ENHANCING SUSTAINABLE CONSTRUCTION IN THE BUILDING SECTOR OF UGANDA USING EMBODIED CARBON ACCOUNTING

Nathan Kibwami

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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All work related to the above publications was undertaken by the candidate under guidance of his supervisor who is the co-author of the publications.

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Dedication

This thesis is dedicated to my family and friends. Time and again, you kept asking me…

"You man, are you still there?"

"What are you doing?"

"Are you done?"

"How far?"

"What is the progress?"

"When are you finishing?"

"When are you coming back?"

…I hope I can now provide you with some answers.

Abstract

There is an inextricable linkage between sustainable construction (SC) and carbon emissions – the former cannot be effectively attained if the latter is ignored. Since the building sector accounts for one-third of annual global carbon emissions, taking action to reduce buildings' emissions is necessary so as not to undermine SC. However, the predominant focus on the operation phase of buildings has increased the relative importance and magnitude of embodied carbon (EC), which are emissions associated with constructing buildings. Accounting for EC is necessary, since it presents a plethora of opportunities to enhance SC. This initiative should be extended to developing countries in which, although EC assumes significant importance, it is hardly researched about.

This work contributes to understanding and possible enhancement of SC in the building sector in Uganda by investigating the integration of EC accounting in construction practices. Process modelling was used to describe the existing practice (as-is system) so as to identify potential areas for improvement. Mathematical modelling was used to develop a model that was implemented as a software tool, using rapid application development. Using process modelling, the model was integrated into the as-is system to create a new (to-be) system. This system was empirically evaluated using structured interviews with built environment professionals.

Findings show that the to-be system can facilitate SC. It was also found to be institutionally feasible, although high implementation costs were envisaged. The to-be system addresses distributional considerations, such as legitimacy, transparency, and fairness. The challenges and recommendations for implementation were identified. This research provides a tangible option for Uganda's building sector, and developing countries alike, to explore alternatives of promoting SC through EC accounting. Although the to-be system is unique to Uganda, its components, such as the mathematical model, provide new insights into improving quantification and accounting for EC worldwide.

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List of abbreviations

AMMR	Ambiguous mixed-method research
ANOVA	Analysis of variance
BC	Building Control
BP	Building Project
BPMN	Business Process Modelling and Notation
BRE	Building Research Establishment
BSI	British Standards Institution
CA EPBD	Concerted Action Energy Performance of Buildings Directive
CaMeT	Carbon Measurement Tool
CASE	Computer-Aided Software Engineering
CCU	Climate Change Unit
CDM	Clean Development Mechanism
CIB	International Council for Building
CO_2	Carbon dioxide
DCLG	Department for Communities and Local Government
EMMR	Explicit mixed-methods research
DP	Development Permission
EC	Embodied Carbon
ED	Executive Director
EE	Embodied Energy
EI	Environmental Impact
EIA	Environmental Impact Assessment
EISd	Environmental Impact Study
EISm	Environmental Impact Statement
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
HA	Hybrid Analysis
IETC	International Environmental Technology Centre
IFIAS	International Federation of Institutes of Advanced Study
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
KG	Kilo gram
LA	Lead Agency
LCA	Life Cycle Assessment
LCEA	Lifecycle Energy Analysis
LCI	Lifecycle Inventory
LCIA	Lifecycle Impact Assessment
MJ	Mega Joules
MWLE	Ministry of Water, Lands and Environment
NE	National Environmental
NEMA	National Environment Management Authority
OC	Operational Carbon
OECD	Organisation for Economic Co-operation and Development
OMG	Object Management Group

PA	Process Analysis
PB	Project Brief
PFCC	Parliamentary Forum on Climate Change
PH	Public Hearing
PO	Presiding Officer
PP	Physical Planning
PPC	Physical Planning Committee
PV	Photovoltaics
RAD	Rapid Application Development
RECM	Resources Efficiency and Conservation Measures
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SETAC	Society of Environmental Toxicology and Chemistry
SFC	Strategic Forum for Construction
SME	Subject Matter Expert
SPSS	Statistical Package for the Social Sciences
ToR	Terms of Reference
UBOS	Uganda Bureau of Statistics
UNCED	United Nations Convention on Environment and Development
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
VBA	Visual Basic for Applications
VV	Verification and validation
WBCSD	World Business Council for Sustainable Development
WMO	World Meteorological Organization

Chapter 1
Introduction

This chapter presents the background to the study, thereby establishing the research context and also rationalising the significance of the research problem. The aim, objectives, and hypotheses of the research are presented, followed by an outline of the methods used in the investigation. The delimitations of the research, general limitation to the research, and a discussion of the overall structure of this thesis are also included.

1.1 Background to the study

The fifth Intergovernmental Panel on Climate Change (IPCC) report released in 2014 showed that greenhouse gas (GHG) emissions – commonly referred to as carbon emissions – that emanate from the building sector had more than doubled between 1970 and 2010 (IPCC, 2014). The dangers posed by carbon emissions cannot be underestimated especially in light of scientific evidence that links increased atmospheric concentration of carbon emissions to global warming. As a consequence of global warming, “the atmosphere and oceans have warmed, the amounts of snow and ice have diminished, [and] sea level has risen” (IPCC, 2013). These occurrences have been linked to extreme events such as flooding, loss of biodiversity, and food insecurity. Global warming is indeed referred to as one of the foremost challenges facing humankind in the 21st century (de Wilde and Coley, 2012). To reduce reoccurrences of such undesired extreme events that are concomitant with global warming, it is necessary to limit carbon emissions. Since the building sector significantly contributes to the global carbon emissions, the case for tackling emissions associated with the building sector is persuasive. However, there is growing evidence to suggest that success in tackling carbon emissions associated with buildings is contingent upon implementing appropriate strategies for enhancing sustainable construction (Giesekam et al., 2015; Häkkinen et al., 2015; Knight and Addis, 2011).

Since tackling carbon emissions from buildings is inextricably linked with promoting sustainable construction, addressing carbon emissions is a top priority on the agenda for promoting sustainable construction in the building sector. The concept of sustainable construction is widely interpreted as the application of the principles of sustainable development to construction. According to a widely quoted definition, sustainable development is development “that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987). However, sustainable development requires balancing environmental, economic, and social pillars of sustainability (Edum-Fotwe and Price, 2009; Parkin et al., 2003). Therefore, in the building sector, sustainable construction is perceived as a means through which it contributes to achieving environmental, economic, and social sustainability (CIB, 1999). To further the sustainability agenda of the building sector, prevailing evidence (e.g. UK’s Code for Sustainable Homes (DCLG, 2010)) suggests that integrating a metric of carbon emissions in the environmental sustainability assessment of buildings is a potential way forward.

Until recently, the focus on carbon emissions from buildings has been the operation phase (e.g. reducing emissions from heating, lighting, cooking etc.), largely because this phase accounts for the largest percentage (over 80%) of emissions from buildings (Kua and Wong, 2012; Sartori and Hestnes, 2007). However, as buildings are progressively designed to stricter operation-energy efficiency, operation carbon (OC) emissions will gradually reduce. Unfortunately, this reduction will be at the expense of increasing the relative proportion and magnitude of embodied carbon (EC) emissions which are associated with various activities of utilising energy (e.g. material manufacture and transportation) during constructing buildings (Iddon and Firth, 2013; Monahan and Powell, 2011). For instance, using heavy-weight construction techniques like concrete walls can improve energy efficiency and thus reduce OC emissions but leads to more EC emissions since it involves using more energy/carbon intensive materials like cement (Hacker et al., 2008; Cole, 1998). Therefore, focusing only on OC cannot fully deliver the aspirations of promoting sustainable construction in the building sector, unless EC accounting is also brought into focus.

Recent research suggests that EC should indeed be integrated in the environmental assessment of buildings, so as to enhance sustainable construction (Kibwami and Tutesigensi, 2016b; Häkkinen et al., 2015; Teh et al., 2015; Yuan and Ng, 2015; Knight and Addis, 2011). For some recent practices like in the UK, local planning authorities started requiring infrastructure developers to demonstrate how they use “materials that are sustainable and have low embodied carbon” (see Brighton and Hove, 2013, p.162). In addition, there is also an increasing number of guidelines supporting the inclusion of EC in environmental assessment of buildings (Franklin and Andrews, 2013; RICS, 2012; BSI, 2011). Therefore, it is plausible to suggest that integrating the assessment of EC in existing construction practices could enhance sustainable construction.

Although the consideration of EC in the sustainability assessment of buildings is a worthwhile pursuit, the prevailing type of boundaries and quantification procedures that are used limit wider application of the sustainability concept in building projects. These prevailing practices, whether voluntary (see Franklin and Andrews, 2013; RICS, 2012) or mandatory (see Brighton and Hove, 2013) put emphasis on the cradle-to-gate boundary. While this boundary arguably presents the least complications in accounting for EC, it does not provide a complete picture of the sustainability initiatives regarding building projects, since activities like on-site construction are excluded. Moreover, the prevailing quantification procedures of EC are aggregated, which does not facilitate the source of emissions to bare on the quantification in a manner that allows differentiating the contribution of the different energy sources, to the resulting EC. This for instance limits the application of some drivers for sustainable construction, such as choosing material suppliers who use less carbon-intensive energy sources, because aggregated approaches do not reveal the type of energy sources used. In order to expand the application of EC in furthering the sustainability agenda in the building sector, the prevailing boundaries and quantification approaches need to be extended and revised, respectively. This, as argued in this research, requires consideration of the cradle-to-construction completion boundary, and disaggregation of EC.

Extension and improvement of the prevailing boundaries and quantification procedures used in EC accounting requires significant contextualisation. For instance, consideration of the cradle-to-construction completion boundary in lieu of cradle-to-gate boundary necessitates considering the whole buildings' development approval process (i.e. from planning permission to commissioning of the building). However, development approval regimes vary by country, implying that using the cradle-to-construction completion boundary in accounting for EC requires aligning it with a country's development approval processes. Meanwhile, quantifying EC in a disaggregated way could imply, among other things, distinguishing the energy sources to a level of regions within a particular country (e.g. energy from coal mined in region A, versus energy from coal mined from region B). Therefore, the research problem of this study emanated from the need to develop country-specific means for integrating EC accounting in the development approval process of building projects in order to enhance sustainable construction.

1.2 Research aim and objectives

Against the background presented in section 1.1, the author sought to contribute towards the understanding and possible realisation of sustainable construction through accounting for EC. The aim of this research was therefore to develop a means of accounting for EC in the development approval process of buildings in Uganda, so as to enhance sustainable construction. The investigation warranted pursuit of four objectives, as outlined below.

1) To describe the current development approval process of building projects in Uganda.
2) To explore the possibility of integrating EC accounting in the current development approval process of building projects in Uganda.
3) To develop an approach to facilitating the integration of EC accounting in the development approval process of building projects.
4) To propose and evaluate a to-be system of enhancing sustainable construction, based on integrating EC in the development approval process of building projects in Uganda.

1.3 Hypotheses

In quantitative studies, hypotheses, which are traditionally stated in form of a null and alternate hypothesis, are specifically used to shape and focus the purpose of the study (Creswell, 2014). As this study was also quantitative, the following hypotheses, which were conceived from reviewing literature (Chapter 2 and Chapter 3), were considered. The hypotheses were based on evaluating the to-be system.

- **Hypothesis H1**: null hypothesis $H1_0$ – the to-be system does not facilitate sustainable construction; and alternative hypothesis $H1_1$ – the to-be system facilitates sustainable construction.

- **Hypothesis H2:** null hypothesis $H2_0$ – the to-be system has cost implications; and alternative hypothesis $H2_1$ – the to-be system has no cost implications.

- **Hypothesis H3:** null hypothesis $H3_0$ – the to-be system has no benefits; and alternative hypothesis $H3_1$ – the to-be system has benefits.

- **Hypothesis H4:** null hypothesis $H4_0$ – the to-be system does not address distributional considerations; and alternative hypothesis $H4_1$ – the to-be system addresses distributional considerations.

- **Hypothesis H5:** null hypothesis $H5_0$ – the to-be system is not institutionally feasible; and alternative hypothesis $H5_1$ – the to-be system is institutionally feasible.

1.4 Outline of methods

This section presents an overview of how the methods used in this work were approached, followed by an outline of methods that were used to achieve each of the four research objectives.

1.4.1 Overview

The choice of methods to address the research objectives was based on the overall theoretical perspective adopted, and the purpose of the objectives. In so doing, a distinction between methods and research methods became necessary. Methods were interpreted as the various techniques (e.g. for collecting data, for analysing data, etc.) available to use in a study (Fellows and Liu, 2009), whereas research methods were interpreted as the techniques for collecting data (Denscombe, 2010; Bryman, 2001). As such, not all methods used in this work were research methods, whereas all the research methods used were methods. In order to maximise the chance of realising the research objectives, and also enhance validity of this research, various methods and/or research methods were used as appropriate, to address the four objectives of this work. In so doing, the principles of triangulation, in form of having to use more than one research method and/or data sources (see later in Chapter 4, section 4.1.3.3), were employed.

1.4.2 The methods for each research objective

An outline for the methods used to address each of the four research objectives is provided hereunder.

1.4.2.1 Methods for describing the current development approval process

So as to achieve the first research objective, practices related to the current development approval process of building projects, herein referred to as the as-is system, were described. A standard method of process modelling which involved process discovery, process mapping, verification, and analysis, was considered. Process discovery, process mapping, and verification were used whereas analysis was used to achieve the second research objective. Relevant literature was used in process discovery to identify the prevailing formal processes which were then, through process mapping, modelled into process diagrams using the Business Process Modelling and Notation (BPMN). The result was a process model of the as-is system. Verification of the as-is system involved intra-design and empirical verification. Intra-design verification involved ascertaining whether the as-is system adhered to various process modelling rules, and also, whether all its relevant components had been included as per the literature from which it was conceived. Using semi-structured interviews, the as-is system was empirically verified to ascertain whether it conformed to formal procedures.

1.4.2.2 Methods for exploring the possibility of EC accounting

So as to explore the possibility of integrating EC accounting in the as-is system (i.e. the current development approval process of building projects) in Uganda, the as-is system was examined. The standard method of process modelling used in achieving the first research objective was considered. Although this method consists of four stages – process discovery, process mapping, verification, and analysis – only the analysis stage was applied in this case. Based on practices documented elsewhere, the as-is system was analysed to identify what was needed to address EC. The findings, which suggested a need for an approach that can facilitate the integration of EC in the current development approval process, informed the following research objective.

1.4.2.3 Methods to develop an approach to facilitating the integration of EC emissions

According to the findings from the first research objective, the approach to facilitating the integration of EC accounting in the development approval process of building projects warranted developing a quantification model for EC. As such, a mathematical model was developed and incorporated into a software tool. The mathematical model was developed using standard mathematical modelling procedures which involved formulation of the problem, stating assumptions, deriving equations, and verification. Formulation of the problem was based on the findings from addressing the first research objective, and extant literature. The assumptions of developing the mathematical model were also garnered from literature. Mathematical formulations involved using several algebraic equations to express various components of the mathematical model. Dimension analysis and peer review were used in the verification of the mathematical model. Using an agile software development method of Rapid Application Development (RAD), the mathematical model was incorporated into a software tool. The procedure of developing the software involved architectural design, model design, architectural building, prototyping, and verification. In architectural design, the software's components and their relationships were identified based on what the mathematical model prescribed. In model design, Visual Basic for Applications (VBA) was used to develop various customised functionalities within Microsoft Excel 2010. Given that the software was an Excel based application, its architectural design was structured into a graphical user interface, business logic, and data access/storage. Prototyping was used to progressively improve the software into a final acceptable version. In developing the software, module testing and integration testing were used as means of verifying that it was built correctly.

1.4.2.4 Methods for proposing and evaluating to-be system

To propose and evaluate the to-be system, the output (i.e. the as-is system) from the first research objective and the output (i.e. the mathematical model) from the third research objective were integrated to create the to-be system. The method of developing the to-be system was the same as the one described in section 1.4.2.1 (i.e. process modelling), with the exception that empirical verification and analysis were not conducted, since the to-be system was non-existent. Evaluation of the to-be system was conducted using structured face-to-face interviews with built environment professionals. Evaluation involved assessing several aspects such as: whether the to-be system was effective in promoting sustainable construction; whether the to-be system was cost effective; whether the to-be system was institutionally feasible; the suitable format of introducing the to-be system; the kind of buildings that should be considered in the to-be system; and the professionals suitable for the to-be system's fundamental component of EC accounting.

1.5 Delimitations of the research

In research, delimitations are often unavoidable and this research was no exception. Delimitations refer to the self-imposed research boundaries within the researcher's control which limit the scope of the research (Mauch and Park, 2003). The choice of problem to investigate, the objectives and research questions considered, and the methods adopted, are some of the aspects that can be construed as delimitations. The delimitations in this thesis, which were shaped in a way that the researcher aspired to gain a better understanding of the research topic, are identified as follows.

1.5.1 Focusing on Uganda

Funding which supported this work was obtained on the premise that this research would directly contribute to addressing a contemporary problem in the researcher's home country. To this end, the researcher chose to delimit all the empirical investigations of this research to Uganda. Moreover, it is evident from literature that prevailing efforts of accounting for EC in the building sector are concentrated in developed countries, with little or no consideration in developing countries (Brighton and Hove, 2013; Franklin and Andrews, 2013; RICS, 2012). Hardly any study on EC can be traced from Africa (Cabeza et al., 2014), yet embodied energy of buildings in developing countries can be large (Levine et al., 2007). The empirical investigations, which involved two episodes of data collection, consisted of two local planning authorities in the first episode (i.e. empirical verification of the as-is system), and a target sample of 120 built environment professionals in the second episode (i.e. evaluation of the to-be system). However, focusing on Uganda does not negate generalising this research's findings because Uganda's circumstances are not so different from those of other countries', more so, in the developing world. In addition, some of the outputs from this research, such as the mathematical model, are of universal application.

1.5.2 Philosophical framework

As elaborated later in Chapter 4, the philosophical framework that guided how this research contributed to knowledge was delimited to positivist epistemology and objectivist ontology. Equally, the principles of the scientific method, which among other things, involve testing hypotheses, were employed in creating new knowledge.

1.6 General limitation to the research

Limitations, which are outside the researcher's control, largely emanate from methodological considerations of a study and as such, can affect the interpretation or generalizability of a study's findings (Mauch and Park, 2003).

The general limitation identified in this work is its cross-sectional nature. In other words, the findings of this research were based on data that were collected from a 'one-off snapshot' of the prevailing situation. The alternative 'longitudinal' research option was not feasible because of time constraints. For instance, it would require implementation of the proposals made in this work before they could be evaluated. Within the constraints of typical 3-4 year PhD study timelines, this would not be feasible. This kind of limitation is not surprising since most PhD research is usually cross-sectional by necessity (Fellows and Liu, 2009). Meanwhile, the various limitations that applied to specific parts of this research are discussed with the conclusions provided for each of the research objectives in Chapter 9.

1.7 Structure of the thesis

This section provides a justification of the structure that was followed in presenting this thesis and a brief discussion of the contents in each chapter and appendices.

1.7.1 Justification of the thesis structure

As can be seen in Figure 1.1, this thesis largely follows a structure that is described as typical of quantitative research studies (see Creswell, 2014; Fellows and Liu, 2009). An arrangement consisting of a combined 'results and discussion' was adopted because it was the most appropriate way to present the outputs from the research objectives (Murray, 2011). This kind of arrangement eliminated unnecessary repetition and cross-referencing which could have occurred if 'results' and 'analysis/discussions' were presented in separate chapters. Perhaps most importantly, it was necessary to mind about the readers of this thesis – combining results and analysis/discussions provides readers with a 'one-stop shop' for the most important matters of a thesis (Dunleavy, 2003). Meanwhile, given that each of the research objectives had its own method (and/or research method), equally, each objective's output resulted into 'results and discussions'. However, the outputs from one objective fed into the subsequent objective and all together, in a coherent manner, the four objectives contributed to fulfilling the overarching aim of this research. Therefore, the overall 'results and discussions' of this thesis are presented in a logical sequence across Chapters 6 to 8. To sum up, the thesis consists of an introduction (Chapter 1), literature review (Chapter 2 and 3), methods (Chapter 4 and 5), results and discussion (Chapters 6 to 8), and conclusions and recommendations (Chapter 9). A brief discussion of what is contained in each of these chapters is presented in the following section.

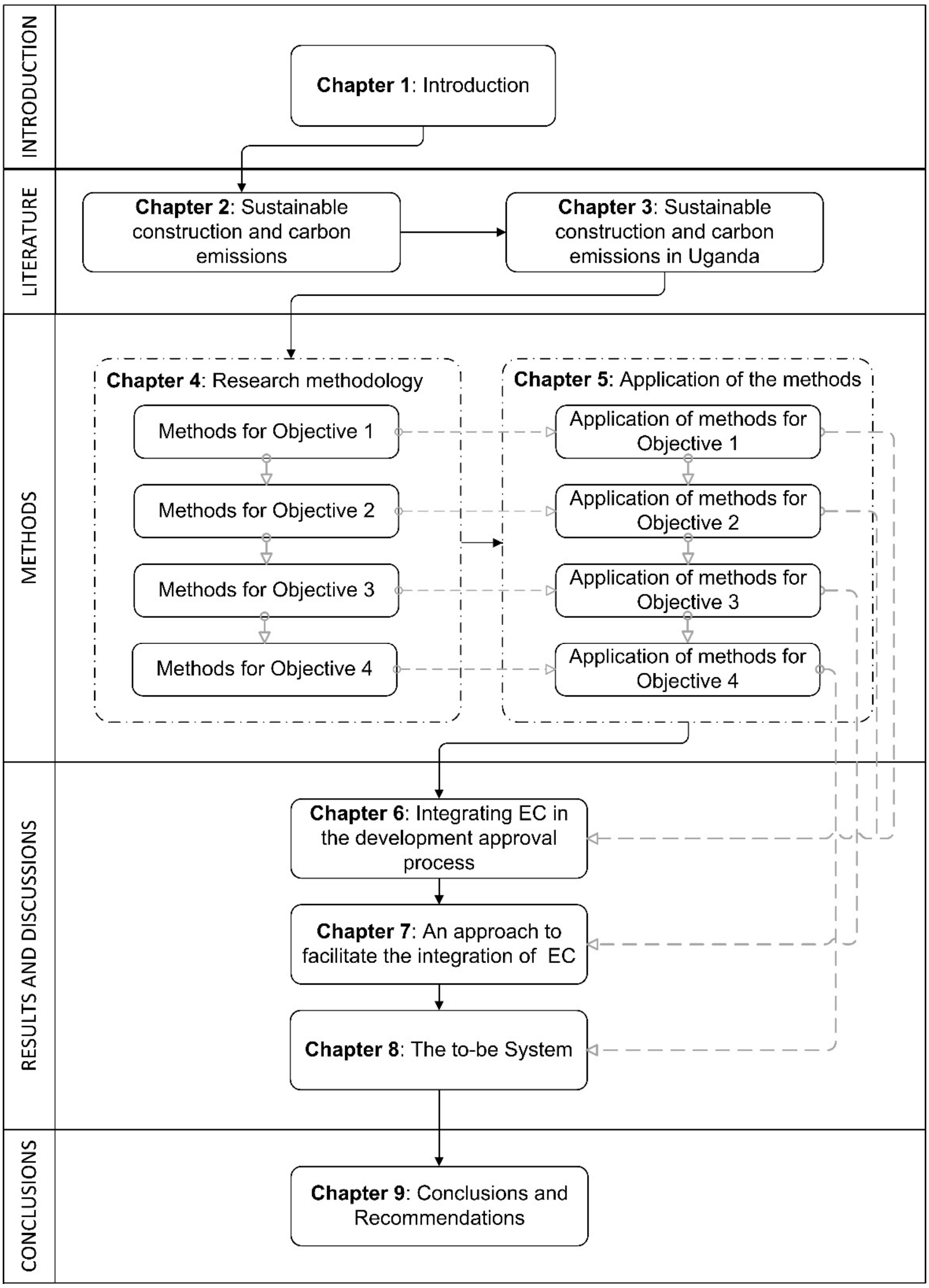


Figure 1.1 Diagrammatic representation of the thesis structure

Source: Author's construct

1.7.2 Contents of the thesis chapters

Chapter 1 provides an introduction to the entire thesis. It presents the background to the study which establishes the research context and also rationalises the significance of the research problem. The aim, objectives, and hypotheses of the research are presented. The outline of the methods used to address each research objective, the delimitations of this research, general limitation to this research, and the overall structure of this thesis are also presented.

Chapter 2 provides a review of relevant literature to present the state-of-the-art practices regarding sustainable construction and carbon emissions. As such, the gaps in knowledge, which this research addresses at a strategic level, are identified. The chapter therefore establishes the broader context of the study with respect to the concept of sustainable construction and how it relates to sustainable development. The drivers of sustainable construction are also presented, thereby revealing the inextricable relationship between sustainable construction and carbon emissions. The effects of carbon emissions and the endeavours being undertaken to mitigate are highlighted. Initiatives of addressing emissions in the building sector are presented, with emphasis on the need to consider EC. The various aspects of sustainable construction and accounting for EC discussed in Chapter 2 help to explain the assumptions made in the development of the EC quantification model presented in Chapter 7, and evaluation of the to-be system in Chapter 8.

Chapter 3 provides a review of literature so as to extend the discussions on sustainable construction and carbon emissions to the country context of Uganda. Chapter 3 therefore identifies the gaps in knowledge at a tactical level. The status of accounting for carbon emissions in the building sector in Uganda is discussed in order to highlight the gaps in the practice. A discussion about sustainable construction in Uganda is also provided. The perceived good practices derived from the state-of-the-art practices presented in Chapter 2 are used as a basis for positing what should be done in filling the gaps identified in Uganda. As such, a way forward to address carbon emissions and sustainable construction in Uganda is presented.

