indicated their readiness to participate in the interview sessions, but this number subsequently increased to seven (7) interviewees during the period (Table 5.4). Most of the interviewees belong to the FM categories officially attached to manage the respective facilities. Only two (2) occupants participated in the interview proceedings, as most intended participants cited the bureaucratic red tape and the safety of their work as limitations. However, the responses were deemed to be saturated, as interviewees seemed unanimous on the various questions posed (Stringer, 2014: 113).

Table 5.4: Response rate of the interviewees in the selected cases

Interviewees	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**Summary**
FM	-	2	1	1	1	**5**
User	1	1	-	-	-	**2**
Total per case	**1**	**3**	**1**	**1**	**1**	**7**

5.3.2.2 Demographics of interviewees

Seven (7) interviewees participated at this stage of the interview (Table 5.5). C_2 have three (3) participants when compared to one (1) participant each for the other four (4) cases. The researcher attributed this C_2 peculiarity to the ownership structure of the case. The developer of C_2 also served as the sustainability consultant that allow the adoption of the design and build (D&B) procurement model that enhanced the integrated process design (IPD). This closed and integrated setting enabled a one-stop- shop for information gathering and approval for data collection. The interviewees were purposively selected and their demographics can be seen in Table 5.5.

Table 5.5: Interviewees' demographics

S/N	Cases	Position	Ownership structure	Qualification	Industry experience (years)
1	C_1	Occupant	Private	B.Tech.	8
2	C_2	FM	Private	Honours	7
3	C_2	FM	Private	Honours	11
4	C_2	Occupant	Private	Honours	9
5	C_3	FM	Private	Honours	12

6	C_4	FM	Public	B.Tech.	7
7	C_5	FM	Private	Honours	13

The narratives from the emergent transcripts emanating from the interviews were so identified and discussed along with other data sources in the pre-set themes.

5.3.3 Documents review

In response to the dearth of certified lean construction projects in South Africa, necessary for the rationalization of robust lean-sustainable construct, within the research area, documents of three (3) certified lean-sustainable cases were sourced and reviewed from the USA, where the construct under consideration is renowned. The document reviews were carried out for the purposes of corroborating the prevailing evidence from other sources within the context of the South African construction industry (Yin, 2014: 105).

5.3.4 Archival records

The Green Building Council South Africa (GBCSA), a body responsible for the rating and promotion of sustainable building in South Africa, archives all the certified completed projects within the region. The GBCSA archival records highlight the characteristics of the star-rated buildings. Characteristics such as sustainability building features, star rating (4, 5, or 6), project teams, project floor areas, and total points earned and areas of point allocation were presented. The researcher mailed the council chairman, and was directed to the GBCSA database for the available information on their archival records on https://www.gbcsa.org.za/projects/case-studies/. This source of evidence in conjunction with other relevant projects' links as made available during 2015 SASBE Conference on Green Building project tour were used in the data mix. The archival records, which are the domiciliary of the rated facilities in South Africa, also aided the researcher in identifying the population for the theoretical sampling.

5.3.5 Physical observation

The selected cases were physically observed through a tour of the facilities. These observations were carried out in phases. The first was during the SASBE Conference on 11 December 2015, when two of the selected cases (C_1 and C_3) were among the facilities visited. The second was during the interview sessions for cases C_2 and C_5. These observations were carried out to help confirm the various claims made about the facility using the observation protocol developed based on the claims on the archival records (Figures 5.1 – 5.5). The physical observation allowed the researcher the ability to physically see the sustainability features and ask relevant questions about the effectiveness of the deployed technologies. Figures 5.1 – 5.5 present some innovative features (green technology) deployed in meeting the GBCSA ratings in the selected cases.

These qualitative evidences were deployed to make sense of the thread of narratives observed in the mix data sources emanating from the five (5) selected cases in this study. The quantitative and qualitative data were then analyzed, presented, and triangulated during discussion of the findings. Conversely, the excerpts of such narratives which are aligned with the pre-set themes were so identified in within and cross-case patterns.

Figure 5.1: Central HVAC system fitted with automatic climate control system

Figure 5.2: Arrangement of Photovoltaic solar panel for alternative power source

Figure 5.1: Rain-water harvesting doom for water management

Figure 5.2: Underground grey water tank for water recycling

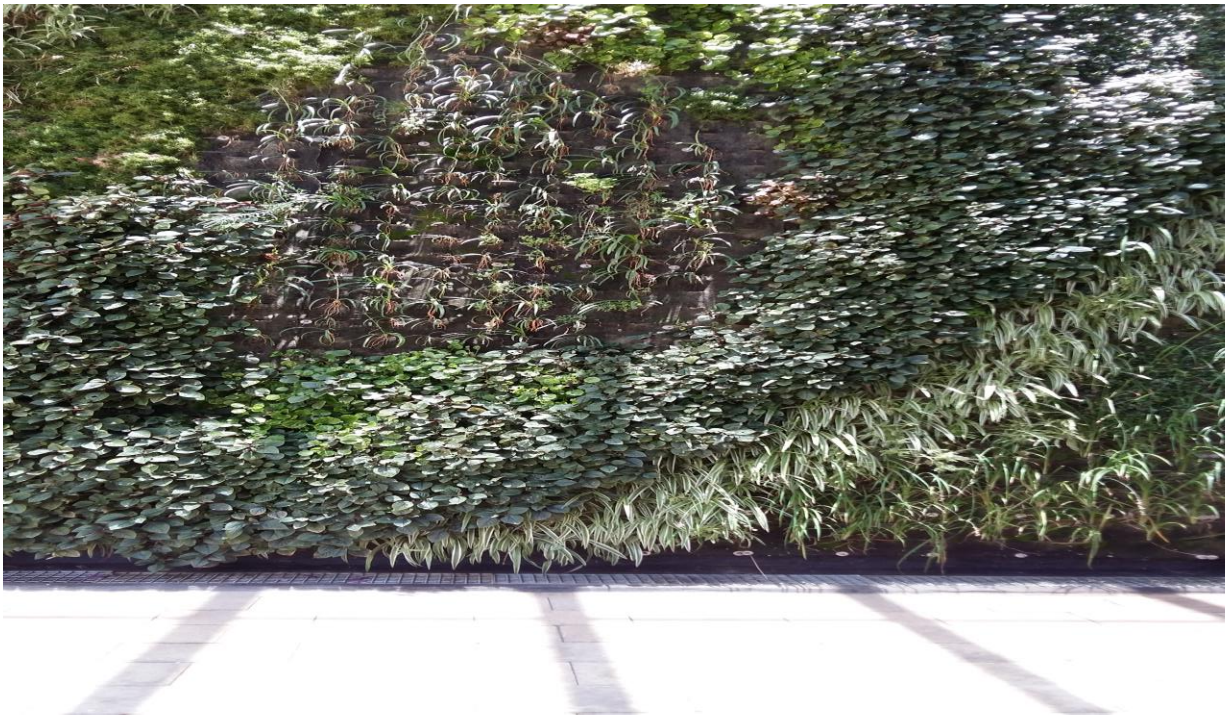


Figure 5.3: Nurturing of selected plants for wall greening

5.4 Data analysis, presentation and discussion (Triangulation)

The results emerging from various sources of data analysis will be presented and insights drawn to give meaning to the lines of argument along the pre-set themes (see section 5.2). Detailed samples of statistical analysis outputs are presented in Appendix 5.

5.4.1 Sustainable construction practices

This theme is concerned with the identification of sustainable construction practices and the perception of stakeholders concerning their significance to the cases under consideration. Claims pertaining to the prevalence of sustainable construction practices within the projects were examined. This was carried out to evaluate the sustainability features, the understanding of the elements of sustainable construction, and the level of sustainability concept adopted in the selected cases. The analysis of the survey respondents covering the level of adoption of sustainable construction is presented using the descriptive statistics based on the mean item score (MIS). The MIS of the variables along with its ranking were presented for each case (Table 5.6). Table 5.6 presents the MIS of the C_1 – C_5, based on participants' perceptions as reflected on a five-point Likert scale (1 indicates never, 2 indicates rarely, 3 indicates neutral, 4 indicates often, 5 indicates very often), on the deployment of sustainable practices (material and techniques) on the project. Table 5.6 revealed that in:

C_1: energy efficiency and material and water reduction with the highest MIS (4.13), were ranked joint 1st and the most important issues considered in the production of the project. Other variables with more than 3 in MIS are: durability, energy conservation, renewable source, and pollution reduction, whilst life cycle costing and biodegradable materials with MIS (2.00) and (1.88) respectively ranked lowest, in 11th and 12th positions and considered less important in the rating.

C_2: energy efficiency and material and water reduction having MIS (4. 63) and (4.50) ranked 1st and 2nd respectively, with durability, energy conservation, pollution reduction, and local availability having MIS of 3 and above, whilst life cycle costing and innovation with MIS (2.63) and (2.50) ranked lowest at 11th and 12th respectively, along with local material availability, embodied energy, 5Rs, (reduce, reuse, renew, recycle, and rethink) and innovation were perceived below average in practice.

C_3: energy efficiency and material and water reduction having MIS (4. 20) and (4.00) were ranked 1st and 2nd respectively. Durability, energy conservation, renewable source, renewable energy and pollution reduction were with (MIS > 3), but embodied energy, 5Rs, and innovation were ranked joint 9th with MIS (2.60) and biodegradable with MIS (2.83) ranked lowest in 12th place.

Table 5.6: Rankings of sustainable construction practices as observed in the cases

Sustainable Practice	Case 1	Case 2	Case 3	Case 4	Case 5	**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	**Rank**
Energy Efficiency	4.13	4.63	4.20	4.67	4.33	***4.39***	***1st***
Material & H_20 Reduction	4.13	4.50	4.00	4.50	4.33	***4.29***	***2nd***
Pollution reduction	3.00	4.25	3.40	3.83	3.83	***3.66***	***3rd***
Durability	3.38	3.50	3.00	3.50	4.00	***3.48***	***4th***
Energy Conservation	3.38	3.38	3.40	3.50	3.50	***3.43***	***5th***
Local availability (material & technology)	2.88	3.25	2.80	3.33	4.33	***3.32***	***6th***
Renewable source	3.25	3.25	2.80	3.17	2.33	***2.96***	***7th***
Embodied energy	2.88	2.88	2.60	2.83	2.83	***2.80***	***8th***
Innovation	2.25	2.50	2.60	2.50	3.67	***2.70***	***9th***
5Rs	2.50	4.00	2.60	2.50	1.67	***2.65***	***10th***
Life cycle costing	2.00	2.63	2.80	2.67	2.50	***2.52***	***11th***
Biodegradable	1.88	2.88	1.40	2.83	1.33	***2.06***	***12th***

Source: Researchers Fieldwork, 2016

Key: 5Rs; Reduce, Recycle, Reuse, Refine and Report.

C_4; energy efficiency and material and water reduction having MIS (4. 67) and (4.50) were ranked 1st and 2nd respectively. Other factors with (MIS > 3) are: durability, energy conservation, local availability and pollution reduction. However, life cycle costing ranked 10th (MIS – 2.64), and 5Rs and innovation were ranked joint lowest in 11th place with MIS (2.50).

C_5: have energy efficiency and material and water reduction with the highest MIS (4.39), ranked joint 1st, with durability, energy conservation, innovation, and pollution reduction perceived to have MIS of greater than 3 to be considered important, whilst 5Rs and biodegradable materials with MIS (1.67) and (1.33) respectively ranked lowest in 11th and 12th positions and hence were deemed not important enough for consideration.

The outcomes of these perceptions' rating within $C_1 – C_5$ can be inferred to be similar across cases with no significant deviation across cases. This might be as a result of the purposive sampling that limits the cases to the selection of the best (5- or 6-star) possible cases. Another possible explanation might be the commonality of some of the sustainability consultants in some of the cases that might have skewed the design towards similar competences for delivering client specifications.

Evidence emerging from the cross-case pattern shows that energy efficiency, material and water reduction, and pollution reduction with MIS (4.39, 4.29, and 3.66) were ranked 1st, 2nd and 3rd respectively. It can then be inferred that the main concern of the project teams as regards the sustainability of their products was hinged on technologies that could provide efficient energy management, reduced material and water usage and reduced environmental pollution. Along with these practices are durability, energy conservation, and local material sourcing (MIS > 3) were also perceived to be worthy of consideration in the procurement practices, while other variables – such as biodegradable materials (2.06), life cycle costing (2.52), and 5Rs (2.65) were rated 12th, 11th and 10th respectively, along with innovation, embodied energy, and renewable energy (MIS < 3) – were perceived to be less important within the case study. Interestingly, Madu and Kuei (2012: 7) and Rafindadia *et al*. (2014: 457) have made similar submissions that basic principles such as energy modelling, reduce resource consumption, environmental hazards mitigation, use of sustainable material resources, and adopting cyclic processes will promote the act of renewed and reused resources, and decrease in the use of energy and new mining for natural resources. Development of new infrastructures based on these findings could address the International Energy Agency (IEA) concerns of existing buildings consuming more than 40% of the world's total primary energy and accounting for 24% of global carbon dioxide emissions to existing buildings (Howe, 2010: 1).

The installations of various sustainable technologies on the facilities to provide for renewable and efficient energy use, water recycling and reduced water usage are all evidence from the physical observation. Best practice design for light and HVAC (and no ozone-depleting substances, ODP), large photo-voltaic system, rainwater harvesting and low-flow fixture installations for water, hot water generated through solar panels, live metering display, and access to public transportation, are all common features in the facilities inspected. The effectiveness of such facilities was also attested to be the FMs during the tour.

Most of the interviewees corroborated the survey findings. They highlighted the importance of energy efficiency and reduced water usage to be paramount among the preferred value placed on a project by operators and the occupants. This fact was also reiterated by interviewee 2 when he said:

> "*If the right technology that is efficient and durable can be deployed to reduce the energy and water consumption in our buildings, the built environment management encumbrances would have reduced substantially* …."

This shows the importance of energy and water reduction to the attainment of sustainable targets of the built environment. The recent COP21 has also placed the building industry in a prime position in meeting the global goals of improved health and well-being, industry productivity, and the target of reducing global warming by 2 ^{o}C and building related emissions by 80 gigatonnes by 2050 (Green Building Council South Africa (GBCSA), 2016).

5.4.2 Lean construction practices

The adoption of the lean construction practices in the production of selected cases was explored. The exploration process allows the evaluation of the level of application of the lean and related lean tools used during the project's production. The level of the uptake of the lean concept and the general understanding within the industry is demonstrated in the cases. The lean principle/ techniques are necessary for enabling sustainability (Novak, 2012: 54). However, the development of this concept is still at its infancy: most lean and lean-related concepts adopted within the industry are not acknowledged as lean principles. This state of understanding cannot be better placed than what the PS1 and PS2 respectively proffer. According to them:

"Lean isn't even a concept in this country. If you go to someone and say lean construction, they'd look at you and actually question, what are you talking about? It's just a concept that hasn't found its way into mainstream construction in the country (PS1)."

"I would love to be one that would really get lean construction as a genuine construction technology implemented in South Africa. I think it would make a huge difference and more importantly, I think especially in public sector construction it would bring huge value to South Africa as a whole, I mean in some projects I deal with costs that are just ridiculous and that's purely because it doesn't have to be lean (PS2)."

This state of affairs is not really surprising in that the Lean Council has just been launched in South Africa, coupled with the fact that the philosophy is still evolving in most developing nations. The analysis of the survey respondents' covering the level of adoption of lean construction is presented using the descriptive statistics similar to that deployed in 5.4.1 (Table 5.7). Table 5.7 shows:

Table 5.7: Lean construction practices in the case studies

Lean practice	Case 1	Case 2	Case 3	Case 4	Case 5	**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	**Rank**
Concurrent engineering	3.75	4.13	3.00	3.83	3.17	***3.58***	***1st***
Just-in-time	3.38	3.38	3.40	3.50	3.83	***3.50***	***2nd***
Visualization tool	3.50	3.88	3.40	3.50	2.83	***3.42***	***3rd***
Daily huddle meeting	3.13	2.88	3.40	3.00	3.50	***3.18***	***4th***
Value analysis	3.00	3.50	3.20	3.17	2.67	***3.11***	***5th***
Total Preventive management	2.88	3.13	3.00	2.83	2.33	***2.83***	***6th***
First-run studies	2.75	3.00	3.00	3.00	2.33	***2.82***	***7th***
Pull approach	2.38	3.00	2.60	3.17	2.50	***2.73***	***8th***

Total quality management	2.38	3.25	1.00	3.17	3.17	***2.59***	***9th***
Prefabrication	2.13	2.88	2.60	2.83	2.00	***2.49***	***10th***
Last planner	1.25	3.13	1.40	2.50	1.50	***1.96***	***11th***
Six sigma	1.00	2.25	1.40	2.33	1.67	***1.73***	***12th***
5S	1.00	2.25	1.00	2.33	1.00	***1.52***	***13th***
Kaizen	1.00	2.25	1.00	2.33	1.00	***1.52***	***13th***
Kanban	1.00	2.25	1.00	2.33	1.00	***1.52***	***13th***

Source: Researchers Fieldwork, 2016

C_1: the respondent in C_1 perceived concurrent engineering (MIS – 3.75), visualization tool (MIS – 3.50), Just-In-Time (MIS – 3.38), daily hurdle meeting (MIS – 3.13), and value analysis (MIS – 3.00), were ranked 1st, 2nd, 3rd, 4th, and 5th respectively, as the important lean principles adopted during production of the facility. The mean score is above the neutral value, tending to often be deployed during the operation. However, other listed variables score below 3, which implies they are rarely used or heard of by the respondent on the project.

C_2: shows that concurrent engineering with MIS (4.13) ranked 1st, visualization tool (MIS – 3.88) ranked 2nd, value analysis (MIS – 3.50) ranked 3rd, Just-In-Time (MIS – 3.38) at 4th position, and total quality management with MIS (3.25) ranked 5th. Last planner, total preventive management, pull approach and first-run studies were all perceived by the respondents to be important enough to be considered during production of their project, with MIS greater than 3. Lean principles such as prefabrication, Kaizen, Kanban, 5s, Six-sigma were either unknown or perceived as less important for adoption.

C_3: the respondent in C_3 perceived visualization tool, Just-In-Time, and the daily hurdle meeting with joint MIS (3.40) as ranked 1st as adopted during the construction process. Value analysis, preventive management and first-run studies with joint (MIS – 3.00), which signalled the neutrality of the respondent towards their adoption. All other listed variables had mean scores below 3, which implied they were rarely used or heard of by the respondent on the project.

C_4: showed that concurrent engineering with MIS (3.83) ranked 1st, while the visualization tool and Just-In-Time (MIS – 3.50) were joint 2nd. Other lean tools/techniques perceived to have been used during C_4 production were pull approach, total quality management, value analysis, and first-run studies with a minimum mean score of 3, whilst other lean practices were relatively unknown to the respondents.

C_5: the respondent in C_5 perceived Just-In-Time (MIS – 3.83) as the most preferred lean principle and regular daily hurdle meetings with MIS (3.50) ranked 2nd, as adopted during the construction process. Concurrent engineering and total quality management with (MIS – 3.17) were joint 3rd in the ranking, as completed the lean practices above average on the perception list of the respondents. All other listed variables had mean scores below 3, which implied they were rarely used or heard of by the respondent on the project.

It was apparent from the questionnaire survey findings that there was low adoption of the lean principles and techniques within the cases. This could be attributed to the slow rate of adoption and understanding of the concept. The concept of low adoption might explain the general low ratings achieved by the lean tools compared to sustainability principles on the cases. It is evident that C_1 – C_5 show varying patterns in the preference level that might also be linked to the lack of consensus among the project teams. However, concurrent engineering, visualization tool, Just-In-Time and daily hurdle meeting feature prominently on the preference list of the project teams. However, it is said that these tools are of different functions and complexity that require different levels of manpower and cost outlay for its adoption/operation, compared to the benefits accrued from their adoption (Suresh, Bashir & Olomolaiye, 2012: 380).

The cross-case pattern indicates that concurrent engineering, Just-In-Time, visualization tools, daily hurdle meeting, and value analysis with MIS of 3.58, 3.50, 3.42, 3.18 and 3.11 respectively, were considered important and possibly adopted across all the cases by the project teams. This is not surprising, as it is similar to the outcome of the case study work of Simonsson *et al*. (2012: 35) on the performance of two bridge projects, where 'increased visualization' of materials, resources and information brought about work-flow improvement, increased understanding and ease of measurable lead time, inventory level and reduced production costs. Salem *et al*. (2005: 1) also reported that increased visualization, daily huddle meetings, and first- run studies achieved more effective outcomes. However, the performance of concurrent engineering is somewhat surprising when compared to the expectations of the tool champions and the research team in tools such as last-planner, prefabrication and Kaizen. These outcomes are an indication of the scope of lean tools/techniques used within the South African construction industry. Each lean tool can be deployed separately or in combination with other techniques to achieve the prime target of eliminating waste and breaking barriers to work-flow towards continuous improvement and respect for people (Rybkowski, Abdelhamid & Forbes, 2013: 84).

5.4.3 Synergy between lean construction and sustainability in rated green projects

The nature of relationship between lean and sustainability was examined within the context of the South African construction industry using the selected cases. The section examined the link between the two concepts and highlighted major areas of synergy for project improvement. The core principles of the lean-sustainability concept are similar to the integrated project delivery (IPD) model. The IPD model in construction can be seen as the adoption of principles, methods and behaviours for design and construction of projects, in a culture of efficient and effective collaboration in an organization (Baiden *et al*., 2006: 14). Table 5.8 shows the perceptions of the project teams on the integration of sustainability and lean construction.

Table 5.8: Lean construction and sustainability integration in green rated buildings

Linkage between L-S	Case 1	Case 3	Case 5			**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	**Rank**
Both reduced Resources use	4.88	5.00	4.80	5.00	4.83	**4.90**	**1st**
Reduced waste & pollution	4.75	4.88	4.60	4.83	2.83	**4.38**	***2nd***
LC catalyst to Sustainability	4.00	4.00	4.00	4.00	3.50	**3.90**	***3rd***
Enhanced value creation	4.00	3.88	4.00	3.83	3.33	**3.81**	***4th***
Enhanced traditional practices	4.00	4.00	4.00	4.00	3.00	**3.80**	***5th***
Both are closely linked	3.13	2.75	3.40	2.83	2.67	**2.96**	***6th***

Source: Researchers Fieldwork, 2016

Key: L-S; Lean and Sustainability, LC; Lean construction.

The results presented on Table 5.8 show that the project teams attest to the synergy that exists within two concepts. Lean construction and sustainability work in unison towards enhancing the efficiency and effectiveness of the production processes. The major benefits of the synergy that existed between the two concepts are felt mostly across cases in the areas of reduced resources utilization, reduced waste and pollution, enhanced value creation, and improved traditional practice, and lean construction serves as catalyst for sustainable practice. Most areas of interaction attained a mean score (> 3) across cases, demonstrating a similar pattern to sustainable construction practice (see 5.2.1).

These discoveries are expected as various scholars (Koskela, 1992: 34; Novak, 2012: 54; Curatolo *et al*., 2014: 433) have earlier predicted such synergy for waste elimination and enhanced industry performance. Interestingly, PS3 affirmed the same position with the results of the survey:

> "*It could be lean but there's other processes such as BREEAM (green practice) that's linked to lean thinking. Lean as a philosophy works really well but it does need a whole, client, contractor, consultant, sub-contractor holistic approach where they all think in the same lines. Traditional contracting like this (current project) is very transactional; I'll give you this for this. And as long as both parties are happy then you do it whereas lean and green are questions that you ask is, should I be asking for this in the first place? Or am I happy with what I've already got.*"

This statement alludes to the fact that there are inherent benefits in the integration of the two concepts that is distinct from the traditional practices. Conversely, these apparent benefits have not been fully maximized by the industry stakeholders. This current state of continuous loss of opportunities could still be traced to the level of understanding and the development of the concepts. As PS4 (policy administrator) alleged:

> "*We are only saddled with the responsibility of regulating and promotion of the local industry, but these new concepts (lean and sustainability) are alien to us and not within our statutory books*."

Based on the argument above, the researcher can deduce that though there are some levels of understanding of the lean-sustainability concept within the research sample and the associated benefits therein for the industry, the larger stakeholders have failed to convert these opportunities to critical element into industry-inclusive sustainable development. This scenario is still so, as a result of the low uptake that is largely due to lack of understanding of the concept, which still persists in the region.

5.4.4 Barriers to lean-sustainability concept

Resistance to change is a common phenomenon (barrier) to a new concept similar to lean-sustainable construction in an industry setting (Smit *et al*., 2011: 256). A clear understanding of these barriers and the root causes allow for proper development and uptakes of new innovations. Therefore, the barriers to lean-sustainability construction examined (Table 5.9). Table 5.9 discovered that in:

C_1: cost implication (MIS – 5.00) was perceived as the greatest barrier to the adoption of the new concept, while leadership and organizational culture were considered 2nd and 3rd respectively, followed by stakeholders' awareness and demands at 4th. Political and policy issues with material availability were jointly rank at 5th place. The smallest barrier to lean-sustainability construction is the level of uncertainty towards the concept in the industry.

C_2: the greatest barrier for the lean-sustainability concept in this case is the cost implication with MIS – 5.00. Leadership (MIS – 4.88) and stakeholders' awareness and demands (MIS – 4.63) were ranked 2nd and 3rd respectively. Organizational culture, political and policy issues, material availability and uncertainty were also perceived to be hindrances to the adoption of the concept.

C_3: cost implication (MIS – 4.80) was perceived as the greatest hindrance militating against the adoption of the lean-sustainability concept, followed by organization culture, stakeholders' awareness and demands, leadership issues, political and policy issues, and material availability that were all perceived as hindrances with MIS greater than 3. Only uncertainty was regarded as a lesser barrier to the implementation of lean-sustainable concept with less than 3 in MIS.

C_4: have cost implication (MIS – 5.00) as the biggest hindrance to the adoption of lean-sustainability. Leadership was perceived to be closest to the cost premium, with MIS of 4.83, and stakeholders' awareness and demands and organization culture – MIS of 4.67 – were joint 3rd on the barriers ranking. Material availability, uncertainty, and political and policy issues were ranked in that order.

C_5: cost implication (MIS – 4.33) was perceived as the utmost barrier to the adoption of lean-sustainability concept, while stakeholders' awareness and material availability were ranked joint 2nd, followed by leadership and uncertainty, ranked joint 4th. Organizational culture was also perceived as a barrier with MIS of greater than 3, with political and policy issues perceived as less of a hindrance by the role-players in the case study.

Table 5.9: Barriers to lean-sustainable construction

Barriers	Case 1	Case 2	Case 3	Case 4	Case 5	**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	**Rank**
Cost implication	5.00	5.00	4.80	5.00	4.33	**4.83**	***1st***
Leadership	4.50	4.88	3.80	4.83	3.33	**4.27**	***2nd***
Stakeholders' awareness and demands	4.25	4.63	4.00	4.67	3.50	**4.21**	***3rd***
Organizational culture	4.38	4.50	4.20	4.67	3.17	**4.18**	***4th***
Material availability	3.63	4.38	3.40	4.50	3.17	**3.82**	***5th***
Political & policy issues	3.63	3.13	3.60	3.17	2.67	**3.24**	***6th***
Uncertainty	3.13	3.25	2.80	3.17	3.33	**3.14**	***7th***

Source: Researchers Fieldwork, 2016

Even though lean-sustainability premium (cost) was highly ranked as the greatest barrier in all the cases, the performance of other barriers varies on the perception level. This is not surprising as Wilreker (2011: 6) and Windapo (2014: 6088) held in their works that cost concepts serve as a limiting factor in the promotion and adoption of sustainable construction as they proffer a proper understanding of sustainable cost; economics can be of great benefit to the industry's innovative practices.

Based on the summary of the cross-cases, it can deduced that the cost implication (sustainability premium), with MIS of 4.83, is perceived as the greatest hindrance to the attainment of sustainability in the built environment. This perspective of the sustainability premium among the stakeholder's is also at variance with each fragment of project role players, which does not resonate with the principle of collaboration that can enhance the pursuance of a common project's goal (lean-sustainability). This perspective was echoed by a consultant:

> *"Retrospectively, the main barrier to lean is the non-understanding of what it is there for. Many people see lean as something being driven by the clients as a way to save money on sustainable construction, and clients see sustainable designs basically associated with the premium. The problem .... primary barrier(s) to sustainable construction is cost ... whereas actually the holistic philosophy around lean-sustainability is that all parties benefit so you go into the process knowing that you are part of the process but having improved yourself financially. And the clients draw up a tender with a combination of both the best price and whatever wins the tender."*

Most consultants agree with this view. This state of varying standards for projects' sustainability premium is robbing the industry of the expected benefits associated with lean-sustainability adaptability within the industry and stems from the cultural and structural values such as the lack of cooperation and integration within a known fragmented sector; project stages and various professional of operationalizing projects into fruition (Thompson & El-haram, 2011: 1087; Bygballe & Sward, 2014: 5).

In corroborating this statement, an interviewee stated:

> *".... Today is not a good day, the air-conditioning is blaring and it's either on full heat or full cold because there's no insulation in this cabin. The insulation costs for this cabin would be nothing compared to the estimated time (related cost) that we've been here and this building's got a 20 years' life cycle or so. But, the question is always how much more do I have to spend on the project. And it's such a shame because it can make a huge difference and people don't realise that if you invested upfront, the long term savings on the project far outweigh the short term savings or the cost on the capital investment. Power is just going to get more and more expensive, the more of it that you use, the more your long term outlay" (PS1).*

This statement alludes to the low level of understanding of the sustainability concept and the demand within the community. Fewer available sustainable facilities are owned by corporate bodies geared towards industry competitiveness and the enhancement of corporate image, as displayed in C_1, C_3, C_4, and C_5. That might also account for the low rating given to other sustainable practices such as life cycle costing, innovation, 5Rs, embodied energy, and utilization of biodegradable material in the industry.

Other barriers like leadership, stakeholders' awareness and demands, organization culture, material availability along with political and policy issues, and uncertainty were discovered as hindrances to the adoption of the lean-sustainability concept within the industry. These barriers have MIS greater than 3, hence, rated above average as expressed by the participants, which inferred that they are hindrances to sustainability uptakes. This is not surprising as studies have identified clients' demand, leadership, limited material and selection, and professional culture as barriers to sustainability concepts (Mate, 2006: 3; Kang, Kang & Barnes, 2008: 17; Jacobs, 2011: 215).

However, the outcomes in Table 5.8 follow no particular order in relation to the common characteristics (ownership structure and star rating) of the cases. Therefore, the researcher went further by conducting a Kruskal-Wallis test in an attempt to fully understand the statistical divergence of the phenomenon (Table 5.10).

The variability of the barriers along cases as revealed by the Kruskal-Wallis Test shows only two barriers – B_2 (leadership) and B4 (cost implication) – reflecting some level of significance (Table 5.10). A closer look at mean rank of leadership and cost implication within cases shows that C_5 has the least mean rank reflection for both leadership and cost implication. This revelation in itself does not uphold the proposition as C_5 has similar characteristics to three other cases in the group. In all, the variables examined under barriers are considered relevant in hindering the implementation and adoption of lean-sustainability construction principles.

Table 5.10: Kruskal-Wallis Test of Cases on the Lean-Sustainability barriers

Barriers (B)	B1	B2	B3	B4	B5	B6	B7
Chi-Square	3.718	10.272	3.665	13.286	4.662	5.355	9.299
df	4	4	4	4	4	4	4

Asymp. Sig.	.445	.036	.453	.010	.324	.253	0.54

a. Kruskal-Wallis Test
b. Grouping Variable: cases

Key: B_1; Organization culture
B_2; Leadership
B_3; Uncertainty
B_4; Cost implication
B_5; Stakeholders' awareness and demand
B_6; Political and policy issues
B_7; Material availability

Overcoming these barriers require a holistic and in-depth evaluation of the industry for adequate and sustainable 'drivers' that can bring about change, build trust and establish a new culture of constant learning, improvement and perfection among the stakeholders in the construction industry. Naney, Goser and Azambuja (2012: 292) argue that implementation of new concepts in the construction industry needs to be fast-tracked in order to reach a tipping point and attain more acceptability in the industry; they also imply that the barriers hindering the lean-sustainability concept is partly responsible for holding back more rapid uptakes.

5.4.5 Drivers for lean-sustainability concept

Embracing an innovation often requires a commensurate driver for meaningful changes to occur. Emerging symptoms of the unsustainable way to built environment development over the last centuries suggest the need for new ways to pursue this development. Challenges such as global climate change, urban pollution and environmental degradation with its attendant increment in global industry competitiveness have brought forth and continue to be the driver for sustainable development (Wu & Wu, 2012: 65; Yao, 2013: 4). The drivers for LSC were investigated (Table 5.11).

The results in Table 5.11 revealed that in:

C_1: environmental concern and social responsibility (MIS - 4.50) were jointly considered as the most important drivers for lean-sustainability construction, followed by the need for efficiency and effectiveness, industry competitiveness, and stakeholders demand which jointly ranked 3rd (MIS – 4.38). Other drivers for the adoption of the L-S concept are leadership, inflow of innovative staff, and changing legislation perceived to be worth consideration with MIS > 3,

C_2: inflow of innovative staff (MIS – 4. 25) was ranked 1st, followed by industry competitiveness, environmental concern and social responsibility, and stakeholders' demand jointly ranked 2nd (MIS – 4. 13), driving the uptake of lean-sustainability concept within the case study. Other relevant variables with up to 3 MIS are leadership, changing legislation and need for efficiency and effectiveness. The higher rating attained by the inflow of innovative staff, as contrary to issues like environmental concern and efficiency and effectiveness in C_2, might be related to the nature of the case, being a regulatory agency needing to demonstrate innovation,

C_3: need for efficiency and effectiveness, and industry competitiveness were ranked 1st (MIS-4.80), and 2nd (MIS – 4.60) respectively. Stakeholders' demand and environmental concern were joint 3rd (MIS – 4.20). Others with MIS > 3 were social responsibility, leadership, inflow of innovative staff, and changing legislation,

C_4: environmental concern and social responsibility, industry competitiveness, and stakeholders' demand, and inflow of innovative staff were jointly ranked 1st (MIS – 4.17), perceived to be central to the adoption of the L-S concept. Other drivers in C_4 were leadership, need for efficiency and effectiveness and changing legislation with MIS > 3.

C_5: industry competitiveness (MIS -5.00) was the main driver for the adoption of the lean-sustainability concept, followed by need for efficiency and effectiveness (MIS – 4.50) and inflow of innovative staff (MIS – 4.17), ranked 2nd and 3rd respectively. Drivers such as leadership, changing legislation, and social responsibility were perceived to have a strong influence on lean-sustainability practice with MIS > 3. Variables such as stakeholders' demand and environmental concern were perceived less of a priority (MIS < 3) by the respondents. These patterns exhibited in C_5 demonstrate that the organization is concerned about the industry cutting edge for productivity available in the private sector.

Table 5.11: Drivers for lean-sustainable construction

Drivers	Case 1	Case 2	Case 3	Case 4	Case 5	**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	**Rank**
Industry competitiveness	4.38	4.13	4.60	4.17	5.00	**4.45**	***1st***
Need for efficiency & effectiveness	4.38	3.50	4.80	3.50	4.50	**4.14**	***2nd***
Inflow of innovative staff	4.00	4.25	3.80	4.17	4.17	**4.08**	***3rd***
Social responsibility	4.50	4.13	4.00	4.17	3.17	**3.99**	***4th***
Environmental concern	4.50	4.13	4.20	4.17	2.83	**3.97**	***5th***
Stakeholders' demand	4.38	4.13	4.20	4.17	2.83	**3.94**	***6th***
Leadership	4.00	3.88	3.80	3.83	3.83	**3.87**	***7th***
Changing legislation	3.50	3.63	3.00	3.50	3.33	**3.39**	***8th***

Source: Researchers Fieldwork, 2016

The summary of the cross-case patterns indicates industry competitiveness, need for efficiency and effectiveness, and inflow of innovative staff as the main driver for L-S concept. These drivers are perceived to make the lean-sustainability concept worth pursuing. Finch and Zhang (2013: 306) allude to these facts when identifying the drivers for sustainable practice in construction industry to include competitive edge, winning more contract/financial incentive, and attracting and retaining good employees. The prominence of 'internal' drivers such as industry competiveness, issues relating to efficiency and effectiveness, and inflow of innovative staff as major drivers for sustainability, may have come about because of the characteristic private organizations' preference for productivity and profit margin over other forms of drivers in the industry (Othman, 2011: 176;

Suresh, Bashir & Olomolaiye, 2012: 380; Madu & Kuei, 2012: 7). It can then be said that the dated tripods of 'cost, quality and time' management related to economic concerns still hold the key to innovations. Other aspects of the TBLs, such as social responsibility and environmental concern, follow in that order of hierarchy on the perception level. Then, variables such as stakeholders' demand, leadership, and changing legislation are at the rear-end of the perception level. The low rating attributed to demands, leadership and legislation was echoed by the PS4:

> *"There's no sufficient drive for clients to embed sustainability thinking in projects yet. The building regulations don't go far enough yet in driving change. Once it becomes financially difficult for a client to avoid sustainability, then it becomes a much bigger issue."*

This statement was corroborated by other FM practitioners in the study. The sentiment expressed here is also a reflection of the industry preparedness for innovative assimilation. The needed framework to drive innovation (lean-sustainability) uptakes is still inadequate among the stakeholders. This inadequacy in the framework guiding the industry is responsible for the lack of clients' inclusion of sustainability as part of value specifications on their projects. Furthermore, it can be deduced that the few sustainable projects are being driven by separate motives, as demonstrated by the developers of these infrastructures. This sentiment was made known by C_2:

> "*The major driver behind the procurement of our facility is to serve as a prototype for the development of sustainable culture in the built environment, being saddled with the environmental affairs. And ... often, infrastructures under development are not with these sustainable features*."

Most respondents' comments resonate with this assertion. Whilst most private organisations have developed green facilities to demonstrate leadership positions, others affirm that it is to promote staff productivity. This level of variability in the drivers, especially as highlighted in C_2 and C_4, which are separated ownership structure and star rating, avails the researcher to look further by conducting a Kruskal-Wallis Test in an attempt to fully understand this phenomenon (Table 5. 12).

Table 5.12 indicates that most P-Values are less than 0.05, which can be interpreted as that the drivers for the cases show significance difference among cases. However, D_2 (Leadership), D_3 (Changing legislation), and D_4 (Inflow of innovative staff) with P-Values greater than 0.05 show no significant difference among cases. Therefore, at 5% level of significance, the proposition holds for most drivers. Consequently, the researcher took a further look at the mean rank of the drivers per case to elicit more insights. D_1 (Need for efficiency and effectiveness) and D_5 (Industry competitiveness) record the lowest mean ranks in cases C_2 and C_4. Although, C_2 and C_4 belong to the group of 6-star ratings, the only viable explanation for this scenario is that they are owned by a regulator and sustainable consultant respectively. Therefore, C_2 and C_4 are developed not purely for commercial purposes but rather as prototypes for sustainability promotion. C_5 accounts for the lowest mean rank in (D_6 – D_8) and that itself does not show a definite pattern to merit definite conclusion. Based on these findings, there is no definite pattern to explain the variability.

Table 5.12: Kruskal-Wallis Test of Cases on the Lean-Sustainability Drivers

Drivers (D)	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
Chi-Square	11.872	.955	1.126	2.652	10.413	13.762	15.976	10.280
df	4	4	4	4	4	4	4	4
Asymp. Sig.	.018	.917	.890	.618	.034	.008	.003	.036

a. Kruskal-Wallis Test
b. Grouping Variable: cases

Key: D_1; Need for efficiency & effectiveness
D_2; Leadership
D_3; Changing legislation
D_4; Inflow of innovative staff
D_5; Industry competitiveness
D_6; Stakeholders demand
D_7; Environmental concern
D_8; Social responsibility

However, the results identified industry competitiveness, need for efficiency and effectiveness, inflow of innovative staff, social responsibility and environmental concern as the main drivers for the L-S concept across cases. These, along with stakeholders' demand, legislation and industry leadership, are necessary to break the industry barriers. Fast-tracking these lean-sustainability drivers in the industry will enhance value creation and bring about the necessary benefits for the built environment.

5.4.6 Benefits (indicators) of lean-sustainability on project performance

The primary aim of this study is to develop a mechanism that can leverage on the synergy between lean and sustainability to the benefit of infrastructure development. However, the paucity of studies, dwelling on the impact of lean and sustainability on construction project performance is notable. This paucity accounts for the lack of industry indicators for measuring the performance of lean-sustainability concept (Novak, 2012: 52; Campos *et al*., 2012: 31; Khosravis & Afshari, 2011: 186). Subsequently, the researcher carried out an exploratory study to assess the indicators required for measuring the integrative implementation of lean and sustainability concepts in an infrastructure project. These indicators can be seen as a standard of judgement by which lean and sustainable values can be measured. The work is presented in the *Proceedings of the CIB World Building Congress, 2016 Volume IV*. The benefits of lean-sustainability construction were examined (Table 5.13).

Table 5.13 demonstrates in the following cases that:

C_1: the implementation of lean-sustainability construction was perceived to have performed best in increased stakeholders' collaboration, overall industry continuous improvement, and increased organizational learning, with MIS of 4.50, and jointly ranked highest. These were followed by enhanced benefits such as improved industry competitiveness edge, improved cost/time/quality schedule management, increased environmental value chain, improved planning and risk management, improved H&S records, and reduced energy and resources consumption in that order. Reduced pollution and emission, matching business and environment, improved 5R/renewable resources, improved flexibility and adaptability, reduced dispute, enhanced employment and skill development, increased technological advancement, and increased affordability are all perceived above average in the benefits rating.

Table 5.13: Benefits of Lean-Sustainability Construction in the Industry

L-S indicators	Case 1	Case 2	Case 3	Case 4	Case 5	**Aggregate**	
	Mean	Mean	Mean	Mean	Mean	**Mean**	***Rank***
Improved industry competitiveness	4.38	4.25	4.20	4.17	4.50	**4.30**	***1st***
Industry continuous improvement	4.50	4.25	4.60	4.00	4.17	**4.30**	***1st***
Increased stakeholders collaboration	4.50	3.88	4.60	4.00	4.00	**4.20**	***3rd***
Increased organizational learning	4.50	3.88	4.60	4.00	3.67	**4.13**	***4th***
Improved schedules management	4.25	4.13	4.20	4.17	3.67	**4.08**	***5th***
Improved environmental responsible value chain	3.88	3.75	4.00	3.83	4.00	**3.89**	***6th***
Matching business & environment	3.50	4.00	3.60	4.00	4.17	**3.85**	***7th***
Improved H&S records	3.75	3.75	4.00	3.83	3.83	**3.83**	***8th***
Improved planning & risk management	3.88	3.75	3.80	3.50	3.83	**3.75**	***9th***
Reduced pollution & emission	3.50	3.88	3.60	3.83	3.50	**3.66**	***10th***
Reduced E&R consumption	3.75	3.63	3.60	3.67	3.00	**3.53**	***11th***
Increased affordability	3.25	3.63	3.40	3.50	3.83	**3.52**	***12th***
Improved flexibility & adaptability	3.25	3.75	3.40	3.83	3.33	**3.51**	***13th***
Increased technological advancement	3.63	3.13	3.40	3.17	2.83	**3.23**	***14th***
Enhanced employment & skill dev.	3.38	2.88	3.00	3.00	3.83	**3.22**	***15th***
Improved 5Rs/renewable resources	3.25	3.63	3.00	3.67	2.00	**3.11**	***16th***
Reduced dispute	3.00	2.75	3.00	2.83	3.17	**2.95**	***17th***

Source: Researchers Fieldwork, 2016

Key: L-S; Lean-sustainability, 5Rs; Reduce, Recycle, Reuse, Refine and Report,

C_2: industry continuous improvement and improved industry competitiveness edge were perceived joint 1st with MIS of 4.25. This was closely followed by improved cost/time/quality schedule management (MIS – 4.13) in 3rd position. Other indicators of lean-sustainability concepts with greater than 3 in MIS are: matching business and environment, reduced pollution and emission, increased organization learning, increased stakeholders' collaboration, improved environmental responsive value chain, improved H&S records, improved planning and risk management, reduced energy and resources consumption, improved 5R/renewable resources, increased affordability, and increased technological advancement. However, indicators such as enhanced employment and skill development and reduced dispute with MIS of 2.88 and 2.75 respectively were rated the least.

C_3: increased stakeholders' collaboration, overall industry continuous improvement, and increased organization learning, attaining MIS of 4.60, were jointly ranked 1st, followed by improved cost/time/quality schedule management and Improved industry competitiveness edge (MIS – 4.20) at joint 4th position. Other improvements were in the areas of increased environmental value chain, improved H&S records, and reduced energy and resources consumption, matching business and environment, and reduced pollution and emission in that order. Indicators such as improved planning and risk management, improved 5R/renewable resources, improved flexibility and adaptability, reduced dispute, enhanced employment and skill development, increased technological advancement, and increased affordability were all perceived above average in the importance rating.