Chapter 4 presents the research methodology. The theoretical perspective that was adopted is discussed in relation to epistemological, ontological, and methodological considerations. In line with the theoretical perspective chosen, the appropriate methods for addressing objective one, objective two, objective three, and objective four, are presented and justified.

Chapter 5 presents application of the methods. Therefore, the chapter focusses on how the methods and/or research methods presented in Chapter 4 were implemented to achieve each of the four research objectives.

Chapter 6 presents results and discussions arising from describing the current development approval process of building projects in Uganda, and exploring the possibility of integrating EC accounting in the development approval process. A description of the existing formal procedures related to the development approval process (as-is system) is provided using process modelling. Results from the verification of the as-is system are also presented and discussed. The major outputs are two process models that represent the status before empirical verification and another after empirical verification (i.e. verified as-is system). Findings from analysing the verified as-is system are presented and the gaps in the existing practice are highlighted. Suggestions on what needs to be done in order to address the identified gaps are outlined. This leads to the following chapter that addresses the fundamental identified gap in quantifying EC.

Chapter 7 presents results and discussions from developing an approach to facilitate the integration of EC accounting in the development approval process of building projects. A mathematical model for quantifying EC is presented in a series of nine algebraic equations. The structure and operation of the developed excel based software tool, the Carbon Measurement Tool (CaMeT), is also presented and discussed. The outputs of Chapter 7 provide the ‘missing piece of the puzzle’ that is required to revise the as-is system described in Chapter 6, in order to create the to-be system described in Chapter 8.

Chapter 8 presents results and discussions related to proposing and evaluating the to-be system of enhancing sustainable construction, based on integrating EC accounting in the development approval process of building projects in Uganda. As such, a process model of the to-be system is presented, based on the outputs from Chapters 6 and 7. The results and discussions pertaining to evaluation of the to-be system include: preliminary analysis, effectiveness of the to-be system, cost-effectiveness of the to-be system, distributional considerations of the to-be system, institutional feasibility of the to-be system, format of introducing the to-be system, kind of buildings to consider in the to-be system, and professionals suitable for EC accounting. Findings from qualitative data analysis are also presented, in which the challenges of implementing the to-be system are identified.

Chapter 9 provides conclusions and recommendations of this thesis. The conclusions include what this research set out to do, what was found, significance, contributions to knowledge, and the limitations that apply. These aspects are presented for each of the four research objectives, consistent with the logical sequential structure of this thesis. Recommendations are also provided by reflecting on the limitations and the envisaged improvements of the to-be system.

1.7.3 Appendices to the thesis

Extra information that was considered relevant, though not appropriate to be presented within the thesis' chapters, has been included in several appendices and cited in the respective chapters, as elaborated below.

- **Appendix A** contains information about BPMN elements and rules used in process modelling. This information therefore augments the method of process modelling that was used to address research objectives one and four. Appendix A is cited in Chapter 5, and Chapter 6.
- **Appendix B** contains the research instruments which were employed in the relevant stages of data collection under objective one (i.e. empirical verification of as-is system) and objective four (i.e. evaluation of the to-be system). Appendix B is cited in the relevant sections of Chapter 5.
- **Appendix C** contains information about research ethics. Some procedures that were followed in fulfilling the ethical requirements were inherent of the research methods used for objective one and objective four. Therefore this appendix is cited in the relevant sections of Chapter 5. In addition, this appendix presents relevant ethical approval

documents demonstrating evidence of fulfilment of the ethical requirements (i.e. ethical approval in Uganda and UK) for this research.

- **Appendix D** presents child-level process model diagrams for the as-is system. The process model for the as-is system presented in Chapter 6 is a ‘parent’ high-level collapsed process model. Therefore, this appendix presents the detailed contents (i.e. child-level activities) of the expanded activities of the as-is system.
- **Appendix E** presents some extra screen shots of the graphical user interface of the software tool (CaMeT) which was developed. The appendix is cited in Chapter 7.
- **Appendix F** presents child-level process model diagrams (i.e. child-level activities) for the to-be system. Like the as-is system, the to-be system presented in Chapter 8 is a ‘parent’ high-level collapsed process model and therefore, its detailed contents are what Appendix F, which is cited in Chapter 8, presents.

Chapter 2
Sustainable construction and carbon emissions

In this chapter, relevant literature on sustainable construction and carbon emissions is reviewed in order to identify gaps in knowledge which this research addresses at a strategic level. A discussion on sustainable construction and how this concept relates to sustainable development is provided. Meanwhile, the concept of carbon emissions is also discussed, thereby highlighting the inextricable relationship between sustainable construction and accounting for carbon emissions. The state-of-the-art practices in accounting for EC and how it is presently integrated in building projects is also discussed, in light of promoting sustainable construction. Lastly, a chapter summary is presented.

2.1 Sustainable construction

In this section, the definition, and therefore interpretation of sustainable construction, is explored. The various drivers for sustainable construction are also presented.

2.1.1 Definition of sustainable construction

Acknowledgment of sustainable construction manifested in 1994 during the first international conference on sustainable construction which was held in Tampa, Florida, United States of America (Kibert, 1994). In that conference, sustainable construction was defined as "… creating and operating a healthy built environment based on resource efficiency and ecological design" (Hill and Bowen, 1997). Other commentators suggest that sustainable construction should be viewed as the responsibility of the construction industry towards sustainability (Bourdeau, 1999; Hill and Bowen, 1997). However, Kibert further suggested that sustainable construction should be construed as a subset of sustainable development (Kibert, 2008). This concurs with the assertion that sustainable construction is the means through which the construction industry contributes to achieving sustainable development (CIB, 1999). Based on these definitions, in this work, sustainable construction was interpreted as the application of the principles of sustainable development to construction.

Since sustainable construction is related to sustainable development, sustainable construction practices should therefore address the pillars of sustainability. According to a widely quoted definition, sustainable development is development “that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987). From the Venn diagram presented in Figure 2.1, achieving sustainable development requires intersection of the environmental, economic, and social pillars of sustainability. The environmental pillar of sustainability largely concerns minimising harmful impacts of an activity on the environment, whereas economic sustainability is concerned with maintaining a high level of economic growth without compromising people’s needs (Gan et al., 2015; Majdalani et al., 2006; Adetunji et al., 2003). Meanwhile, according to Adetunji et al. (2003), the social pillar of sustainability concerns addressing the legal, moral, and ethical obligations in the society within which an activity is carried out. As such, in order to promote sustainable construction in line with the principles of sustainable development, the three pillars of sustainability ought to be optimised.

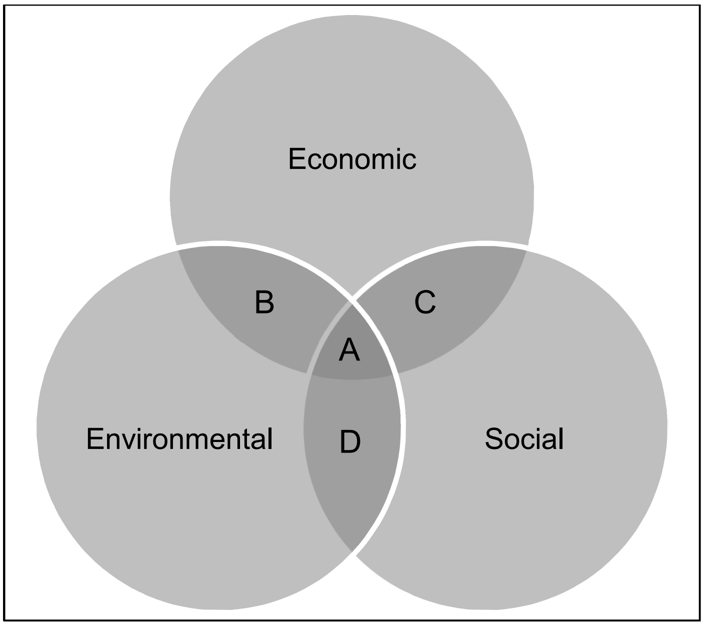


Figure 2.1 Three pillars of sustainability

A is Sustainable development (3rd order sustainability); B, C and D are 2nd orders of sustainability. Source: Edum-Fotwe and Price (2009)

With reference to Figure 2.1, sustainable construction can be interpreted to manifest in several states. Consideration of one pillar only, two pillars only, and all the three pillars relates to first order, second order, and third order states of sustainable construction, respectively. In the construction industry, sustainable construction has hitherto been largely interpreted in terms of the first and second order states of sustainability that relate to ‘environmental’, and ‘environmental and economic’ pillars, respectively (Zainul Abidin, 2010; Majdalani et al., 2006; Bourdeau, 1999). As such, environmental and economic sustainability pillars have hitherto been optimised at the expense of the social sustainability pillar (Shen et al., 2010; Edum-Fotwe and Price, 2009). This is exacerbated by the fact that social sustainability is often the least understood amongst the three pillars of sustainability, and consequently, often the least considered (Lehtonen, 2004). Therefore, one of the challenges in promoting sustainable construction is the creation of strategies that can facilitate optimising the three pillars of sustainability, so as to progress towards achieving the often elusive third order state of sustainability.

2.1.2 Promoting sustainable construction

In order to promote sustainable construction, literature suggests that several drivers for sustainable construction, which can be structured into environmental, economic, and social drivers, should be considered (see Table 2.1, Table 2.2, and Table 2.3). Strategies that aim to promote sustainable construction should therefore facilitate at least one of such drivers of sustainable construction. Optimising all of such drivers of sustainable construction is often impossible and thus a compromise is inevitable (Hill and Bowen, 1997). Therefore, a strategy that facilitates the largest number of the drivers for sustainable construction would greatly contribute to promoting sustainable construction practices. In the building sector, a bulk of strategies (e.g. EU’s *European Performance of Buildings Directive* (CA EPBD, 2014), the Code for Sustainable Homes in the UK (DCLG, 2010)), hitherto put emphasis on energy efficiency, which relates to driver number 2 in Table 2.1. A plausible explanation for this emphasis on energy efficiency lies in the effects of utilising energy. The production of energy (e.g. burning fossil fuels) engenders a phenomenon of carbon emissions whose impact is now recognised as a foremost threat to sustainable development.

Therefore, promoting sustainable construction in the building sector is inextricably linked to minimising carbon emissions associated with creating and maintaining buildings (Giesekam et al., 2015; Häkkinen et al., 2015; Knight and Addis, 2011).

Table 2.1 Environmental drivers for sustainable construction

	Environmental drivers	Reference
1	Reduce the use of resources such as energy, water, and materials, during in construction	Chen et al. (2010); Kibert (2008); Trufil and Hunter (2006); BRE and Cyril Sweett (2005); Bourdeau (1999); Hill and Bowen (1997)
2	Optimise lifecycle energy use (i.e. embodied and operating energy) in buildings	Chen et al. (2010); Shen et al. (2010); Kibert (2008); Nelms et al. (2007); BRE and Cyril Sweett (2005); Bourdeau (1999)
3	Recycling of products	Chen et al. (2010); Bakhtiar et al. (2008); Kibert (2008); Nelms et al. (2007); James and Matipa (2004); Bourdeau (1999); Hill and Bowen (1997)
4	Reuse of products	Chen et al. (2010); Kibert (2008); Nelms et al. (2007); James and Matipa (2004); Bourdeau (1999); Hill and Bowen (1997)
5	Use of renewables in preference for non-renewables	Hill and Bowen (1997)
6	Minimise pollutants that cause environmental degradation	Chen et al. (2010); Shen et al. (2010); Bakhtiar et al. (2008); Trufil and Hunter (2006); BRE and Cyril Sweett (2005); Bourdeau (1999); Hill and Bowen (1997)
7	Environmental labelling and voluntary rating schemes	Tan et al. (2011); Bakhtiar et al. (2008); Du Plessis (2007); Manoliadis et al. (2006); James and Matipa (2004); Bourdeau (1999); Hill and Bowen (1997)
8	Implementation of environmental management during construction stage such as documenting requirements in contract specifications	Hill and Bowen (1997)
9	Inclusion of environmental aspects in decisions during construction (e.g. buying greener materials)	Bourdeau (1999); Hill and Bowen (1997)
10	Development of comprehensive data bases	Du Plessis (2007); Bourdeau (1999)
11	Enforcement and compliance with environmental regulations	Tan et al. (2011); Bakhtiar et al. (2008); Du Plessis (2007); James and Matipa (2004)

Table 2.2 Economic drivers for sustainable construction

	Economic drivers	Reference
1	Financial affordability for intended beneficiaries	Bakhtiar et al. (2008); Nelms et al. (2007); Hill and Bowen (1997)
3	Employment creation such as using labour intensive construction.	Chen et al. (2010); Shen et al. (2010); Hill and Bowen (1997)
3	Competitiveness through advancing practices that advance issues of sustainability	HM Government (2009); Hill and Bowen (1997)
4	Choosing environmentally responsible suppliers/contractors who demonstrate environmental performance	Tan et al. (2011); Bakhtiar et al. (2008); Du Plessis (2007); Rwelamila et al. (2000); Hill and Bowen (1997)
5	Incentives for those applying a sustainability measure (e.g. lower interest rates, tax exemption, etc.) and vice versa	Du Plessis (2007); Nelms et al. (2007); Manoliadis et al. (2006); Hill and Bowen (1997)
6	Use of local resources (e.g. materials and workforce) in construction	Abidin and Pasquire (2007); Du Plessis (2007); James and Matipa (2004); Bourdeau (1999)

Table 2.3 Social drivers for sustainable construction

	Social drivers	Reference
1	Poverty alleviation	Edum-Fotwe and Price (2009); Hill and Bowen (1997)
2	Operations of a development to be compatible with local needs	Shen et al. (2010); Edum-Fotwe and Price (2009); Hill and Bowen (1997)
3	Education and training to increase awareness	Tan et al. (2011); Edum-Fotwe and Price (2009); Bakhtiar et al. (2008); Du Plessis (2007); Manoliadis et al. (2006); Bourdeau (1999); Hill and Bowen (1997)
4	Corporate social responsibility	Trufil and Hunter (2006)
5	Health and safety at workplace	Reyes et al. (2014); Shen et al. (2010); Edum-Fotwe and Price (2009); HM Government (2009); Bourdeau (1999); Hill and Bowen (1997)
6	Developing capacity and skills	Edum-Fotwe and Price (2009); HM Government (2009); Du Plessis (2007); Nelms et al. (2007); Hill and Bowen (1997)

2.2 Carbon emissions

This section presents a discussion about the concerns of carbon emissions, the general response in addressing carbon emissions, and carbon emissions from buildings.

2.2.1 Why carbon emissions are a concern

Since the pre-industrial period, there has been persistent increase in the concentration of greenhouse gases (GHGs) in the atmosphere, a situation which has led to changes in the climate system (IPCC, 2007a). These GHGs, such as carbon dioxide, methane, and nitrous oxide (Kyoto Protocol, 1998), form a blanket that does not allow heat radiated from the earth's surface to escape, consequently causing a 'greenhouse effect' (Hegerl et al., 2007; Dincer and Rosen, 1999). The greenhouse effect causes global warming which results into raising the temperature of the earth's surface, with potentially severe consequences such as "increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007b p.30). Those consequences, which are collectively referred to as climate change, have been linked to devastating events like flooding, loss of biodiversity, and food insecurity. To this end, climate change is arguably referred to as one of the greatest threats to survival of humankind.

Amongst all the GHGs released into the atmosphere, carbon dioxide (CO_2) accounts for the largest share, as can be seen from Figure 2.2. The dominancy of CO_2 suggests that compared with other GHGs, CO_2 significantly contributes to global warming. As such, in addressing GHGs, CO_2 is used as the reference for understanding how the climate is warmed by other GHGs (Forster et al., 2007). The extent of contribution of a GHG to global warming, measured over a given time interval, is referred to as the global warming potential (GWP). Using CO_2 as the reference gas, with its GWP set to 1, the GWPs of other GHGs are derived and expressed as CO_2 equivalents (CO_2eq) (Forster et al., 2007). For instance, the GWP of methane is 25 times more than that of CO_2, if a period of 100 years is considered (see Table 2.4). Thus: 1 kg of methane = 25CO_2eq, implying that 1 kg of methane equals to (and has the same effect as) 25 kg of CO_2 over a 100-year period. For most GHGs, the GWP reduces as the time horizon increases since the gases are gradually removed from the atmosphere through various natural processes. Since CO_2 accounts for the largest volume, it is the most important GHG to mitigate. As such, terminologies such as carbon emissions, CO_2eq emissions, are often interchangeably used to refer to a 'basket' of GHGs. In this work, the term 'carbon emissions' was adopted.

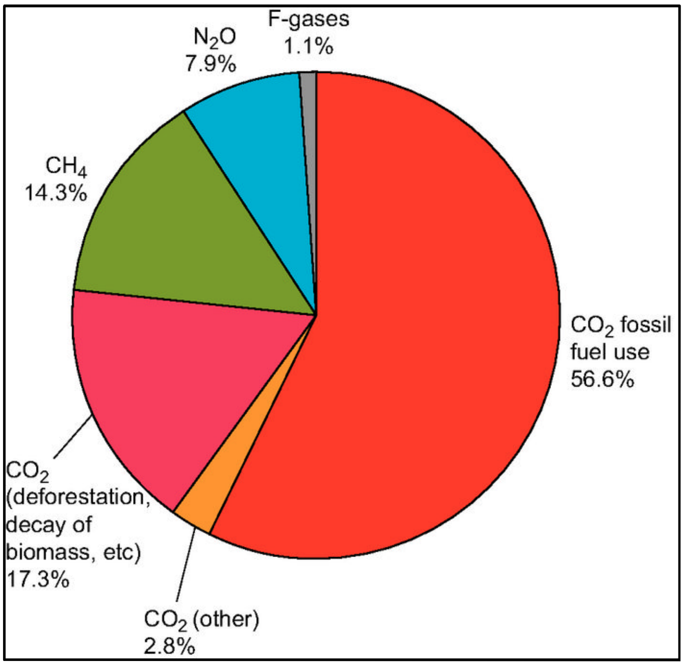


Figure 2.2 Global human-caused greenhouse gases as of 2004

Source: IPCC (2007a)

Table 2.4 Global Warming Potential of major greenhouse gasses

Greenhouse gas (GHG)	**Global warming Potential (GWP) for three commonly referenced time-horizons**		
	20 years	100 years	500 years
Carbon dioxide	1	1	1
Methane	72	25	7.6
Nitrous oxide	289	298	153

Source: Forster et al. (2007)

Unfortunately, humankind, to whom climate change poses a great threat, is largely responsible for its occurrence. Scientific evidence suggests that there is a high prevalence of anthropogenic causes, that is, "[h]uman-induced warming of the climate system" (Hegerl et al., 2007 p.665). In other words, the concentration of carbon emissions in the atmosphere has largely been a result of various activities undertaken to fulfil human needs (Forster et al., 2007). Such activities include: burning of fossil fuels (e.g. oil, coal and gas) to produce energy, deforestation for agriculture and settlement, and cement production for construction (UNEP/UNFCCC, 2002). Although such activities are necessary, to steer economic development, it is crucial that deliberate attempts are undertaken to reduce carbon emissions, so as not to undermine sustainable development.

2.2.2 Overview of global response

Reactions to addressing carbon emissions can be traced back to as early as 1979, when "… the First World Climate conference recognised climate change as a serious problem" (UNEP/UNFCCC, 2002 p.17). In the subsequent years, debates on climate matters increased, culminating into a need for autonomous technical advice on climate change. In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) set up an Intergovernmental Panel on Climate Change (IPCC) to regularly provide worldwide scientific appraisals on the state of climate (IPCC, 2010). To date, the IPCC reports, which are published in five-year intervals, serve as the normative reference for climate change matters. By providing evidence about the physical science basis, impacts, adaptation, vulnerability, and mitigation of climate change (Levermore, 2008), IPCC reports have hitherto had a seminal influence on the global actions towards addressing climate change.

The first IPCC assessment report which was released in 1990 triggered the formation of the United Nations Framework Convention on Climate Convention (UNFCCC) in 1992. The salient objective of the UNFCCC was to foster mechanisms to stabilize atmospheric carbon concentrations and therefore prevent human interference with the climate system (UNEP/UNFCCC, 2002). Later, IPCC's second assessment report of 1995 played an important role in the adoption of the Kyoto Protocol of 1997 (IPCC, 2010). This protocol, which later came into force in 2005, strengthened actions against climate change by setting emission targets to be met by the industrialised countries that were signatory (i.e. Annex 1 countries) (UNEP/UNFCCC, 2002). These countries had to reduce their emissions by 5% of 1990 levels during the initial commitment period of 2008 to 2012. The developing countries (i.e. non-Annex 1 countries) also had their obligations towards enabling the achievement of emission reduction targets (Kyoto protocol, Article 12). The revised commitment period, which was adopted in the 'Doha amendment to the Kyoto protocol', stipulated another 8-year period (2013 to 2020) to reduce emissions by 18% below those of 1990

(UNFCCC, 2013). The fifth IPCC assessment report revealed that "continued [carbon emissions] will cause further warming […] of the climate system. Limiting [this] will require substantial and sustained reductions of [carbon] emissions" (IPCC, 2013, p.19).

The need to reduce carbon emissions has recently been accentuated by the Paris agreement. This agreement, which was adopted at the UNFCCC Conference held in December 2015 in France, is the first universal agreement committing all countries to reduce carbon emissions (UNFCCC, 2015). In the wake of fossil-fuelled emerging economies like China, India, and other developing countries in Africa, committing to drastic carbon emission reductions is an ambitious resolution, but worth undertaking, if such countries are to avoid the development path trodden by the wealthy countries. Globally, realisation of substantial emission reductions will require focussing on the most carbon-intensive sectors, such as the building sector, which presents the largest single opportunity for drastically reducing carbon emissions (UNEP, 2009; Cheng et al., 2008; Levine et al., 2007).

2.2.3 Carbon emissions from buildings

Not only are buildings a considerable threat to the depletion of the finite natural resources, they also contribute significantly to the global carbon emissions. Buildings account for 17% of the world's fresh water usage, 25% of the wood harvest, and 40% of material flows (Roodman and Lenssen, 1995). In terms of energy and carbon emissions, the building sector globally consumes up to 40% of the global final energy and releases 30% of the annual global carbon emissions (WBCSD, 2012; UNEP, 2009). If the energy consumed during the construction phase is considered, buildings account for more than 50% of the global energy consumption (WBCSD, 2012). With the increased construction activities, especially in developing countries, coupled with inefficiencies in existing buildings globally, emissions from buildings are envisaged to increase (UNEP, 2009). Given such statistics, reducing emissions from the building sector makes a significant contribution towards realising global carbon emission reduction targets which have to be met to limit adverse climate change and therefore foster sustainable development.

Analogous to fixed capital costs and recurring running costs, carbon emissions caused by buildings consist of embodied carbon (EC) emissions and operation carbon (OC) emissions (Ibn-Mohammed et al., 2013; Iddon and Firth, 2013; Purnell, 2011; Hammond and Jones, 2008b). Whereas OC emissions occur when the building is in use, EC emissions happen in the various processes, such as material manufacture and transportation, that are associated with constructing a building (Hacker et al., 2008; Cole, 1998). Studies suggest that the operational phase contributes the biggest (circa 80%) proportion of energy-related carbon emissions from buildings (Aye et al., 2012; Kua and Wong, 2012; Sartori and Hestnes, 2007). Indeed, it is suggested that the potential of reducing emissions in buildings largely exists in ensuring energy efficiency in activities like heating, cooling, lighting, and cooking, which transpire during the operational phase of buildings (UNEP, 2009; Levermore, 2008). As such, there has been a tendency for international and national initiatives to focus on addressing energy efficiency in the operation phase of buildings.

Several international and national initiatives have been registered towards reducing emissions from buildings, especially, in the operation phase. For instance, in the European Union (EU), the Energy Performance of Buildings Directive (EPBD) was legislated with a cardinal objective of improving energy performance in buildings (CA EPBD, 2014). This directive required EU member countries to establish a methodology for calculating energy performance, set minimum energy performance requirements, issue energy performance certificates, and carry out inspection of boilers and air conditioning (BRE, 2006a; BRE, 2006b). In response to the directive, many countries have hitherto implemented the requirements aimed at reducing OC emissions. In the UK for instance, building regulations were (and are continuously) revised to ensure progressive improvements in energy efficiency of buildings (BRE, 2006a). Such strict energy efficiency standards, which are certainly not only limited to UK, have greatly contributed to improving energy efficiency, thereby reducing OC emissions.

Unfortunately, the success in reducing emissions associated with the operation phase of buildings shall come at a cost. There is a profound concern that as OC emissions are progressively reduced, especially through applying strict energy efficiency regulations, the magnitude of EC emissions will increase both in relative proportion and real terms (Ibn-Mohammed et al., 2013; Wener and Burns, 2012; Monahan and Powell, 2011). As can be seen from the illustration in Figure 2.3, the progressive increase in the operational energy efficiency requirements for new buildings reduces OC emissions but not EC emissions as the latter are constant. As such, the predominant ratio of 20:80 in relation to EC and OC emissions of a building is certainly changing to magnitudes of 40:60 (Wuppertal Institute, 2011; Lane, 2007). Meanwhile, construction methods, such as using heavyweight construction to reduce OC emissions can also result into increased EC emissions (Monahan and Powell, 2011; Hacker et al., 2008). Although heavyweight construction is associated with good thermal properties which may reduce the need for heating or cooling, the materials used, such as concrete, lead to high emissions. Therefore, in low operational-energy buildings, embodied energy can amount to substantial proportions (40%) of the building's lifecycle energy use (Thormark, 2002). As recent reviews suggest (Ibn-Mohammed et al., 2013), global efforts in reducing carbon emissions associated with buildings cannot be fully realised if embodied energy (EE) and EC emissions are ignored. Moreover, given the inextricable linkage between carbon emissions and sustainability (see section 2.1.2), for holistic enhancement of sustainable construction, strategies that focus on energy efficiency need to consider EC emissions as well.