C_4: improved cost/time/quality schedule management and improved industry competitiveness edge were perceived to be the best benefits derived from the production of this infrastructure and jointly ranked 1st, with MIS of 4.17. These was followed by matching business and environment, increased organization learning, and increased stakeholders' collaboration (MIS – 4.00) at joint 3rd. Indicators such as improved environmental responsive value chain, improved H&S records, reduced energy and resources consumption, improved planning and risk management, reduced pollution and emission, improved 5R/renewable resources, increased affordability, increased technological advancement, and enhanced employment and skill development were perceived to be benefits of the concept. Only reduced dispute with MIS of 2.83 was perceived as below average on the benefits scale.

C_5: the implementation of the lean-sustainability concept in infrastructure production was perceived to have led to an improved industry competitiveness edge (MIS – 4.50), ranked 1st among other benefits. Overall industry continuous improvement and matching business and environment were rank joint 2nd with MIS of 4.17. Other benefits of lean-sustainability construction as perceived by the stakeholders with MIS greater than 3 are; increased environmental value chain, increased stakeholders collaboration, increased affordability, enhanced employment and skill development, improved H&S records, improved planning and risk management, improved cost/time/quality schedule management, reduced energy and resources consumption, reduced pollution and emission, improved flexibility and adaptability, and reduced dispute. However, benefits relating to improved 5R/renewable resources and technological advancement were not so rated.

It can be said that most of these cases exhibit high degrees in indicators that are performance-related. Issues such as competitive advantage, continuous improvement, organizational learning and collaboration rank creditably in the eyes of the respondents. However, it is not surprising as most private organizations strive to stand out among peers in their area of operation. Various researchers affirm that implementation of lean-related principles enhances value creation and continuous improvement in terms of client satisfaction, improved efficiency, enhanced productivity and increased profitability within the industry amidst overcoming constraints, as demonstrated in the sustainable construction (Suresh, Bashir & Olomolaiye, 2012: 38; Aziz & Hafiz, 2013: 679).

Based on the summary of the cross-cases, improved industry competitive edge and industry continuous improvement are ranked the best (MIS – 4.30) benefits derived from the adoption of the lean-sustainability concept in the production of built environment infrastructure. This is in line with Madu and Kuei's (2012: 4) assertion that proactive companies adopt sustainable management principles, knowing that the outcome leads to long-time economic and social benefits. Increased stakeholders' collaboration and increased organizational learning are also rated strongly by the respondents as they were placed 3rd and 4th respectively. The dated indicators for project performance of an improved cost, time and quality schedule management came 5th with MIS of 4.08. Although this is a strong performance for time and cost within the general variables, it is somewhat contrary to most of the commentators relating to their attached importance to the success of sustainable development. A sample of this view was demonstrated by the FM in C_3:

> "*Sadly a lot of these benefits are just there. Value is there. But value is often discussed and the best value unfortunately is very often the cheapest price. That's not always the best value. The best value in my mind is actually ensuring long-term benefits to the public as opposed to short-term goals or short-term benefits or cost.*"

This view was corroborated by most respondents in the survey comment to underline the importance of overachieving in terms of cost and time schedule and quality specifications to the success of lean-sustainable construction. Other forms of derived benefits with MIS greater than 3 are: improved environmental value chain, matching business and environment, improved H&S records, improved planning and risk management, reduced pollution and emission, reduced energy and resources consumption, increased affordability, improved flexibility and adaptability, increased technology advancement, enhanced employment and skill development, and improved 5R/renewable resources, in that order. However, reduced dispute among the stakeholders was perceived slightly below average at MIS of 2.95. Overall, the accrued benefits cut across the TBLs of sustainability dimensions of economic, social and environmental issues. These outcomes agree with the work of Rafindadia *et al*. (2014: 456) that the lean-sustainability concept aimed at moving projects away from the traditional management-oriented ambits of time, cost and quality, and prioritised economic, environmental and social impacts of construction projects.

The significance of each of these benefits associated with the lean-sustainability concept within the industry was tested by deploying a one-sample t-test (Table 5.14).

Table 5.14: T-test (one-sample) for benefits of lean-sustainability construction in the industry

	Test Value = 2.5					
	T	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Improved cost, time & quality schedule management	19.366	31	.000	1.594	1.43	1.76
Improved environmental responsive value chain	23.149	31	.000	1.375	1.25	1.50
Improved H&S records	12.535	31	.000	1.313	1.10	1.53
Reduced energy & resource consumption	11.925	31	.000	1.063	.88	1.24
Reduced pollution & emission	13.554	31	.000	1.156	.98	1.33
Matching business & environment	16.972	31	.000	1.344	1.18	1.51
Improved industry competitiveness	19.162	31	.000	1.813	1.62	2.01
Improved 5R/Renewable resources	5.271	31	.000	.688	.42	.95
Improved flexibility & adaptability	11.506	31	.000	1.031	.85	1.21
Increased organization learning	13.000	31	.000	1.625	1.37	1.88
Reduced dispute	2.811	31	.008	.406	.11	.70
Increased stakeholder collaboration	14.812	31	.000	1.688	1.46	1.92
Enhanced employment and skill development	4.673	31	.000	.719	.41	1.03
Industry continuous improvement	14.750	31	.000	1.719	1.48	1.96
Improved planning & risk management.	8.932	31	.000	1.219	.94	1.50
Increased technological advancement	6.819	31	.000	.750	.53	.97
Increased affordability	6.715	31	.000	1.000	.70	1.30

Source: Researchers Fieldwork, 2016

The result in Table 5.14 presents the significance (i.e. P-Value) of each of the benefits of lean-sustainability construction in a two-tailed test. However, the demonstrated significant values have to be halved to accommodate for the one-tailed test required for this type of testing (i.e. $U > U_o$). U_o was fixed at the 2.5 level, and the rating scale adopted considered higher rating 4 and 5 as good and excellent respectively. Based on the five-point Likert scale, the indicators were considered important with a mean of 2.5 and above. The significance level was at 95% in accordance with the risk levels in social science. Fortunately, since the two-tailed results suggest that all variables are significant (< 0.05), and the reduction process have no effect on the outcome. The results show all factors are considered important, that is, a broader appeal for sustainability is demonstrated in the cases.

Also, the variability of the benefits between cases ($C_1 – C_5$) was examined using the Kruskal-Wallis test for grouping variables (Table 5.15). The result suggests that only two benefits (matching business and environment and improved 5R/renewable resources) have significant different within cases. A further check of the two benefits through the mean rank revealed that regarding matching business and environment, C_1 had the lowest mean rank (11.25), and C_5 with the highest mean rank (21.60), whilst in improved 5R/renewable resources, C_5 has the lowest mean rank (3.50) and C_4 with the highest mean rank (22.17).

Table 5.15: Kruskal-Wallis Test of Cases on the benefits of integrating lean and Sustainability

Benefits	LSB_1	LSB_2	LSB_3	LSB_4	LSB_5	LSB_6	LSB_7	LSB_8	LSB_9	LSB_{10}	LSB_{11}	LSB_{12}	LSB_{13}	LSB_{14}	LSB_{15}	LSB_{16}	LSB_{17}
Chi-Square	6.494	2.583	.670	7.742	2.085	11.13	2.733	16.92	6.751	8.784	.264	7.325	5.126	6.336	1.482	5.507	1.753
df	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Asymp. Sig.	.165	.630	.955	.102	.720	.025	.603	.002	.150	.067	.992	.120	.275	.175	.830	.239	.781

a. Kruskal-Wallis Test

b. Grouping Variable: cases

Key:

LSB_1; Improved Cost, time & quality schedule management
LSB_2; Improved environmental responsive value chain
LSB_3; Improved H&S records
LSB_4; Reduced energy & resource consumption
LSB_5; Reduced pollution & emission
LSB_6; Matching business & environment
LSB_7; Improved industry competitiveness
LSB_8; Improved 5R/Renewable resources
LSB_9; Improved flexibility & adaptability
LSB_{10}; Increased organization learning
LSB_{11}; Reduced dispute
LSB_{12}; Increased stakeholder collaboration
LSB_{13}; Enhanced employment and skill development
LSB_{14}: Industry continuous improvement
LSB_{15}; Improved planning & risk management.
LSB_{16}; Increased technological advancement.
LSB_{17}; Increased affordability

5.4.7 Influence of stakeholders on lean-sustainability paradigm uptake

The interactions between social and natural systems are mostly dependent on the activities of the industry stakeholders. The action and inaction of the role players influence the uptake and operationalization of innovative outcomes. The lean-sustainability paradigm can only be driven through collaboration, coordination and communication (3Cs) between key project participants, their commitment to the concept, understanding and early involvement and contract conditions (Rafindadia *et al*., 2014: 456). Therefore, the stakeholders' role in engendering the lean-sustainability paradigm in the construction industry to move towards the tipping point (full engendering) was examined. In doing this, the respondents' perceptions on the influence of the role players were represented in the histogram presented in Figure 5.6.

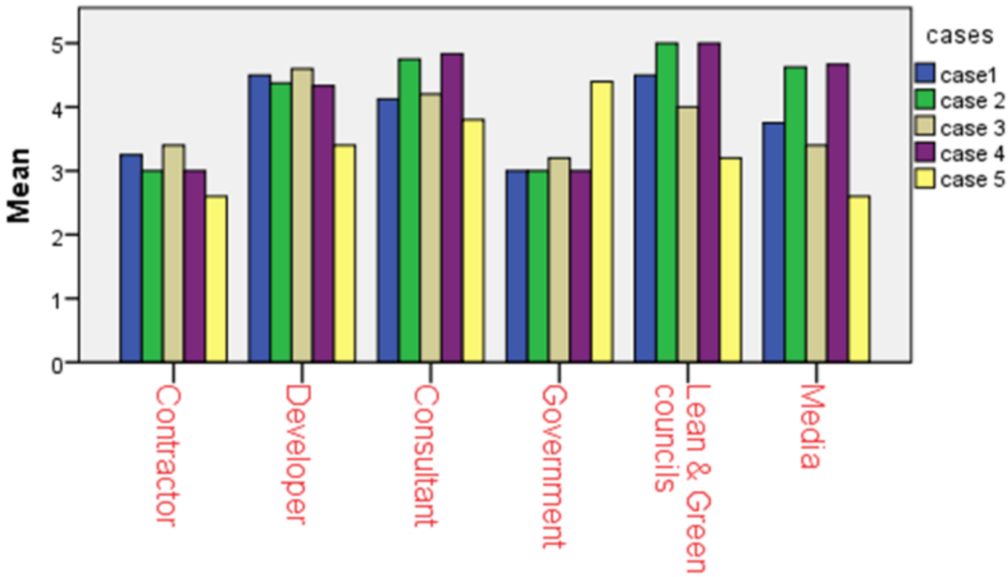


Figure 5.6: Influence of role-players on the operationalization of lean-sustainability construction

The results in Figure 5.6 depict the MIS of the respondents' perceptions of the influence of key role players on the actualization of lean-sustainable principles during the production of infrastructure projects. The Green Councils consultants (especially, in sustainability), as the Lean Council is at its infancy in South Africa, and developers of the projects were considered very influential in the attainment of the lean-sustainability goals within and across cases. The relevance of these bodies could not be more justified, considering the basic principles of sustainable construction. Succinctly put, sustainability in construction involves the deployment of sustainable procurement concepts, which basically involves principles such as whole-life costing, integrated design, waste management, energy modelling, corporate social responsibility (CSR) and community engagement, and the use of sustainable material resources (Rafindadia *et al*., 2014: 456). These principles are mainly situated within the purview of various consultants, backed with the developer's authority (i.e. demand and finance), and as promoted by the relevant councils. This state of affairs was set out by PS2:

> *"I mean, lean construction before it starts to work, needs a certain amount of enlightenment. Once you can get that level of enlightenment then every time you go into a client meeting and you want to introduce a measure of sustainability for whatever reason, if you can drive that through lean principles, say you can drive that by demonstrating to the client firstly, why? Secondly, the outcomes, especially long- term, when you can do whole life cycle costing and analysis effectively, but the problem is*

that, there's not a lot of people that can do that. Do you know that in this country, it takes PhD level individuals to do that for someone and then there are not a lot of them around? So whereas at the moment, a client can pick up a phone to a thousand architects and say I want one of these, how much it is going to cost, the same client cannot pick up a phone and go like, I want you to do a whole life cycle analysis for this building for the next sixty years."

This statement depicts the influence that can be wielded through collaboration between the developer and consultants on the operationalization of the lean-sustainability concept in the construction industry. Unfortunately, it also revealed some inherent hindrances associated with the practice. These barriers are in the form of the skills shortage, the immediate premium, and lack of adequate sensitization of the benefits that can be accrued in the long-term. Other role-players like government, contractors, and media also attained a MIS above average. These ratings justified their importance and proved that the Integrated Design Process (IDP) often deployed in lean-sustainability practices requires the project teams to work as a whole for successful operation. It is clear that for a complex ideology such as sustainability to be operationalized in a fragmented industry like construction demands a holistic legislative framework. The specific legal framework is needed to guide sustainable procurement (contract) between the stakeholders', and the media angle is necessary for proper community engagement. This was corroborated by PS4;

"if you look at sustainability within the broader aspect, the only element that is in the appointment document that you could say that has some element of sustainability is the requirement that 30% of the project value, a minimum of 30% of the project value needs to be procured from the province not even the immediate community. Other good practice and social benefits (quality and environmental process) are in-house initiatives, peculiar to each firm."

Finding solutions to the aforementioned problems is, however, a daunting task but not insurmountable, as respondents suggest roles (activities) that the stakeholders can play in mainstreaming the lean-sustainability practices in the industry. Such roles that stakeholders have referred to include: academic, consultant, developer, government official, contractor, and the L&G council member. Some samples of the respondents' recommendations are presented below.

"That output specification needs to include things like sustainability factors"

"We think sustainability advisers are not in the position of power yet and that is so as most legislation in the industry doesn't require them"

"Academia should mainstream lean and sustainability practices and research into the school curriculum"

"Government to provide industry incentive for sustainability practices"

"Lean and sustainability councils to provide workshops for continuous learning and stakeholder engagements.

"Prototype green infrastructures by government to limits uncertainties"

Detailed presentation of these recommendations will be itemized and presented in the next chapter on the mechanism development.

5.5 Summary of Findings.

The summary of findings is thematically highlighted in Table 5.15.

Table 5.16: Summary of findings

Themes	Summary of findings
Sustainable construction practices	➢ The results of the study suggested that energy efficiency, material and water reduction, reduced pollution, durability, energy conservation and local material sourcing are the major features of sustainable construction in the industry. ➢ Other sustainable practices in the industry include the adoption of biodegradable materials, life cycle costing, innovation, and embodied and renewable energy. ➢ Efforts that are therefore made in appropriate design solutions and technologies that could engender effective and efficient energy management, reduced material and water usage are most important to the sustainability of built environment infrastructure.
Lean construction practices	➢ The conclusion that can be drawn from the cases is the apparent low understanding and adoption of the lean concept in South Africa construction industry. ➢ Although the stakeholders adopted some lean and lean tools-related principles, its recognition within the industry practice is still in an embryo stage.

	➢ Surprisingly, concurrent engineering is the most popular efficiency concept within the industry. ➢ Lean tools such as Just-In-Time, visualization tools, daily hurdle meetings, and value analysis are commonly deployed as catalysts for enhanced sustainability goals. ➢ Other features such as those the literature advocates, such as the last-planner, prefabrication and Kaizen, are rarely deployed yet.
Synergy between lean construction and sustainability practice	➢ The synergy between lean construction and sustainability practice for the lean-sustainability paradigm suggest that it is, however, not yet a formal operational concept within the South African construction industry. ➢ L-S has enhanced the efficiency and effectiveness of the production processes. ➢ The major benefits of the synergy exists in the areas of reduced resources utilization, reduced waste and pollution, enhanced value creation, improved traditional practice, and the fact that lean construction serves as catalyst for sustainable practice. ➢ The synergy was made possible through the adoption of an innovative platform for infrastructure delivery in a collaborative manner.
Drivers for lean-sustainability concept in South Africa	➢ Embracing an innovation in a fragmented industry such as construction often requires a commensurate driver for meaningful changes to occur. ➢ The major drivers for the lean-sustainability paradigm in the South African construction industry include: drive to gain industry competitiveness edge, the market environment that now requires higher efficiency and effectiveness for success, and inflow of innovative staff. ➢ Other industry drivers are: winning more contracts/financial incentive, and the motivation to attract and retain good employees. Social responsibility and environmental concern, stakeholders' demand, leadership issues and changing legislation form part of the factors that drive lean-sustainability concept within the industry. ➢ It can be said that the dated tripods of 'cost, quality and time' management related to economic concerns still hold the key to innovations.
Barriers to lean-sustainability concept in South Africa	➢ Resistance to change is a common phenomenon (barrier) to a new concept similar to lean-sustainable construction in an industry setting. ➢ One significant barrier to the lean-sustainability paradigm for infrastructure delivery is the sustainability premium. The cost implication served as the greatest hindrance to the attainment of sustainability in the South African built environment.

	➢ Other factors such as the lack of L-S industry leaders, awareness and demands of stakeholders, rigid organization cultures, limited sustainable material for selection along with political and policy framework, and uncertainty among stakeholders were discovered as hindrances to the adoption of the lean-sustainability concept within the industry.
Benefits (indicators) of lean-sustainability on project performance	➢ In order for LSMI to be adjudged effective, the ability to measure the performance of its product must be demonstrated. ➢ The most substantial benefits derived from the adoption of the lean-sustainability concept in project delivery in South Africa include: improved industry competitive edge and industry continuous improvement, increased stakeholders' collaboration and increased organizational learning. ➢ Outperforming cost and other schedules, improved environmental value chain, matching business and environment, improved H&S records, improved planning and risk management, reduced pollution and emission, reduced energy and resources consumption, increased product affordability, flexibility and adaptability, increased technology advancement, enhanced employment and skill development, improved renewable and resources usage and reduced industrial dispute were other associated benefits of L-S adoption in project delivery within the industry. ➢ These outcomes have demonstrated a broader appeal for industry sustainability by moving projects away from the traditional management-oriented ambits of time, cost and quality, and prioritised economic, environmental and social impacts of construction projects. ➢ This conclusion was further corroborated by the results of the t-test and the Kruskal-Wallis test for the significance and variability of these benefits (see Table 5.13 & 5.14). The t-test result shows that all tested variables are significant (< 0.05) and the Kruskal-Wallis test shows no significant variability, as most P-Values are greater than 0.05 and no definite pattern appears accounting for others with less than 0.05, based on the proposition tested.
Influence of stakeholders on lean-sustainability paradigm	➢ The action and inaction of the project stakeholders influence the uptake and operationalization of innovative outcomes. ➢ The lean-sustainability paradigm can only be driven through key project participants providing leadership, their commitment to the concept, understanding and early involvement in the areas they can influence. ➢ The client/developer, the Green Councils (lean at infancy), and consultants (especially, in sustainability) were better

	positioned to influence and engender the adoption of a L-S paradigm in the South African industry. ➢ Contractors as well as sub-contractors with various consultants also have influence on L-S infrastructure delivery on major concepts such as: whole-life costing, integrated design, waste management, energy modelling, corporate social responsibility (CSR) and community engagement, and the use of sustainable material resources inherent in its successful adoption.

5.6 Summary

The chapter explains how the data were collected and analyzed in providing insights into the research questions towards meeting the study objectives. Qualitative and quantitative data were sequentially collected within the five selected cases. The analysis adopted a thematic approach based on seven distinct sub-headings: sustainable construction practices, lean construction practices, synergy between lean construction and sustainability in rated green projects, barriers to lean-sustainability concept, drivers for lean-sustainability concept, benefits (indicators) of lean-sustainability on project performance, and stakeholders' role in engendering a lean-sustainability paradigm in order to proffer answers to research questions 1 - 3 of the study. The interview transcripts as well as the semi-structured sections of the questionnaire survey were analysed using content analysis. The structured section of the questionnaire survey was analyzed statistically using statistics tests such as the MIS, T-test and Kruskal-Wallis Test. The MIS was used to rate the perceived importance of the rated factors. The T-test was used for the significance of the benefits of L-S practice, whilst the Kruskal-Wallis Test was to test variability of results across cases. Succinctly put, the chapter shed light on objectives I to III of the research study, as set out at the onset of this chapter. The findings explain features of lean-sustainability, its practices and principles. The chapter examined the integration (lean-sustainability) of the concepts, the drivers and barriers, highlighting the benefits of such practices in the industry, along with the stakeholders' roles for engendering such practices. These findings are discussed in Chapter 5, in line the conceptual framework and the experts' opinions will be used to develop the mechanism in Chapter 6.

6.0 MECHANISM DEVELOPMENT AND EVALUATION

6.1 Introduction

This chapter introduces the development and testing of the mechanism proposed for the integration of lean and sustainability in project delivery in South Africa. The section is set out to accomplish the main aim of this research. The derivatives from the previous chapters (Chapters 2, 3 and 5) on one hand, and the expert's scrutiny on the other, serve as the basis for the mechanism's development and the subsequent evaluation. The chapter also presents the route-map guiding the implementation of the proposed mechanism. This chapter achieves objectives 4 and 5 of the study.

6.2 The Problem

In response to the gradual deterioration of the global socio-ecological stability, it seems the world is determined to save the universe from heading to collapse. The issue of climate change and its associated symptoms has driven the various adversaries of the world towards the *socially constructed reality* of working in unison in establishing common sustainability goals. The continual demonstration of the proximal consequences of climate change has served the sustainability path as an important strategy to engage and mobilize publics around sustainability issues (Spence & Pidgeon, 2010: 656). The most recent effort (COP21) in France, ensued by the Paris agreement, in Sustainable Development Goals (SDGs) that has placed the built environment in a prime position in meeting the global goals of improved health and well-being, industry productivity, and the target of reducing the global warming by 2^{o}C and building-related emissions by 80 gigatonnes by 2050 (Green Building Council South Africa (GBCSA), 2016: 1).

The relevance of creating a workable synergy between lean and sustainability for infrastructure development is evident. This drive for innovative ways to change, in the current Business As Usual (BAU) model of construction practice and infrastructure delivery, which runs contrary to the needs of sustainability in the built environment, is increasingly advocated.