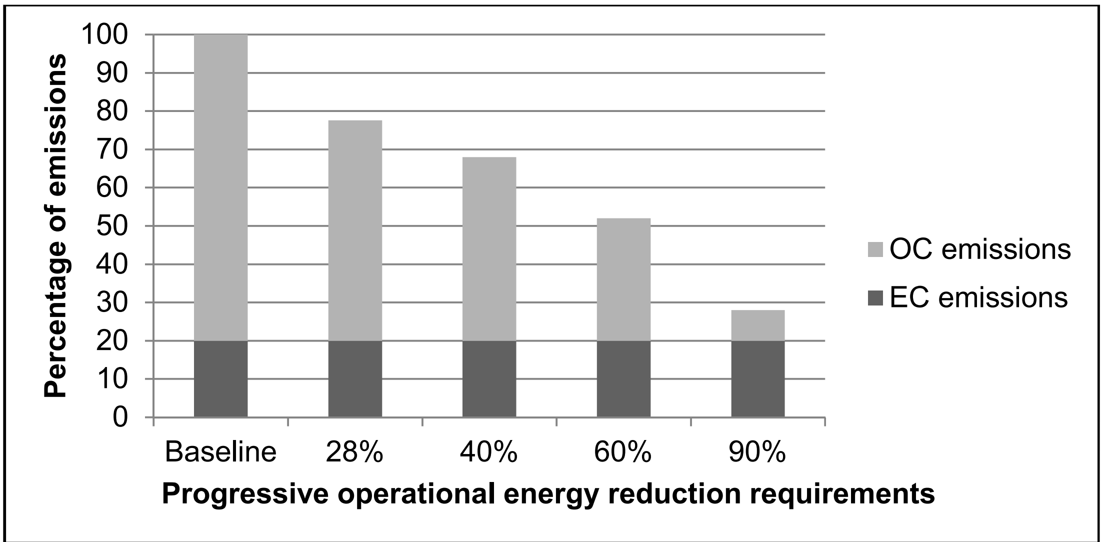


Figure 2.3 Impact of toughening building regulations in UK

Source: adapted from Lane (2007)

Extant research and practice suggests that EC should be considered in the environmental assessment of buildings because it potentially enhances sustainable construction (Häkkinen et al., 2015; RICS, 2012; Knight and Addis, 2011). In the UK for instance, some local planning authorities started requiring infrastructure developers to demonstrate how they use "materials that are sustainable and have low embodied carbon" (see Brighton and Hove, 2013, p.162). In the case of Hong Kong, Yuan and Ng (2015) argued that a quantitative assessment of EC should be integrated in building environmental assessments. Similar arguments are expressed in Teh et al. (2015) wherein initiatives of integrating carbon metrics into the planning stages of building projects in Australia were discussed. Therefore, it is plausible to suggest that implementing EC accounting in building projects can promote sustainable construction. However, as argued in the next section (section 2.3), success in utilising EC accounting to enhance sustainable constructions depends on how EC emissions are interpreted, and consequently, accounted for.

2.3 Embodied carbon emissions from buildings

In this section, the definition and forms of EC/EE, boundaries of EC/EE, and accounting for EC are discussed.

2.3.1 Definition and forms of embodied carbon/energy

Although the definition of EC is often derived from that of EE, this does not imply that the two terms can be interchangeably used. According to the Oxford Dictionary of English, embodied refers to "include[d] or contain[ed] as a constituent part" (Oxford, 2014a). Taking an example of a material, the energy embodied in a material (i.e. its embodied energy), measured in MJ/kg of that material, is the energy required to produce that material (Hammond and Jones, 2008b). EC emissions can therefore be referred to as emissions resulting from using EE (Wener and Burns, 2012). However, that definition only holds for emissions that are energy-related. Although there is profound relationship between energy and carbon emissions (Lenzen, 1998), manufacture of some materials such as cement and steel can result into non-energy related emissions (Hammond and Jones, 2008b; Worrell et al., 2001). Therefore, EC can also include other kinds of emissions that are not energy-related but process-related. It follows that a material with high EE may not necessarily have high EC, especially where the source of that energy (e.g. hydroelectricity) causes less or no carbon emissions. Therefore, although related, the two terms, EE and EC, should not be interchangeably used since associated values are not always directly proportional (Wener and Burns, 2012). For that reason, the definition of EC of a product should be interpreted in relation to its derivatives (e.g. energy-related EC, non-energy-related EC, or both). This research focused on energy-related EC since burning of fossil fuels is hitherto the leading cause of anthropogenic carbon emissions (IPCC, 2013).

In defining EC, evidence suggests that there is little consensus, since varying forms of EE are discussed in extant literature. Essentially, there are no straight forward answers when it comes to the question of what to include or exclude in describing embodied impacts. As illustrated in Figure 2.4, the three major forms of EC emanate from initial, recurring, and final energy related to production, operation, and end-of-life phases of a building, respectively. For instance, the definition in Cole and Kernan (1996, p.308) limited EE of a building to *initial embodied energy*, that is, the “initial energy used to acquire raw materials and manufacture, transport and install products”. While Cole and Kernan’s definition excluded energy expended in building maintenance and refurbishment, the definition of EE highlighted in Dixit et al. (2010) includes what is referred to as *recurring embodied energy*, which is the energy expended in maintenance and refurbishment of a building, and *final embodied energy*, which is the energy used to decommission the building. That perception, which is expressed in Dixit et al. (2010), is also shared by various scholars (Brown et al., 2014; Ibn-Mohammed et al., 2013; Jiao et al., 2012; Hacker et al., 2008). Meanwhile, it is argued that energy expended by labour (i.e. personal energy derived from food and lifestyle support energy) should also be included as part of the “whole embodied energy” of a building (Jiao et al., 2012 pp.21-22). These variations of defining EE have perhaps led to a conclusion that “there is no single definition of building embodied carbon emissions” (Li et al., 2014, p.402). Until such differences can be resolved, it is plausible to consider operational definitions of EC. Therefore, EC is ubiquitously defined as per a particular study’s scope, with respect to the boundaries of the building’s lifecycle phase considered.

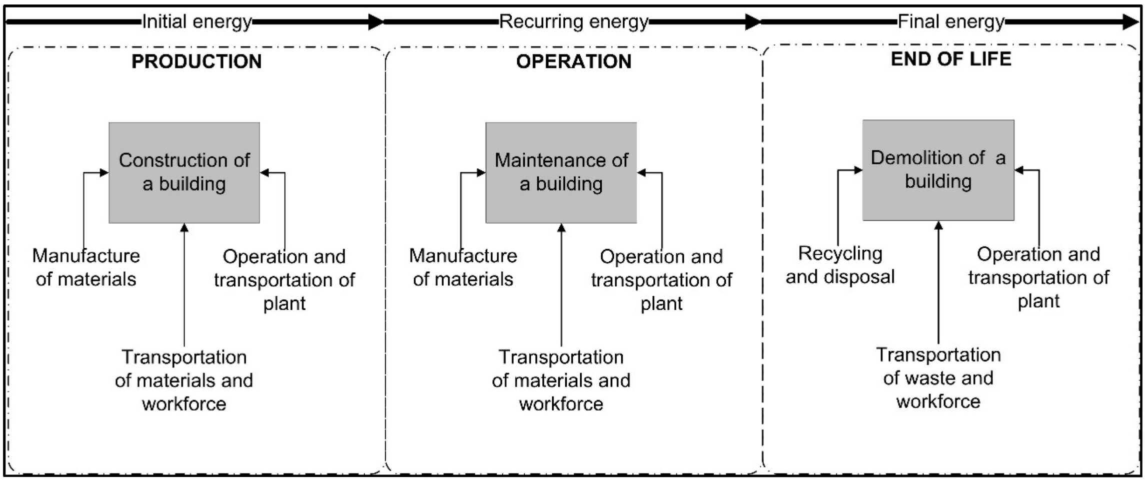


Figure 2.4 Forms of embodied energy and carbon emissions

Source: Author's construct

2.3.2 Boundaries of embodied carbon

There are various boundaries of EC that can be demarcated regarding the various lifecycle phases of a building. As shown in Figure 2.5, from the upstream to the downstream processes associated with the lifecycle of a building, the following boundaries can be defined: cradle to factory gate (A), cradle to construction site (A+B), cradle to construction completion (A+B+C), cradle to grave (A+B+C+D+E), and cradle to cradle (A+B+C+D+E+F). These boundaries are further discussed below.

2.3.2.1 Cradle-to-gate

This boundary includes all upstream processes (e.g. mining of raw materials) associated with production (e.g. of materials, equipment etc.) until they are ready for despatch at the 'factory gate'. More often than not, most products' embodied impacts are specified using this phase, taking into account all necessary upstream processes related to producing the product. Indeed some databases, such as Hammond and Jones (2011), specify embodied impacts of materials using cradle-to-gate. This, as argued by Hammond and Jones, alleviates some potential complexities associated with variations of transportation modes and distances to the point of use (ibid). Unsurprisingly, most of the prevailing guidelines on EC accounting are based on the cradle-to-gate boundary (see Franklin and Andrews, 2013; RICS, 2012). However, the cradle-to-gate boundary largely restricts EC of a building to construction materials, since other activities (e.g. transportation to site, on-site equipment use) that occur outside the factory gate are excluded. This limits the consideration of sustainable construction to production of construction materials only. Moreover, materials like sand and aggregates consume low energy in production, and also have low density, but their transportation to site can greatly contribute to EC (Hammond and Jones, 2011). Therefore, the cradle-to-gate boundary does not give a true representation of sustainability initiatives in relation to building's EC.

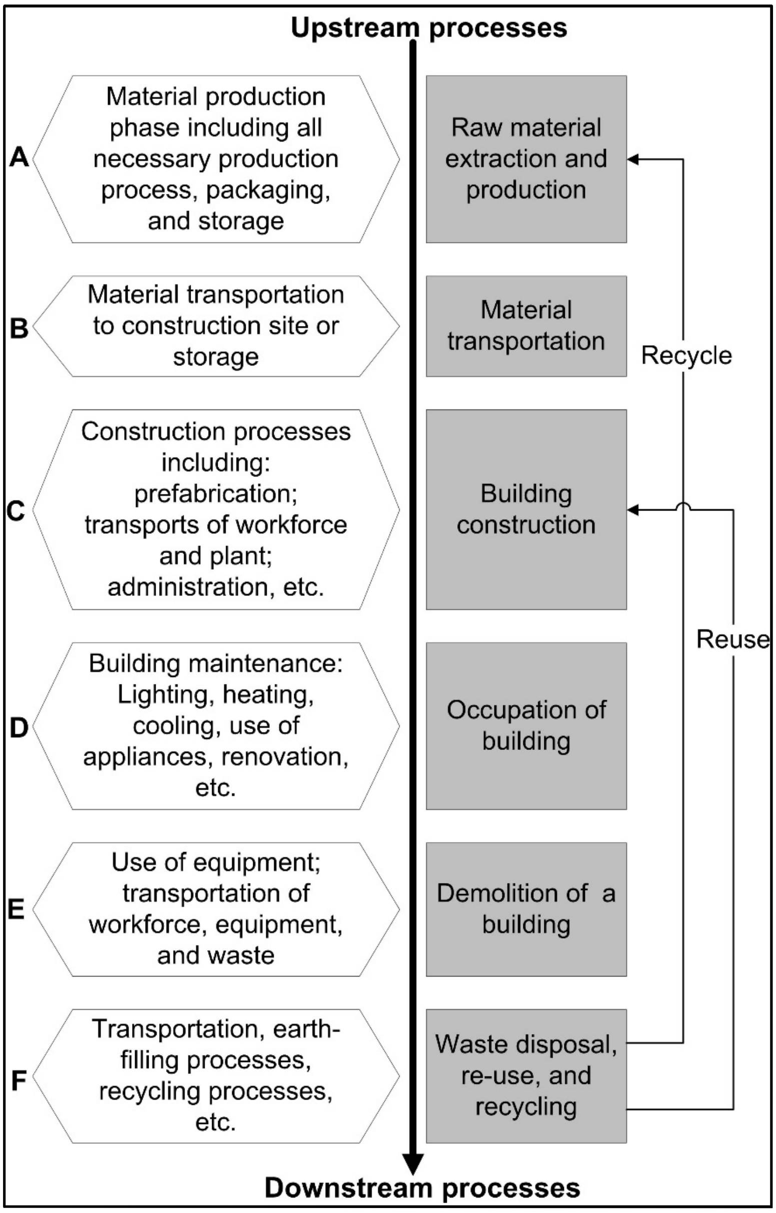


Figure 2.5 The life cycle stages of a building's energy use

Source: adapted from Dixit et al. (2012)

2.3.2.2 Cradle-to-site

If products are transported to the construction site, the boundary is then extended from cradle-to-gate to cradle-to-site. In that case, EC will therefore be defined as emissions associated with processing and supplying products to site or point of use (Hammond and Jones, 2010). As argued in the preceding section 2.3.2.1, the magnitude of EC from the cradle-to-site boundary is significant for components that consume less energy in manufacturing, yet possess low density (Hammond and Jones, 2011). This boundary is also relevant where factory-to-site haulage distances are considerably long (Broun and Menzies, 2011; Gustavsson and Sathre, 2006). However, similar to the cradle-to-gate boundary, the cradle-to-site boundary omits activities that occur beyond the delivery of products to site. Equally, in terms of promoting sustainable construction, the cradle-to-site boundary limits the consideration of sustainability initiatives to production and transportation of construction materials only.

2.3.2.3 Cradle-to-construction completion

This boundary considers all embodied impacts up to a point where construction is finished, and the building is ready for use. This phase is what several studies often classify as constituting the ‘initial’ EC/EE of a building (Ibn-Mohammed et al., 2013; Dixit et al., 2012; Hacker et al., 2008) (see also Figure 2.4). Unlike the previous cradle-to-site boundary, cradle-to-completion includes the construction phase, thereby accounting for construction activities such as equipment use. The 13 studies reviewed in Yan et al. (2010) suggest that this phase usually includes EC from: manufacture of building materials, transportation of building materials, transportation of construction equipment, on-site use of construction equipment, transportation of workers, and disposal of construction waste. The cradle-to-construction completion boundary gives a more complete picture of embodied impacts and sustainability initiatives of a building project, although it excludes activities occurring in the operation/use of the building.

2.3.2.4 Cradle-to-grave

Cradle-to-grave considers the operation phase and subsequent demolition at the end of a building’s life span. Studies suggest that, in addition to the previous boundary of cradle-to-completion, cradle-to-grave includes ‘recurring’ EC due to the maintenance and refurbishment of the building, and ‘demolition’ EC (Brown et al., 2014; Wan Omar et al., 2014; Dixit et al., 2012; Jiao et al., 2012). However, scepticisms abound when EC occurring after constructing a building is accounted for. Studies suggest that accounting for post-construction EC requires making assumptions that are not only difficult but also unrealistic in the long run (Hong et al., 2015; Li et al., 2014; Wan Omar et al., 2014). For instance, predicting energy-use behaviour and number of renovations is increasingly becoming difficult due to the effect of technological advancements that improve energy efficiency. Studies in which such assumptions have been made (e.g. in Brown et al., 2014; Varun et al., 2012; Hacker et al., 2008), are not invalid, but suffer from uncertainty. Equally, the extent to which the cradle-to-grave boundary can be applied in addressing sustainability aspects of buildings is open to uncertainties.

2.3.2.5 Cradle-to-cradle

Upon demolition of the building, if the materials are recycled, the boundary traverses a complete cycle of cradle-to-cradle, since downstream processes would have been considered. The building’s components can be disposed of, recycled into similar products, recycled into different products, or directly re-used. Whereas this boundary is what some studies have described as the most inclusive (Wener and Burns, 2012), it also suffers problems similar to those highlighted in the cradle-to-grave boundary (section 2.3.2.4). For instance, for a building with a life expectancy of 60 years, predicting how materials will be recycled or recovered in 60 years’ time may not be an easy undertaking. In addition, changes in product design, consumer behaviour, legislative restrictions (e.g. banning usage), and disposal behaviours compound the complications (Blanpain et al., 2014). If the various boundaries of EC are considered as existing on a continuum, with ‘cradle’ and ‘grave’ on either of its extreme ends, cradle to construction completion is the most realistic boundary in furthering the initiatives of sustainable construction.

2.3.3 Accounting for embodied carbon

Accounting for EC is concerned with quantification, composition, and methods of accounting, as discussed hereunder.

2.3.3.1 Quantifying embodied carbon

Quantification of EC is relatively a new research area that, by that very fact, is not without its controversies. In elementary terms, a carbon account of a product is obtained by multiplying its quantity (e.g. kg of material, litres of fuel, etc.) with the carbon emission factor (i.e. kgCO_2 per kg, kgCO_2 per litre, etc.). However, this procedure is not as straight forward when it comes to accounting for EC. Unlike OC, which can easily be assessed by considering monthly energy bills or using energy simulation models (e.g. Hacker et al., 2008), accounting for EC emissions is notoriously challenging, laborious, and often controversial (Li et al., 2014; Dixit et al., 2010; Langston and Langston, 2008). For instance, the approach used in Purnell (2011) to analyse EC of "simple beams and columns" was criticised to be "overly simplistic and uses inappropriate functional units and system boundaries" (Sathre et al., 2012, p.3595). The fact that Purnell maintains "the system boundary used in my study is not wrong, but merely an alternative pragmatic approach…" confirms that there are still grey areas in quantifying EC (Purnell, 2012, p.3597).

A comprehensive review of literature revealed that in quantifying EC, most studies use 'aggregated' approaches. In such approaches, the different energy sources (e.g. diesel, coal, biomass etc.) that contribute to EC cannot be readily accounted for (see Table 2.5). The major shortcoming of aggregated approaches is that they assume emissions from the different energy sources to be homogeneous. For instance, in calculating EC, Huberman and Pearlmutter used a carbon emission factor of 100kgCO_2 per unit energy for all the different energy sources they considered (Huberman and Pearlmutter, 2008). Such assumptions present shortcomings similar to those in economics, when inflation is interpreted based on a specific 'basket of goods', yet goods in that basket may widely differ (in quality, preference, and price changes) hence making the sole inflation figure non-representative for different goods. Moreover, EC possesses significant levels of uncertainty due to variation of energy mixes (Hammond and Jones, 2010); aggregation just compounds such uncertainties.

Table 2.5 Aggregation and disaggregation of embodied impacts

Source	Country	Disaggregation/ Aggregation [a]		
		A	B	C
Cole (1998)	Canada		√	
Scheuer et al. (2003)	USA	√		
Dias and Pooliyadda (2004)	Sri Lanka			√
Guggemos and Horvath (2005)	USA	√		
Gustavsson and Sathre (2006)	Sweden		√	
Norman et al. (2006)	Canada	√		
Asif et al. (2007)	UK	√		
Nässén et al. (2007)	Sweden	√		
Citherlet and Defaux (2007)	Switzerland	√		
Dimoudi and Tompa (2008)	Greece	√		
Hacker et al. (2008)	UK	√		
Huberman and Pearlmutter (2008)	Israel	√		
Upton et al. (2008)	USA	√		
Zabalza Bribián et al. (2009)	Spain	√		
Gustavsson and Joelsson (2010)	Sweden	√		
Gustavsson et al. (2010)	Sweden			√
Yan et al. (2010)	Hong Kong	√		
Monahan and Powell (2011)	UK		√	
Airaksinen and Matilainen (2011)	Finland	√		
Broun and Menzies (2011)	UK	√		
Aye et al. (2012)	Australia	√		
Cuéllar-Franca and Azapagic (2012)	UK		√	
Kua and Wong (2012)	Singapore	√		
Van Ooteghem and Xu (2012)	Canada		√	
Varun et al. (2012)	India		√	

[a] A – study used aggregated EC coefficients; B – study highlighted the constituent EC related to the respective fuels sources but the results were aggregated; C – study highlighted the constituent EC related to the respective fuels sources and the results can be disaggregated.

From the extant literature reviewed, aggregation is promoted in various ways, commonest of which include: use of ball-pack average carbon emission factors for varying materials (see Aye et al., 2012; Huberman and Pearlmutter, 2008); use of generic country average emission factors (see González and García Navarro, 2006; Cole, 1998); and use of emission factors with undisclosed energy sources (see Broun and Menzies, 2011; Dimoudi and Tompa, 2008; Asif et al., 2007). Without articulating what each energy source contributes to emissions means that it would be difficult, if not impossible, to explore alternatives of reducing EC such as opting for energy sources that have lower emissions. Relating to the inflation analogy again, the inflation figure does not provide enough information for someone to identify goods with lower prices.

Equally, aggregated approaches offer little help to identify energy sources that have lower emissions.

Contrary to aggregated approaches, in disaggregated approaches, the different energy sources (e.g. diesel, coal, biomass etc.) that contribute to EC are readily accounted for. In that way, the author contends, it is possible to explore alternatives of reducing EC such as substituting energy sources that have high emissions with alternatives that have lower emissions. Most importantly, since disaggregation enables energy sources to bear on the quantification of EC, this can facilitate sustainable construction in a number of ways, such as: environmental labelling of products; use of less carbon intensive energy sources; use of locally sourced energy; choosing suppliers who use less-carbon intensive energy sources, and so forth. Certainly, such aspects relate to the drivers of sustainable construction elaborated in section 2.1.2. Therefore, it is reasonable to suggest that in order to account for EC in a way that facilitates promoting sustainable construction, disaggregated approaches should be used.

2.3.3.2 Composition of buildings' embodied carbon

Literature suggests that the sources of EC include: manufacture and transportation of construction materials, use and transportation of equipment/plant, and transportation of labour/workforce, as discussed below.

2.3.3.2.1 Construction materials

There is a consensus that construction materials contribute the biggest proportion of buildings' embodied impacts, with estimates of up to 90% in some cases (Chang et al., 2012 p.794; Purnell and Black, 2012; Hughes et al., 2011; Nässén et al., 2007 p.1599; Scheuer et al., 2003 p.1057). Indeed, most strategies on promoting sustainable construction focus on construction materials (Brighton and Hove, 2013; RICS, 2012). Through processes of raw-materials extraction, processing, and necessary logistics to the place of use, the energy expended leads to emissions (Hammond and Jones, 2008b). However, as discussed earlier in section 2.3.1, not all emissions from manufacturing materials are energy-related. There are also process emissions which result from chemical processes like calcination of lime in cement manufacture (Hammond and Jones, 2008a; Nässén et al., 2007). Literature suggests that the common materials known to be both energy and carbon intensive include concrete/cement, steel, bricks/blocks, and glass (see Table 2.6). Therefore, for quick wins in tackling EC of buildings, and therefore promote sustainable construction, such materials should be investigated.

Table 2.6 Common energy and carbon intensive materials

Source	**Country**	**Material (s)**			
		Concrete	**Steel**	**Bricks/ blocks**	**Glazing/ glass**
Cole (1998)	Canada	√	√		
Dias and Pooliyadda (2004)	Sri Lanka	√	√	√	
Guggemos and Horvath (2005)	USA	√	√		
Gustavsson and Sathre (2006)	Sweden	√	√		
Asif et al. (2007)	UK	√			√
Dimoudi and Tompa (2008)	Greece	√	√	√	
Huberman and Pearlmutter (2008)	Israel	√	√	√	√
Upton et al. (2008)	USA	√	√		
Gustavsson and Joelsson (2010)	Sweden	√			
Monahan and Powell (2011)	UK	√	√	√	
Broun and Menzies (2011)	UK			√	
Aye et al. (2012)	Australia	√	√		√
Cuéllar-Franca and Azapagic (2012)	UK	√		√	√
Kua and Wong (2012)	Singapore	√	√		
Van Ooteghem and Xu (2012)	Canada	√	√		√

2.3.3.2.2 Equipment

Essentially, constructing a building may require a variety of equipment ranging from manual, to power operated equipment, all requiring energy for various purposes (Cole, 1998). The energy required may include electricity needed for power-tools, and fuel such as diesel and petrol needed to operate and transport equipment (Kofoworola and Gheewala, 2009). The major determinants of the extent of carbon emissions from equipment include: the type of energy used, the rate of consumption, and duration of equipment operation (Marshall et al., 2012; Palaniappan et al., 2012; Cole, 1998). However, the magnitude of emissions may also depend on other secondary factors like operating efficiency (Lewis et al., 2011), nature of materials and type of building assembly (i.e. wood compared with concrete) (Cole, 1998), and emissions rate of equipment (Ahn et al., 2010). Therefore, emissions from construction equipment result from operation and transportation of the equipment (Hughes et al., 2011; Cole, 1998).