The review of the management corpus in the area of sustainability also necessitates the need for a more comprehensive mechanism for the South Africa construction industry (see Chapter 3). Most of the existing sustainability models focused mainly on the interaction of the natural and social systems, and organizational sustainability management (SM). The paucity of models for integrating lean with sustainability, especially within the developing country context, is noted. Overall, very few models focus on organizational learning capacity to embrace lean and sustainability concept (Novak, 2012: 52).

6.3 Utility of proposed mechanism in resolving existing problem

The industry stakeholders and innovative advocates have called for a paradigm shift towards lean-sustainable construction (LSC). Such a shift will engender the evolution of a sustainable built environment through industry-efficient and effective deployment of limited resources and techniques. This new paradigm shall emerge when stakeholders are equipped to critically assess the impact of the interaction between natural and social systems. This interaction to be meaningful, is by focusing on areas for improvement, in meeting sustainable built environment requirements in terms of socio-economic and environment dimensions. Industry stakeholders should be able to evaluate their current practices in terms of the lean-sustainability concept, and what is required to move towards the set target. Development of a workable framework for meeting these requirements is beneficial to the industry, thus making such an endeavour worthwhile. The developed framework will provide the adaptive form of governance needed for socio-technical systems such as infrastructure delivery systems, in response to the gradual deterioration of the global socio-ecological stability.

6.4 Mechanism Development process

According to the work of Awuzie (2014: 165), which cited Bernard and Ryan (2010) on model development, there are three critical stages of mechanism development. These stages include i) identification of key constructs to be included in the mechanism, ii) identification of the relationship between these key constructs and a representation of these relationships, and (iii) validation of these relationships for validity for most, if not all of the scenarios being modelled. Nevertheless, the previous work of Milhram (1972), as cited by Fellow and Liu (2008: 117), has identified five distinct stages of mechanism development and validation (Modelling Process). These stages are as presented in Figure 6.1.

The model development and validation perspectives portrayed by both works mentioned above possess shared basic principles and highlight the importance of proper validation of the developed model. The study draws from these basic principles in forming a major part of data collection towards the mechanism development, testing and validation in boosting the confidence levels in the emerging theory (Awuzie, 2014: 165).

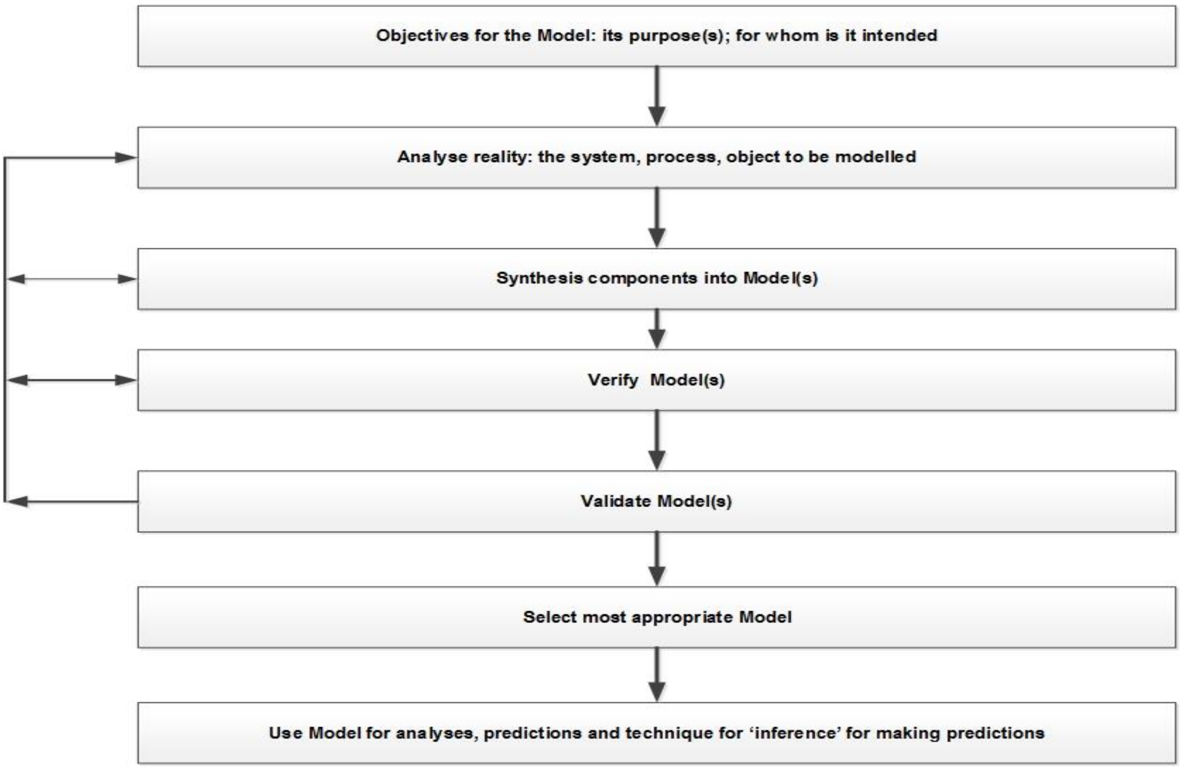


Figure 6.1: The Modelling Process (Mihram, 1972, cited in Fellow and Liu, 2008: 117)

6.4.1 Mechanism development

The mechanism was developed through case study-based research design discussed in previous chapters. The insights from literature, the questionnaire survey, and interviews contributed towards the development of the mechanism. The aforementioned review of the sustainability management (SM) corpus led to the discovery of the transformation process model. The transformation process model (TPM) is an organization-wide SM initiative for stakeholders' interactions between social and natural systems in response to the competitive landscape in the new global economy (Madu & Kuei, 2012: 5). Sustainability strategies and capabilities are increasingly important and complex for innovative enterprises in competitive environments around the world. For an organization to simultaneously achieve excellence in sustainable development dimensions of economic, environmental, and social performance, it must undergo a transformation process. Such a process would engender a change from the BAU approach to a sustainable state. The TPM was upgraded to serve the intended purpose through the infusion of the core principles of lean and sustainability in meeting the industry requirement for a new mechanism that could create the right synergy between the two concepts.

The researcher adopts the scholarly work of Novak (2012: 54), which is based on the proposition that there can be a synergistic link between lean construction and sustainability, as expressed through the construct of value. Value creation through the lean-sustainability paradigm in a project life cycle could lead to new competences and new organizations for continuous improvement and further innovative opportunities (see Figure 3.10). The mechanism development stages of identification of component parts, relationship between principal components, flow (logic), and its assessment was systematically followed. This process of mechanism development was underpinned by the theories of change (ToC). Figure 6.2 highlights the area of evaluation towards the development of the mechanism.

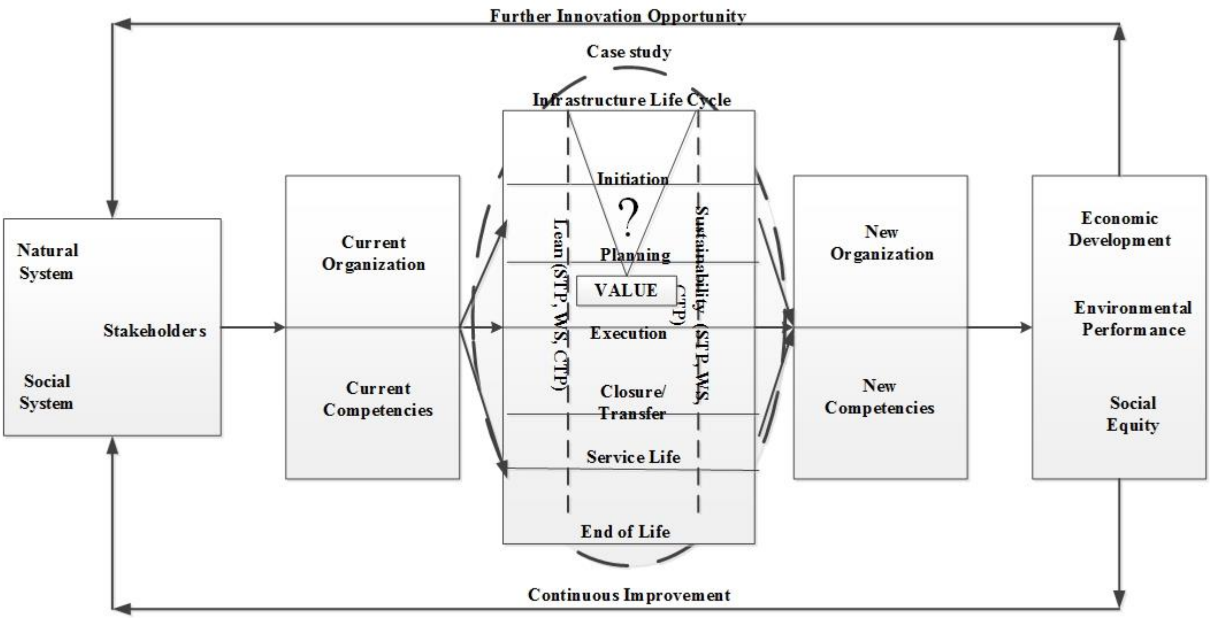


Figure 6.2: First draft for lean-sustainability mechanism for infrastructure (LSMI): Evaluation Constructs (adapted from Madu and Kuei, 2012: 8; Novak, 2012: 54)

6.4.2 Identification of component parts

The operationalization of the lean-sustainability concept consists of all the perceived components of lean construction and sustainability construction practices and the expected outcomes. In other words, the expected lean-sustainability platform for project delivery should demonstrate features such as resources, drivers, barriers, activities, outputs, the outcomes and the ultimate impact. The proposed LSMI construct will comprise varying distinct but related parts which include: current state evaluation, the drivers for change, the lean-sustainability integration concept, and the infrastructure life cycle value streams (transformation) – barriers (current challenges), infrastructure delivery, life cycle, stakeholders' involvement, and success factors.

6.4.2.1 The current industry state

The South Africa construction industry is still embedded in the practices replete with Business as Usual (BAU) tendencies. Such practices are not aligned with the set sustainability goals. The BAU concept still dominates industry practices where sustainability is not part of the clients' specification for project performance outcomes, sustainability awareness is still low, the industry-skilled professionals for sustainability practices are still minimal and the policy framework guiding sustainability is near non-existent in the way the industry pursues infrastructure delivery in meeting the needs of the community. These needs have to be addressed in a way that is socially and ecologically responsible. Lessons from the developed world suggest that greater urgency is needed now in making sustainable interventions, while new infrastructures are being created, rather than try and change things after technically exceeding the ecosystem's carrying capacity (Du Plessis, 2007: 67).

This 'overshoot' as a result of construction activities distorts the ecosystems and affects various facets of daily living: environmental pollution, global warming, resource depletion and environmental degradation, ozone layer depletion and economic downturn. Green (sustainability) targets come with a high premium, where budget and schedule targets are usually not met, and issues relating to low productivity, materials and process wastes, low skills and unemployment, lack of efficiency and effectiveness, increasing poverty levels, amongst others, still persist. Succinctly put, no visible attempt is being made towards integrating lean and sustainability in the development of sustainable infrastructure in the built environment. These revelations have changed the stakeholders' views and spurred project actors to embrace a paradigm shift towards environmental responsiveness especially in construction practices –

a new drive in the sector towards change in the way the stakeholders pursue our developmental needs.

6.4.2.2 Drivers for change

The drivers of lean-sustainability need to be identified and evaluated at the present state. Where these drivers are strong enough to inspire change, then the pressure to change in an innovative way arises. In order to experience holistic organisational change, the stakeholders must be ready for comprehensive transformation (Parker, 2008: 3). Drivers such as the environment, law and regulations, internal and external policies, industry competiveness, rising energy cost, social and community demands, availability of non-renewable energy, needs for new skills, employment level, technological advancement, desire for intra and inter-generational justice and equity, amongst others, have contributed significantly towards society's increased focus on a new approach to developmental activities.

The integration of L-S happens to be one of such new paradigms within the context of infrastructure delivery. These drivers call for a new way of interaction between social and natural systems in meeting both internal and external stakeholders' demands, promotes the adoption of the new concept, as obtained in the integration of lean construction and sustainability practices. The new innovation (lean-sustainability concept) comes with a hope of bringing about a broader appeal to sustainability. As lean-sustainability construction sustains continuous improvement throughout the project life cycle in pursuance of stakeholders' satisfaction, it creates a more effective, efficient and profitable industry working towards sustainability (Suresh, Bashir & Olomolaiye, 2012: 379).

6.4.2.3 The lean-sustainability integration concept

Lean-sustainability integration is an attempt to produce a new socio-technical regime for infrastructure delivery. The pathway to the future goal, as prescribed by the industry niches, is through the integration of lean and sustainable construction practices in the infrastructure life cycle. The operationalization of the lean-sustainability concept is backed by the necessary frameworks that can move its adoption towards the tipping point and create values (Figure 6.3).

Figure 6.3 illustrates the process by which lean practices serve as catalyst for efficient and effective sustainable practices in built environment infrastructure procurement. Lean construction and sustainable practice integration can have a more significant impact on infrastructure development. The lean-sustainability concept has a positive impact on multiple measures of operational performance when operationalized simultaneously rather than discretely (Novak, 2012: 54).

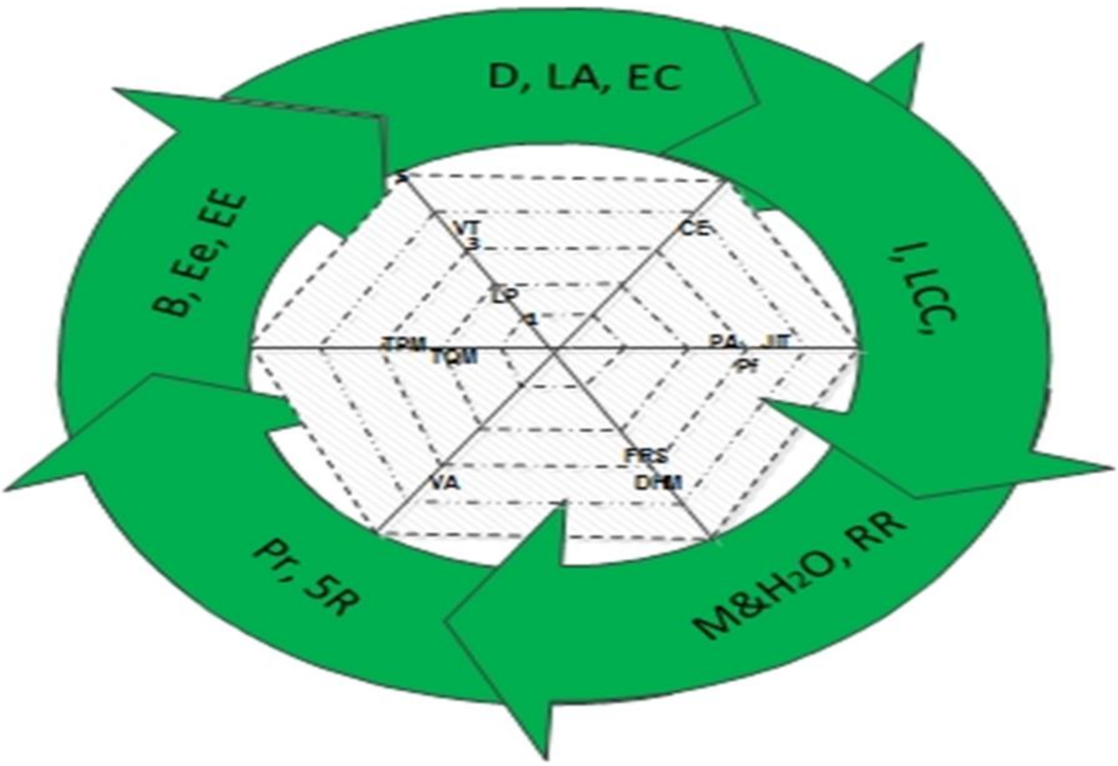


Figure 6.3: Lean and sustainable practices integration in South Africa (Researcher fieldwork, 2016)

Legends:

Sustainable practices (outer layer)

M&H_2O – Material and water reduction; EE – Energy Efficiency; D – Durability; EC – Energy conservation; RR – Renewable Resources; Ee – Embodied energy; LA – Local availability; I – Innovation; B – Biodegradable; LCC – Life cycle costing; 5Rs – Recycle, reduce, reuse, rethink, refine; Pr – Pollution reduction.

Lean construction practices (inner web)

VT – Visualization tool; LP – Last planner; TQM – Total quality management; TPM – Total preventive management; JIT – Just-in-time; PA – Pull approach; P_f – Prefabrication; VA – Value analysis; FRS – first run studies; DHM – Daily huddle meeting.

The integration between sustainable practices and lean construction practices is akin to a moving car. The car (sustainable infrastructure) has sustainability practices as the engine and lean construction practices serve as the lubricant for efficient running towards sustainability.

The green outer layer represents sustainable practices; suggesting the new green initiatives of LSMI as identified by the stakeholders. The practices were not in order of preference because every sustainable practice adopted increases the chance for quick delivery of the primary goal (sustainability), whilst the inner web (lean tool and practices), presented in respect of the current mean rating of lean tool and practices. This is to demonstrate the low level of awareness, but it is not compulsory to adopt every lean tool in a single operation (see section 5.4.2). Hence, the integration of lean practices and sustainable construction in this manner will sustain continuous improvement throughout the project life cycle in pursuance of client satisfaction, create more effective value, and efficient risk management by effectively challenging the dated belief that key performance indices (KPI) of cost, time and quality cannot be pursued simultaneously in the construction industry (Dulaimi & Tanamas, 2001: 2; Suresh *et.al*, 2012: 379). Furthermore, the integration would transform the industry (infrastructure values) towards the path of sustainability.

6.4.2.4 Infrastructure transformation (life cycle)

In order to successfully transform from the BAU to the lean-sustainability concept in industry infrastructure delivery, the organisational ways of doing things must be transformed in many areas: culture, process and stakeholders' relationship. These include changes in values and human behaviour, in process and function, coordination and control, and the power within the organization (Smit *et al.*, 2011: 255). Transformation (change) can occur in an integrated project delivery (IPD) model amongst the niches or platforms, drawing from the experience of the stakeholders for best practices (Forbes & Ahmed, 2011: 67). This IPD model of project delivery is strengthened by coming together and evaluates projects from initiation stages to service life, critically assessing the sustainability barriers and how the lean process can serve as a catalyst for efficiency and effectiveness in sustainable construction practices in each stage to create value that leads to successful performance.

The transformation process must have a buy-in from the stakeholders. Although the transformation process is a shift from one stable state to another that involves the technical, physical and material considerations in sustaining the society, most of the upstream activities and the innovative measures are situated within the innovative platform (niches) (Geels, 2010: 495). Stakeholders' leadership is critical to the industry's ability to nurture the environment for innovative reasoning (Harvey, Speier & Novecevic, 2001: 900; Bahner & Stroh, 2004: 183). The support for the act of creating such an environment in practice is a necessity for transformation to occur. The stakeholders have to constantly break the barriers of the successful integration of the lean-sustainable value construct by meeting the success factors over the infrastructure life cycle (Figure 6.4).

Figure 6.4 presents the evaluation of the infrastructure life cycle value stream through operationalization of the lean-sustainability concept. The shift to a lean-sustainability paradigm in the social-technical system leads to value creation and continuous improvement (Houvila & Koskela, 1998: 2). Figure 6.4 highlights the barriers of the current states, the transformation that could occur through L-S practices, and the expected future state (success factors). A thorough understanding of these barriers and hindrances to sustainability targets allows for the development of the pathways to success.

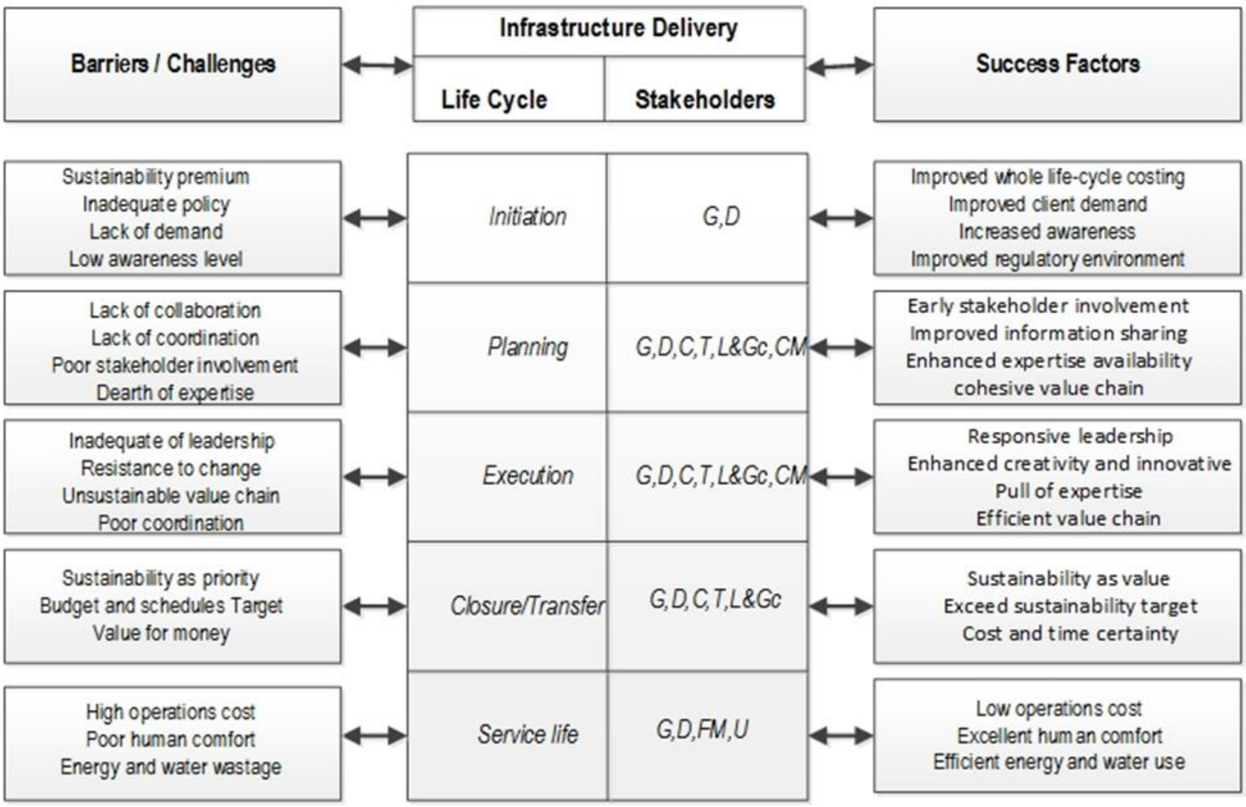


Figure 6.4: L-S Value Streams in Infrastructure Delivery Life-cycle (Researcher fieldwork, 2016)
Legend:

G – Government; D – Developer; C – Consultants; T – Contractor
LGC – Lean and Green Councils; CM – Community; FM – facility manager; U – Users.

This target of attaining the success factors is principally made possible through collaboration, coordination and communication, known as the 3Cs. These are three connecting opportunities critical to attaining success and embedding integrated (IPD) concepts as inherent in lean-sustainability construction (Forbes & Ahmed, 2011: 67). Smit *et al*. (2011: 256 – 257) identify certain principles such as communication, participation and involvement, facilitation and support, negotiation and rewards as strategies to overcome resistance to change in a socio-technical system. In other words, effective environmentally responsible construction demands the commitment of stakeholders to cultural and system changes, an integrated environment system with normal work processes, involving close cooperation and collaboration with all stakeholders, that starts as early and as visible possible throughout the building's life cycle:

- **Collaboration:** Working with stakeholders by adopting an integrated project delivery (IPD) strategy. Early appointment and involvement of all stakeholders from the project conception stage and seeking relevant opinions of the expertise regarding what works in critical (planning, design and execution) stages – this helps in straightening the fragmented lean-sustainability value chain and limits the effect of associated barriers in order to achieve project targets. Collaboration allows the project participants to change their typical approach by making the projects' overall success the primary goal which leads to industry sustainability. Seeing projects as a collective enterprise by aligning rewards with project-wide optimization motivates project team members to practically take ownership of the project success for improved performance. According to earlier researchers, 'Team orientation and trust are essential for mobilizing creativity, and cultural transformation is as a result of the process of emergence – the whole is more than the sum of its parts. This cultural transformation involves using system principles of openness, purposefulness, multi-dimensionality, and emergent property, system dimension; membership, decision system, measurement system, organizational processes, and throughput processes, and system methodology. The system transformation, however, is possible due to the influence that the relatedness of the parts of a system has on the behaviours of the parts (Luisi & Houshmand, 2009: 101; Forbes & Ahmed, 2011: 67).

- **Coordination:** This addresses the questions of holistic community management involving leadership, employee fulfilment, conflict management, and cultural acceptance that thus have economic, environmental, and social impacts (Epstein, 2009: 24). Leadership in the innovative platform is needed for the organization of the stakeholders involved for a successful transformation process, as is the ability to create the framework that will guide the operationalization of various tasks in an orderly manner among the various segments of project teams. Standardization of activities by implementing standard procedures is often the means to reduce variability in both conversion and flow processes. Coordination increases predictability of the work process. The processes (tasks) must be properly delineated and assigned to competent organizations (role players) to enhance proper value streaming – earlier appointments of sustainability and lean consultants makes the difference. Lichtig (2006: 12) and Forbes and Ahmed (2011: 67) state that impeccable coordination leads to workflow predictability, reduces project fragmentation and serves as catalyst to project success.

- ***Communication***: Engagement and proper communication serve as lubricant to the aforementioned 2Cs. Effective communication is the ingredient for successful collaboration and coordination for a project-based industry. Adequate and unfiltered communication creates values and confers on the stakeholders the right success factors and benefits, whilst breaking the structural and cultural barriers within organizations. Efficient communication increases transparency and work variability and reduces rework. Communication enables infrastructure projects' outcome goals (i.e. sustainability) to be better aligned with stakeholders' needs and thus enables acceptability (Lichtig, 2006: 12; Forbes & Ahmed, 2011: 67; Abdullahi *et al*., 2016: 89).

These three principles enable proper interrelation within the innovative niches and enhance creative ideas through the infrastructure life cycle and a smooth transformative transition in LSMI. It breaks the systems and cultural barriers by working with stakeholders in an efficient and effective manner necessary for transformation. The lean-sustainability concept sustains continuous improvement throughout the project life cycle in pursuance of stakeholders' satisfaction, and creates a more effective, efficient industry prime for sustainability (Novak, 2012: 54; Suresh, Bashir & Olomolaiye, 2012: 379). The effectiveness of these principles can be continually improved through continuous learning and improvement.

6.4.2.5 Continuous learning and improvement

One of the major barriers to lean-sustainability integration is the current state of leadership in the industry particularly the lack of knowledge and the low awareness level in the industry. Nevertheless, the effort to increase value is an incremental and iterative activity that can only be carried out continuously (Madu & Kuei, 2012: 5). Understanding the L-S concept will require constant training, awareness and enlightenment campaigns, and learning through the job. Lessons learnt should be documented and adapted in future projects. Completed projects or activities serve as a learning curve and a reference for future measurement and improvement. Sustainability is a complex concept; its full understanding is similar to pursuing perfection among industry stakeholders.

6.4.2.6 Industry Stakeholders (niches)

Stakeholders in the lean-sustainability paradigm cut across various facets of endeavour, as sustainability and infrastructure delivery touches every aspects of community life. These suggest the wide ranges of knowledge and technicality required for creating the stakeholders for a holistic evaluation and setting pathways for success in a complex case (sustainability). The safest way to successful transformations is to gather all the right people, with experience in the field, and support the need for innovative change, to form the niches needed to influence the innovation platform at the right time. In most complex operational contexts, as obtainable in lean-sustainable construction, stable niches can be symbolic, neutral or competitive. According to Maru *et.al.* (2016: in press), each state has "a practical implication for who should be in the innovation platform and for how the innovation platform can develop strategies to effectively manage its relationships with socio-technical regime and thus increase its chances of success."

Naney *et.al*. (2012: 292) posit that stakeholders need to understand the barriers to innovation in order to develop strategies to remove them and create change. Overcoming barriers requires a holistic and in-depth evaluation of the industry for adequate and sustainable 'drivers' that can bring about change, build trust and establish a new culture of constant learning, improvement and perfection among the stakeholders in the construction industry.

The most referred stakeholders in the LSMI that could contribute significantly to the aim of engendering the lean-sustainability concept in infrastructure development in moving towards the broader built environment sustainability are: government/agencies, academia, consultants, contractors, lean and green councils, community, developers/clients, national and international groups. This study shows the niche for LSMI in the South African context, and their expected role in engendering the L-S concept in infrastructure delivery in the industry (Figure 6.5).

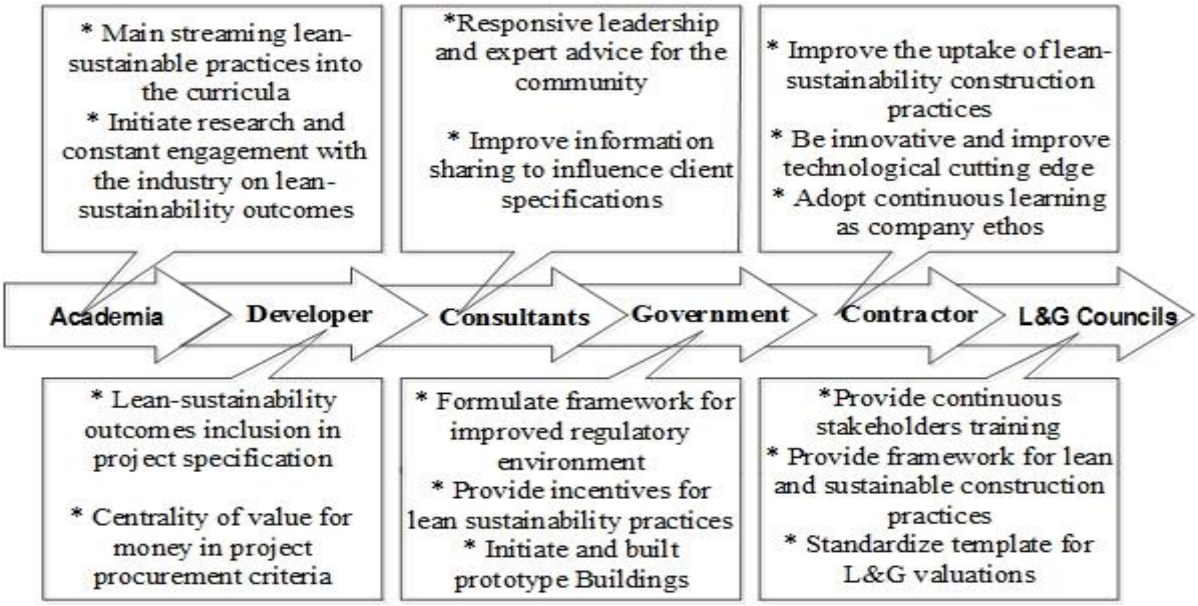


Figure 6.5: The stakeholder's role in engendering lean-sustainability concept in infrastructure development (Researcher fieldwork, 2016)

Key: L&G: Lean and Green Councils

Figure 6.5 thematically presents the survey outcomes of how the stakeholders could influence the lean-sustainability uptakes. It indicates that with continuous (learning and improvement), moving forward in an arrow-like manner and working with stakeholders, the adoption and implementation of the concept will move towards the tipping point and attain more acceptability in the industry. This will be significant for the industry as lean-sustainability integration can be attained and the path for innovation and transformation will be laid.

Corfe (2013: 1) expresses the opinion that when considering sustainability issues, it is normally a preferred choice to relate the key areas to the processes which can be influenced by sustainability leaders. Therefore, the stakeholders' roles highlighted here would influence climate change mitigation and promote socio-economic dimensions of the built environment through lean-sustainability processes in; procurement, design, innovation, people, and better regulation in the industry. Consequently, the prime target is the adoption of these processes simultaneously in order to attain a sustainable result. This will provide the right platform for the industry to understand the sustainability concept from a strategic and a holistic point of view.

6.4.3 Relationship between principal components

The mechanism is based on the concept of the Transformation Process Model and the theory of change (see section 3.6). The mechanism is developed through a logical linking of multiple sequential areas of inquiry such as: (1) evaluating the current state of the industry and setting the future goal amidst the barriers and drivers for innovation; (2) evaluating the impact of lean-sustainability principles on stakeholders' interaction with natural and social systems, (3) the critical evaluation and development of these core sustainability competences for sustainable development; (4) the correlation between increased cohesiveness of lean and sustainability with the enhanced project performance and the impact on the project whole life cycle; (5) exploring the relationship of a case – infrastructure values – with both internal and external communities sustainability values; and (6) examining the opportunity for this broader vision of sustainability to serve as a point of reference for organizations' continuous improvement and further innovation opportunities in infrastructure development, as the mechanism is not an end in itself but the means.

Based on these relationships between LSMI mechanism components, the second draft of the proposed mechanism is hereby presented (Figure 6.6).

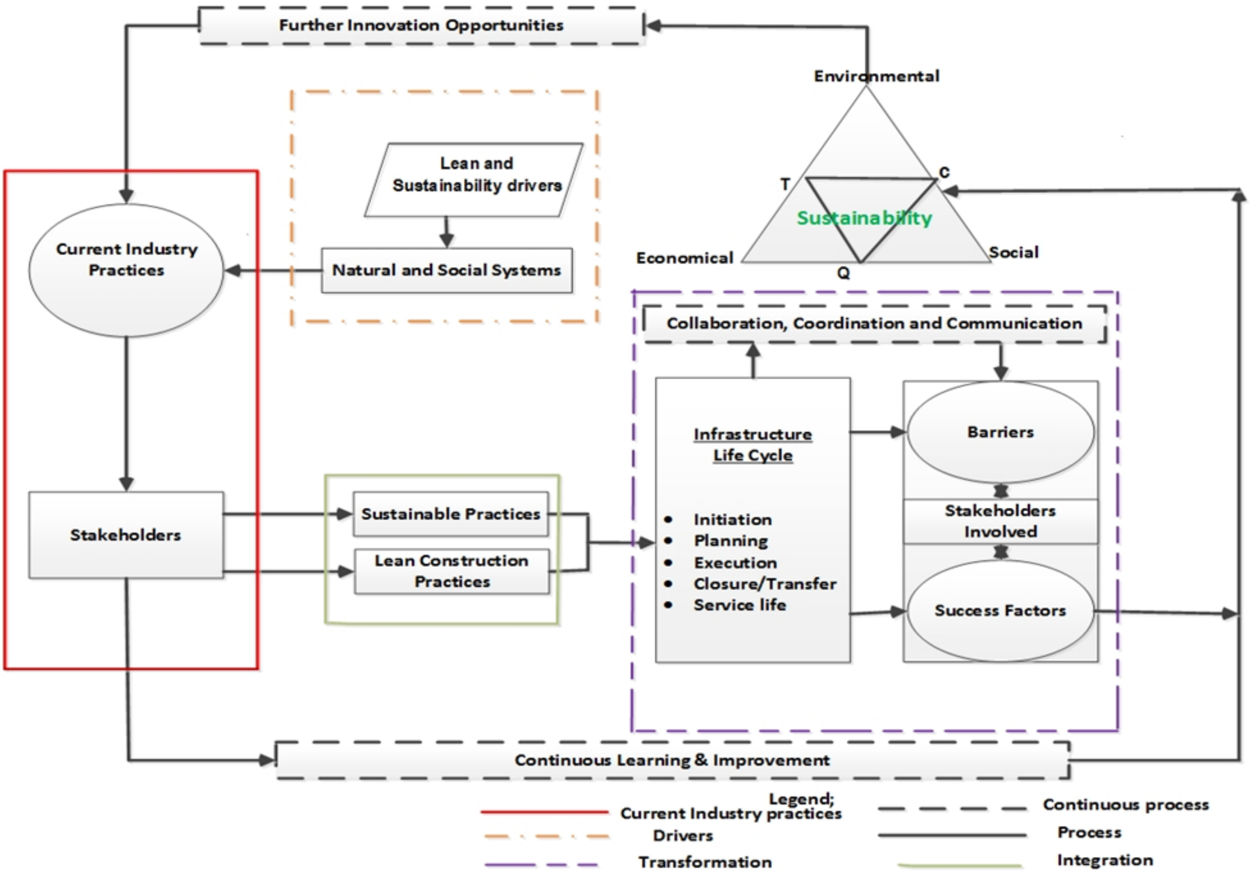


Figure 6.6: Second LSMI Draft for Project Delivery (Researchers fieldwork, 2016)

6.4.4 The flow (logic)

The mechanism is aimed at allowing construction stakeholders to evaluate and analyze their interaction with the natural system within the purview of the lean-sustainability paradigm and assessing its benefits, not only within the infrastructure life cycle but the built environment as a whole. The mechanism is an attempt to re-invent the wheel through innovation, moving from traditional practice to lean-sustainability paradigms. It is expected that the mechanism should avail stakeholders with the framework for assessing and evaluating the lean-sustainability platform and how they affect the overall business concept. Hence, borrowing from the 'cause–effect' principle of ToC (logic model) – an 'if then' sequence of interaction within the construct, such that, when applied within the construct to each component, it logically reads: "If we have stronger drivers for sustainability (change), then we can pursue lean-sustainability activities within the resources available for our infrastructure projects"; "If we pursue lean-sustainability activities, then we can create values in infrastructure life -cycle"; "If we have real values through infrastructure life cycle, then we will secure lean-sustainability benefits";

and "If our infrastructures exhibits L-S indices, we have built environment-sustainable development". Moving from the left to the right in a systematic manner, the various segments of this matrix to innovative thinking have to be considered in the mechanism (Wyatt Knowlton & Phillips, 2013: 11).

6.5 Assessment of the mechanism

Assessment and evaluation criteria are critical to the successful implementation of any innovative platform. The impact of an intervention cannot be measured, so assessment and evaluation will be near zero. This accounts for the importance the ToC attached to the performance mapping of socio-technical change in order to understand the underpinning process of what works and wanting to learn from it (Guijt, 2007: 7-12). Assessment of LSMI is the evaluation and understanding of short- to intermediate/long-term outcomes (new industry practices, L-S indicators) – toward its ultimate impact (Sustainable development) and further innovative opportunities.

6.5.1 New industry practices

> "*Clearly, once a transformation is done and a process for sustainability is mature, a new organization is born" (Madu & Kuei, 2012: 9*).

This is an industry state with new competences and new values. Embracing change by operationalizing LSMI in construction organization would engender change in the beliefs, values, and attitudes of people in the industry and the community as a whole. The stakeholders are more aware of what works and, most importantly, have the right competences to attain the set goals. There is adequate understanding of clients' demands, well-trained professionals, and the right polices and well-regulated industry, amongst other factors that guide the industry towards sustainability – a state where stakeholders are willing to act for its own benefits (intrinsic good) and also for the larger society (Madu & Kuei, 2012: 9).

The industry will act with motivation for innovative ideas, and swift technological adoption in pursuance of cutting-edge, socio-ecological compliance and attainment of unique positions in the marketplace (Bahner &Stroh, 2004: 181). In socio-technical systems, Buchannan and Huczynski (2004: 28) opine that transformed organizations would have the capacity to evaluate and respond to issues such as political, economic, social, technological, legislative, and ecological factors by modifying their organizational structures, organizational strategies, management styles, working practices, employment patterns and innovative solutions to suit their overall vision and objectives. These states engender the production of new building infrastructures that demonstrate lean-sustainable indicators (values).

6.5.2 Lean-sustainability indicators

Monitoring progress in operationalizing LSMI thus requires the identification of operational indicators that provide manageable units of information on economic, environmental, and social conditions that can be measured (Isa & Emuze, 2016: 557). The indicators assist developers and others stakeholders to gain a more comprehensive view of the LSMI impacts on infrastructure project performance throughout the project's life-cycle.

This stage of LSMI engenders the production of building infrastructures that demonstrate lean-sustainable indicators (values). The new infrastructures in the built environment create a broader appeal to sustainability values within the stakeholders. These infrastructures have outperformed the clients' time and cost schedules and meeting social and environmental dimensions, in addition to economic sustainability (Figure 6.7). As the sustainability concept continues to gain acceptability amongst clients and the industry, the scope for define 'value' is now enlarged to cover specific sustainability criteria in terms of environmental, social and economic dimensions (Pasquire & Salvatierra-Garrido, 2011: 128; Jackson & Robert, 2000: 1).

Figure 6.7 demonstrates the assessment of lean-sustainability indicators as perceived by the projects' actors in the five cases under consideration in the study (see section 5.4.6). This web represents the three dimensions of sustainability plotted with a perceived mean score. The blue line shows the economic indicators, the pink social indicators, and the red environmental indicators. The adoption of the mean rating here is to demonstrate the current situation in the context of South Africa. This allows for further assessment and evaluation overtime.

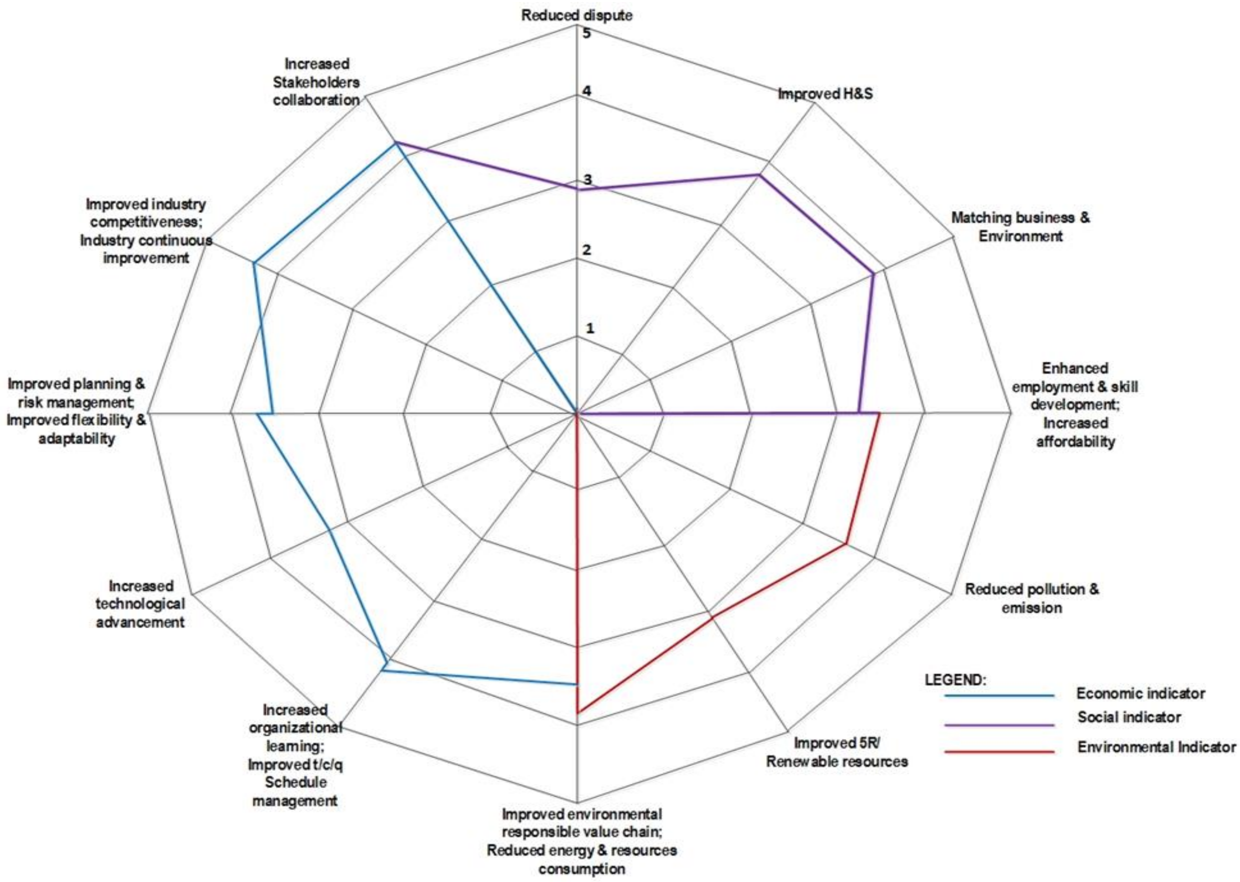


Figure 6.7: Assessment of L-S indicators as perceived by the projects' actors (Researcher fieldwork, 2016)

- Economic dimension: Functional organization runs on the premise of a continuum that based its long-time performance indicator on growing financial assets. Only a clear evaluation and understanding of cost-benefit analysis of innovative interventions trigger stakeholders towards sustainability adoption. Sustainable practice needs to be economically viable in the long run and must also serve as the catalyst to process productivity. The LSMI adopts integrated whole-life thinking by benchmarking, and assessment/evaluation throughout the whole life of the urban infrastructure (Madu & Kuei, 2012: 5; Wagner, 2012: 225; Yao, 2013: 8). The economic angle also suggests the industry needs to meet the needs of its external community in a socially responsible way (Wagner, 2012: 225). It is based on this, that LSMI provided for the survival of the organization through the processes of reduced costs, increased productivity, increased customer and community goodwill that will contribute both to profitability and corporate sustainability, and sustainable development at large.