2.3.3.2.3 Workforce

In construction activities, especially in developing countries which highly employ human labour in lieu of machinery, the contribution of workforce to EC is not negligible (Boustead and Hancock, 1979). EC from workforce majorly emanates from two components: energy (from manpower) derived from food, and energy from commuting to and/or from place of work.

a) EC from manpower energy

EC from manpower energy is usually disregarded because of “complexity and ambiguity” (Dias and Pooliyadda, 2004 p.564), and unclear methods associated with assessing manpower energy (Mpakati-Gama et al., 2011). However, Boustead and Hancock suggested that human activities are not devoid of manpower energy, although a greater portion (> 50%) is utilised for life sustenance other than working (Boustead and Hancock, 1979). In the same vein, some authors, such as Jiao and colleagues, critique studies that ignored inclusion of human labour energy (Jiao et al., 2012). The argument put forward is that EC of a building should include EC from energy derived from food consumed by workforce. However, in Jiao et al. (2012), there was no clarification on the proportion of the workforce’s energy that was used for construction activities yet, as elaborated in Boustead and Hancock (1979), life sustenance takes a substantial portion of manpower energy. This confirms that procedures for assessing manpower energy are largely unclear, warranting exclusion of the resulting EC by most studies.

b) Transport energy

The impacts from transportation of workforce are quite straight forward although largely depend on the context. In the case of motorised transportation, the energy used (e.g. petrol, diesel) could be associated with carbon emissions. However, the recent European CEN TC 350 standards on assessing sustainability of construction works exclude energy, and therefore EC, associated with workforce transportation (BSI, 2011). But in the UK, some initiatives suggest that EC from workforce transportation should be accounted for (SFC and Carbon Trust, 2010). Cole proved that workforce transportation can significantly contribute to EC from onsite construction activities, especially where labour-intensive construction is involved (Cole, 1998). Meanwhile, differences in life style also matter. In Jiao et al. (2012), wherein two countries were compared, the variation of energy expended by construction workers in New Zealand and China was because the use of privately owned cars among Chinese construction workers was very rare, compared to the New Zealand workers. Therefore, while inclusion of EC associated with workforce transportation is important, it depends on the context and associated lifestyle.

2.3.3.3 Methods of accounting for EC

The predominant methods of accounting for EC include Life Cycle Assessment and energy analysis, as discussed below.

2.3.3.3.1 Life Cycle Assessment

Before the term Life Cycle Assessment (LCA) was coined, varying nomenclature was used to serve similar purposes. For instance, terms such as environmental profiles, integral environmental analysis, profile analysis, ecobalances were used until early 1990s when the ‘LCA’ terminology was proposed (Klöpffer, 2012; Bauman and Tillman, 2004). Subsequent years saw various initiatives, such as the Society of Environmental Toxicology and Chemistry (SETAC), endeavouring to refine LCA (Dixit et al., 2012; Bauman and Tillman, 2004). SETAC and several of other practical guidelines (e.g. The Institute of Environmental Sciences of Leiden University, Netherlands) of conducting LCA were instrumental in developing a universal standard – ISO 14040 1997 (Bauman and Tillman, 2004). In the ISO 14040 standard, LCA is referred to as the “compilation and evaluation of the inputs, outputs and the potential environmental impacts of the product system throughout its lifecycle” (ISO, 2006a p.2).

Although LCA has attracted wide preference as a method for evaluating buildings’ environmental impacts such as EC, it has equally faced criticisms. Interestingly, the limitations of using LCA for buildings also double as the justifications. Early use of LCA is credited to the manufacturing industries, specifically packaging, where processes are usually more standardised than those in the building sector (Bauman and Tillman, 2004). For buildings, the inherent complexity associated with their assemblage makes use of LCA a challenge (Ramesh et al., 2010). Nonetheless, due to the complexities associated with buildings, LCA is the better approach to examine such complexities (Scheuer et al., 2003). To this end, there is widespread use of LCA in assessing environmental impacts, such EC associated with buildings (see Moncaster and Symons, 2013; Monahan and Powell, 2011; Gustavsson et al., 2010; Hacker et al., 2008; Asif et al., 2007; Scheuer et al., 2003). Some studies also suggest that results from a study that employed LCA principles are preferable for secondary use, especially for comparison purposes (Hammond and Jones, 2008a). Therefore, although LCA is criticised to be inappropriate for buildings, as it was originally developed for factory-made products, it is arguably the best EC assessment method available.

The methodological framework of LCA consists of four phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation (ISO, 2006a).

a) Goal and scope definition

This first phase of LCA basically elaborates the focus of the study, a focal point in distinguishing one study from the other. In defining the goal, the aims and intended audience for the study are elaborated, whereas the scope definition specifies the product studied, functional unit, system boundaries, and data requirements, among others (ISO, 2006a). The methodological approach of any LCA, and its corresponding solution, is based on the aim of carrying out the LCA (Bauman and Tillman, 2004). Therefore, although LCA is often iterative whereby for instance, the scope may be refined as the study progresses (ISO, 2006b), clarifying the appropriate aim of the LCA-study is very important.

b) Life cycle inventory analysis (LCI)

The previous phase of goal and scope definition sets out the preliminary plan for executing the life cycle inventory analysis (LCI) phase (ISO, 2006b).

Denoted as the second phase, LCI is an intensive process since it involves several aspects such as: collection of the data that are paramount to addressing the goals; computation of inputs and outputs flows (i.e. material and energy) of the product under study; and allocation of inputs and outputs to different products or processes (ISO, 2006a). The scale of data collection is an important aspect at this phase and depends on the product of the study. Considering a building, arduous tasks are inevitable since buildings are complicated. The assemblage of varying materials, various contractual parties, unstandardized operations and processes, all presents buildings as uniquely complex products (Ramesh et al., 2010). Bauman and Tillman reasoned that this is why earlier LCA studies were time-consuming since computer usage was not ubiquitous. (Bauman and Tillman, 2004). Presently, use of software is a common strategy to alleviate such complications. For instance, in Van Ooteghem and Xu (2012) ATHENA software was used, in Cuéllar-Franca and Azapagic (2012) GABI software was used, while SimaPro software was used in Monahan and Powell (2011). It is therefore commonplace to use commercially available software in conducting LCA, or even better, develop customised software tools to serve specific purposes (see Moncaster and Symons, 2013; Guggemos and Horvath, 2005).

c) Life cycle impact assessment (LCIA)

The lifecycle impact assessment phase is aimed at defining the environmental significance of the inventory generated in the previous phase (Bauman and Tillman, 2004). This phase should be well planned in order to attain the goal and scope of the study (ISO, 2006b). The ISO standard lists mandatory and optional elements to be carried out. Mandatory elements include: impact category selection, classification, and characterisation, whereas optional elements include normalisation, grouping, weighting, and data quality analysis. Definition of mandatory and optional elements is hinged on aspects of objectivity and subjectivity (Bauman and Tillman, 2004). The mandatory elements are more objective as they are majorly scientific-based, compared to the optional elements which are contextual. In practice, the common elements considered are: classification, characterisation, and weighting (Bauman and Tillman, 2004). In assessing buildings, the objective elements such as classification and characterisation are most preferred due to lack of consensus on subjective elements such as weighting (Filimonau et al., 2011). Classification entails assigning the LCI results (e.g. amount of carbon dioxide, materials, water etc.) to the impact category (e.g. climate global, resource depletion) they belong. Characterisation is then applied, whereby, equivalent factors are used to convert the LCI results into a common unit of the impact category. For instance, all GHGs can be converted to carbon dioxide equivalent (CO_2eq) to reflect the global warming category (ISO, 2006b; Bauman and Tillman, 2004).

d) Life cycle Interpretation

The interpretation phase entails evaluation of the outcomes in relation to the LCA-study aims, such that conclusions can be drawn (Bauman and Tillman, 2004). The ISO (2006b p.24) standard places significant emphasis on interpretation of the results in relation to the stated goal and scope. However, where results do not fit into the stated goal and scope of the study, the goal and scope can be revised. Certainly, LCA is iterative and therefore, there are options of revisiting earlier stages (ISO, 2006a). In the case of buildings, the interpretation of results is predominantly based on the energy quantified. This yields another form of LCA – Lifecycle energy analysis (LCEA). LCEA of buildings is the LCA analysis that uses energy as the measure for gauging the environmental impacts of buildings (Huberman and Pearlmutter, 2008; Fay et al., 2000). In the LCEA procedure, based on the total energy intake of the building, the associated carbon emissions can be deduced and the environmental impacts can be conceptualised (Ramesh et al., 2010). Therefore, it suffices to assert that using LCA to assess EC of buildings relies on principles of energy analysis.

2.3.3.3.2 Use of energy analysis in buildings

Seminal work on energy analysis is credited to the International Federation of Institutes of Advanced Study (IFIAS) (Roberts, 1975). Upon convening in 1974 to deliberate on regulations regarding computation of energy embedded in goods and services, IFIAS agreed to call the process 'energy analysis' and subsequently, a more elaborative definition of energy analysis was agreed upon. Energy analysis was defined as "...the determination of the energy sequestered in the process of making a good or service …" (Roberts, 1975 p.345). Since then, other definitions have been suggested. In Mortimer (1991 p.374), energy analysis was defined as "a means for calculating the total amount of energy required to provide goods or services", whereas in Alcorn and Baird (1996 p.319), energy analysis is presented as a process "...used to determine the amount of energy used to perform activities and provide specific goods or services". From all these definitions, it is clear that energy analysis involves identifying the processes and/or activities contributing to a good or service, such that associated energy, and thus EC, can be computed. In that way, energy analysis is construed as a device for mapping out EC of a product (Alcorn and Baird, 1996).

The overarching goal of energy analysis is to assess the primary energy needed to produce an output (Mortimer, 1991). A distinction between *primary* and *final* energy is crucial to fulfilling the goals of energy analysis. Primary energy analysis takes into account all the inputs and losses along the energy chain-flow, contrasted with *delivered/final* energy analysis that does not take into account the same (Gustavsson and Joelsson, 2010). Delivered energy does not put into consideration aspects like extraction, processing, and distribution losses and therefore if a study assess EC based on delivered energy, it overlooks some underlying environmental impacts of energy (Gustavsson et al., 2010; Fay et al., 2000). Quantitatively, for any given source of energy, its primary energy is more than its final energy (Thormark, 2002). Therefore, where delivered energy values are used in assessing EC, they have to be converted into primary energy values by using appropriate conversion factors (Omar et al., 2014).

Analysis of energy flows is essential in order to identify whether the resulting EC is based on 'delivered' or 'primary' energy. The analysis of energy flows is facilitated by thermodynamic principles of energy changes and balances (Hammond and Jones, 2008b; Mortimer, 1991). As per the first law of thermodynamics, energy can neither be created nor destroyed but can change from one form to another and remains constant in a closed 'system'. Therefore, to account for energy in a closed 'system', specifying an accounting boundary is necessary (Mortimer, 1991 p.375). The boundary helps to delimit the energy inputs that are specific to the process or product being studied. This necessitates defining the direct (i.e. delivered) and indirect (i.e. primary) energy inputs (Mortimer, 1991). The direct energy is used in the main process (e.g. steel fabrication) whereas the indirect energy is used to create the inputs (e.g. mining iron ore) to the main process. For this reason, EC is often quoted as based on the summation of emissions from direct and indirect energy (Crawford et al., 2006; Mortimer, 1991). Alternatively, the terms scope 1 (i.e. direct) and scope 3 (i.e. indirect) of EC are also used (Defra/DECC, 2012).

Whereas tracing for direct energy is quite obvious, tracing for indirect energy is often tedious, warranting regression analyses. Regression analysis serves as a means of structuring a systemised approach for analysing inputs in a defined boundary (Hammond and Jones, 2010; Roberts, 1975). The regression concept, as explained in IFIAS (1978), is underpinned by progressions through various levels of energy use. As shown in Figure 2.6, level 1 contains the direct energy used in the main process, beyond which the boundary can be expanded further upstream to level 2 which includes the inputs used to provide the materials of the main process. This can go as far as level 3 which includes energy for the capital equipment, level 4 which includes energy for machines used for making capital equipment, and so forth. As noted in IFIAS (1978), a truncation at level 2 can capture 90-95% of the total energy used. However, Roberts argued that the choice of regression level to adopt is usually a subjective one and in most cases, it is determined by the energy analysis technique adopted (Roberts, 1975).

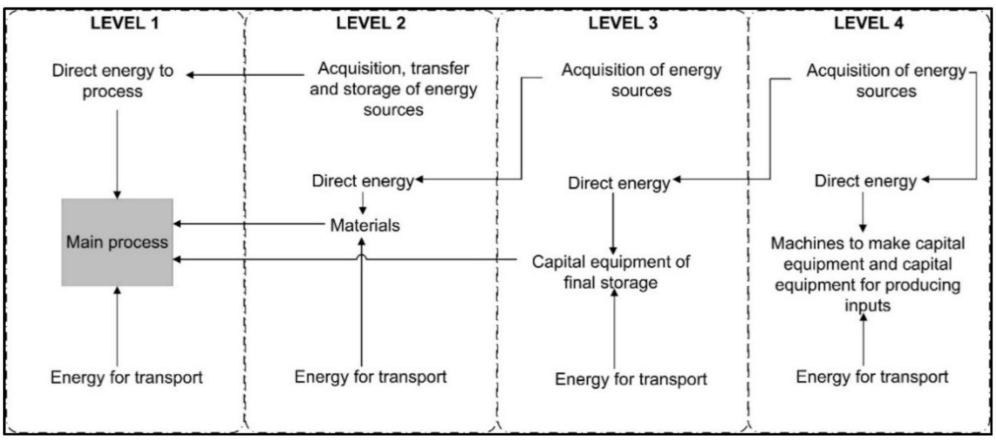


Figure 2.6 Regression levels in defining the product boundary

Source: Adapted from IFIAS (1978)

The widely documented energy analysis techniques are: process analysis (PA), input-output analysis (IOA), and hybrid analysis (HA). In Alcorn and Baird (1996, p.319), PA is defined as a "… systematic examination of the direct and indirect energy inputs to a process". Meanwhile, the IOA technique credits its roots from macro-economics, as it was initially developed in economic research problems and later adopted for energy analysis (Hammond and Jones, 2008b; Bullard et al., 1978; Roberts, 1978). In IOA, energy flows are traced by analysing monetary flows to and from economic sectors, through mapping the financial output of each sector with the corresponding energy used (Alcorn and Baird, 1996). HA, as the name suggests, is an amalgam of PA and IOA. Since HA combines data from PA and IOA in various ways (Crawford et al., 2006), hybrid-variants can be realised (e.g. PA-based and IOA-based hybrids), depending on the dominance of a technique adopted. As such, each of these three – PA, IOA and HA – energy analysis techniques has its own merits and demerits.

Several studies have discussed the merits and demerits associated with PA, IOA, and HA (e.g. Murray et al., 2010; Hammond and Jones, 2008b; Crawford et al., 2006; Lenzen and Dey, 2000; Alcorn and Baird, 1996; Mortimer, 1991). PA is suitable for assessing direct but not indirect energy, while the reverse applies for both IOA and HA. For assessing indirect energy, PA is criticised for the subjectivity involved in deciding the truncation point, which is usually set at level 2 (refer to Figure 2.6) (Lenzen and Dey, 2000). The unavoidable use of sector averages in IOA implies that the IOA technique poses challenges in evaluating a specific individual product (Murray et al., 2010). Thus IOA is usually associated with aggregated results (Bourgault et al., 2012). PA is suitable for a specific process or product and can also take into account technological advancements regarding products' manufacture processes (Gustavsson et al., 2010). Although PA does not give 'complete' results, by 50% sometimes (Lenzen and Dey, 2000), accuracies of up to 90% can be registered (Hammond and Jones, 2010; Murray et al., 2010). Depending on the intentions of assessing EC, if the merits/demerits associated with each technique are considered, it is possible to choose the energy analysis technique suitable for a particular investigation.

2.4 Chapter summary

This chapter has presented a review of literature linking sustainable construction and carbon emissions. The gaps in knowledge that this research addresses at a strategic level have been identified. Regarding sustainable construction, the definition and interpretation of sustainable construction has been elaborated, in relation to sustainable development. The drivers of sustainable construction, structured into environmental, economic, and social drivers have been highlighted. It has been argued that with regards to promoting sustainable construction, a focus on energy efficiency is paramount as this engenders carbon emissions. Consequently, the phenomenon of carbon emissions, of which a major consequence is climate change, has been highlighted as a defining challenge of the 21st century. Global initiatives to address climate change through limiting emissions have been discussed. The building sector has been identified as a significant contributor to the global emissions. It has been argued that EC emissions from buildings ought to be considered as this potentially promotes sustainable construction. However, it has been shown that the predominant EC accounting boundary of cradle to-gate should be expanded to construction-completion in order to take into account wider aspects that facilitate sustainable construction. In addition, the prevalent quantification procedures of EC have been discussed. It has emerged that aggregation of EC presents several limitations of which some limit furthering the sustainability agenda. Quantification of EC should therefore be revised so as to accommodate disaggregation, an aspect that has been argued to greatly facilitate the drivers of sustainable construction. Therefore, the author suggests that in order to fill these gaps in knowledge, it is necessary to formulate disaggregated approaches of quantifying EC, considering the boundary of cradle-to-construction completion, such that sustainable construction can be enhanced. The next chapter provides a review of literature so as to highlight the issues of sustainable construction and carbon emissions, albeit focusing on the Ugandan context.

Chapter 3
Sustainable construction and carbon emissions in Uganda

In the preceding chapter, the state-of-the-art regarding sustainable construction and carbon emissions has been discussed, thereby identifying the gaps in knowledge at a strategic level. This chapter extends this discussion by focusing on the country context of this research, so as to identify the gaps in knowledge at a tactical level. As such, a discussion about carbon emissions and sustainable construction in Uganda is provided, and lastly, a chapter summary is presented.

3.1 Carbon emissions in Uganda

In this section, the following are discussed: national and economic circumstances in Uganda, limiting of carbon emissions in developing countries, policy initiatives on carbon emissions in Uganda, and initiatives on limiting carbon emissions.

3.1.1 National and economic circumstances

Natural and economic circumstances present Uganda as a land locked developing country (UNCTAD, 2011). As illustrated by two maps (Africa and Uganda) shown Figure 3.1, Uganda is located in the East African region, bordered by South Sudan, Kenya, Tanzania, Rwanda, and Democratic Republic of Congo. The country covers an area of 241,550 sq. km of which 18% is covered by inland water and swamps. Average temperatures range from 16 to 31^{o}C, with annual rainfall of 700-2000mm although the north eastern region faces more extreme temperatures and lower precipitation. The population of Uganda was recently estimated at 35 million people, growing at a rate of 3.2% annually with approximately 1.8 million people inhabiting the country’s capital, Kampala. The country’s economy is predominantly agrarian, since the agricultural sector employs 72% of the population and also contributes 85% of the country’s total exports (UBOS, 2013; The Republic of Uganda, 2010).

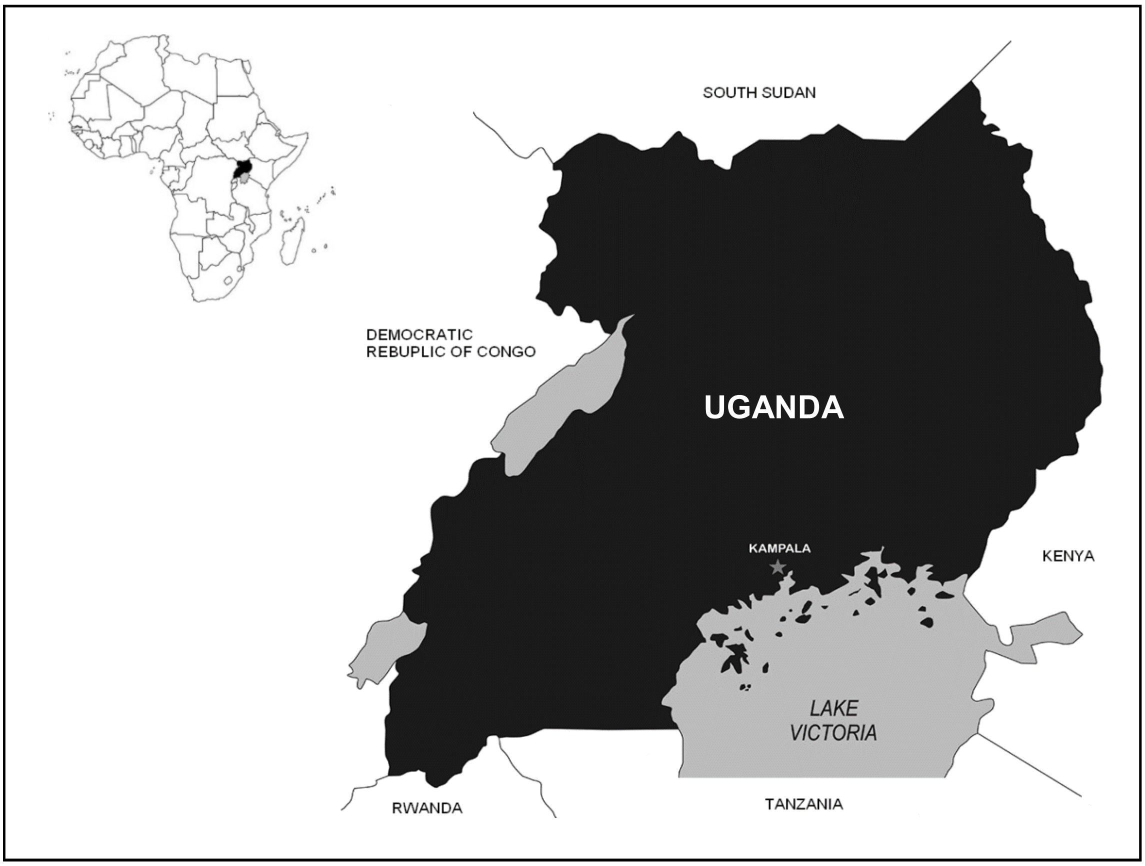


Figure 3.1 Uganda (right) and its location in Africa (left)

Source: Adapted from Worldatlas (2013)

3.1.2 Limiting carbon emissions in developing countries

It is widely acknowledged that a large amount of carbon emissions concentrated in the atmosphere was caused by activities such as industrialisation undertaken in developed countries (Dincer and Rosen, 1999). This situation often raises an equity question regarding who should be responsible for decarbonisation. It may seem irrational to commit developing countries in mitigating a menace they never caused. Indeed, some commentators argue that it is the developed countries that are supposed to reduce emissions (Davies and Oreszczyn, 2012). However, such assertions are fallible, especially in light of recent developments like the Paris Agreement, in which developed and developing countries alike are required to limit their emissions (UNFCCC, 2015). It is everyone's responsibility to reduce carbon emissions because the effects of climate change are no respecter of geographical boundaries. For instance, "emissions of sulphur dioxide from an electricity plant in the UK may contribute to a change in fish populations in a small lake in Scandinavia" (Mickwitz, 2003 p.417). Therefore, developing countries like Uganda are expected to follow a low carbon-path to development, in order not to repeat the same mistakes made by the developed world.

Although developing countries like Uganda have hitherto contributed little to carbon emissions, these countries are the most vulnerable to the impacts of climate variability (Boko et al., 2007). Climate change models for Uganda predict "…increase in temperature in the range of 0.7° C to 1.5° C by 2020" (World Bank, 2012 p.18). The country's bi-modal climate of two rainy seasons per year is no longer predictable, since rainy seasons are becoming wetter and dry seasons more recurrent and longer (The Republic of Uganda, 2010; Olsen, 2006). This has triggered several disasters like landslides, floods, and prolonged droughts, all of which have knock-on effects to the country's economy. A major concern is that climate change might undo developments the country has hitherto achieved (Olsen, 2006). Therefore, Uganda's participation in the initiatives of addressing carbon emissions is well founded.

3.1.3 Policy on carbon emissions in Uganda

Being party to several global initiatives, Uganda subscribes to the global climate change-regulatory policy. The country's first discernible action was the involvement in the second World Climate Change conference which was convened in Geneva in 1990 (Olsen, 2006). The country was also represented in the subsequent United Nations Convention on Environment and Development (UNCED) which was held in Brazil in 1992 (Olsen, 2006). Uganda signed the UNFCCC in 1992 and ratified it a year later (UNEP/UNDP, 2009; MWLE, 2002), whereas it acceded to the Kyoto Protocol (1998) in 2002 (UNFCCC, 2012). In line with the reporting requirements of UNFCCC (1992), Uganda's first national communication to the UNFCCC was made in 2002, followed by the second in 2014, detailing several aspects about commitments to addressing climate change (MWLE, 2014; MWLE, 2002). It is clear that in Uganda, response to addressing climate change abounds.

Several institutional and policy initiatives have been undertaken in Uganda to address climate change and carbon emissions. Through the Department of

Meteorology, which is under the auspices of Ministry of Water and Environment (MWE), a Climate Change Unit (CCU) was set up in 2008, with a main purpose of reinforcing the country's implementation of the UNFCCC and the Kyoto Protocol (CCU, 2012). Meanwhile, a parliamentary forum on climate change (PFCC) was also set up with a major aim of addressing stresses resulting from climate change (The Parliament of Uganda, 2012). Regulatory instruments, such as the climate change policy, are also underway to "…ensure a harmonised and coordinated approach towards a climate resilient and low-carbon development path for sustainable development in Uganda" (World Bank, 2012).

3.1.4 Initiatives to limit carbon emissions

It is currently estimated that the transport sector contributes the most (72%) carbon emissions in Uganda (MWLE, 2014), and as such, considerable efforts have been registered to curb emissions associated with transport. Magezi explored options of curbing GHG emissions in the transport sector through reducing traffic congestion and fuel consumption (Magezi, 1998). That study recommended replacement of smaller passenger vehicles with bigger ones, introduction of non-motorised lanes, and traffic decongestion. Another study by Mukwaya explored regulatory planning approaches for reducing carbon emissions in the transport sector within Kampala (Mukwaya, 2007). It was noted that traffic congestion, increased importation of used (i.e. second hand) vehicles, and inadequate settlement planning are among the factors that exacerbate carbon emissions from the transport sector (ibid). In November 2011, under a project of Vehicle Design, an electric car (the KIIRA Electric Vehicle) was road-tested (Makerere University, 2012). The concept behind the invention was enshrined in sustainable transportation systems that are free from carbon emissions (Matovu et al., 2012). Future plans of the project involved producing bigger capacity electric passenger service vehicles in order to reduce emissions from public transportation. Meanwhile, a renewable energy policy which was passed in 2007 prescribes a target of biofuel blend of up to 20% in the transport sector by 2017, in order to reduce carbon emissions from transportation (The Republic of Uganda, 2007). All these initiatives affirm that there is a drive to limit carbon emissions in Uganda's transport sector.