- Environmental dimension: Winkler (2010: 293) and Corfe (2013: 1) agree that the major challenge to the long-time survival of the world is the effects of climate changes and how to preserve the natural resources that provide essential functions for the well-being of the society. LSMI, thus, advocates that stakeholders focus on ecosystem-related issues such as: waste minimization, innovative technology for friendly environment, maximization of available water bodies, alternative energy sources, fostering harmony between supply chains and nature, environment reclamation and framework for sustainability practice compensation, amongst others. The lean-sustainability concept should be built on the premise that economic development must resonate with the interests of the future generations and the essential needs of the earth, which must include greenhouse gas depletion, biodiversity and ecosystem protection (Madu & Kuei, 2012: 7).
- Social dimension: The sustainability social dimension basically centres on the people, and the community well-being of the society where the industry operates. Social responsibility encompasses basic concepts such as corporate citizenship/philanthropy, labour practice indicators, human capital development, social reporting, talent attraction and retention, and industry-specific criteria (Madu & Kuei, 2012: 7). According to Dong (2012: 445), sustainability goes beyond construction industry's critical mandate and process of providing infrastructure, to reflect an organization's concern with the social needs of its employees and extended environment. It further extends its resources to uplift the community and improve quality of life, improve social civilization, maximize the health and comfort, avoid harm and do what is right, be just and fair, and ultimately obey the law of the land. Industries must strive to archive the status of 'corporate social image' and utilize locally sourced materials and skills, in efficient and effective ways, to create jobs.

It is in meeting these TBLs that sustainability can truly be entrenched within the built environment and a holistic industry transformation would have emerged that is all-encompassing.

6.5.3 Sustainable development

An infrastructure market with a new value paradigm would engender a healthy economy, environmental quality, and social and cultural heritage within the built environment (Novak, 2012: 52). The new paradigm shifts the infrastructure delivery process towards best practices, moving towards a cleaner ecosystem and resource sectors that prioritizes environmental safety along with its socio-economic impact in a project's life cycle. Adopting the best technological options in saving water and energy consumption in an infrastructure-useful life, at a reduced management cost contributes minimally to the emission carbon-dioxide (CO_2) and ozone depletion substances towards the attainment of SDGs in South Africa.

6.5.4. Further innovation

Once transformation is achieved and a process for sustainability is mature, new competencies are attained leading to the birth of a new organization (stable state). The new stable state (sustainable built environment) is then prime for further innovative opportunities, as the sustainability infrastructure idea is not a ‘product’ but a ‘process’ that is subject to continuous improvement (Finch & Zhang, 2013: 306). Hence, the transformational process assumes a continuous cycle. The organization operates as an open system that evaluates the process maturity for sustainability at a point of reflection, receives feedback from its internal as well as external environments for further innovation and continuous improvement opportunities. This process on one hand involves evaluation of the logic constructed during evidence-based planning and the value creation relative to risks and costs in relation to the current stable state. On the other hand, it scrutinizes the scope, sequence, uptakes and quality of activities (Wyatt Knowlton & Phillips, 2013: 9). These testing and evaluation components complete the cycle in LSMI. Thus, the proposed LSMI is as presented in Figure 6.8.

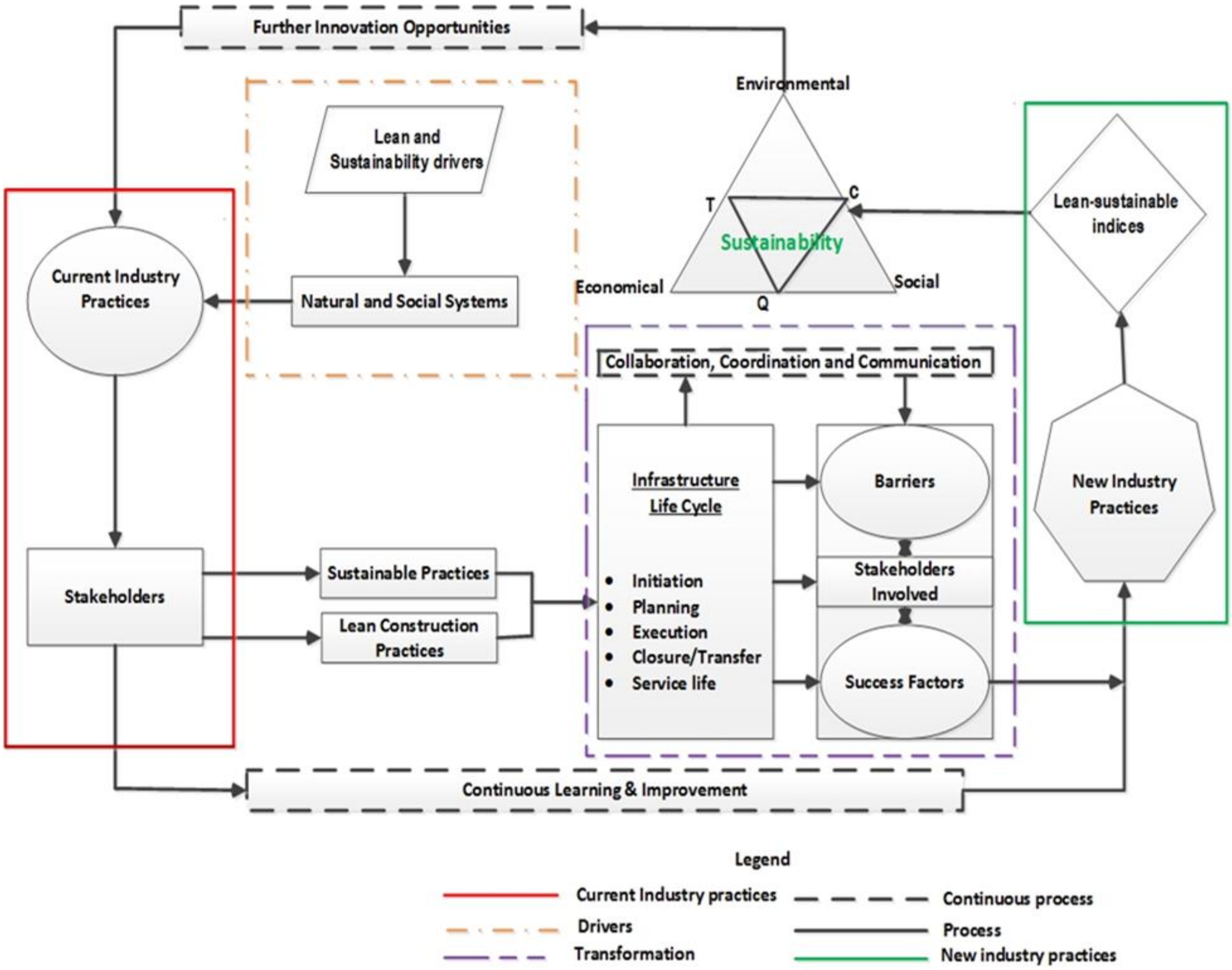


Figure 6.8: Proposed lean-sustainability mechanism for infrastructure (LSMI) project delivery in South African built-environment (Researchers fieldwork, 2016)

Figure 6.8 presents the proposed LSMI for project delivery in the South African built environment. The LSMI is aimed at offering practical guidelines for sustainability industry leaders and their value chain on how to be more sustainable than in traditional systems. It is a mechanism that, if adopted, will lead to various forms of waste minimization and prevention of environmental hazards such that the long-time benefit will be socio-economic viability. Table 6.1 presents the LSMI route-map.

The LSMI route-map is a brief description of the mechanism and the guidelines to the adoption and implementation of the lean-sustainability concept in infrastructure projects delivery for sustainable development. The route-map is the sub-set of the areas of enquiries as presented in the above section.

Table 6.1: A route-map to Lean-Sustainability Mechanism for Infrastructure (LSMI)

Stage	Brief description
Current industry state	Business as Usual (BAU) where: the unsustainable ways that the stakeholders interact with the social and natural system in search of development still persist with its attendant symptoms.
Drivers	Issues concerning the environment, social and the economy have contributed significantly towards society's increased focus on the integration of lean-sustainability concepts. These drivers call for a new way of interaction between social and natural systems in meeting both internal and external stakeholders' demands, promotes the adoption of the new concept (lean-sustainable construction).
Stakeholders	The niche: the affected stakeholders meet in an integrated manner to evaluate their current state and hence set future target and set template on how the target can be met – immediate and longtime (Backcasting).
L-S Integration	The pathway to the future goal is through integration of lean and sustainable construction practices in the infrastructure life cycle. Backed by the necessary frameworks that can move it towards the tipping point.
Transformation	It is expected that drawing from the general theory of socio-technical innovation and social-ecological change inherent in lean and sustainability practice, transformation (change) can occur in the infrastructure life cycle through *collaboration, coordination, and communication (3Cs*) in an integrated project delivery (IPD) manner among the niche, drawing from the experience of the role players for best practices. By coming together and evaluate projects from initiation stages to service life. Critically assessing the sustainability barriers and how lean process can serve as catalyst for efficiency and effectiveness in sustainable construction practices in each stage to create values that leads to success factors.
Continuous learning and improvement	The effort to increase value is an incremental and iterative activity that can only be carried out continuously. Completed projects or activities serve as a learning curve and a reference for future measurement and improvement.
New industry practices	This is an industry state with new competences and new values. The stakeholders are more aware of what works and most importantly have the right competences to attain the set goals. There is an adequate understanding of clients' demands, well-trained professionals, and the right policies and well-regulated industry amongst other factors that guides the industry towards sustainability.
New infrastructure	This stage engendered the production of building infrastructure that demonstrates lean-sustainable indicators (values).

Built environment sustainability –	It is expected that such infrastructure would engender a broader appeal for 'sustainability' within the built environment by increasing the pace and depth of its implementation, and create values that exceed the green (sustainability) targets while also achieving budget and schedule targets. More so, creating a value paradigm shift by satisfying the demands of both internal and external stakeholders. This new value paradigm is expected to create a healthy economy, environmental quality, and social and cultural heritage within the built environment.
Further innovation	The built environment sustainability then follows with the room for *further innovative opportunities*, as the sustainability infrastructure idea is not a 'product' but a 'process' that is subject to continuous improvement. Once this transformation is achieved and a process for sustainability is mature, new competencies are attained leading to the birth of a new organization. However, the transformational process assumes a continuous cycle. The organization operates as an open system that evaluates the process maturity for sustainability at a point of reflection, receives feedback from its internal as well as external environments for further innovation and continuous improvement opportunities. This process involves evaluation of value creation relative to risks and costs.

The general ideology behind LSMI for the South African construction industry is that of a mixed sustainability perspective likened to the diluted version of strong sustainability – a situation where the nation develops its infrastructure smartly within what is ecologically balanced. This position was adopted in consideration of the measurable infrastructural gap and ever-increasing population growth amidst a limited resources base. In pursuance of stated developmental goals, the critical natural capitals such as ozone layer, the carbon cycle and the hydrological cycle cannot be traded for other forms of capital, as their depletion would endanger human survival since environment accounts for natural resources and ecosystem services needed for economic and social development.

6.6 Mechanism Evaluation

Evaluation has been seen as a process that determines the quality of research output, often broadly classified into internal and external validity (see sub-section 4.4.4). According to Bock (2001: 53), mechanism evaluation is a scientific process of demonstrating the quality of work towards achieving the research objectives as demonstrated by the researcher and peer reviewed within the industry knowledge base. Other researchers should regard a piece of research as knowledge that can be replicated and assimilated into the knowledge base of a field of study (Rowley, 2002: 20; Yin, 2014: 45). Case study internal validity is the strength of a cause-effect link that is dependent on the absence of spurious relationships, whilst external validity is the extent to which the findings can be analytically generalized to other contexts that were not part of the original study, when based on the relevance of similar theoretical concepts or principles (Yin, 2014: 236 – 239).

6.6.1 Testing procedure

The approach adopted was to look for variability between the views of the study participants in the development of the mechanism and the expert population. The response from the participants in the development of the mechanism serves to demonstrate internal validity. The mechanism has also been validated through seminar presentations of the initial framework and the lean-sustainability indices used as part of the mechanism development presented in academic conferences. The advantage of larger participants (external experts) in the evaluation process of the mechanism is to prove the external validity of the research that might enhance the possibility of generalization beyond the research sample (Xiao, 2002: 103; Yin, 2014: 45).

This model evaluation process tested and refined the various components of the mechanism. The testing of the proposed mechanism was achieved through a questionnaire survey of the experts on various workings of the mechanism. Survey design was adopted to elicit experts' consensus, drawing from their industry experiences on phenomena such as current trends, requirements, and the possible centrality of the mechanism to industry practice. Experts' survey is ideal for an in-depth analysis, as it helps to ascertain a cohesive consensus view, explore in-depth opinions, judgments and evaluations of a particular subject (Creswell, 2009: 145; Fellows & Liu, 2008: 158; Tracy, 2013: 167).

6.6.2 Justification of the sample size and questions

An expert sample was randomly drawn from the International Council for Building (CIB) world population (www.cibworld.nl). The CIB W065 (Organization and Management of Construction), W098 (Intelligent and Responsive Buildings), W116 (Smart and Sustainable Built Environment), TG88 (Smart Cities) and TG93 (Building Zero Energy Settlements) were sampled based on their relevance to the context. These groups, in conjunction with the initial participants of the study for the development of the proposed mechanism, were sampled. In particular, 101 semi-structured surveys were electronically administered to evaluate the mechanism (Collis & Hussey, 2003: 66). Table 6.2 describes the demographics of the sample.

Table 6.2: Demographics of Validation Sample

Participants' classification	Sources	Area of specialization	Qualification median	Coding
Internal	Cases	Project teams	Honours	$I_1 - I_{23}$
External	CIB	Academia	PhD	$E_1 - E_{78}$

The mechanism was assessed in relation to it robustness for engendering industry change, applicability as well as the reasoning logic. The involvement of the external experts' view is aimed at incorporating a sound theoretical base to the proposed mechanism. The internal experts gave the practical dimension to the final mechanism. The survey questions were conducted using both structured and semi-structured questions (Appendix 1), which covered the mechanism robustness, the reasoning (logic) of the mechanism, areas of merit, areas of concern, and suggested improvement based on experience.

6.6.3 Results of mechanism evaluation exercise

Table 6.3: presents the results of the mechanism evaluation. Overall, the general feedback on the mechanism presents a positive outlook. The experts surveyed gave positive remarks on the LSMI and its components, the systematic approach to its development applauded, as well as its applicability. The LSMI was classified as being a product of pioneering research with clear and comprehensive underlying relations, within its context or scope. Moreover, the developed mechanism was seen to be compatible with global contemporary thinking in an attempt for a new approach to sustainable infrastructure delivery.

Table 6.3: Mechanism evaluation results

Experts	Admin.	Returned	Questions	Response		Comments		
				Yes	No	Merit	Concern	New idea
Internal	23	14	logic	14	-	14	-	3
			Robustness	14	-			
External	78	27	logic	27	-	27	-	2
			Robustness	27	-			
Total	101	41		41	-	41	-	5
Perc. (%)	100	41		100	-	100	-	12

Table 6.3 shows the mechanism validation results. Out of the total 101 survey questionnaires administered, a total of 41 were returned and deemed useful for the intended purpose. This represents approximately 41% success rate.

The survey participants agreed that the LSMI was robust enough and covered important issues necessary for the operationalization of the lean-sustainability concept in the South African construction industry. Generally, the participants affirmed the uniqueness of the LSMI in demonstrating the innovative features that can transform the current industry practices and avail the industry of some useful tools needed for raising awareness and understanding of lean-sustainability implementation issues, the associated benefits of lean-sustainability construction and the evaluation of the concept in project delivery efforts within construction organization. Its implementation should engender increased stakeholders' awareness and action bias, new leadership attitudes, knowledge, skills, and new industry culture. Some samples of the comments of the survey participants are given below:

> *"The mechanism reflects the vision and aspiration of (the) South African construction industry and its implementation would engender sustainability in the built environment (I_3)."*

> *"This is a very good mechanism that has been developed with a view to integrating lean and sustainability in infrastructure delivery in the South African built environment. My comments are based on my experience as researcher within the industry for over two years and as a practitioner in the construction industry. The areas I found more interesting and advantageous to the industry are transformation and new industry practice suggested by the framework. These will go a long way to promote the triple bottom line of sustainability that is apparent in the framework by addressing the chief challenges of present construction procurement practices in the South African built-environment (E_7)."*

> *"Bringing lean and sustainability together is key in that, non-value activities that have over the years created impediments resulting in not meeting project objectives of cost, time and quality will become a thing of the past as clients will have value for their money. To this end, it will be a win-win situation for contractors that want to bid low and make enough profit, workers that want improved welfare, clients that want value for their money and the environment that has perpetually been degraded (E_{23})."*

"Definitely LMSI looks holistically at how to engender sustainability in project life cycle (I_4)."

The feedback on LSMI appropriateness for an emerging concept of sustainability in the industry was also very positive. Some of the internal participants described the mechanism as very interesting and expressed their happiness in having access to LSMI and their willingness to adopt some of its principles for future works. However, some participants' comments suggest some ideas and areas of improvement for LSMI operationalization. Some of such suggestions are:

"*The new practices should read "improved practices" because they are not entirely new to the industry but to be done in a better manner that will enhance sustainability both in practice and theory (E_9)."*

Some of the respondents agree with the comment of I_{20} for the needs to highlight the leadership role is such a framework for industry transformation:

"The transformation phase should include leadership, as it takes better leaders to operationalize the 3Cs for successful integration. And moreover, each project life cycle's phases have its peculiarities and the specific leader that can truly be of influence (I_{20})."

These suggested areas of improvement were analyzed in the light of consistency with other comments, the available literatures and data to justify their worthiness for incorporation in the LSMI.

6.6.4 Improvement

The comment of I_{20} was viewed in line with the contemporary literature on ToC, lean and sustainability practices. Various researchers have demonstrated the importance of leadership to the quest for organizations' sustainable management and development outcomes (Yukl, 2008: 708; Wyatt Knowlton & Phillips, 2013: 8; Opoku & Ahmed, 2015 (ed.); Emuze, 2015: 25). Leadership is needed to create robust partnership amongst various stakeholders. The fruitful outcome of any innovative ideas could depend largely on leadership influence on its uptake and the management of the contingencies. For example, the clients strongly influence the nature of the procurement system to be adopted in a project that has direct bearing on its suitability for earlier collaboration, while the consultant's influence on the design and its contents has a direct bearing on the sustainability outcomes, and the contractor is to operationalize the whole process into fruition, to be followed by the FM through the useful-life.

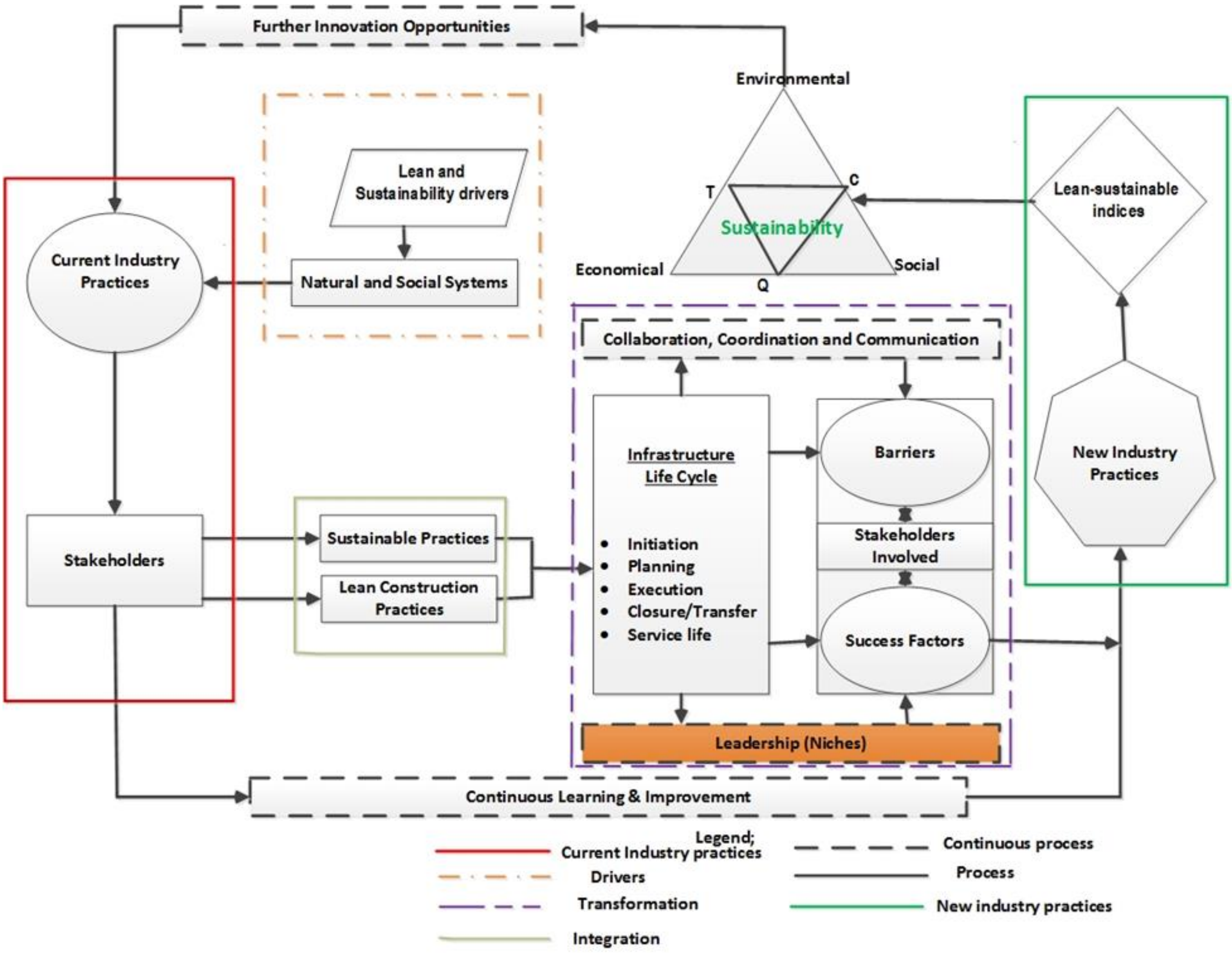


Figure 6.9: Final lean-sustainability mechanism for infrastructure (LSMI) project delivery in South African built-environment (Researchers fieldwork, 2016)

According to Wyatt Knowlton and Phillips (2013: 8), one of the basic short-term outcomes of innovative change is the emergence of better leaders – leaders with better awareness and action bias, a new culture, new knowledge and skill enough to influence changes. Successful construction management practice is often made efficient with a leaner group for decision-making, management and risk control and cultural change inherent in leadership-based solutions (Sullivan *et.al*, 2006: 113; Nishida & Hua, 2011: 519). It is on these premises that the leadership concept was introduced to the LSMI in the transformation phase of the mechanism (*brown shaded area* – Figure 6.9).