Considerable efforts have also been directed to addressing emissions from the energy sector, since it is also a major source of emissions. In Twaha et al. (2012), an investigation was carried out to explore an alternative source of electricity based on solar photovoltaics (PV). It was argued that solar energy could be an emission-free supplement to the country's electricity in lieu of diesel-based energy sources. Another study analysed the GHG mitigation potential in using biomass energy, in lieu of diesel-powered generators in a certain village consisting of 22,000 people (Zanchi et al., 2013). It was revealed that in the village, a wood gasification plant could save an average of 21.3 tonnes of CO_2eq emissions per year, translating into over 50% of emissions avoided. Other researchers analysed the feasibility of two wood-fired electricity production plants which were installed in two separate districts in Uganda (Buchholz et al., 2012). Analyses revealed that in one of the districts, wood gasification could lead to annual CO_2 emissions savings of up to 771 tonnes. These initiatives suggest that there is potential in using renewable energy to address emissions. Indeed, this is further supported by the country's renewable energy policy which set a target of 61% reliance on renewable energy by 2017 in order to promote sustainable utilisation of energy sources in Uganda (The Republic of Uganda, 2007). Therefore, the agenda on promoting sustainability in terms of limiting carbon emissions from the energy sector of Uganda, is alive.

3.2 Sustainability in the building sector

This section contains the following discussions: general issues related to construction in Uganda, challenges and opportunities in promoting sustainable construction, enhancing sustainable construction in Uganda, and the proposed way forward.

3.2.1 Construction in Uganda

The construction industry is of significant importance to Uganda's economic development. Construction activities contribute 14% to the total gross domestic product (GDP) (UBOS, 2013), while construction-related businesses employ the largest number of people per business (UBOS, 2012). Construction activities, which cover public and private sectors, predominantly involve construction of roads, bridges, and buildings (UBOS, 2013). However, most construction work involves residential, commercial, industrial, and institutional buildings (UBOS, 2014; Muhwezi et al., 2012). This suggests that the building sector accounts for a significant proportion of activities in the construction industry. Within the building sector, there is persistent increase in residential and commercial construction activities. As shown in Figure 3.2, data on building plans approved in various local authorities suggests that residential buildings account for the largest share of building construction activities, followed by commercial buildings. Increase in building construction activities is envisaged due to the need for curbing the housing shortage and provision of necessary infrastructure such as schools and hospitals requisite for meeting the demands of the ever increasing population (UN-Habitat, 2010; Kalema and Kayiira, 2008; The New Vision, 2008). However, the increase in building construction presents several challenges.

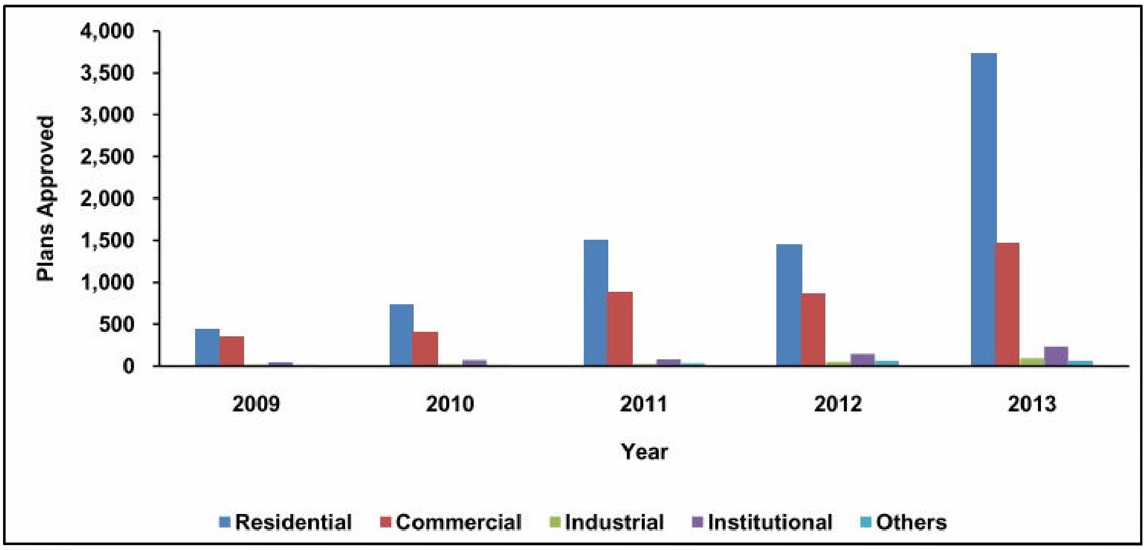


Figure 3.2 Building plans in Uganda approved from 2009 to 2013

Source: UBOS (2014, p.52) which was based on a sample of 25 municipalities and 60 town councils across Uganda.

Building construction in Uganda faces many challenges that are not unique to a developing country. The prevalent low level of industrialisation means that there is low productivity, since construction activities are highly labour intensive, largely involve unskilled labour, and use primitive construction methods (Alinaitwe et al., 2007; Alinaitwe et al., 2006). The impacts of construction activities on the environment are severe, especially due to unsustainable material production processes (Muhwezi et al., 2012). A recent study by

Hashemi and colleagues found that the average energy consumed in small-scale brick manufacturing in Uganda is up to 5 times higher than that in developed countries (Hashemi et al., 2015). This supports claims presented in the IPCC report, that embodied energy of buildings in developing countries can be large (Levine et al., 2007). Therefore, there is a need to develop strategies that can enhance sustainable construction practices in Uganda, in terms of optimising energy efficiency in the construction process of buildings.

3.2.2 Challenges and opportunities

Embracing sustainable construction in developing countries like Uganda is by no means an easy call, not to mention that the concept of 'sustainability' is relatively new in such countries (CIB and UNEP-IETC, 2002). Developing countries face multiple stresses emanating from a number of factors such as extreme poverty, housing shortages, and poor governance, all which often lead to conflicting interests when deciding what needs to be done to address such stresses without undermining sustainable development (Du Plessis, 2007). According to 'Agenda 21 for sustainable construction in developing countries', the major barriers to implementing sustainable construction in developing countries include: lack of capacity of the construction sector; uncertain economic environment; lack of accurate data; minimal interest in issues of sustainability, and paucity of research into sustainability (CIB and UNEP-IETC, 2002).

Despite the challenges, there is growing advocacy for the need to promote sustainable construction practices in developing countries. The state of underdevelopment in these countries avails them an opportunity to avoid some of the mistakes the developed countries made, and therefore, tread a more sustainable path to development (CIB and UNEP-IETC, 2002). Unlike in the developed world where maximisation of sustainable construction opportunities is limited by the fact that most buildings that will be operating in decades to come are already built, in the developing world, such buildings are either being built or yet to be built (UNEP, 2009). Therefore, in developing countries like Uganda, what is being constructed now should be "sustainable in every sense of the word" (Du Plessis, 2007).

In most developing countries especially in Africa, EC assumes a greater importance, since carbon emissions in the operation phase (i.e. OC) of buildings are negligible. For instance, only 5% of Ugandans have access to electricity, which is moreover largely sourced from hydropower, a less carbon-intensive energy source (The Republic of Uganda, 2002). Cooking, which usually consumes a significant amount of operation energy, is mostly based on biomass (e.g. charcoal and fuel wood) (Kees and Feldmann, 2011), which is also a renewable energy source. Indeed, biomass accounts for 90% of the energy needs in Uganda (Buchholz and Da Silva, 2010). Space heating, which typically accounts for most carbon emissions from buildings globally, especially in cold countries (Ramesh et al., 2010), is not necessary in a tropical country like Uganda. Although cooling (i.e. air conditioning) might be necessary, it is largely unaffordable in tropical developing countries (Emmanuel, 2004). On the whole, these arguments suggest that EC accounting is relevant to developing countries, and should be the focus in the strategies for enhancing sustainable construction. Unfortunately, there is a paucity of studies on EC in developing countries, especially in Africa (Cabeza et al., 2014; Ramesh et al., 2010). Therefore, presently, the potential of using EC to enhance sustainable construction in developing countries like Uganda is unexplored.

Due to the paucity of initiatives to address carbon emissions in buildings in developing countries, the United Nations resolved "to assist national and local governments in reviewing and updating building laws and regulations, with view of promoting low carbon practices" (UN-HABITAT, 2013, p.6). Consequently, an East African initiative, to which Uganda is party, was started to promote energy efficiency in buildings with a hope that the prospective review of regulations in the region should take into account matters of energy efficiency. A resources efficiency and conservation measures (RECM) standard was drafted (UN-HABITAT, 2013). The RECM standard, which is to be mandatory for commercial buildings, is anticipated to promote energy efficiency and reduction of emissions. However, this standard has several challenges. Firstly, there are unclear circumstances surrounding its adaptation to building regulations. Secondly, the standard focuses on the operation phase of buildings, disregarding the importance of considering EC. Thirdly, there is limited knowledge on how such a standard will enhance sustainable construction. This limited knowledge, coupled with the lack of studies on the extent of awareness and interpretation of sustainable construction amongst various stakeholders in the building sector in Uganda, makes it difficult to understand whether the assessment of EC is appreciated as a potential enhancer for sustainable construction in Uganda.

3.2.3 Implementing EC accounting in Uganda

Hill and Bowen asserted that attainment of sustainable construction in developing countries largely depends on the mechanisms in place for environmental assessment (Hill and Bowen, 1997). Based on this assertion, it can be reasoned that in order to implement EC accounting, so as to enhance sustainable construction in Uganda, the environmental management framework has to be invoked. This is underscored by extant studies demonstrating that sustainable construction is mostly interpreted in the dimension of environmental sustainability (Zainul Abidin, 2010; Majdalani et al., 2006; Bourdeau, 1999) (see also discussions in Chapter 2 section 2.1.2). As such, the operationalisation and criteria for selecting environmental policy have to be considered.

3.2.3.1 Operationalising environmental policy

Literature suggests that environmental policy can be defined in various ways: based on function (all policies related to the environment are environmental policy), based on institutions concerned (all policies undertaken by an environmental institutions are environmental policy), and based on purpose (policies intended to improve or prevent deterioration of the environment are environmental policy) (Mickwitz, 2003; Lundqvist, 1996 p.16). In Roberts (2011 p.40), environmental policy is defined as “a set of principles and intentions used to guide decision making about human management of environmental capital and environmental services”.

Environmental policy is operationalised by environmental policy instruments which are categorised into regulation instruments (the ‘carrot’), economic instruments (the ‘stick’) and information instruments (the ‘sermon’) (Weber et al., 2013; Mickwitz, 2003; Vedun and van-der-Doelen, 1998). Therefore, a proposed strategy of promoting sustainable construction should be assessed in terms of its suitability as a regulatory instrument, economic instrument, or information instrument. Regulation instruments (e.g. permits, standards, bans etc.), which are the most widely used, aim at modifying the options available to the public through a 'command and control approach' (Mickwitz, 2003; OECD, 1994); the UK Climate Change Act (2008) is a vivid example. Economic instruments (e.g. emission taxes, subsidies, garbage collection charges etc.) aim at altering and influencing the benefits or costs associated with the targeted action (Weber et al., 2013; Mickwitz, 2003). Economic instruments provide a market mechanism and leave the decision to the potential 'offender' to select the most viable option (Gupta et al., 2007; OECD, 1994). The information instrument (e.g. eco labelling, 'green' campaigns, rating systems etc.), which is "the softest and most lenient tool", aims at altering the priorities related to the targeted measure through disclosing environmentally related information (Gupta et al., 2007; Mickwitz, 2003; Vedun and van-der-Doelen, 1998 p.104). Therefore, it is necessary to understand whether assessment of EC, as a policy, should be introduced in Uganda through regulatory, economic, or information instruments.

3.2.3.2 Criteria of selecting environmental policy

The IPCC specified four principle criteria of considering environmental policies (Gupta et al., 2007). It is therefore plausible to hypothesise that a policy on introducing the assessment of EC in Uganda should fulfil such criteria, as explained below.

3.2.3.2.1 Effectiveness

Effectiveness of a policy is judged on the extent to which its outcomes correspond to the intended goals (Mickwitz, 2003). It is "a judgment about whether or not the expected objectives and targets have been achieved" (European Environment Agency, 2001 p.9), and also, the extent to which the effects can be claimed to be resultant of the measure (Huitema et al., 2011; Gysen, 2006). Effectiveness of a measure is assessed by comparing its effects with the intended objectives (Gysen, 2006; European Environment Agency, 2001). Gysen suggests that outcomes of an environmental policy, which usually occur in the mid to long term, may include reduction of emissions, use of recycling, change of transport modes and so forth (Gysen, 2006). Therefore, effectiveness of introducing EC accounting in Uganda can be judged on whether it could promote sustainable construction.

3.2.3.2.2 Cost implications

In Mickwitz (2003), cost-effectiveness and cost-benefit analysis are presented as criteria for considering an environmental policy, based on its cost implications. Cost-effectiveness analysis involves asking whether the results of a policy justify the resources used or needed (Mickwitz, 2003). Attaining a policy's objectives at minimum cost to the society implies that the policy is cost-effective (Gupta et al., 2007; European Environment Agency, 2001). Meanwhile, cost-benefit analysis involves asking whether the benefits are worth the costs (Mickwitz, 2003). The major difference between cost effectiveness analysis and cost benefit analysis is that for the latter, all the consequences (costs and benefits) of a policy have to be quantified in monetary terms (Boardman et al., 2013; Mickwitz, 2003). This usually makes cost benefit analysis difficult due to problems of data unavailability and several complications associated with measuring indirect costs or benefits (Boardman et al., 2013; Gupta et al., 2007; Mickwitz, 2003). In practice, cost effectiveness is often the easier and widely used criterion since it can accommodate 'qualitative' (i.e. non-numeric) assessments (Mickwitz, 2003). In the case of Uganda, this can involve assessing whether new institutions are required, whether the procedures are easy to understand, and whether EC accounting can contribute to other benefits (Gupta et al., 2007).

3.2.3.2.3 Distributional considerations

Consequences of an environmental policy can be unequally distributed, which justifies the need to assess distributional considerations of EC accounting in Uganda. Distributional considerations include fairness, transparency and legitimacy (Gupta et al., 2007). Regarding fairness, a measure, whether considered economically viable or effective, can face strong opposition if the society perceives it as 'unfair' (IPCC, 2007a). In Mickwitz (2003) fairness is discussed in relation to whether participants have equal opportunities for participating and accessing relevant information. Meanwhile, transparency and legitimacy, which relate to democratic accountability, should also be considered. (Huitema et al., 2011; Mickwitz, 2003). In transparency, the intentions of a policy are assessed to check their clarity, whereas for legitimacy, the policy is assessed to check whether it is acceptable (Huitema et al., 2011; Mickwitz, 2003).

3.2.3.2.4 Institutional feasibility

Institutional familiarity can make a policy popular and conversely, where the policy contravenes the norms of the society, it can be vehemently opposed (IPCC, 2007a). Perceptions on institutional feasibility are assessed based on several considerations. Firstly, the policy has to be compatible to the existing legal system (IPCC, 2007a). In other words, it has to be legally acceptable (Huitema et al., 2011; Newcomer et al., 2010). Secondly, it is crucial to assess compatibility of the policy with national priorities (Huitema et al., 2011). The need to reconcile environmental policy with national priorities, especially for developing countries, cannot be over emphasized (Bwango et al., 2000). Thirdly, relevance of the policy is important; its goals should be able to address the needs of the context (Mickwitz, 2003). Interrogatively, "are the objectives [such as improving sustainable construction] justified in relation to needs?" (European Environment Agency, 2001 p.20). Fourthly, persistence of the policy is equally important. Persistence is discussed in Mickwitz (2003) as related to assessing whether effects of a measure have a lasting bearing. Lastly, the policy should be assessed to check whether its effects are predictable such that those affected could prepare in advance of its implementation (Mickwitz, 2003).

3.2.4 Way forward on enhancing sustainable construction

Based on the foregoing discussions, the author suggests that addressing EC and sustainable construction in the building sector of Uganda requires integrating EC accounting into the prevailing practices of constructing buildings, similar to budding initiatives that have been identified elsewhere like in UK, Hong Kong, and Australia (see Chapter 2 section 2.2.3). However, before such suggestions can be implemented in Uganda, thorough research, in which four objectives should be fulfilled, is necessary. Firstly, there is need to describe the current development approval process of building projects in Uganda. Secondly, based on such description, the possibility of integrating EC accounting in the development approval process can be explored. This necessitates scrutinising the current practices related to the development approval process of building projects in order to identify gaps and opportunities of addressing EC during the construction of buildings. Thirdly, there is need to develop a better approach that can facilitate integrating EC accounting in the development approval process of buildings, since it was observed that the prevailing approaches of accounting for EC are limited in scope and are usually aggregated (Chapter 2, section 2.3). The approach developed should therefore surpass the prevailing approaches so as to alleviate constraints on enhancing sustainable construction. Fourthly, based on the approach developed and findings from exploring the possibility of integrating EC accounting in the development approval process, a new system should be developed. However, the system should be evaluated in order to, among other things, ascertain whether it addresses the criteria of selecting environmental policy.

3.3 Chapter summary

Literature reviewed in this chapter has suggested that developing countries like Uganda have not yet heeded the call for addressing EC emissions, yet embodied impacts from buildings in such countries can be large. Although initiatives of addressing carbon emissions have been registered in Uganda, there is limited knowledge on how accounting for EC could enhance sustainable construction. This is compounded by a general the lack of studies on the extent of awareness and interpretation of sustainable construction in the building sector in Uganda. Therefore, it is difficult to understand whether the assessment of EC is appreciated. Although a way forward has been suggested, it necessitates thorough research to address the following objectives: describing the current development approval process of building projects in Uganda, exploring the possibility of integrating EC accounting in the development approval process; developing an approach to facilitate the integration of EC accounting in the development approval process of building projects; and proposing a system of enhancing sustainable construction. The system developed, it has been argued, should be evaluated so as to ascertain whether it, among other things, fulfils the criteria of selecting environmental policy. The next chapter discusses the appropriate research methodology to address these four objectives.

Chapter 4
Research methodology

This chapter begins with discussing the theoretical perspectives of the research. The epistemological and ontological issues, together with their corresponding implications, are discussed. The theoretical perspective adopted in this research is presented followed by a discussion of various concepts including the scientific method, triangulation, research approach, research validity, verification and validation, and research style. Consistent with the theoretical perspective taken, the relevant methods to address objective one, objective two, objective three, and objective four, are discussed. The chapter ends with a summary.

4.1 Theoretical perspectives

This section discusses the concept of research, theoretical perspectives in general, epistemological issues, ontological issues, and the specific theoretical perspective of this research.

4.1.1 The concept of research

Research can be defined as "…the process of systematically gathering and analysing information in order to gain knowledge and understanding" (Kervin, 1992 p.9). Fellows and Liu further suggest that a research activity is associated with "a careful search", "investigation", and "contribution to knowledge" (Fellows and Liu, 2003 p.3). These definitions allude to the idea that the activity of researching is largely associated with contributing to and/or generating knowledge. Therefore, it can be inferred that doing a research is tantamount to making a knowledge claim. However, making a knowledge claim raises a question of what can be regarded as acceptable knowledge. Bryman suggested that answering such a question requires philosophical assumptions (Bryman, 2001), which according to Crotty (1998), are contained in the theoretical perspective that a researcher brings to a study.

4.1.2 Theoretical perspectives generally

Theoretical perspectives, which are alternatively referred to as world views (Creswell, 2014), or paradigms (Guba and Lincoln, 2005), delineate the methodology, analysis, and reporting of findings in a research (Creswell, 2014; Crotty, 1998). Therefore, a researcher ought to demonstrate awareness of the origins and implications of theoretical perspectives which are associated with epistemological and ontological issues (Fellows and Liu, 2009; Hart, 1998 p.50).

4.1.2.1 Epistemological issues

Epistemological issues deal with investigation of ‘knowledge’, such as tracing its origins, describing its nature, and defining what it is (Fellows and Liu, 2009). According to Crotty (1998), epistemological assumptions provide a philosophical base upon which the knowledge generated in a research can be legitimised. The predominant epistemologies are positivism and interpretivism (Creswell, 2014; Bryman, 2001). Positivism, which is dominant in natural sciences, holds that there is a world free of values, beliefs, perceptions, and cultural contexts from which facts and reality can be objectively investigated (Denscombe, 2010; Fellows and Liu, 2003; Hart, 1998). Generating knowledge from a positivist ‘lens’ starts with theory and is based on carefully crafted methods to uncover reality that is believed to exist out there, independent of the investigator’s cognition (Creswell, 2014; Guba and Lincoln, 2005). Post positivism, a variant of positivism, shares similar perceptions though asserts critical realism – reality can only be imperfect and probabilistically true (Guba and Lincoln, 2005; Crotty, 1998). Interpretivism, an alternative to the positivism orthodoxy, is a domain of social and human sciences. Interpretivists contend that reality is only constructed and therefore varies since people’s backgrounds, beliefs and contexts do vary (Fellows and Liu, 2003; Bryman, 2001; Hart, 1998). Therefore, an interpretivist ‘lens’ relies on the various individuals’ subjective meanings of reality from which interpretations are made to develop theory (Creswell, 2014). In interpretivism, the investigator is not disassociated from the study-objects; what is described as reality, is dependent of the investigator’s cognition resulting from interacting with the study objects (Guba and Lincoln, 2005; Fellows and Liu, 2003). From these interpretations of positivism and interpretivism, it is clear that knowledge is based on ontological considerations which involve questioning the meaning of ‘reality’.

4.1.2.2 Ontological considerations

Ontological considerations are concerned with reality or existence of the entity investigated whether it is external to the actors (i.e. objectivism), or instead constructed by the actors’ perceptions (i.e. constructionism) (Fellows and Liu, 2009; Bryman, 2001). Whereas objectivism ontology holds that reality, meaning, and objective truth exist out there in the world waiting to be discovered, according to the constructionism ontology, no objective truth exists out there waiting to be discovered but can only be constructed (Bryman, 2001; Crotty, 1998). Constructionism ontology therefore presupposes the existence of multiple realities since it acknowledges that different people can construct meaning in different ways, even regarding the same aspect (Hart, 1998).

4.1.3 Theoretical perspective of the research

The epistemological and ontological position taken is revealed in this section. The nature of this research in relation to the scientific method is also discussed. The concept of triangulation, as used in this research, is presented. The research approach taken and the issues of research validity, verification and validation, and research style are discussed.

4.1.3.1 Epistemological and ontological position taken

This research was skewed to positivism epistemology and objectivism ontology. Knowledge was generated based on objective measures whereby existing theory and carefully crafted methods guided the investigations in order to isolate the influence of the researcher from the objects of study. The ontological assumptions were extended to critical realism which implied that the generated knowledge could be described as tentative. The objectivism ontological position that was taken presupposed existence of objective reality because investigating a topic on carbon emissions in a constructivist epistemological stance would be counterproductive to the available objective scientific evidence about climate change and the need to reduce carbon emissions (see Hegerl et al., 2007). Carbon emissions are a reality and result from widely known causes such as burning fossil fuels and deforestation. Similarly, the effects (e.g. global warming) and mitigation measures (e.g. use of renewable energy) are widely acknowledged. This inferred that reality, truth, and meaning about the investigation were objective hence justifying positivism and objectivism positions as the boundaries of conceptualising the knowledge that was generated.

4.1.3.2 Scientific method

Since positivism and objectivism allure to principles of the scientific method (Festinger et al., 2005; McNeill and Chapman, 2005), knowledge that was generated in this research was based on the scientific method. Adherence to the scientific method followed deductive reasoning whereby literature was reviewed to identify relationships between variables, based on which hypotheses were formulated. Hypotheses were interpreted as "educated guess[es]" derived from "what the researcher thinks may be happening based on previous reading, research and observation" (Fellows and Liu, 2009 p.127; Festinger et al., 2005 p.8; McNeill and Chapman, 2005 p.32; Fellows and Liu, 2003 p.119). Generally, the procedures of the scientific method, which are widely documented in several works (Festinger et al., 2005; Guba and Lincoln, 2005; Hart, 1998), were implemented by the researcher in a way of having to come up with a research idea, translate it into an answerable question, propose hypotheses, collect data, analyse data to test hypotheses, and make conclusions in order to build-on, test, and extend existing theory.

4.1.3.3 Triangulation

Having used more than one research method in this study, in which case each generated different types of data, it became necessary to discuss how the concept of triangulation manifested in this work. Triangulation is the use of two or more research methods, data sources, investigators, or theoretical positions, within the same study (Denscombe, 2010; Bryman, 2001; Duffy, 1987). Accordingly, four types of triangulation are discussed in literature (Creswell, 2014; Denscombe, 2010; Bryman, 2001; Thurmond, 2001; Duffy, 1987). As can be seen from Table 4.1, methodological and data triangulation were the most appropriate in this work. The overarching benefit of triangulation, irrespective of any type, is that it provides greater confidence in the data and/or findings of the study (Denscombe, 2010; Bryman, 2001). Perhaps more importantly, triangulation minimises the risks of relying on a single research method that may not be a panacea to effectively addressing all the research objectives (Hammersley, 2008). Duffy asserts that triangulation should be construed as a 'vehicle', which when used appropriately, combines different research methods, data sources, and so forth, in a manner that produces richer insights into complex phenomena (Duffy, 1987). However, some commentators criticise the use of triangulation (e.g. data triangulation) for it assumes a 'single reality' since it is ultimately focussed on finding areas of convergence in the data, yet study subjects may perceive things in a different way (Hammersley, 2008). However, such criticisms are dismissible, especially in studies like this one, where the philosophical perspective adopted assumed 'single' but not 'multiple' realities.