Therefore, the final route-map to LSMI is as presented in Table 6.4.

Table 6.4: The final route map to LSMI

Stage	**Description**
Current industry state	Business as Usual (BAU) where: the unsustainable ways that the stakeholders interact with the social and natural system in search of development still persist with its attendant symptoms.
Drivers	Issues concerning the environment, social and the economy have contributed significantly towards society's increased focus on the integration of lean-sustainability concepts. These drivers call for a new way of interaction between social and natural systems in meeting both internal and external stakeholders' demands, promotes the adoption of the new concept (lean-sustainable construction).
Stakeholders	The niche: the affected stakeholders meet in an integrated manner to evaluate their current state and hence set future targets and set templates on how the target can be met – immediate and long-term (backcasting)
L-S Integration	The pathway to the future goal is through integration of lean and sustainable construction practices in the infrastructure life cycle, backed by the necessary frameworks that can move it towards the tipping point.
Transformation	It is expected that drawing from the general theory of socio-technical innovation and social-ecological change inherent in lean and sustainability practices, transformation (change) can occur in the infrastructure life cycle through *collaboration, coordination, and communication (3Cs*) in an integrated project delivery (IPD) manner among the niche, drawing from the experience of the role players for best practices, by coming together and evaluating projects from initiation stages to service life, critically assessing the sustainability barriers and how lean process can serve as catalyst for efficiency and

	effectiveness in sustainable construction practices in each stage to create values that lead to success factors.
Leadership (Niche)	Leadership is needed to create robust partnership amongst various stakeholders (Niches). The fruitful outcome of any innovative ideas could depend largely on leadership influence on its uptake and the management of the contingencies. It is only an organization with the right leadership that can engender innovative cultural and structural changes and working with stakeholders.
Continuous learning and improvement	The effort to increase value is an incremental and iterative activity that can only be carried out continuously. Completed projects or activities serve as a learning curve and a reference for future measurement and improvement.
New industry practices	This is an industry state with new competences and new values. The stakeholders are more aware of what works and, most importantly, have the right competences to attain the set goals. There is an adequate understanding of clients' demands, well-trained professionals, and the right policies and well-regulated industry amongst other factors that guides the industry towards sustainability.
New infrastructure	This stage engendered the production of building infrastructure that demonstrates lean-sustainable indicators (values).
Built environment sustainability	It is expected that such infrastructure would engender a broader appeal for 'sustainability' within the built environment by increasing the pace and depth of its implementation. It would create values that exceed the green (sustainability) targets while also achieving budget and schedule targets – more so, creating a value paradigm shift by satisfying the demands of both internal and external stakeholders. This new value

	paradigm is expected to create a healthy economy, environmental quality, and social and cultural heritage within the built environment.
Further innovation	The built environment sustainability then follows with the room for *further innovative opportunities*, as the sustainability infrastructure idea is not a 'product' but a 'process' that is subject to continuous improvement. Once this transformation is achieved and a process for sustainability is mature, new competencies are attained leading to the birth of a new organization. However, the transformational process assumes a continuous cycle. The organization operates as an open system that evaluates the process maturity for sustainability at a point of reflection, receives feedback from its internal as well as external environments for further innovation and continuous improvement opportunities. This process involves evaluation of value creation relative to risks and costs.

6.7 Summary

This chapter highlights the lean-sustainability mechanism for infrastructure (LSMI) delivery, as a transformational route for sustainable built environment. The mechanism was based on the principles of lean construction and sustainability and how their integration can drive the needed change in the construction sector. Sources such as the expert opinions, archival records, and literature review were utilized with the findings emerging from Chapter 5 in developing the mechanism. The mechanism was evaluated through feedback from internal and external participants to generate internal and external validity of the model. The model provides an adaptive form of governance needed for socio-technical systems such as infrastructure delivery systems, in response to the gradual deterioration of the global socio-ecological stability. This chapter, therefore, accomplished the main aim of the thesis.

7.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Introduction

This chapter is the concluding part of this report. It presents the main research findings relative to the research process, the aim and objectives of the study, recommendations, and areas of further study. The chapter also provides a succinct summary of the research work.

7.2 Summary of the Thesis

The current traditional construction practice has been deemed ill-equipped to deliver on sustainable infrastructure. As a remedy, previous studies have called for the integration of lean and sustainability concepts and practice during project delivery. The general consensus is that there is need for more comprehensive work on methodologies to be scientifically developed and empirically verified for this synergy to emerge and benefit the industry. Such consensus signals the need for scientifically based mechanisms for the integration of lean and sustainability in construction.

In effect, the aim of this research work was to develop a mechanism for operationalizing the integration of lean and sustainability in the South African built environment sector. The specific objectives of the study were to: 1) evaluate the impact of lean on construction through critical examination of its features, processes and drivers; 2) evaluate the effect of sustainability on construction through critical examination of its features, processes and drivers; 3) determine the common themes between lean and sustainability in construction to enact synergy between the two concepts; 4) establish context-specific mechanisms for operationalizing the integration of lean and sustainability in construction; 5) evaluate the impact of the mechanism on construction.

The study was tailored to achieve the development of the research problem and clear understanding of the context (Chapter 1 and 2), the development of conceptual and theoretical perceptions underpinning organizational change leading to LSMI (Chapter 3), the methodology deployed in achieving the set objectives (Chapter 4); resultant data analysis and discussion (Chapter 5); development of the LSMI mechanism and evaluation (Chapter 6); and conclusion and recommendation (Chapter 7).

In Chapter 1 the background to the study, the problem statement, the research question and sub-questions, the scope of the study, the study assumptions, and the aim and objectives of the study and its justification were presented. Chapter 2 presented the review of relevant literature pertaining to the subject area. The focus of the chapter was on the concepts of lean and sustainability and their features, drivers and barriers, and the concept of change towards sustainable development in South Africa. Chapter 3 explored the theoretical and conceptual framework of the study, an attempt at creating common themes between the two concepts was made, and the existing lean and sustainability models was evaluated, Transformational Process Model (TPM) was adapted and underpinned by the Theory of Change (ToC). Chapter 4 presented the philosophical underpinning of the research, the various paradigms, research methodology, case-based method and case selection, design of interviews and/or mixed method protocol, and how the data were collected and treated. Chapter 5 focused on presentation of the findings and data analysis of the research study, answers were proffered to research questions in meeting the research objectives. Chapter 6 developed and presented the proposed mechanism and the validation process. Chapter 7 summarized the whole study, conclusions drawn, recommendations, and areas of further study pertaining to the study.

In particular, Chapter 4 demonstrated the three distinct stages of answering the research objectives. Stage one focused on the lean construction and sustainability practices and the features thereof in South Africa's construction industry (Objectives 1 and 2). Stage two focused on the areas of linkage between lean construction and sustainability practices, drivers and barriers, and the benefits in infrastructure development (Objective 1, 2 and 3). The final stage of the study dwelled on the development, refining and validating of Lean-Sustainability Mechanism for Infrastructure (LSMI) for operationalizing the lean-sustainability concept towards sustainability in the South African construction industry (Objectives 4 and 5).

7.3 Conclusions Relative to Research Problem

The study seeks to proffer solutions to the problem statement as previously stated (see section 1.5). The reflection on what kind of mechanism could engender the implementation of lean and sustainability concepts in an infrastructure project for the benefit of end users produced the research problem statement that "the lack of empirical framework for the integration of lean construction concept as a catalyst for sustainability hinders the creation of project value and continuous improvement in South Africa."

The main contribution of the study is the development of the LSMI model for operationalizing the L-S concept and its benefits in South African infrastructure development. This contribution was demonstrated by assessing the LSMI impact on projects' life cycle and its management process among the stakeholders. In meeting these demands, the sustainability management corpus and the process improvement techniques in lean frameworks were reviewed. This led to the conceptualisation based on the emergence of the TPM as a capable concept for mechanism development that can deliver sustainability. The 'value' concept was adopted as the main construct for evaluating these outcomes (benefits) with the project's life cycle and the reasoning logic were underpinned by the ToC (see Chapter 3). The major conclusions drawn from the research study are based on the critical evaluation of the sub-questions, which are;

- How is value created with lean in construction?
- How is value created with sustainability in construction?
- What are the criteria for enacting synergy between lean and sustainability?
- What is the mechanism for driving lean and sustainability in construction?
- How can such mechanism improve construction?

These areas of evaluation are grouped, following the three core basic stages of enquiry earlier described to meet the demand of research objectives (see section 7.2) and presented as follows:

7.3.1 Lean construction and sustainability practice in the South African construction industry

The research work reveals the trend of lean construction and sustainability practices in the South Africa construction industry. The study explores how the two concepts have been implemented and the issues relating to their adoption within the industry. There are varying perceptions and levels of understanding of the lean concept and sustainable construction within the literature and among the industry stakeholders.

7.3.1.1 Sustainable construction practices

The results of the study suggested that energy efficiency, material and water reduction, reduced pollution, durability, energy conservation and local material sourcing are the major features of sustainable construction in the industry. Other sustainable practices in the industry include the adoption of biodegradable materials, life cycle costing, innovation, and embodied and renewable energy. Therefore, appropriate design solutions and technologies that could engender effective and efficient energy management, reduced material and water usage are most important to the sustainability of built environment infrastructure.

7.3.1.2 Lean construction practices

The conclusion that can be drawn from the cases is the apparent low understanding and adoption of the lean concept in the South Africa construction industry. Although the stakeholders adopted some lean and lean tools-related principles, its recognition within the industry practice is still emerging. Surprisingly, concurrent engineering is the most popular efficiency concept within the industry. Lean tools such as Just-In-Time, visualization tools, daily hurdle meetings, and value analysis are commonly deployed as catalysts for enhanced sustainability goals. Other features are the literature champions such as the last-planner, prefabrication and Kaizen that are rarely deployed yet (Table 5. 7). Lean tools adoption enhanced sustainability improvement in the form of eliminating waste and works flow efficiency and continuous improvement. It is then necessary to enlighten the stakeholders of the benefits of lean-sustainability integration to the industry stakeholders as a whole.

7.3.2 Areas of linkage between lean construction and sustainability practices

As indicated in Figure 5. 1, the nature of the relationship between lean and sustainability was examined within the context of South African construction industry. This section examined the link between the two concepts and highlighted major areas of synergy for project improvement.

7.3.2.1 Synergy between lean construction and sustainability practice

The synergy between lean construction and sustainability practice for the lean-sustainability paradigm suggests that, though not yet a formal operational concept within the South African construction industry, the lean-sustainability paradigm has enhanced the efficiency and effectiveness of the production processes. The major benefits of the synergy exists in the areas of reduced resources utilization, reduced waste and pollution, enhanced value creation, improved traditional practice, and that lean construction serves as a catalyst for sustainable practice. This synergy was made possible through the adoption of an innovative platform for infrastructure delivery inherent in the integrated project delivery (IPD) model. The IPD principles, methods and behaviours for design and construction of projects create the right platforms for operationalizing the lean-sustainability paradigm, in a culture of efficient and effective collaboration in an organization, which cannot be achieved in the traditional system. Industry leaders should be developing with the skills required to engender such complex infrastructure delivery practices, so that such an ethos can permeate throughout the system.

7.3.2.2 Drivers for lean-sustainability concept in South Africa

Embracing an innovation in a fragmented industry such as construction often requires a commensurate driver for meaningful change to occur. The major drivers for the lean-sustainability paradigm in the South African construction industry include drive to gain an industry competitiveness edge, the market environment that now requires higher efficiency and effectiveness for success, and inflow of innovative staff. Other industry drivers are: winning more contracts/financial incentives, the motivation to attract and retain good employees. Social responsibility and environmental concern, stakeholders' demands, leadership issues and changing legislation form part of the factors that drive the lean-sustainability concept within the industry. It can then be inferred that the dated tripods of 'cost, quality and time', management-related to economic concerns, still hold the key to innovations.

7.3.2.3. Barriers to lean-sustainability concept in South Africa

Resistance to change is a common barrier to a new concept similar to lean-sustainable construction in an industry setting. One significant barrier to the lean-sustainability paradigm for infrastructure delivery is the sustainability premium. The cost implication served as the greatest hindrance to the attainment of sustainability in the South African built environment. This cost scenario has been ascribed to lack of understanding of the L-S concept and the dearth of life-cycle costing in the industry. The stakeholders' variance towards the cost perspective also hinders the operationalization of the new concept that calls for new cultural and structural values such as cooperation and collaboration for the growth of the industry. Other factors such as the lack of lean-sustainability industry leaders, awareness and demands of stakeholders, rigid organization cultures, limited sustainable material for selection along with political and policy frameworks, and uncertainty among stakeholders, were discovered as hindrances to the adoption of the lean-sustainability concept within the industry.

7.3.2.4 Benefits (indicators) of lean-sustainability on project performance

The purpose of this study is to develop a mechanism (LSMI) that can leverage on the synergy between lean and sustainability to engender a sustainable built environment. In order for LSMI to be adjudged effective, the ability to measure the performance of its product must be demonstrated. The most substantial benefits derived from the adoption of the lean-sustainability concept in project delivery in South Africa includes: improved industry-competitive edge and industry-continuous improvement, increased stakeholders' collaboration and increased organizational learning. These could be adduced to demonstrate a new cultural and structural change within construction organization, where working together is becoming an ethos. Outperforming cost and other schedules, improved environmental value chain, matching business and environment, improved H&S records, improved planning and risk management, reduced pollution and emission, reduced energy and resources consumption, increased product affordability, flexibility and adaptability, increased technology advancement, enhanced employment and skill development, improved renewables and resources usage and reduced industrial dispute were other derived benefits of lean-sustainability adoption in project delivery within the industry. These outcomes have demonstrated a broader appeal for industry sustainability by moving projects away from the traditional management-oriented ambitions of time, cost and quality, and prioritized economic, environmental and social impacts of construction projects. This conclusion was further corroborated by the results of the t-test and the Kruskal-Wallis test for the variability of these benefits (see Tables 5.13 & 5.14). The t-test result shows that all tested variables are significant (< 0.05) and the Kruskal-Wallis test shows no significant variability, as most P-Values are greater than 0.05 and there is no definite pattern accounting for others with less than 0.05.

7.3.2.5 Influence of stakeholders' on lean-sustainability paradigm.

The action and inaction of the project stakeholders influence the uptake and operationalization of innovative outcomes. The lean-sustainability paradigm can only be driven through key project participants providing leadership, their commitment to the concept, understanding and early involvement in the areas they can influence. In examining the level of influence in which various stakeholders have on the actualization of lean-sustainability practice in the industry, the client/developer, the Green councils (lean at infancy), and consultants (especially in sustainability) were better positioned to influence and engender the adoption of the lean-sustainability paradigm in the South African industry. The three groups are the first point of contact in initiating and deployment of sustainable procurement concepts. Contractors as well as sub-contractors with various consultants also have influence on lean-sustainability infrastructure delivery on major concepts such as: whole-life costing, integrated design, waste management, energy modelling, corporate social responsibility (CSR) and community engagement, and the use of sustainable material resources inherent in its successful adoption. The management of these stakeholders thus requires an integrative form of infrastructure procurement such as IPD and earlier involvement of core stakeholders in project delivery.

7.3.3 Development, refining and evaluating of Lean-Sustainability Mechanism for Infrastructure (LSMI) in South Africa construction industry

The sustainability management (SM) corpus was reviewed and evaluated for appropriate mechanism for operationalizing the integration of lean and sustainability concepts within the concept of the study. The review corroborated the study's problem statement on the lack of empirically developed framework for integrating lean and sustainability and more so in developing economies such as the South African construction industry. This review led to the discovery of the transformation process model (TPM). The common stages process for developing an organizational model was also reviewed and adopted for the development of the needed mechanism. The TPM is an organization-wide SM initiative for stakeholders' interactions between social and natural systems, as a response to the competitive landscape in the new global economy.

TPM was modified by merging with the core principles of lean and sustainability in meeting industry requirements for a new mechanism that could create the right synergy between the two concepts. Moreover, value was used as a construct for lean-sustainability infrastructure life cycle evaluation. The reasoning behind the lean-sustainability paradigm was underpinned by the theories of change to create an adaptive form of governance needed for socio-technical systems such as infrastructure delivery, in response to the gradual deterioration of the global socio-ecological stability – lean-sustainability mechanism for infrastructure (LSMI) in the South African construction industry. The LSMI provides the platform for stakeholders' involvement and empowerment focus on work process in an effective and efficient manner to facilitate continuous improvement. It breaks the systems and cultural barriers by working with stakeholders necessary for innovative transformation. LSMI sustains continuous improvement throughout project life cycle in pursuance of stakeholders' satisfaction, creates an industry prime for sustainability. The proposed LSMI was refined through the validation process. The validation used a survey of the industry experts to generate feedback for LSMI improvement, leading to the final LSMI.

7.4 LSMI Contributions to Knowledge

The study developed a comprehensive mechanism for operationalizing the integration of lean and sustainability for project delivery. The developed mechanism provided an adaptive form of governance needed for socio-technical systems such as infrastructure delivery systems, in response to the gradual deterioration of the global socio-ecological stability. This form of government was achieved through focus on building infrastructure life cycle for improvement, in meeting the sustainable built environment in terms of socio-economic and environment dimensions. Based on the evaluated mechanism, the main contributions of the LSMI include:

1) The compilation of lean-sustainability indicators for holistic evaluation of infrastructure performance: these indicators would assist developers and others stakeholders to gain a more comprehensive view of the L-S impact on project performance through its life cycle.
2) The provision of a knowledge base for stakeholders intending to understand and/or operationalize the lean and sustainability paradigm in the South Africa construction industry.
3) The identification of the main transformational issues in L-S context for industry continuous improvement.
4) The recording of areas in the project life cycle where L-S values can be created in favour of the stakeholders.

Based on the aforementioned, the apathy towards the adoption and operationalization of L-S paradigm in infrastructure delivery amongst the South African construction stakeholders can be overcome with the adoption and implementation of LSMI. It serves as route map for innovative and proactive organizations to attain efficiency in the infrastructure value chain, in their drive towards sustainability. The developed mechanism is followed with an explicit route map that can easily be understood by industry stakeholders and functions as guideline information as to how L-S integration can be implemented. It also affords construction organizations the ability for self-appraisal for gaps toward sustainability targets.

7.5 Limitations of LSMI

It should be noted that the empirical data generated in the research process were limited to non-residential building projects. Whereas four out of the five adopted cases were in the ownership of the private sector, only one of the cases is deemed to be funded from government sources. This scenario works contrary to the initial study scope of evaluating public infrastructures in South Africa and arises as a result of unavailability of the right numbers of GBCSA-rated public infrastructures within the scope and context of the study. Nevertheless, the construction environment remains the same for all cases and, therefore, has no effect on the context for developing LSMI.

However, it must be said that the mechanism does not claim to have answers to all the issues of operationalizing L-S integration in the industry. The LSMI limitations can be highlighted as follows:

1) The limited number of GBCSA-rated cases (vis-à-vis the concentration of such infrastructures in mainly two provinces) and the non-availability of the whole role players limit the width and breath of the proposed study.
2) The mechanism as a tool is to clarify L-S adoption and implementation paradigms. However, its success is not a guarantee as it depends largely on the right leadership to engender the right cultural and structural changes and working with stakeholders.
3) The mechanism does not provide a quantitative measure of its success rate in the industry.

7.6 Recommendations and Further Studies

7.6.1 Recommendations for policy and practice

Based on the insights from the research findings, some recommendations that have implications for policy and industry practice are relevant. This is to improve the uptake and implementation of the L-S paradigm in infrastructure delivery. It is herein argued that:

1) L-S paradigm requires better leaders to engender its principles. Integrated forms of project delivery are required to deliver the type of value chain needed for L-S infrastructure, which can only be actualized through better leaders.
2) A legal framework beyond traditional processes is required to promote sustainability practice. This would create a platform for standardized operation for lean and sustainable practices.
3) There has to be a passable level of commitment, knowledge and skills among industry stakeholders, including understanding the basic concepts for successful operationalization of lean and sustainability.

4) There is need for synergy between lean and Green Councils to enhance the benefits of lean and sustainability integration.
5) The industry should adopt the principles of sustainable management (SM). The organizational system, culture, people's values, norms and behaviour must be modified in order to contribute to an appropriate collective culture and structure of the organisation.
6) Lean and sustainability training should form an integral part of the continuous professional development (CPD) for contractors and other role players in the built environment. The knowledge for adoption and implementation of the paradigm can serve as a limiting factor for the perceived premium.
7) Collaboration between the construction industry, universities, and government is highly recommended for L-S transition. Stakeholders should work closely with their supply chain to ensure that they adhere to the same principles.

The listed recommendations have implications on the successful operationalization of lean and sustainability in the built environment.

7.6.2 Recommendations for further research

1) The LSMI was a logical arrangement of basic components for programme improvement (transformation process) in complex socio-technical systems such as infrastructure delivery. There is scope for further work on what suitable procurement system could lessen the effect of its complexity by reducing stakeholders' conflicts.

2) The LSMI concept can be mathematically represented by scientific weighting of the lean-sustainability parameters in tangible numerical values, which can enable additional buy-in from project actors.

3) There is need for further study on a strategic plan to evaluate the cost-benefit analysis of operationalizing lean-sustainability integration on an organizational level, whereby resources (inputs) are measured against benefits (outputs) based on the research methodology adopted for this study.

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APPENDIX 1

4 April 2016

The Project Participants,

Sir / Madam,

Re: A Mechanism for Lean and Sustainability: The Case of Infrastructure Projects in South Africa

This survey is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this survey is to collect data towards the development of a mechanism for operationalizing lean and sustainability in South Africa infrastructure projects, in order to attain sustainable built environment.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof. F.A. Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….
Rasheed Babatunde Isa (Doctoral Student)

……………………………………………….
Prof FA EMUZE
Head of Department: Built Environment

Central University of Technology, Free State

SECTION A: BIO DATA

Please select from the range of options supplied for each of the following and tick (√) the appropriate option that suits your response.

1. What is your highest academic qualification?
   ND ☐ B, Tech ☐ Honours ☐ Masters ☐ PhD ☐ Others ……………

2. What is your professional affiliation?, if any:
   CPM ☐ Engineers ☐ Q.S ☐ Architect ☐ Others ……………………..

3. What is your number of years of experience in the industry?
   0-5 ☐ 6-10 ☐ 11-15 ☐ 16-20 ☐ above 20 ☐

4. In what capacity are you involved in the project?
   Client/client rep. ☐ Designer ☐ Consultant ☐ Engineer ☐
   CPM ☐ Contractor ☐ Regulator ☐ Others…………………

SECTION B

5a. Sustainable construction that will meet socio-economic and environment dimensions can only be achieved through effective and efficient deployment of both material and techniques. From 5 (very often) to 1(Never), what is the extent of occurrence of following sustainable practices on the project?

S/N	Practice	Very often	Often	Neutral	Rarely	Never
1	Renewable source					
2	Biodegradable					
3	Aids energy efficiency					
4	Durability and life span					
5	Reduction (air, land & water) pollution					
6	Reduction (materials & water) usage					
7	Local availability					
8	Embodied energy					
9	Reuse of waste product					
10	Rethink strategy (innovation)					
11	Energy conservation					
12	Life cycle costing					

5b.Any specific comment please
………
……..

6a.Lean principles / techniques for enabling sustainability. From 5 (very often) to 1(Never), what is the extent of adoption of the following lean practices for the project?

S/N	Practice	Very often	Often	Neutral	Rarely	Never
1	Visualization tool					
2	Just-in-time					
3	Daily huddle meeting					
4	Last planner					
5	5S					
6	Kaizen					
7	Kanban					
8	Six sigma					
9	Concurrent engineering					

10	Pull approach					
11	Total quality management					
12	Value analysis					
13	Total preventive management					
14	First run studies					
15	Prefabrication techniques					

6b.Any specific comment please
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7a. Lean construction (LC) and sustainable construction (SC) an ideal partners. From 5 (very high) to 1(very low), to what extent is the link between LC and SC in your organization?

S/N	Link	Very high	High	Average	Low	Very Low
1	The two concepts seem closely linked					
2	Integration enhances value creation					
3	Both enhances the traditional practices					
4	The two concepts reduce construction waste and pollution					
5	LC serves as catalyst to sustainability					
6	Both reduces resources use					

7b. any specific comment please
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8a.Synchronising lean and sustainability engendered values. From 5(excellent) to 1(very poor), to what extent can you rate your project to have perform in relation to the following indicators?

S/N	Indicator	Excellent	Good	Average	poor	Very poor
1	Cost, time and quality					
2	Environmental responsible value chain					
3	Health and safety					
4	Energy and resource consumption					
5	Pollution and emission					
6	Matching business and environment					
7	Industry competitiveness					
8	5R / Renewable resources					
9	Flexibility and adaptability					
10	Organisational learning					
11	Dispute					
12	Stakeholder collaboration					
13	Employment and skill development					
14	Continuous improvement					
15	Planning and risk management					
16	Technological advancement					
17	Affordability					

8b. any specific comment please
………
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9a.The uptakes of innovation and organizational change can only be attained by certain factors. From 5 (very high) to 1(very low), what is the extent of the influence the following drivers on lean-sustainable practices in your organization?

S/N	Driver	Very high	High	Average	Low	Very Low
1	Need for efficiency and effectiveness					
2	Leadership					
3	Changing legislation					
4	Inflow of innovative staff					
5	Industry competitiveness					
6	Stakeholders demand					
7	Environmental concerns					
8	Social responsibility					

9b.Any specific comment please

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10a.The uptakes of innovation and organizational change are usually hindered by certain restraining forces. From 5 (very high) to 1(very low), what is the extent of the influence the following barriers to lean-sustainable practices in your organization?

S/N	Barrier	Very high	High	Average	Low	Very Low
1	Organizational culture					
2	Leadership					
3	Uncertainty					
4	Cost implication					
5	Stakeholders awareness and demands					
6	Political and policy issues					
7	Material availability					

10. Any specific comment please

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11. Construction stakeholders influences the stake on drivers and barriers to any industry innovation. From 5 (very high) to 1(very low), what is the extent of the influence the following stakeholders to lean-sustainable practices in your organization/industry?

S/N	Stakeholders	Very high	High	Average	Low	Very Low
1	Academia					
2	Contractor					
3	Developer					
4	Consultant					
5	Government					
6	Lean and sustainability council					
7	Media					

11b.Please comments on how the following stakeholders can influence lean-sustainable practices in the industry?

S/N1.……………………………………………………………………………………………
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S/N2……………………………………………………………………………………………
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S/N3……………………………………………………………………………………………
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S/N4……………………………………………………………………………………………
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S/N5……………………………………………………………………………………………
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S/N6……………………………………………………………………………………………
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S/N7……………………………………………………………………………………………
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12. What is your experience during the project and how can such process be improved?

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13. Any general comments on the project, please specify?

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Thanks for your time

APPENDIX 2

4 April 2016

The Facility Manager/ Users,

Sir / Madam,

Re: A Mechanism for Lean and Sustainability: The Case of Infrastructure Projects in South Africa

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this interview is to collect data towards the development of a mechanism for operationalizing lean and sustainability in South Africa infrastructure projects, in order to attain sustainable built environment.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….
Rasheed Babatunde Isa (Doctoral Student)

……………………………………………….
Prof FA EMUZE
Head of Department: Built Environment

Interview Guideline

Bio data

1. Name:
2. Occupation:
3. Level of experience:
4. Academic qualification:
5. Professional affiliations, if any:
6. Relationship with the facility:

Sustainable facilities

S/N	Focus Area	Related questions
7	Certification focus	On what standard is the facility rated? What score does the facility attained? On what rating criteria do the facility earns it points? On what rating criteria the facility does not met?
8	Comparative focus	Could you please compare this facility with a similar conventional building in terms of convenience; thermal comfort, management and maintainability?
9	Context focus	What are the sustainability criteria that the facility need to achieve?
10	Cost-benefit analysis	Are you aware of life cycle costing? How can you rate the associated benefits of this facility against the extra cost of sustainability components? Kindly elaborate? How can you rate the relationship between the cost and the benefits accrued?
11	Criterion-focused evaluation	Based on your experience, by what criteria do you expect a facility of this nature to be evaluated? Please mention them.
12	Descriptive focus	What do you perceive is the major selling point of this facility? What do you think can be observed overtime?
13	Effectiveness focus	Is the facility meeting its pre-set goals; please explain? Is the facility meeting the design targets, e.g., energy and maintainability savings, as projected? Please elaborate. If yes, what can you say is the critical factor for the success? If no, what can you say is the critical factor for the failure?
14	Efficiency focus	Are you satisfied with the performance of this facility? Will you rather pay a bit more for this type of facility?

		How will you judge your productivity in this facility? Please explain. Can you say you are getting more value for money? Please elaborate
15	Formative evaluation	Do you think this facility can be improved during at the formative stage, If yes, how?
16	Goal-based focus	Please, kindly explain how this facility meet the goals of sustainability dimension of economy, environment and society?
17	Knowledge focus	From your experience, what can be learned from this facility for future projects?
18	Outcomes evaluation	To what extent do you think the stakeholders (client, users, project participants etc.) outcomes are being attained? Please mention your own expectation.
19	sustainability promotion	From your experience, what role do you think the following stakeholders play/can play to the realisation of the facility and how can they embed such practices to enhance it uptakes in the industry; Academia, Contractor, Developer, Consultants, Government, Lean & sustainability councils, and Media
20	Summary evaluation	In general, what can you say is the overall merit of this type of facility? What do you think can further be done to improve this facility? Base on the benefits accrued, Can you recommend this type of facility for future development?

Thanks for your time

APPENDIX 3

Semi-Structured Interview Guidelines for Pilot Study

Biodata

1. Name:
2. Occupation:
3. Level of Experience:
4. Academic qualification:
5. Professional Affiliations, if any:

Sustainability-related

6. What do you understand about the term 'sustainable development/sustainability"
7. How would you describe your level of understanding?
8. Are you aware of the sustainability agenda at CUT?
9. In your opinion, what are the expected outcomes of this agenda?
10. Are you aware of any contribution which may be required of you and/or your role in the attainment of thee outcomes?
11. How does your present role affect the delivery of these outcomes?
12. Based on your experience and knowledge, would you say that the sustainability tenets are being successfully integrated into your project/workplace/ academic curricula/research?
13. If yes, how?
14. What challenges have you faced in the implementation of these sustainability principles?
15. What factors do you consider as being critical to the successful implementation of sustainable development in CUT's operations, research and curricula?
16. What are the drivers for sustainable development at CUT?

Value- related

17. Based on your experience, how is value created through the delivery of public sector projects?
18. What are the common determinants of value in public sector construction?
19. Have you come across the use of lean construction ideas and methods in construction sector? If yes, please share your experience.
20. Based on your experience, what are the barriers to lean construction and sustainable construction in construction sector respectively?
21. Do you think lean practice can serves as catalyst for sustainability in construction? If yes, kindly explain how.

Thanks for your time

APPENDIX 4

1 October 2016.

Dear Members,

Re: A Mechanism for Lean and Sustainability: The Case of Infrastructure Projects in South Africa

This expert survey is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State, South Africa.

The aim of the questionnaire is to validate a mechanism that has been developed for the integration of lean and sustainability ideas when delivering infrastructure projects in South Africa. The mechanism was developed through case based research design. Interviews and focus group discussion were used to evolve the model. Participants in the interviews and focus group sessions include projects teams (designers, contractors, etc.), facility manager and users.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………
Rasheed Babatunde Isa (Doctoral Student)

………………………………………………….
Prof FA EMUZE
Head of Department: Built Environment
Coordinator: CIB TG59 – People in Construction.

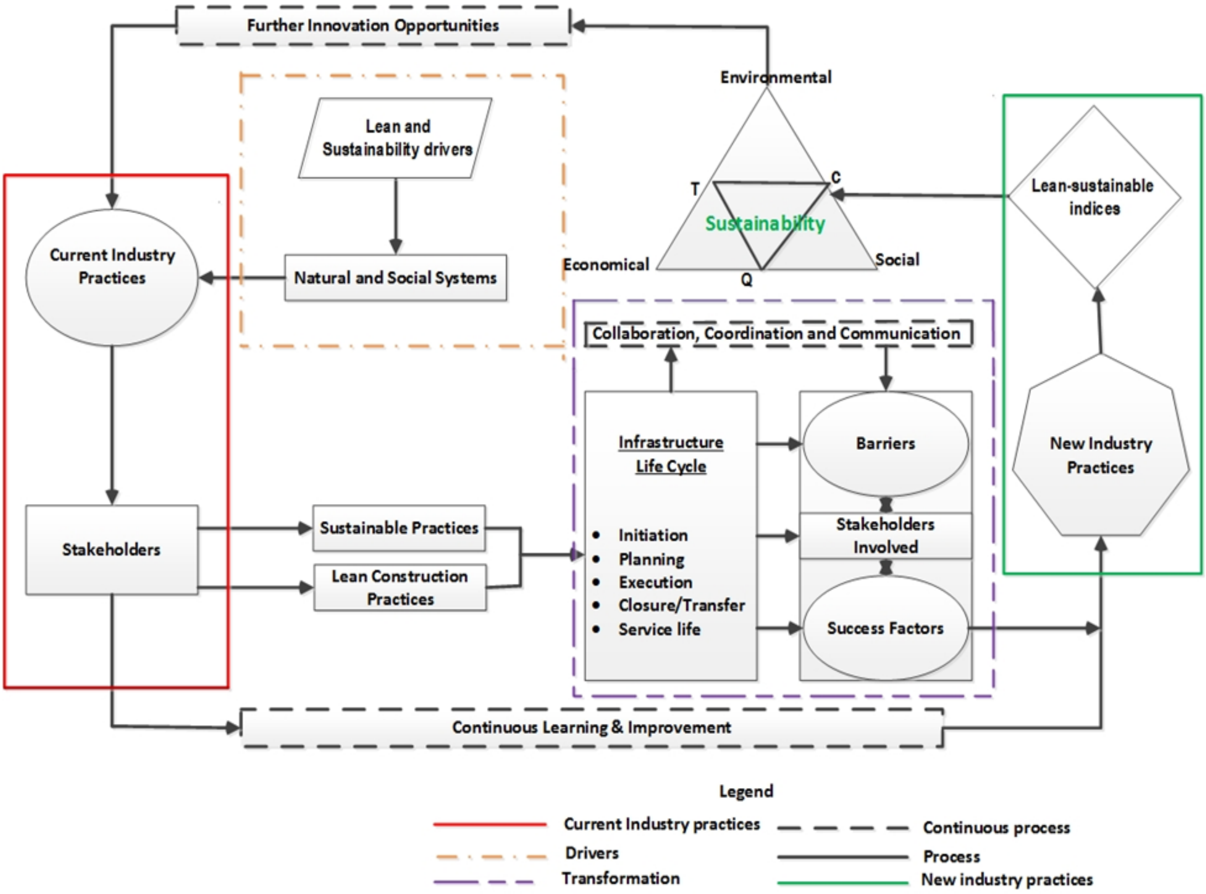

Figure 1: A mechanism for integrating lean and sustainability in infrastructure project delivery in South Africa built-environment.

The mechanism is based on the concept of Transformation Process Model proposed by Madu and Kuei (2012). The theory of change underpinned the development of the mechanism. It is anticipated that the proposed mechanism will engendered sustainability in infrastructure delivery through the adoption and integration of lean and sustainable construction practices. The brief description of the route-map for the mechanism is as presented in Table 1 below.

Table 1: Brief description of the route-map for the framework

Current industry state	Business as Usual (BAU) where: the unsustainable ways that the stakeholders interact with the social and natural system in search of development still persist with its attendance symptoms.
Drivers	Issues concerning the environment, social and the economic have contributed significantly towards society's increased focus on the integration of lean-sustainability concepts. These drivers call for a new way of interaction between social and natural systems in meeting both internal and external stakeholders demands, promotes the adoption of the new concept (lean-sustainable construction).
Stakeholders	The niche: the affected stakeholders meet in an integrated manner to evaluate their current state and hence set future target and set

	template on how the target can be met – immediate and longtime (Backcasting)
Integration (L-S)	The pathway to the future goal is through *continuous learning and improvement* of the integration of lean and sustainable construction practices through infrastructure life cycle.
Transformation	It is expected that drawing from the general theory of socio-technical innovation and social-ecological change inherent in lean and sustainability practices. Transformation (change) can occur in the infrastructure life cycle through *collaboration, coordination, and communication (3Cs*) in an integrated design process (IDP) manner among the niche; drawing from the experience of the role players for best practices. By coming together and evaluate projects from initiation stages to projects service life. Critically assessing the sustainability barriers and how lean process can serve as catalyst for efficiency and effectiveness in sustainable construction practices in each stages to create values' that leads to success factors.
New industry practices	This is an industry state with new competences and new values. The stakeholders are more aware of what works and most importantly have the right competences to attain the set goals. There is an adequate understanding of client's demands, well-trained professionals, and the right polices and well-regulated industry amongst other factors that guides the industry towards sustainability.
New infrastructure	This stage engendered the production of building infrastructures that demonstrates lean-sustainable indicators (values).
Built – environment sustainability	It is expected that such infrastructure would engender a broader appeal for 'sustainability' within the built-environment by increasing the pace and depth of its implementation That is, exceed the green (sustainability) targets while also achieving budget and schedule targets. More so, creating a value paradigm shift by satisfying the demands of both internal and external stakeholders. This new value paradigm is expected to create a healthy economy, environmental quality, and social and cultural heritage within the built environment
Further innovation	This then follows with the room for ***further innovative opportunities***, as the sustainability infrastructure idea is not a 'product' but a 'process' that is subject to continuous improvement.
Continuous improvement	The effort to increase value is an incremental and iterative activity that can only be carried out continuously. Completed projects or activities serves as a learning curve and a reference for future measurement and improvement.

- Do you agree with the logic (reasoning) behind this mechanism? Yes ( ), No ( )

- Do you think the mechanism is robust enough to engender change in the industry?
  Yes ( ), No ( )
- If no, please indicate areas of concerns:
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- If yes, please indicate areas with merit:

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- Based on your expert knowledge, what general ideas should be incorporated into the model.
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  ………………………………………………………………………………………

MANY THANKS FOR YOUR VALUED CONTRIBUTIONS

APPENDIX 5

Descriptive Statistics

Sustainable const. practices	N	Minimum	Maximum	Mean	Std. Deviation
Renewable source	32	2	4	3.00	.622
Biodegradable	32	1	3	2.16	.847
Energy efficiency	32	3	5	4.41	.560
Durability	32	2	5	3.47	.803
Pollution Reduction	32	2	5	3.53	.879
Material & H20 Reduction.	32	3	5	4.31	.738
Local Availability	32	2	5	3.28	.991
Ebodied energy	32	2	4	2.81	.471
Reuse (waste prod.)	32	1	4	2.38	.793
Innovation	32	1	4	2.62	1.008
Energy conservation	32	2	4	3.41	.712
Life cycle costing	32	1	5	2.50	.842
Valid N (listwise)	32				

Descriptive Statistics

Lean Practices	N	Minimum	Maximum	Mean	Std. Deviation
Visualization tool	32	2	5	3.34	.865
Just-in-time	32	2	4	3.47	.718
Daily huddle meeting	32	2	4	3.13	.707
Last planner	32	1	3	1.84	.847
5S	32	1	3	1.56	.914
Kaizen	32	1	3	1.56	.914
Kanban	32	1	3	1.56	.914
Six sigma	32	1	3	1.69	.896
Concurrent engineering	32	1	5	3.25	1.704
Pull approach	32	1	4	2.72	1.276
Total quality magmt.	32	1	5	2.84	1.439
Value analysis	32	1	4	3.03	.861
Total Preventive magmt.	32	1	4	2.75	.718
First run studies	32	1	4	2.78	.706
Prefabrication	32	1	4	2.47	.915

Valid N (listwise)	32				

Descriptive Statistics

L-S LInks	N	Minimum	Maximum	Mean	Std. Deviation
Both closely linked	32	1	4	2.94	.619
Enhance value creation	32	1	5	3.81	.693
Enhance trad. practice	32	2	4	3.81	.592
Reduce waste & pollution	32	2	5	4.44	.914
LC as catalyst to Sust.	32	3	4	3.91	.296
Both reduce Resources use	32	4	5	4.91	.296
Valid N (listwise)	32				

Descriptive Statistics

L-S benefits	N	Minimum	Maximum	Mean	Std. Deviation
Cost, time & quality	32	3	5	4.09	.466
Environ. respons. value chain	32	3	4	3.88	.336
Health & safety	32	3	5	3.81	.592
Energ. & Resource consuptn.	32	3	4	3.56	.504
Pollution & emission	32	3	4	3.66	.483
Matching buss. & environm.	32	3	5	3.84	.448
Industry competitiveness	32	3	5	4.31	.535
5R/Renewable resources	32	2	4	3.19	.738
Flexibility & adaptability	32	3	4	3.53	.507
Organisation learning	32	3	5	4.13	.707
Dispute	32	2	5	2.91	.818

Stakeholder collaboration	32	3	5	4.19	.644
Employment and skill dev.	32	2	5	3.22	.870
Continuous improvement	32	3	5	4.22	.659
Planning & risk mangmt.	32	3	5	3.72	.772
Technological advancement	32	2	5	3.25	.622
Affordability	32	2	5	3.50	.842
Valid N (listwise)	32				

Descriptive Statistics

Drivers	N	Minimum	Maximum	Mean	Std. Deviation
Need for eff. & effect.	32	3	5	4.06	.840
Leardership	32	3	5	3.88	.421
Changing legislation	32	2	5	3.47	1.047
Inflow of innovative staff	32	3	5	4.09	.530
Industry competitiveness	32	3	5	4.41	.560
Stakeholders demand	32	2	5	4.00	.762
Environmental concern	32	2	5	4.03	.740
Social responsibility	32	3	5	4.06	.716
Valid N (listwise)	32				

Descriptive Statistics

Barrirs	N	Minimum	Maximum	Mean	Std. Deviation
Organizational culture	32	2	5	4.28	1.085
Leadership	32	2	5	4.34	1.004
Uncertainty	32	2	4	3.16	.515
Cost implication	32	4	5	4.88	.336

Stakeh. awareness & demands	32	2	5	4.28	.851
Political & policy issues	32	1	5	3.22	.832
Material availabilty	32	3	5	3.94	.801
Valid N (listwise)	32				

Descriptive Statistics

Stakeholders	N	Minimum	Maximum	Mean	Std. Deviation
Academia	32	2	4	3.56	.840
Contractor	32	2	4	3.06	.435
Developer	32	2	5	4.28	.772
Consultant	32	3	5	4.37	.707
Government	32	3	5	3.25	.568
Lean & Green councils	32	3	5	4.44	.840
Media	32	2	5	3.91	.928
Valid N (listwise)	32				

Descriptive Statistics for single case

	N	Minimum	Maximum	Mean	Std. Deviation	Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
Cost, time & quality	8	4	5	4.25	.463	.000	1.481
Environ. respons. value chain	8	3	4	3.87	.354	8.000	1.481
Health & safety	8	3	5	3.75	.707	-.229	1.481
Energ. & Resource consuptn.	8	3	4	3.75	.463	.000	1.481
Pollution & emission	8	3	4	3.50	.535	-2.800	1.481
Matching buss. & environm.	8	3	4	3.50	.535	-2.800	1.481
Industry competitiveness	8	3	5	4.38	.744	-.152	1.481
5R/Renewable resources	8	3	4	3.25	.463	.000	1.481

Flexibility & adaptability	8	3	4	3.25	.463	.000	1.481
Organisation learning	8	3	5	4.50	.756	.875	1.481
Dispute	8	2	5	3.00	1.195	-1.204	1.481
Stakeholder collaboration	8	3	5	4.50	.756	.875	1.481
Employment and skill dev.	8	2	5	3.38	1.061	-.940	1.481
Continuous improvement	8	3	5	4.50	.756	.875	1.481
Planning & risk mangmt.	8	3	5	3.87	.835	-1.392	1.481
Technological advancement	8	3	5	3.62	.744	-.152	1.481
Affordability	8	2	5	3.25	1.035	-.448	1.481
Valid N (listwise)	8						