Table 4.1 Types of triangulation

Type of triangulation	**Definition (s) and relevance (i.e. Yes √ or No ×) to this study**
Methodological triangulation	Using more than one research method in the same study (√) Using both quantitative and qualitative data in the same study (√)
Data triangulation	Using data from different sources or informants (√) Using data collected at different times in the same study (×) Using data from more than one geographical, cultural, or social context (×)
Investigator triangulation	Using more than one investigator/researcher in the same study (×)
Theory triangulation	Using more than one theoretical position in the same study (×)

Source: Creswell (2014); Denscombe (2010); Bryman (2001); Thurmond (2001); Duffy (1987).

Triangulation should be used consistently with the theoretical perspectives adopted in a study (Hammersley, 2008). Depending on the type used, triangulation can be applied in a study that has adopted a quantitative, qualitative, or a combination of both research approaches (Thurmond, 2001). Hammersley noted that a common misconception about triangulation is limiting this term to combining of qualitative and quantitative research approaches (i.e. mixed-methods research) (Hammersley, 2008). Yet triangulation that involves using more than one research method in a single study does not imply using mixed-methods research but rather, it is the theoretical perspectives, nature of the research objectives, data, and analytic techniques adopted that determine whether the study can be classified as quantitative, qualitative, or mixed (Fellows and Liu, 2009). In this work, which adopted a quantitative research approach as discussed in the next section, methodological and data triangulation were used as appropriate, in addressing the various research objectives.

4.1.3.4 Research approach taken

There was need to delineate a research approach since a given epistemological or ontological position is usually associated with either quantitative (QUAN) or qualitative (QUAL) research approaches (Creswell, 2014; Fellows and Liu, 2009). These two research approaches are often referred to as the “primary classification” of research (Fellows and Liu, 2003 p.9). Quantitative research builds on (or tests) existing theory following deductive reasoning which involves scrutinising existing theories, examining relationships among variables, and suggesting propositions for which if corroborated, theory can be enriched (Bryman, 2001). In quantitative research, the intention is to produce generalizable and replicable findings, following a standard reproducible research procedure (Creswell, 2014). Meanwhile, qualitative research focuses on building theory whereby, exploration of an aspect is undertaken without any preconceptions and theories emerge at the end of investigation (Fellows and Liu, 2009). Qualitative research involves addressing emerging questions and analysis of data in an inductive reasoning in order to come up with general themes, following a flexible research procedure (Creswell, 2014). According to Creswell, a mixture of qualitative and quantitative research approaches is possible, especially upon adopting pragmatic epistemologies (Creswell, 2014). However, mixing of research approaches demands cautious interpretation. Crotty opined that combining a positivism epistemology with a constructionism ontology in a single study is “problematic” and ”certainly does appear contradictory” (Crotty, 1998, p.15). Indeed, this has hitherto been a subject of several debates.

In the mid 1990s, a debate which emanated from the “culture of the industry and the culture of research” and “the role of theory in construction management” generated intriguing discussions regarding the efficacy of positivist and/or non-positivist research methods in construction management research (see Runeson, 1997; Seymour et al., 1997; Seymour and Rooke, 1995). Seeking to address unresolved issues arising from that debate, Rooke and Kagioglou suggested that there should be rules for evaluating and improving non-positivist research in construction management research (Rooke and Kagioglou, 2007, p.979). While the legacy of the debate was still questionable even after a decade from when the debate started (Dainty, 2008), its effects linger on. Recently, Holt and Goulding coined a research approach which they claimed to be applicable in building and construction research – the ambiguous mixed-method research (AMMR) (Holt and Goulding, 2014). Those authors argue that whereas explicit mixed-methods research (EMMR) "makes explicit the intention to achieve a QUAN/QUAL paradigmatic mix, […], AMMR […] does not make such explicit, but which does so in its application" (Ibid, p.249). However, this research differs from such opinions by way of choosing to be "consistently objectivist" (Crotty, 1998, p.15). As such, a firm position on the quantitative research approach is taken, which, as has been elaborated in the foregoing discussions, is characterised by scientific deductive reasoning, positivism, and objectivism.

4.1.3.5 Research validity

Research validity is the degree to which the research's findings and conclusions correctly reflect the reality of the situation (Kervin, 1992). The epistemological, ontological, and research approach that was undertaken influenced how the validity of this research was assessed. Given the theoretical considerations in this research (i.e. positivism and quantitative research approach), validity was assessed by ensuring internal validity, external validity, reliability, and rigour (Guba and Lincoln, 2005). Internal validity concerned whether the variables accurately represent the effect, whereas external validity ensured the possibility of generalising from the sample to the population (Fellows and Liu, 2009; Kervin, 1992). Meanwhile, reliability concerns whether a measure produces consistent results (Fellows and Liu, 2009). All these aspects of research validity (i.e. internal validity, external validity, reliability, and rigour) were considered as appropriate within the methods adopted in addressing each of the four research objectives.

4.1.3.6 Verification and Validation

Research, such as this one, that involves modelling (e.g. mathematical, process, software, and so forth) ought to address issues of verification and validation (Editor, 2014). The terms verification and validation are sometimes used interchangeably, or referred to as if they are a single term – 'verification and validation (VV)' – with no distinction between the two (Maropoulos and Ceglarek, 2010). However, in this work, it was useful to distinguish between the two terms. Boehm interrogatively defined verification as "Am I building the product right?" and validation as "Am I building the right product?" (Boehm, 1984, p.75). Boehm's interpretation of verification and validation widely influenced several subsequent works (Maropoulos and Ceglarek, 2010; Terry Bahill and Henderson, 2005; Ng and Smith, 1998). However, the type of product developed (e.g. mathematical model, process model, software, etc.) shapes the way in which verification and validation is done (O'Keefe and O'Leary, 1993).

Regardless of the type of product and the way in which verification and validation is done, the purpose of verification and validation largely remains the same. Verification is carried out to ensure completeness and consistency of the product, whereas validation is conducted to ensure that the product satisfies the need for which it was developed (Botten et al., 1989; Boehm, 1984; Adrion et al., 1982). A product is complete "to the extent that all of its parts are present", and consistent "to the extent that its provisions do not conflict with each other or with governing specifications" (Boehm, 1984, pp.76-77). Meanwhile, extant literature suggests that validation is essential for a new product or where modifications to an existing product have been made (Maropoulos and Ceglarek, 2010; Aguilar et al., 2008; East et al., 2008).

Based on the foregoing interpretations, in this research, verification and validation were approached in the following way:

- verification was conducted to ensure that a product had been developed correctly and this involved assessing completeness and consistency, and
- validation was considered where a new (or improved) product had been suggested and this involved assessing the worth of the product.

4.1.3.7 Research style

Research strategy, strategies of inquiry, research styles, and so forth, are various terms used to describe ways in which a research can be designed (Creswell, 2014; Yin, 2014; Denscombe, 2010; Fellows and Liu, 2009). The term research style, as proposed by Fellows and Liu, has been adopted in this work (Fellows and Liu, 2009). Literature suggests several research styles but the most prominent include: action research, ethnographic research, experimental research, survey research, grounded theory, and case studies (Creswell, 2014; Yin, 2014; Babbie, 2013; Fellows and Liu, 2009). In choosing a particular research style, priority should be given to a style that ensures research maximises the opportunity to realise the objectives, in a way that is consistent with the epistemological, ontological, and research approach adopted (Fellows and Liu, 2009). Upon considering various features of these research styles, the survey research style was found most suitable (see Table 4.2).

Table 4.2 Comparison of research styles

Research style	Key features compatible (√) and incompatible (×) to this work
Experiment	Requires control of behaviour events/variables (×) Usually carried out in laboratories (except in social sciences) (×) Compatible with the quantitative approach (√) Accommodate statistical generalizability (√)
Survey	Aims for wide and inclusive coverage (√) Can provide snapshot of things at specific point in time (√) Based on empirical enquiry (√) Employs the principle of statistical sampling (√) Aims for generalizability (√) Largely aligned to quantitative data/approach (√) Focuses on contemporary events (√)
Case study	Does not accommodate (statistical) generalizability (×) Focuses on in-depth investigation of a particular phenomenon (×) Largely aligned to qualitative data/approach (×) Focuses on the particular than general (×) Usually based on a naturally occurring phenomenon (×) Focuses on contemporary events (√)
Grounded theory	Dedicated to generating theories (×) Largely aligned to qualitative approaches (×) Propagates an open mind approach to data analysis (×) Based on inductive logic (×)
Action research	Involves both practitioners and the researcher (×) Involves researcher's participation in the process under study (×) Conducted in practical settings (e.g. at work or organisation) (×)
Ethnography	Researcher spends time in field with subjects studied (×) Findings are largely based on the researcher's constructs (×)

Source: Creswell (2014); Yin (2014); Denscombe (2010); Fellows and Liu (2009)

A survey research style is useful in studies, such as this study, that involve description of a certain phenomenon and/or gathering data to ascertain effects of a planned change (Kelley et al., 2003). However, within a particular research style, various methods (and/or research methods) can be employed to accomplish the objectives of a research (Denscombe, 2010). This research adopted a similar approach whereby various methods and/or research methods were used to accomplish the research objectives.

4.2 Methods to describe the current development approval process

Describing the current development approval process in Uganda required adequate knowledge about the development approval practices. Although the author had considerable knowledge about the Ugandan construction practice, basing on such knowledge alone was construed as subjective, and inconsistent with the philosophical assumptions of this work. A viable option was to conduct an empirical enquiry to capture and objectively present the reality of the existing development approval process. Since literature suggested that existing formal practices in Uganda are guided by documentation, such as legislations (Building Control Act, 2013; Physical Planning Act, 2010; National Environmental Act, 1995), a method that could also allow for capture, representation, and verification of such existing practices was deemed appropriate. Broadly, modelling was identified as a suitable option.

In Fellows and Liu (2009 p.73), a model is defined as a simplified, realistic construct to represent a reality. Put another way, a model is “an imitation of reality” (Hangos and Cameron, 2001 p.4). Models are broadly classified into physical (i.e. hardware models) and theoretical models (Mulligan and Wainwright, 2005). Besides being expensive, physical models are downsized versions of real-life phenomena and entail setting up a prototype version of the investigation (Mulligan and Wainwright, 2005). A physical model was not considered since it was impractical to set up a physical downsized version or prototype of the development approval process. The alternative theoretical model was preferred since it offered more flexible and inexpensive ways of describing the existing development approval process. In construction research, the commonest forms of theoretical models are process models and mathematical models (Fellows and Liu, 2009). Since there was no need for quantification, mathematical models were discarded in preference for process models.

A process model can be defined as a “diagram or chart outlining the various steps involved in a particular process or set of processes” (Oxford, 2014b). Process models can be used to describe an existing system for carrying out a process and through analysis, potential areas for improvement can be prescribed (Silver, 2011). In systems engineering, where process modelling is ubiquitously used to represent systems, a system is defined as an “integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective” (Sage and Rouse, 2009, p.1363). As such, process modelling of the existing system for the development approval process of building projects in Uganda, herein referred to as the as-is system, was conducted.

A review of literature on process modelling suggested that a standard process modelling method consists of four stages: process discovery, process mapping, verification, and analysis (Chinosi and Trombetta, 2012; Debevoise and Geneva, 2011; Silver, 2011; Verner, 2004). However, only the first three stages – process discovery, process mapping, and verification – were appropriate in this case. The analysis stage was used to deliver the second research objective (see later section 4.3) that sought to identify areas of improvement in the current practice. The adopted process modelling method was unique in its implementation. The uniqueness was in the timing and purpose of the embedded research method – the subject matter expert (SME) interviews. SME interviews were conducted towards the end (i.e. during verification) in form of data triangulation, but not at the beginning (i.e. during process discovery) as the case is in traditional process modelling methods. Meanwhile, in process modelling, research methods that are used should generate qualitative data, because such data would have richness in process-details narrated by SMEs (Verner, 2004). Generally, interviews can be unstructured, semi-structured, or structured, depending on how a researcher controls the discussion (Creswell, 2014; Denscombe, 2010). In this case, SME interviews were semi-structured because the researcher imposed some limits to the responses by presenting a process model of the as-is system to guide the discussions. Semi-structured interviews offered flexibility to a discussion and availed respondents a chance to expound ideas as well. Chapter 5 section 5.1 provides detailed discussions on how this was implemented.

Research ethics pertaining to the SME interviews were appropriately addressed. It is asserted in the University of Leeds' research ethics policy, and also seconded by various scholars (Denscombe, 2010; Walker, 2010; Fellows and Liu, 2009), that research involving human subjects must be subject to ethics review. Moreover, the University's 'research student handbook' cautions that failure to consider ethical requirements, such as seeking for ethical approval, can have devastating consequences for a research. Therefore ethical requirements which essentially involved seeking for ethical approvals in Uganda and UK had to be fulfilled (see Appendix C). This 'blanket' ethics approval covered the two episodes of data collection in this research, that is, the verification of the as-is system and evaluation of the to-be system explained later in section 4.5.2. Upon obtaining all the necessary ethical approvals, it was not the end of ethical considerations. Potential ethical issues identified were adequately addressed during data collection, data analysis, and reporting of results. For instance: informed consent was obtained from research participants who were recruited without coercion; confidentiality and security of personal data were ensured by adopting anonymisation procedures and secure storage of data (i.e. using the University's encrypted 'M' drive); and in reporting, any direct quotations, where used, do not disclose the identity of the research participants.

4.3 Methods to explore the possibility of EC accounting

To explore the possibility of integrating EC accounting in construction practices in Uganda, the process modelling method described in section 4.2 was used. As earlier discussed, process modelling entails more than just having to come up with a process model of a process since potential areas for improvement can also be identified (Silver, 2011). As such, the fourth stage (i.e. analysis) of the process modelling method described in section 4.2 was applicable in this case to achieve objective number 2. This essentially involved analysing the process model (i.e. as-is system) so as to identify what was required to improve the current development approval process.

4.4 Methods to develop an approach for integrating EC

In this section, methods of developing an approach to facilitate the integration of EC in the development approval process of buildings are discussed. These include methods for developing a model and its implementation into a software tool.

4.4.1 The model

Findings from the second research objective indicated that in order to develop an approach to facilitate the integration of EC accounting in the development approval process, a model for quantifying EC was necessary. In order to develop such a model, a method of modelling was appropriate. In defining what a model is (section 4.2), it was highlighted that models are broadly classified into physical and theoretical models. In this case also, a theoretical model was the best option since it was not realistic to develop a physical model of a building project in order to quantify emissions. Meanwhile, theoretical models can be used for several purposes such as simulation and prediction (Fellows and Liu, 2009; Mulligan and Wainwright, 2005). In this case, the most appropriate model was one that can simulate the reality of the building project and thereby predict the amount of carbon emissions. A theoretical mathematical model, which constitutes "…a set of variables and their interrelationships designed to represent, in whole or in part, some real system or process" (Fellows and Liu, 2009 p.74), was used. Contrasted with other forms of theoretical models, mathematical models represent the real-life situation through mathematical procedures. In building a mathematical model, a real-world problem is translated into a mathematical problem which can be solved and interpreted to address the real-world problem (Hangos and Cameron, 2001).

The method of developing a mathematical model followed standard mathematical modelling principles. Mathematical modelling "…mimic[s] reality by using the language of mathematics" (Bender, 1978, p.1). Literature suggests that mathematical modelling generally involves: formulating the problem, stating assumptions, deriving mathematical formulations, solving the mathematical formulations and interpreting the results, verifying that the mathematical model is correct, and using the mathematical model/solution to address the problem (Meerschaert, 2007; Edwards and Hamson, 2001; Hangos and Cameron, 2001; Murthy et al., 1990; Burghes and Wood, 1980). However, in a single problem, rarely are all these stages executed, and/or executed in a sequence. It is usual for a mathematical modelling procedure to involve rounds of iterations, often excluding some steps that are not of interest or are out of scope (Burghes and Wood, 1980). In this work, the scope of mathematical modelling was limited to problem formulation, assumptions, mathematical formulations, and verification. A detailed account on how these steps were implemented is provided in Chapter 5 section 5.3.1.

4.4.2 Implementing the model into a software

Quantification of carbon emissions is a computationally intense exercise. Recent research suggests that models of quantifying carbon emissions should be implemented with software tools to ease the quantification process (Moncaster and Symons, 2013; Ciroth, 2012). This is important especially for the potential users who might not be interested, if at all knowledgeable, in the complexities of the mathematics behind the model. A tool was therefore developed in order to implement the mathematical model.

The intention was to develop a tool that was in form of software and hence a software development method was necessary. A software development method describes the activities, steps, and procedures performed in a software development process (Stoica et al., 2013). Literature suggests a plethora of software development methods which are broadly classified into two: traditional and agile methods (Fontana et al., 2015; Manimaran et al., 2015; Papadopoulos, 2015; Stoica et al., 2013; Dingsøyr et al., 2012; Misra et al., 2009). A comparison of traditional and agile software development methods is summarised in Table 4.3. In traditional methods, the software development process takes a series of sequential steps which conclude with the developed software tool at the end of the development cycle, whereas agile methods follow an adaptive approach in which several portions of the working software are progressively produced until a final acceptable version (Misra et al., 2009; Gottesdiener, 1995).

Table 4.3 Comparison of traditional and agile software development

	Traditional methods	Agile methods
Examples	Waterfalls model, Spiral model, Unified process, etc.	Rapid application development, Adaptive software development, Extreme programming, etc.
Approach followed	Predictive	Adaptive
Requirements	All requirements have to be specified at onset	Continuous improvement based on emergent requirements and feedback
Flexibility	Follows a formal, rigid bureaucratic structure. Product definitions/technology should be stable	Highly flexible, less formal and interactive. Product definition/technology can vary
Testing of software	Only after coding is done	On every iteration
Scale of projects applicable	Targets large scale organisations, involves large teams	Targets small and medium scale organisations, involves small teams
Costs involved	Relatively high	Relatively low
Timeframe	Usually takes long	Takes a shorter time

Source: Manimaran et al. (2015); Stoica et al. (2013)

The choice between traditional and agile methods can depend on several factors but time, cost, and quality are fundamental (Misra et al., 2009). Two major criticisms of traditional approaches are the long time taken to have the final product and the high costs involved. Due to many activities/processes involved in traditional software development methods, long timeframes and high costs are inevitable (Manimaran et al., 2015; Stoica et al., 2013). Moreover, by the time the software is produced, it may be obsolete and incapable of satisfying the newly emerged user requirements (Beynon-Davies et al., 1999). As such, traditional software development methods are most suitable where time and cost are least important (Manimaran et al., 2015). Meanwhile, whereas traditional software development methods focus on activities, agile methods focus on deliverables, thereby lowering the overall software development costs and timeframe (Beynon-Davies and Holmes, 2002). A PhD scholar ought to be cognizant of the time and financial limitations associated with research and any decision taken, including that of choosing a method, should consider such

(Dunleavy, 2003). To this end, an agile software development method was found to be the most appropriate and thus adopted, following Rapid Application Development (RAD). RAD, which was coined by Martin in the 1990s through several renowned texts (e.g. Martin, 1992), is an agile method that entails successive iteration, improvement and prototyping, all which enhance the software development cycle to be expedited towards the final version (Agarwal et al., 2000). The details of how RAD was implemented are presented in Chapter 5 section 5.3.2.

4.5 Methods to develop and evaluate the to-be system

The methods used to develop and evaluate the to-be system are discussed hereunder.

4.5.1 Development of the to-be system

Like the as-is system, the to-be system was also a process model. As such, the method of process modelling described in section 4.2 which involved process discovery, process mapping, verification, and analysis, was also used to develop the to-be system. However, there were some modifications to that process modelling method. The procedure to achieve the to-be system involved integrating the mathematical model into the process model of the as-is system. Given that these were initially two different types of models (i.e. mathematical model versus process model), the mathematical model was first transformed into a process model. The process model of the mathematical model was then integrated into that of the as-is system, following the process modelling method. Full discussions on how this process modelling method was implemented to achieve the to-be system are presented in Chapter 5 section 5.4.1.

4.5.2 Evaluation of the to-be system

Literature suggests that evaluation consists of verification and validation (Sargent, 2012; Ng and Smith, 1998; Adelman, 1992; Boehm, 1984). Since the to-be system had already been verified during its development (see section 4.5.1), its evaluation focused on validation, that is, ascertaining whether it was the right system built. The overarching aim of this research was to develop a means of integrating EC accounting in the development approval process of buildings in Uganda, so as to enhance sustainable construction. Therefore, the main purpose of validation was to check whether the to-be system would enhance sustainable construction, so as to conclude that it was the right system developed. Since validation involves interaction with potential end-users of the product (Aguilar et al., 2008; East et al., 2008; Oberkampf and Trucano, 2008; Boehm, 1984), evaluation of the to-be system necessitated an empirical enquiry in Uganda.

Environmental policies, to which the to-be system subscribes, are characterised by time-lags that complicate their evaluation. The time-lag presents several complications more so, when studying relationships between cause and effect or action and consequences (Mickwitz, 2003). For instance, it is difficult to assess the extent to which the to-be system can contribute to mitigating global warming, since the impacts of global warming are forecasted to continue for several decades ahead – sea levels will continue rising beyond 2080s (IPCC, 2007b). Besides, this kind of assessment would require to first implement the to-be system, yet implementation was beyond the scope of this research. Therefore, the appropriate kind of evaluation was based on assessing the perceived impacts or changes to the status quo if the to-be system was to be implemented.

Since evaluation involved an empirical enquiry, it became necessary to identify an appropriate research method. Although semi-structured interviews were earlier identified as appropriate in verification of the as-is system (see section 4.2), they were not suitable for validating the to-be system because in this case, quantitative data were also required. Consistent with the principles of methodological triangulation elaborated earlier (see section 4.1.3.3), another research method was considered. The research method that was found most appropriate to validate the to-be system was a structured interview. The structured format of the interview facilitated structured questions and responses that provided quantitative data which was appropriate for conducting various statistical tests used in this work (Kervin, 1992). The structured interview was organised into two parts (see Appendix B, section B.2.3). Each respondent was provided with a visual aid of a show card (see Appendix B section B.2.4) containing the various answering options for each question (Flizik, 2008). This visual aid had several advantages, such as enabling the researcher to control the flow of the interview whilst effortlessly assisting respondents to make a required choice without tasking their memory. A detailed discussion on how the structured interview was implemented, and how the analysis of the resulting data was carried out, is provided in Chapter 5 section 5.4.2.

The ethical considerations discussed earlier (refer to section 4.2) equally applied in this case since validation of the to-be system also involved human participants. As such, necessary ethical approvals (i.e. from UK and Uganda) were obtained (see Appendix C) and all the relevant ethical considerations such as seeking informed consent, ensuring confidentiality and security of personal data were implemented as appropriate. For instance, excerpts from interview transcripts do not reveal the identity of the research participants.

4.6 Chapter summary

This chapter has presented the research methodology used in this research. Theoretical perspectives have been discussed and a theoretical perspective adopted for this research was presented and justified. The adopted theoretical perspective, which was based on positivism epistemology and objectivism ontology, utilises methodological and data triangulation so as to combine more than one research method and data sources or informants within the same study. For each of the four research objectives, the appropriate methods and/or research methods compatible with the selected theoretical perspective have been identified and justified. Process modelling was chosen for addressing objective one and two. Mathematical modelling and RAD were the methods chosen for addressing objective three, whereas process modelling and structured interviews were the methods selected for addressing objective four. The next chapter (Chapter 5) presents a detailed discussion on how the methods presented in this chapter were implemented.

Chapter 5
Application of methods of the research

This chapter focusses on how these methods were applied. The discussions are presented in a logical sequence consistent with the four research objectives. The chapter ends with a summary.

5.1 Describing the current development approval process

This section presents a detailed discussion of the process modelling method used to develop the as-is system which describes the current development approval process. This involved process discovery, process mapping, and verification.

5.1.1 Process discovery

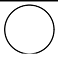
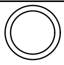
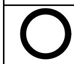
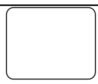
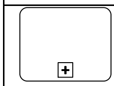
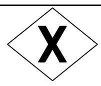
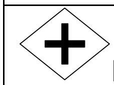
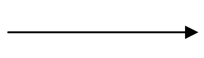
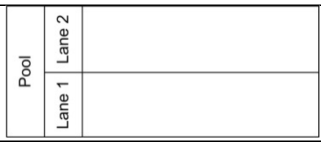
Process discovery was aimed at describing the existing processes; process space, process topology, and process attributes of the processes were identified (Debevoise and Geneva, 2011; Verner, 2004). Under process space, all the relevant subprocesses contained in the development approval process were described. This was based on review of relevant regulations (National Environmental Act (1995), Environmental Impact Assessment Regulations (1998); Physical Planning Act (2010), and Building Control Act (2013)), together with the author's experience and anecdotal evidence on building construction practices in Uganda. In defining process topology and attributes, activities and their flow logic were identified. The overall output from process discovery was a summary of descriptions for subprocesses, with their corresponding activities and flow logic.

5.1.2 Process mapping

Process mapping, which largely followed procedures suggested in Silver (2011) and Chinosi and Trombetta (2012), involved converting process descriptions into process maps, collectively forming a process model diagram of the as-is system. The process mapping procedures involved defining process scope, delineating a high-level process map, and drawing the process model diagram(s). In defining process scope, the important aspects that were addressed included: how a process starts, what determines when it is complete, and the different ways in which it could end (Silver, 2011 p.57). Meanwhile, in the high-level process map, the major activities of the subprocesses were enumerated. Using Microsoft Visio 2013 software, a process model diagram with two tiers was constructed using hierarchical top-bottom diagramming techniques suggested in Silver (2011). Essentially, activities identified in the high-level process map formed the first tier of the diagram. The subprocesses' activities at the high-level had no details since they were presented at an aggregate/collapsed level and as such, they had to be expanded into child-level diagrams. The child-level diagrams therefore formed the second tier of the process model. The hierarchical process modelling approach prescribed that for each collapsed activity of the subprocesses in the top-level diagram, a separate child-level diagram had to be drawn.

Literature suggests several process mapping rules/languages such as flow charts, data flow diagrams, role activity diagrams, petri-nets, unified modelling language, Business Process Modelling and Notation, and so forth (Chinosi and Trombetta, 2012; Fernández et al., 2010; Dijkman et al., 2008; Aguilar-Savén, 2004). Upon careful consideration of several factors not limited to availability, simplicity, usability, complexity, explicitly, and flexibility (Mendling et al., 2010), the mapping rules that were adopted conformed to the Business Process Modelling and Notation (BPMN) grammar (OMG, 2014; White, 2004). BPMN is a widely used process modelling notation and is often referred to as the de facto notation for modelling processes (Silver, 2011; Takemura, 2008). BPMN provides graphical constructs and rules illustrating how to combine the constructs in order to represent real-life or proposed process descriptions (Debevoise and Geneva, 2011; Silver, 2011; Mendling et al., 2010; Recker and Rosemann, 2010; Wand and Weber, 2002). The BPMN standard's graphical elements are primarily grouped into flow objects, connecting objects, and swim lanes. Table 5.1 presents a quick guide to the primary graphical shapes under each of the elements. Although these shapes are the most popular in process modelling with BPMN (Muehlen and Recker, 2008), the standard provides a plethora of shape-variations. For a detailed discussion of BPMN elements including the rules that were used in process modelling, see Appendix A.

Table 5.1 Primary BPMN graphical elements

Name	Example (s)	Function
	Flow objects	
Event	 Start event  Intermediate event  End event	Events denote something that can happen in the process and consequently affect process flow. e.g. waiting for planning approval
Activity	 Task  Subprocess	Activities show work performed in a process e.g. prepare documentation.
Gateway	 Exclusive  Parallel	Gateways represent decisions taken during process flow (e.g. Yes or No for exclusive decisions)
	Connecting objects	
Sequence flow		Sequence flows connect flows objects in order to show the order of how activities are performed
	Swim lanes	
Pool and lanes		A pool acts as a container for the whole process whereas the lanes distinguish responsibilities of various actors within a process.

5.1.3 Verification

Verification, which was conducted to ascertain completeness and consistency of the process model, involved intra-design and empirical verification as discussed below.

5.1.3.1 Intra-design verification

Intra-design verification was conducted whilst designing the as-is system (Verner, 2004; Adelman, 1992). This verification was carried out using 25 process modelling rules garnered from literature (see Appendix A section A.2). Some of these rules (rule number 1 to 20) were based on opinions of authoritative BPMN process modellers (Silver, 2011; Mendling et al., 2010), whereas others (rule number 21 to 25) were based on the BPMN standard (OMG, 2011). To implement the rules that were based on opinions of process modellers, the researcher had to physically inspect the process model to check whether it was consistent with the rules. For instance, as per rule number 8, activities had to be labelled verb-noun (e.g. compute total) and rather not noun-verb (e.g. total computed). For BPMN specific rules, inbuilt BPMN functions of Microsoft Visio 2013 software were used to check for consistence of the process model with BPMN. For example, sequence flows had to only be connected to activities, gateway(s) or event(s). Completeness was checked by constantly comparing the components of the process model with the relevant sections of the regulations. Overall, intra-design verification was an iterative procedure carried out throughout the design phase to ensure that the as-is system was developed correctly. However, in some cases, it was observed that regulations were not prescriptive enough. Literature suggested that generally, a regulation does not need to be prescriptive and in such circumstances, the relevant practice can prescribe what to do (Penny et al., 2001). This suggested that empirical verification of the as-is system was necessary.

5.1.3.2 Empirical verification

Semi-structured interviews were used to empirically verify the as-is system. Two urban local planning authorities (Kampala Capital City Authority and Kira Town Council) were ‘purposely’ selected since they had the highest rates of construction activities in Uganda (UBOS, 2014). This kind of non-probability sampling was used because the development approval process is essentially the same in the whole of Uganda since regulation declares the whole country a planning area (Physical Planning Act, 2010). SMEs, according to Debevoise and Geneva (2011), are individuals that know a process in detail and also have control over it. The relevant SMEs were identified as members of a Physical Planning Committee for each authority because Physical Planning Committees are vested with powers to control development approval (Physical Planning Act, 2010). Eight respondents (Physical Planner, Architect, Engineer, and Environmental Officer) were initially selected, four from each authority. Discussions involved face-to-face interaction and were audiotape-recorded. Essentially, a chart representing the as-is system (Appendix B, section B.1.4) was presented and explained to the informants to offer them an opportunity to easily visualise the end-to-end view of processes. Informants were then asked to describe how the development approval process occurred in formal practice (see Appendix B, section B.1.3).

Data gathered were qualitative and as such, directed content analysis, which is a qualitative data analysis technique, was used. Directed content analysis was appropriate since it was consistent with the deductive positivist philosophical assumptions adopted this research and also facilitated data triangulation. Directed content analysis is normally used to verify or “extend conceptually a theoretical framework or theory” (Hsieh and Shannon, 2005, p.1281) and hence it was appropriate. In the analysis, coding was done using themes which were predetermined based on the as-is system. In qualitative data analysis, coding refers to “an analytic process through which data are fractured, conceptualised, and integrated …” (Strauss and Corbin, 1998, p.3). As such, interview transcripts, which were transcribed verbatim, were then carefully reviewed to identify text (i.e. words and phrases) that described the predefined themes. The identified text was then coded to the respective predefined theme it represented, thereby demonstrating the usefulness of data triangulation. Text that was not coded was further examined to determine whether it formed a subtheme of a predefined theme.

Directed content analysis was not largely amenable to statistical data processing since the output was nonnumeric. Therefore, evidence was presented by showing: codes with exemplars, descriptive excerpts from interviews, and coding frequency (Hsieh and Shannon, 2005; Curtis et al., 2001). Nvivo 10, which is a qualitative data analysis software (Bazeley and Jackson, 2013), was used in the overall structuring and analysis of data. The analysis was guided by the proposition which led to the need for empirical verification, together with examination of rivalling explanations (Yin, 2014). The proposition stated that the as-is system was not a true representation of formal practices. Confirming this proposition involved examining rivalling explanations to determine whether there was evidence to suggest that the as-is system did not represent formal practices. Thus the proposition was to be rejected if no material deviations were found.

5.2 Exploring the possibility of integrating EC accounting

The analysis stage of the process modelling method involved identifying deficiencies in the prevailing process such that areas for improvement could be identified (Verner, 2004). Through critical reflection, analysis of the as-is system's process model was conducted to identify gaps to be filled in order to improve the existing practice. Extant literature was also consulted to provide pointers to what the Ugandan practice could emulate in order to address EC in building projects. According to Verner, gaps that are identified in existing practices are essentially what distinguish the as-is from to-be processes (Verner, 2004). Therefore, the described as-is system provided a basis for identifying what was needed to improve the development approval process of building projects in Uganda.

5.3 An approach to facilitating the integration of EC

This section presents how the mathematical modelling method and the software development method were applied in order to develop and implement the mathematical model, respectively.

5.3.1 The mathematical model

The mathematical model was developed through problem formulation, assumptions, mathematical formulations, and verification.

5.3.1.1 Problem formulation

Problem formulation necessitates a thorough understanding of the world associated with the problem (Berry and Houston, 1995; Murthy et al., 1990). The problem to solve in this case was the need for a model to compute EC emissions of buildings. Literature reviewed in Chapter 2 helped to understand the world associated with the problem. For instance, the mathematical model to be developed had to address disaggregation. Put another way, it had to be developed in a way that enables the energy sources to bear on the quantification, in a manner that allows differentiation of the contribution of the different energy sources. The model also had to take into account the cradle-to-construction completion boundary which, as earlier discussed (see Chapter 2 section 2.3.2), is the most appropriate boundary for quantifying emissions of building projects.

5.3.1.2 Assumptions

A balance between strictness and relaxation of assumptions was necessary. Relaxing assumptions drifts the model away from the reality of the problem, whereas stringent assumptions present difficult solutions (and analysis) but drift the model closer to the reality of the problem (Burghes and Wood, 1980). In deriving assumptions, Bender (Bender, 1978, pp.2-3) suggested that a model should delineate the world into three parts: the part to be neglected, the part potentially affecting the model but not included, and the part the model studies. Too many considerations (i.e. number of variables) can complicate the model, whereas neglecting the 'correct' ones can invalidate conclusions drawn from the model (ibid). The assumption stage was therefore concerned with delineating the appropriate variables for the mathematical model. The components of EC earlier discussed in Chapter 2 (section 2.3.3.2) were used to identify the variables of the model as outlined below:

a) energy-related emissions from manufacturing and transporting construction materials;
b) emissions from construction plant used during construction, limited to emissions from transportation of plant and emissions from onsite-use; and
c) emissions from workforce, limited to emissions associated with the mode (or energy used) for commuting to and from the construction site.

5.3.1.3 Mathematical formulations

Meerschaert suggested that the 'formulation step' involves "selecting the modelling approach" and that "… success at this step requires experience, skill, and familiarity with the relevant literature" (Meerschaert, 2007, p.8). In order to formulate the model, it was imperative to specify the type of mathematical model, analysis technique, modelling technique, and the general structure of the model.

5.3.1.3.1 Type of mathematical model used

The taxonomy of mathematical models is delineated by various attributes of models. Quantitative models respond to questions of inquiry that prescribe quantification (e.g. how much?, how many?), whereas qualitative models are broadly concerned with studying a system and its properties, without necessarily reducing anything to numbers (Saaty and Alexander, 1981). A quantitative model was appropriate in this case since the model dealt with numbers (e.g. quantity of emissions). Unlike dynamic models which are suited for studying systems that entail processes evolving over time (e.g. spread of a disease), static models are time independent (Meerschaert, 2007; Murthy et al., 1990). The proposed model considered static systems whereby emissions were computed at a specific instance in time. This was appropriate due to the great uncertainty usually associated with anticipating change in policy and technology related to emission reductions. Since in deterministic models the values of the variables are predictable with certainty and rather not random as the case is for stochastic or probability systems (Edwards and Hamson, 2001; Murthy et al., 1990), a deterministic approach was adopted for the modelling exercise.

There were various types of equations that could be used in mathematical modelling: differential, integral, algebraic, and difference (Meerschaert, 2007; Edwards and Hamson, 2001; Murthy et al., 1990). It was important that the right equations are chosen for the problem in question (Murthy et al., 1990). Mathematical equations that could succinctly define the relationships between variables were preferred (Edwards and Hamson, 2001). In Murthy et al. (1990), it is indicated that static-algebraic formulations are suitable for modelling deterministic systems. Of the 54 equations in the 25 models (related to embodied energy, greenhouse gases, waste and time-cost parameters of building-projects) of previous studies that were reviewed in Abanda et al. (2013), 40 equations were ‘static-algebraic’. Thus algebraic equations were considered appropriate for deriving the model. Consequently, the type of derived mathematical model was a quantitative-deterministic-static-algebraic model.

5.3.1.3.2 The analysis technique

As earlier discussed in Chapter 2 (section 2.3.3.3.1), life cycle assessment (LCA) is a commonplace technique of analysing environmental profiles of buildings and it was therefore employed. Literature suggests that, combined with energy, LCA evolved into lifecycle energy analysis (LCEA). LCEA of buildings is the LCA analysis that uses energy as the measure for gauging the environmental impacts of buildings (Huberman and Pearlmutter, 2008). LCEA is deemed appropriate for buildings and its intentions are not to substitute LCA but rather, enable assessment of energy efficiency (Fay et al., 2000). In the procedure, LCEA accounts for all energy intakes throughout the building's life time and upon understanding the amount of energy, the associated carbon emissions can be deduced and the environmental impacts of the building can also be conceptualised (Ramesh et al., 2010). The proposed mathematical model subscribed to the partial LCEA approach of cradle to construction completion as per modules A1 to A5 of the BSI (2011) sustainability standard of construction works, and relevant LCA standards (see ISO, 2006a; ISO, 2006b).

5.3.1.3.3 Modelling techniques adopted

In Chapter 2 (section 2.3.3.3.2), the widely used modelling techniques were identified as: process analysis (PA), input-output analysis (IOA), and hybrid analysis (HA). It was also argued that each of these three – PA, IOA and HA – techniques has its own merits and demerits based on which a judgement can be made on the appropriate technique to adopt. This work adopted PA techniques for several reasons. Firstly, although PA does not give 'complete' results, accuracies of up to 90% can be registered (Hammond and Jones, 2010; Murray et al., 2010). Secondly, most mathematical models based on static-algebraic formulations – to which the derived model in this work subscribes – are usually based on PA (see Abanda et al., 2013). Thirdly, since outputs from IOA and HA are aggregated, yet the interest of this model was centred on disaggregation, the PA technique was most appropriate.

5.3.1.3.4 Overall structure of the model

EC emissions of a building project were considered to be the sum of emissions from materials, emissions from plant, and emissions from workforce (Hughes et al., 2011; ICE, 2010). The mathematical model was therefore composed of a series of equations related to emissions from materials, emissions from plant, and emissions from workforce. These equations were obtained upon reviewing extant literature (refer to Table 2.5 in Chapter 2). However, in each equation, a dimensionless disaggregation factor was introduced. This factor was operationally defined as the proportion of energy (e.g. for manufacturing, transportation) derived from a specific energy source j. Multiplying the disaggregation factor with the carbon emission factor of that energy source enabled the outputs of the model to be presented in a disaggregated manner. Meanwhile, carbon emission factors were sourced from secondary data bases and relevant literature. The final derived model and all its constituent equations conformed to the generic structure of algebraic equations suggested in Saaty and Alexander (1981, p.37):

$$a_0\, x^n + a_1\, x^{n-1} + \cdots a_n = 0 \;\; (a_0 \neq 0) \tag{5.1}$$

where a_0, a_1, a_2, a_n are real or complex numbers, and for the degree *n,* there are *n* solutions.

5.3.1.4 Verification of the mathematical model

Although verification is presented last, in reality, it was done concurrently with the formulation of equations. Verification of the mathematical model involved assessing the correctness of the formulated equations. Berry and Houston suggest that "mathematical modelling of a physical world makes sense only if the models are dimensionally correct" (Berry and Houston, 1995, p.121), or according to Bender, dimensionally homogeneous (Bender, 1978). Since any inconsistency or incompleteness of a formulated equation can be detected by running a dimensional analysis of the equation (Langhaar, 1951), dimensional analysis was used to verify the mathematical model. For instance, errors such as incorrect measurement units or omission of a term in an equation could be detected because such an equation would be dimensionally incorrect. The fundamental dimensions of physical quantities are specified as Mass (M), Length (L) and Time (T) (Berry and Houston, 1995; Murthy et al., 1990; Bender, 1978), from which all other dimensions of quantities can be derived. Upon confirming that all the terms which constituted an equation had the same dimensions, it was concluded that the equation was dimensionally homogeneous (Bender, 1978, p.35). Therefore, all the derived equations were rigorously checked for dimension homogeneity. The procedure of achieving this involved a series of steps as outlined below:

- Step 1: State the equation,
- Step 2: Break down the equation into constituent terms and deduce their dimensions,
- Step 3: Substitute the deduced dimensions into each of the terms of the equation,

- Step 4: Reduce and solve the equation's powers,
- Step 5: Inspect remaining dimension (s) on either sides of the equation whether they are similar, and
- Step 6: Confirm whether the equation is dimensionally correct.

Literature suggests that peer review is also an acceptable way of verification (Adrion et al., 1982). In such cases, the feedback provided by peer reviewers can be used to improve the product in order to ensure its completeness, consistency, and correctness. The derived mathematical model was therefore subjected to peer review and the resulting comments were addressed appropriately.

5.3.2 Software tool for implementing model

The RAD process and the RAD software development cycle that were followed in developing the software are discussed below.

5.3.2.1 The RAD process

The RAD process began by defining the requirements of the application to be developed. In this phase, the scope of the work (i.e. data and processes to include) was noted and three time boxes were formulated. A time box is a fixed period for developing a chunk of the application (Gottesdiener, 1995). In RAD, time boxes are used as project control devices; when the duration overruns, the contents in the box may be adjusted and rather not the time box's duration (Beynon-Davies et al., 1999). Multiple time boxes can be executed in parallel, sequentially or staggered (Gottesdiener, 1995). As illustrated in Figure 5.1, a sequential approach consisting of three time boxes was adopted. In each time box, several iterations involving design, modelling (process and data), architectural building and prototyping were conducted, as can be seen from contents of a single time box presented in Figure 5.1. The output of a time box constituted a chunk of an application.

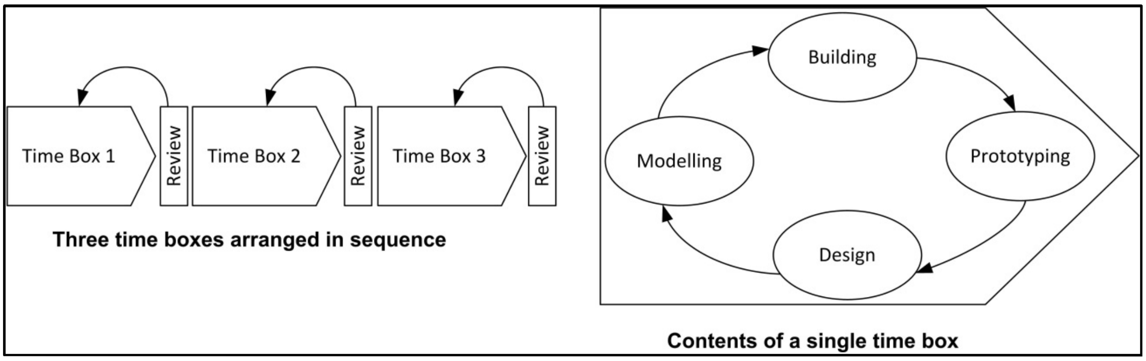


Figure 5.1 Arrangement and contents of time boxes

Source: Adapted from Beynon-Davies et al. (1999); Gottesdiener (1995)

5.3.2.2 The RAD software development cycle

The development cycle of the software involved architectural design, model design, architectural building, prototyping, and verification.

5.3.2.2.1 Architectural design

Architectural design involved specifying the requirements and various dependencies necessary for developing the tool (Gottesdiener, 1995). These were elicited from the information garnered when developing the mathematical model. For instance, from the assumptions considered in the mathematical model, the components of the tool (e.g. manufacture of materials) and their relationships were derived.

5.3.2.2.2 Model design

Although traditionally, software model designs are assembled from scratch, existing designs can be customised to save from reinventing the model design (Gottesdiener, 1995). This, in RAD, is accomplished by using computer-aided software engineering (CASE) tools (Beynon-Davies and Holmes, 2002; Agarwal et al., 2000). Therefore, the developed software was in form of a module of third-party software. Microsoft Excel 2010, hereinafter referred to as ‘Excel’, was the CASE tool used and thus acted as the third-party software. Excel is a package of Microsoft Office suites and was chosen because of its ubiquitous usage, which could potentially facilitate usability and also lower costs of implementing the software (e.g. acquisition and training costs).

In order to develop a robust software tool that took into account various customised functionalities, coding was necessary. Not to be confused with the coding referred to in qualitative data analysis, coding in software engineering refers to writing instructions in a particular programming language that are executed by the software (Agarwal et al., 2010). Using Excel without implementing coding would let the potential users of the software do everything for themselves, a situation that often makes an excel-based application neither robust nor secure (Bovey et al., 2009). Meanwhile, acquaintance with basic computer programming was deemed necessary in order to learn how to write codes. As such, the researcher undertook relevant training in which Python and Visual Basic with Applications (VBA) programming languages were explored. VBA was preferred because it could be easily integrated with Microsoft office applications like Excel.

5.3.2.2.3 Architectural building

In architectural building of the software, BPMN (OMG, 2011), was used to create a 'non-executable' layout of the software in order to conceptualise its overall operation. The general structure of the software was based on typical excel-based application development (Bovey et al., 2009) and had three components: graphical user interface, business logic, and data access/storage (see Figure 5.2). The graphical user interface consisted of all the relevant visible elements (e.g. Forms) that were necessary for the user to interact with the software. The business logic, which was completely VBA code-based, performed the core functions of the software such as accepting input from the user interface and returning output through the user interface. The component of data access and storage was responsible for storage and retrieval of data necessary to perform the software's functions. Data, such as the various constants (e.g. emissions per unit energy) and equations of the mathematical model, were stored using Excel spreadsheets. Reading from and writing to these spreadsheets was accomplished using VBA code (Walkenbach, 2010; Bovey et al., 2009; Mulligan and Wainwright, 2005).

Figure 5.2 Structure of the software tool

Source: Adapted from Bovey et al. (2009)

5.3.2.2.4 Prototyping

Prototyping is an important aspect of a product's development process. A prototype "is a primitive version of a product" (Lauesen, 2005, p.58). Prototyping was aimed at clarifying the requirements of the tool and reviewing other critical design decisions, before the final version was implemented (Lauesen, 2005; Vredenburg et al., 2002; Gordon and Bieman, 1995). Two types of prototyping, 'throw-away' and 'keep-it/evolutionary' were considered (Gordon and Bieman, 1995). Evolutionary prototyping was preferred since the researcher was interested in keeping the progressively improved prototype. Three prototypes were produced for each of the three time boxes. The first prototype was a low fidelity prototype with no functionality but rather hand and/or computer drawn sketches of the user interface of the tool (Lauesen, 2005; Vredenburg et al., 2002). The second prototype had limited functionality and upon revising it, a third 'high fidelity' prototype was produced (Vredenburg et al., 2002). This third prototype was in essence the final version of the tool as it had full functionality for the buttons, menus, and manipulation of data.

5.3.2.2.5 Verification

In software development, verification of software is accomplished by means of testing. The process of software testing, which is notoriously expensive and labour intensive (Ammann and Offutt, 2008), is carried out with the intent of finding and correcting faults in the software (East et al., 2008). Literature suggests various techniques of software testing namely unit testing, module testing, integration testing, acceptance testing, and 'system' testing (Aguilar et al., 2008; Ammann and Offutt, 2008). The software testing techniques that were found relevant in this case were module testing and integration testing. Given that agile software is tested during development (East et al., 2008), module testing and integration testing were both conducted during the architectural building of the software.

In module testing, each of the three components of the software (i.e. graphical user interface, business logic, and data access/storage) was checked to ensure that it worked correctly. VBA and Excel provide several features that were used to accomplish module testing. In VBA debugging mode, it was possible to implement 'stepping into code' to identify potential problems by moving forward or backward through several lines of the code. Error handling was also included to ensure redirection of code execution in case of faults such as runtime errors. While developing the graphical user interface (i.e. user Forms), it was possible to 'Run Macro' in order to view how the final product looked like such that appropriate changes could be made, if necessary. For instance, it was possible to check whether the command buttons on the graphical user interface, if clicked, returned the correct information (e.g. opening, hiding, and cancelling a Form). Excel also provided some functionalities that were used to track errors such as circular referencing in the database spreadsheets.

Upon successfully conducting module testing, integration testing was carried out to ensure that the three components of the software correctly worked together as an integrated whole (Ammann and Offutt, 2008). Emphasis was on checking the functionality of the connections amongst the three components (i.e. graphical user interface, business logic, and data access/storage). Consequently, several questions were addressed:

- Is information entered into the graphical user interface (both preselected and variable) correctly written to the data access/storage (i.e. spreadsheets) upon clicking relevant buttons?
- In case a user enters wrong information (e.g. text instead of number), does the error handling option function?
- Do the outputs of the software compare to manually solved problems?

5.4 The to-be system

This section presents a discussion on how the methods for developing and evaluating the to-be system were applied.

5.4.1 Development of to-be system

Development of the to-be system followed a process modelling method similar to one described in the development of the as-is system, albeit with some modifications as elaborated hereunder.

5.4.1.1 Process discovery

Similar to process discovery of the as-is system, process discovery of the to-be system involved identifying process space, process topology, and process attributes of the to-be system. However, identification of these aspects was based on the as-is system and the mathematical model. Put another way, the to-be system consisted of the as-is system's subprocesses; new subprocesses, and modified as-is system's subprocesses. The new subprocesses were derived from the mathematical model whose equations were translated into activities. For instance, an equation about computing carbon emissions from construction materials was translated into an activity of 'compute materials emissions'. Introducing such a new activity into the as-is system led to modification of some of the as-is system's activities. Therefore, the overall output from process discovery was a summarised description of new (and modified) activities, including their sequence of execution.

5.4.1.2 Process mapping

Process mapping involved converting process descriptions into process maps which collectively formed a process model of the to-be system. Similar to process mapping of the as-is system, process mapping of the to-be system consisted of defining process scope, delineating a high-level process map, and drawing the process model diagram(s) using Microsoft Visio 2013 software. A process model diagram of the to-be system, consisting of two tiers, was constructed. The subprocesses' activities at the high-level had no details since they were presented at an aggregate/collapsed level and as such, they had to be expanded into child-level diagrams. For each to-be collapsed activity of the subprocesses in the top-level diagram, a separate to-be child-level diagram was drawn. However, some activities in the subprocesses of the to-be system were the same as those of the subprocesses in the as-is system. Therefore, only child-level diagrams of activities and/or subprocesses that were new or modified, were presented.

5.4.1.3 Verification

Verification of the to-be system was conducted to ascertain its completeness and consistency. The earlier elaboration in developing the as-is system showed that verification involved intra-design and empirical verification. However, for the verification of the to-be system, empirical verification was not necessary because the to-be system was non-existent. Therefore, only intra-design verification was conducted on the to-be system. Given that the to-be system was based on integrating components, of which some had already been independently verified (i.e. during development of as-is system), intra design verification of the to-be system was limited to new or modified linkages, subprocesses, and activities. This involved checking these components against the 25 process modelling rules (see Appendix A section A.2) using both the automatic inbuilt functions of Microsoft Visio 2013 software and physical inspection of the process model.

5.4.1.4 Analysis of the to-be system

As previously described in developing the as-is system, the analysis stage involves identifying gaps in the prevailing processes such that areas for improvement could be identified. However, analysis of the to-be system in this way, so as to identify areas of improvement, was beyond the scope of this study as this would require implementing the to-be system. This was envisaged as an area for future research, contingent upon implementing the to-be system.

5.4.2 Evaluation of the to-be system

In order to implement the research method for evaluating the to-be system, research design and data analysis procedures were necessary.

5.4.2.1 Research design for evaluating the to-be system

The research design for evaluating the to-be system was interpreted as a plan for gathering data and it consisted of selection of cases, selection of variables, and selection of data sources (Kervin, 1992).

5.4.2.1.1 Selection of cases

In selecting cases, the unit of analysis, basic design, specific research design, and sample design were considered.

a) Unit of analysis

A chosen unit of analysis should be relevant for a research problem, consistent over variables, and able to generate enough cases for analysis (Babbie, 2013; Kervin, 1992). Based on these considerations and literature related to sustainability issues in the building sector, the appropriate unit of analysis was identified as an individual built environment professional (Ametepey et al., 2015; Chen et al., 2010; Zainul Abidin, 2010; Manoliadis et al., 2006; James and Matipa, 2004; Ngowi, 1998). The built environment professionals in Uganda who were relevant to the evaluation of the to-be system were: Architects, Civil Engineers, Quantity Surveyors, and Environmental Impact Assessors.

b) Basic design

A non-experimental basic design was used since there was no need to manipulate independent variables or assign cases randomly (Walker, 2010). However, the cases (e.g. professionals) were randomly selected from the study population.

c) Sample design

Sample design included deciding whether to sample or not, deriving a sample frame, specifying the type of sample, and determining the size of the initial sample. A decision to sample was taken because the costs and time required to cover the entire research population were not affordable (Denscombe, 2010; Fellows and Liu, 2009). A sampling frame, which is an objective list of the population from which a researcher makes selections (Denscombe, 2010), was derived from the publicly available list of practitioners who were accredited to practice their respective professions in 2014. Since the study population (i.e. built environment professionals in Uganda) naturally occurred in strata, a stratified sample, which falls under probability and multistage samples was used (Denscombe, 2010; Fellows and Liu, 2009). Stratification helped to reduce the normal sampling variation which could have occurred if direct random sampling was to be carried out on such a stratified population (Fowler, 2009). Meanwhile, it is generally acknowledged that deciding the size and adequacy of a sample has no standard procedures (Denscombe, 2010; Fowler, 2009), and as such, crafting of some procedures on size and adequacy of sample was necessary. In Kervin (1992), a sample is distinguished into an initial and achieved sample whereby the former describes the cases from which data are to be collected, whereas the latter describes the cases from which data are actually collected. To determine the appropriate size of the initial sample, a ‘large’ sample, which was regarded as one with 30 or more cases (Pallant, 2013; Owen and Jones, 1994), was considered per stratum. Therefore, setting an initial sample size of 30 respondents per stratum ensured that an adequate ‘achieved sample’ would be obtained for performing meaningful statistical analyses irrespective of whether analyses were to be based on all or some of the strata.

d) Specific research design

Given that a non-experimental design was used, two options of specific research design were available: cross-sectional and longitudinal specific designs (Kervin, 1992). In cross-sectional designs, data are collected at a single measurement time point whereas in longitudinal designs, data are collected over two or more time points such that the same variable can be measured over time (Creswell, 2014; Walker, 2010; Fellows and Liu, 2009). Although a longitudinal design would be appropriate to investigate such a phenomenon (e.g. impacts of carbon accounting) that takes time to evolve, this kind of design was not appropriate since it would require implementation of the to-be system. As such, a cross sectional design was preferred.

5.4.2.1.2 Identification and measurement of variables

Variables, which are attributes of the unit of analysis (Kervin, 1992), were selected for majorly two reasons: assessing response validity and evaluation of the to-be system.

a) Assessing response validity

The independent variables that were purposely introduced to assess research validity were ‘years of practicing experience’ and ‘nature of practice’ (e.g.

private consultancy, construction firm, government body, etc.). Majdalani et al. (2006) suggests that responses from professionals possessing over five years of experience enhance internal validity of a research. Respondents were therefore asked to indicate the number of years they had been practicing their respective professions. Meanwhile, initial inspection of the sampling frame suggested that most professionals (80%), irrespective of type, were employed in private consultancy firms. It was therefore necessary to introduce a variable of ‘nature of practice’ to check whether the achieved sample was representative of the study population.

The dependent variables purposely introduced to assess research validity were awareness of sustainable construction and interpretation of sustainable construction. Literature suggests that built environment professionals elsewhere are generally highly aware of sustainable construction. In Zambia, a 60% level of awareness of sustainable construction among construction professionals was reported in James and Matipa (2004) whereas 83% of the practitioners in Ghana were reported to be aware of sustainable construction (Ametepey et al., 2015). However, as there was no literature to confirm the level of awareness in Uganda (see earlier discussions in Chapter 3 section 3.2), a variable related to assessing the general level of awareness of sustainable construction was included. This was based on asking respondents to rate their general level of awareness on a scale of: Not at all aware, Slightly aware, Somewhat aware, Moderately aware, and Extremely aware. Meanwhile, as earlier discussed in Chapter 2 (section 2.1.1), sustainable construction is in most cases interpreted in relation to environmental sustainability. To confirm whether this was the same for Uganda, respondents were provided six statements from which to choose three that best described the term sustainable construction (see Table 5.2). A radar chart and bar graph were used to display how perceptions of sustainable construction varied.

Table 5.2 Understanding sustainable construction

Pillar	Statement
Environmental	Construction practices that minimise harm to the environment such as avoiding constructing in wet lands
	Construction practices that minimise over usage of natural resources like water and sand
Social	Construction practices that practice corporate social responsibility
	Construction practices that enhance quality and satisfaction of human life such as promoting safety at workplace.
Economic	Construction practices that ensure minimal lifetime maintenance costs of buildings
	Construction practices that make profit without compromising people's needs

Source: adopted from Zainul Abidin (2010); Hill and Bowen (1997)

b) Evaluation of the to-be system

The variables for evaluating the to-be system, which were all dependent in nature, were elicited from the literature reviewed in Chapter 2 and Chapter 3, as discussed below. Hypothesis testing, as per hypotheses listed in Chapter 1 section 1.3, was only considered for the four variables related to the criteria of selecting environmental policy.

(i) Perception of effectiveness of the to-be system

The effectiveness of the to-be system was judged on whether it could enhance sustainable construction based on the drivers of sustainable construction identified in Chapter 2 section 2.1.2. These drivers were abstracted into assessable statements (see Table 5.3). Therefore, effectiveness of the to-be system was a composite variable that was assessed by examining the perceptions regarding the extent to which the to-be system, if implemented, contributed to each of the 23 drivers. Responses were recorded based on a Likert scale of: 0 = don't know, 1 = not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely. The resulting data were used to test hypothesis H1.

Table 5.3 Drivers of sustainable construction

	Statement
1[a]	Minimising over usage of resources like energy and materials during construction
2[a]	Improving on the overall energy consumption of buildings
3[a]	Promoting use of waste to manufacture new products
4[a]	Encouraging reuse of a product several times before discarding it
5[a]	Encouraging use of renewables like biodiesel instead of non-renewables like diesel
6[a]	Minimising pollution like carbon dioxide emissions
7[a]	Promoting environmental labelling and rating systems
8[a]	Encourage considering environmental issues during the construction stage
9[a]	Facilitation of decisions to consider materials that are sustainably produced
10[a]	Enabling development of comprehensive data bases related to emissions
11[a]	Enhance enforcement and compliance with environmental regulations
12[b]	Lead to financially affordable options like walking instead of driving
13[b]	Creation of more employment opportunities like using people instead of diesel-equipment
14[b]	Enhancing competitiveness in construction through advancing sustainability practices
15[b]	Enable choosing suppliers or contractors that demonstrate environmental performance
16[b]	Creation of financial incentives
17[b]	Encourage using local materials and workforce
18[c]	Generation of income like for those producing sustainable materials and energy
19[c]	Making construction operations more compatible with local needs
20[c]	Increase awareness about carbon emissions in construction
21[c]	Promoting corporate social responsibility
22[c]	Promoting health and safety at workplace
23[c]	Developing capacity and skills regarding matters of accounting for carbon emissions

[a] Environmental sustainability, [b] Economic sustainability, [c] Social sustainability

(ii) Perceptions of cost implications of the to-be system

Based on the discussions in Chapter 3 section 3.2.3.2.2, assessment of cost implications involved checking whether new institutions are required, whether the procedures are easy to understand, and whether the to-be system can contribute to other benefits, such as carbon trading (see Table 5.4). In this regard, hypotheses H2 and H3 were tested in relation to cost implications and benefits, respectively.

Table 5.4 Assessing perceptions on cost Implications

Item	Descriptors and coding references					
The to-be system contributes to other benefits [a]	1 Strongly disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly agree	0 Don't know'
The to-be system's processes and procedures are easy to understand [b]	1 Not easy at all	2 Not easy	3 Undecided	4 Somewh at easy	5 Very easy	0 Don't know'
Institutional changes required to implement to-be system [c]	1 New institutions		2 Significant modificatio n	3 Minor modificat ion	4 Existing suffice	0 Don't know'

[a] 1 and 2 = does not have benefits (Failure), 4 and 5 = has benefits (Success)
[b] 1 and 2 = Difficult (Failure), 4 and 5 = easy (Success)
[c] 1 and 2 = requires new institutions (Failure), 4 and 5 = does not require new institutions (Success)

(iii) Perceptions of distributional considerations of the to-be system

Table 5.5 summarises how perceptions of distributional considerations were assessed, based on earlier discussions presented in section 3.2.3.2.3. As such, assessing distributional considerations of the to-be system included checking its legitimacy, fairness, and transparency. The data collected were used to test hypothesis H4.

Table 5.5 Assessing perceptions on distribution considerations

Item	Descriptors and coding references					
	1	2	3	4	5	0
Willingness to use the to-be system (Legitimacy) [a]	Extremel y unlikely	Unlikely	Neither likely nor unlikely	Likely	Extremely likely	Don't know'
Fairness of the to-be system (Fairness) [b]	Very unfair	Unfair	Neither fair nor unfair	Fair	Very fair	Don't know'
Clarity of intentions (Transparency) [c]	Very unclear	Unclear	Neither clear nor unclear	Clear	Very clear	Don't know'

[a] 1 and 2 = not legitimate (Failure), 4 and 5 = Legitimate (Success)
[b] 1 and 2 = not fair (Failure), 4 and 5 = fair (Success)
[c] 1 and 2 = not transparent (Failure), 4 and 5 = transparent (Success)

(iv) Perceptions of institutional feasibility

In assessing institutional feasibility (see section 3.2.3.2.4), the to-be system was checked for relevance, legal acceptance, compatibility, persistence, and predictability. Table 5.6 summarises how perceptions of institutional feasibility were assessed in order to test hypothesis H5.

Table 5.6 Assessing perceptions on institutional feasibility

Criterion	Question	Response options [a]	
		No (Failure)	**Yes (Success)**
Relevance	Is the need for sustainable construction worthwhile to pursue?	Not relevant	Relevant
Legal acceptance	Does the to-be system fit into existing regulatory framework?	Not legally acceptable	Legally acceptable
Compatibility	Is the to-be system compatible with national priorities?	Incompatible	Compatible
Persistence	Would you consider the to-be system a persistent solution to minimising emissions?	Not persistent	Persistent
Predictability	Are the impacts resulting from implementing the to-be system foreseeable?	Not predictable	Predictable

[a] An additional response option of 'don't know' was also included to each criterion/question

(v) Perceptions on format of implementing the to-be system

As per earlier discussions on section 3.2.3.1, it was necessary to assess the to-be system in relation to three aspects: implementing it as a regulatory instrument, economic instrument, or information instrument. Respondents were required to choose one that they considered most appropriate.

(vi) Perceptions on the kind of buildings to consider

In the building sector of Uganda, buildings are generally classified into residential and non-residential buildings (UBOS, 2014). According to the third schedule of the National Environmental Act (1995) which lists projects that have to be considered for EIA, non-residential buildings (e.g. shopping centres and complexes, industries, etc.) are mostly referred to. There is no specific reference to which kind of buildings that should be considered. The researcher sought to clarify this by investigating whether the to-be system would be appropriate for residential, non-residential, or all buildings.

(vii) Perceptions on the professionals suitable to conduct carbon accounting

Accounting for EC was a critical task embedded in the to-be system. Literature suggests that there is little consensus regarding who should be responsible for accounting for EC. For instance, Quantity Surveyors are preferred in RICS (2012) whereas engineers are referred to in Franklin and Andrews (2013). It was therefore necessary to collect perceptions of the professionals regarding whom they preferred, amongst Architects, Quantity surveyors, Engineers, and others, to conduct EC accounting. Reasons for the preference were also gathered in form of an optional open-ended question.

5.4.2.1.3 Selection of data sources

The major factor considered in selecting a data source was ability to provide information about all the variables. In research, data sources may include individual self-reports, inside informants, researcher observations, and available data records (Kervin, 1992). Individual self-reports were preferred since the research objects were able to provide information about all the variables, that is, self-information about the independent variables (e.g. work experience) and information about the dependent variables (e.g. perceptions on institutional feasibility of the to-be system). Collection of this information involved asking the research objects relevant questions linked to the variables (Kervin, 1992).

5.4.2.1.4 Form of data collection

The research method of structured interviews was implemented using face-to-face interactions, based on ‘paper and pencil’ format. Although face-to-face interviews are expensive and time consuming compared to other forms of data collection (Denscombe, 2010; Kervin, 1992), there were several reasons to offset such disadvantages. Firstly, since the topic under study was relatively new to Uganda, there could have been a threat to validity and response rate if, for instance, responses were completely self-administered questionnaires. Thus the presence of the interviewer was important to, among other things, demonstrate and explain the operation of the to-be system such that additional clarifications could be given to improve validity of responses (Owen and Jones, 1994, p.316). Secondly, face-to-face interaction offered the researcher an immediate opportunity to validate data since it was possible to sense false information in a way that is impossible in other forms of data collection like questionnaires and telephone interviews (Denscombe, 2010).

The administration of the data collection instruments followed a structured procedure suggested by Creswell (2014). The documents from which the sampling frame was derived contained contact information of the potential informants. The researcher physically visited the addresses of the informants to set up appointments for the interviews. In this initial encounter, the researcher introduced himself to the informants, and also explained the purpose of carrying out the research. Participation was then solicited by first taking the informants through the information sheet and consent process (Appendix B sections B.1.1 and B.2.2). In majority of cases, interviews happened in the initial encounter of recruiting respondents. Where this was not the case, a second meeting was scheduled. Successive attempts for unsuccessful appointments were made throughout the duration (9 weeks) of data collection process, starting from 20th October 2014 up to 19th December 2014. In a typical interview, the respondent was issued a show card (Appendix B section B.2.4). The researcher began by asking the respondent questions (1 to 5) which solicited, among other things, demographic information. The researcher then proceeded to explain the to-be system to the respondent using a chart (Appendix B section B.1.4). The researcher then used a laptop computer to demonstrate computation of EC using the software tool that was developed. After then, the respondent was asked questions 6 to 14.

5.4.2.1.5 Pilot testing

The structured interview was pilot-tested in order to confirm content validity and also revise questions, scales, and formatting, as appropriate (Creswell, 2014). A purposely selected sample (i.e. with characteristics similar to those of the real sample) of 5 postgraduate Ugandan engineering students (3 Masters and 2 PhD) studying at University of Leeds was used for the piloting exercise. The following comments which were received from the piloting exercise were incorporated into the final version of the research instrument:

- structure the interview schedule into two parts – one part about the questions directly related to the to-be system and another on questions not directly related to the to-be system;
- aim to conduct the interview in no more than one hour;
- avoid unnecessarily lengthy questions; trim the responses on question number 7 – these were trimmed from the original 30 items to 23 items; and
- simplify process model diagrams to remove complicated BPMN jargon.

5.4.2.2 Data analysis procedures

Quantitative and qualitative data were each analysed separately as elaborated hereunder.

5.4.2.2.1 Quantitative data analysis

With aid of the statistical package for the social sciences (SPSS) version 19, quantitative data were analysed following a systematic procedure involving data preparation, preliminary data analysis, descriptive analysis, analysis of variation in responses, and analysis of differences.

a) Data preparation

For each interview schedule, a unique 9-digit identification number composed of interview date and interview number (e.g. DDMMYY001) was assigned to fulfil ethical requirements of confidentiality. A code book was then prepared defining and labelling the variables of the study, including assigning numbers/scores to the various response formats. Data were then entered into the statistical software and rigorously screened for errors and omissions.

b) Preliminary data analysis

The achieved response rate was examined by investigating circumstances that influence response rates. Response rate represented the number of respondents in the sample from whom data were gathered, divided by the sample size (Fowler, 2009). Although there seems to be no standard to a minimum acceptable response rate (Fowler, 2009), previous studies offered pointers from which this research benchmarked. Literature suggests that reasons for nonresponse vary: failing to contact respondents, respondents not wishing to participate, and respondents incapable of performing the necessary tasks requisite of data collection (e.g. due to illness, language barrier, illiteracy) (Fowler, 2009, p.49; Baruch, 1999). These aspects were therefore considered in discussing the achieved response rate.

Before conducting statistical analyses, assumptions of the tests chosen were assessed in order to identify violations. Statistical tests are broadly divided into parametric and non-parametric tests, each of which has various assumptions (Walker, 2010). Where the data did not satisfy one of the parametric test assumptions, non-parametric tests were used. The assumptions assessed included: random sampling and independent observations, level of measurement, and normal distribution (Pallant, 2013; Bryman and Cramer, 2011; Walker, 2010).

Response bias, which is the effect of individuals that do not respond (Fowler, 2009), was assessed using wave analysis (Creswell, 2014; Lankford et al., 1995). For the nine weeks of data collection, three waves were derived according to how the data were collected. In SPSS 19 software, a new categorical variable labelled as 'Wave' with three attributes (i.e. wave1, wave2, and wave3) was created. Wave1, wave2, and wave3 corresponded to data collected during week 1 to 3, week 4 to 6, and week 7 to 9, respectively. Appropriate statistical tests were conducted to explore the impacts of the three waves on the responses. Results were used to judge whether, if a fourth wave containing the nonresponses was to be included, there would have been any significant changes in the responses. Significant differences in the three waves signified potential for response bias, and vice versa. This was based on the assumption that usually, data received towards the end of the data collection period are similar to those of non-respondents (Creswell, 2014).

Regarding perception of effectiveness, the 23 items which were measured on a five-point Likert format were collapsed into a single composite variable based on a continuous level of measurement. For instance, for one respondent, the maximum score was computed as 5 (i.e. 5 x 23 /23) and the minimum was 1 (i.e. 1x23/23). A mean score of 3 was taken as the cut-off to distinguish between effective (score > 3) and not effective (score < 3). Although this five-point Likert format has been widely used with similar interpretations (Larsson et al., 2013; Kulatunga et al., 2009; Pheng and Gracia, 2002; Tam et al., 2001), caution was exercised. Collapsing an ordinal-measured variable into a continuous measure meant that ordinal measures were interpreted as interval measures. Treating ordinal scales as interval scales is often criticised (see Jamieson, 2004; Knapp, 1990), but has no harm especially where, like in this work, two-tailed t-tests are used with relatively equal stratified-sample sizes (Baker et al., 1966).

For several items to constitute a scale, they have to possess an acceptable level of internal consistency (Kervin, 1992; DeVellis, 1991). Therefore, for all the 23 items that constituted the scale, their internal consistency was assessed. Cronbach's coefficient alpha (Cronbach, 1951), a widely used measure of scale reliability, and correspondingly, internal consistency (Pallant, 2013; DeVellis, 1991), was used. The scale was considered acceptable if it had a coefficient alpha greater than 0.7 (Pallant, 2013).

Variables that constituted few items were not collapsed but rather interpreted categorically, upon dichotomising them. For instance, a five-point Likert scale (e.g. 1 = strongly disagree, 2 = Agree, 3 = Undecided, 4 = strongly agree, 5 = strongly disagree) was dichotomised into two new categories (e.g. 'agree' for 4 and 5, 'disagree' for 1 and 2). Responses of 'undecided' and 'don't know' were taken to be non-substantive and excluded to improve validity of responses (Foddy, 1993). The categorical variables measured on a dichotomous scale (i.e. Yes and No) required no further adjustment, apart from excluding the 'don't know' responses.

c) Descriptive analysis

Descriptive statistics (e.g. mean, median, range, percentages etc.) provided a useful way of summarising data and offered valuable clues to the need for further analyses (Walker, 2010). Graphs, charts, and tables were used to summarise descriptive data. Some questions, especially whose responses required no further adjustment (e.g. format in which the to-be system should be introduced, the kind of buildings it would apply to, and the suitable professionals to undertake the role of EC accounting) were sufficiently addressed by the descriptive statistics whereas for others, hypothesis tests were necessary.

d) Analysis of variation in responses

Consistent with the concept of data triangulation (i.e. comparing data from different types of informants), tests were carried out to assess the extent of variation in the distribution of responses across the four types of professionals (i.e. Architects, Engineers, Quantity surveyors and Environmentalists). For categorical variables, a non-parametric Chi-square test of independence (Pearson Chi-square test) was used whereas for continuous variables, a one-way between groups analysis of variance (ANOVA) was used (Pallant, 2013; Bryman and Cramer, 2011; Green and Salkind, 2005). However, Chi-square tests generally assume that the 'minimum expected cell frequency' (i.e. number of cases expected in a category) is at least 5 (Bryman and Cramer, 2011; Green and Salkind, 2005). McHugh suggests that where this fundamental assumption is violated, the alternative 'maximum likelihood ratio' can be used (McHugh, 2013). Where significant variations in the responses were found, further analyses, like hypothesis tests, were based on a stratum (i.e. profession type).

e) Analysis of differences – hypothesis tests.

The hypothesis (H1) for perception of effectiveness of the to-be system was tested and the effect size calculated. To accept the null ($H1_0$) hypothesis (i.e. to-be system is not effective), the to-be system had to be significantly scored below the cut-off score of 3. To reject the null hypothesis in favour for the alternative ($H1_1$) hypothesis (i.e. to-be system is effective), the to-be system had to be significantly scored above the set cut-off score of 3. A *t*-test was used to test the hypothesis because this test is primarily used to assess whether the mean score of a variable under consideration significantly differs from a specified constant (Bryman and Cramer, 2011; Green and Salkind, 2005). The *t*-test's basic assumptions were first checked to identify any violations. Meanwhile, it is suggested in Creswell (2014) and also seconded by various scholars (Pallant, 2013; Green and Salkind, 2005), that in addition to reporting significance of results, effect size should also be reported. An effect size "shows the practical significance of the results apart from inferences" (Creswell, 2014, p.165), and it also denotes the magnitude of the difference observed (Green and Salkind, 2005). The effect size d was interpreted to be the extent to which the mean score obtained differed from the cut-off score, in standard deviation units. The approach of calculating d, considering the one-sample t test, was based on a formula shown in equation (5.2) (Green and Salkind, 2005, p.157):

$$d = \frac{t}{\sqrt{n}} \tag{5.2}$$

where: t is the t value (as obtained from SPSS 19 output) and n is the total sample size. Based on Cohen's criteria of classifying effect sizes: 0.2 as small effect, 0.5 as medium effect, and 0.8 as large effect, the obtained effect size was classified accordingly (Cohen, 1988).

The patterns of findings from how sustainable construction was understood were checked to identify any relationships with the effectiveness of the to-be system in promoting sustainable construction. The differences in the scores of effectiveness related to the three categories (environmental - 11 items, social - 6 items, and economic - 6 items) derived from the 23 items used in measuring effectiveness, were explored. The relevant test to use in this case was one that was applicable where the same sample of individuals (e.g. professionals) is tested under three or more different conditions (e.g. scores on the three pillars). As such, two tests were found relevant: one-way repeated-measures ANOVA and the Friedman test, depending on whether data were parametric or non-parametric, respectively (Pallant, 2013). The appropriate test was used to compare the distribution of the scores across the three categories.

Hypotheses H2, H3, H4, and H5 that were related to categorical responses were tested by comparing the observed proportion of cases appearing in the two response options (e.g. No and Yes, Agree and Disagree, etc.) with a hypothesised proportion. A hypothesised proportion of 75% was set based on speculation (Green and Salkind, 2005). Thus the two hypothesised proportions were specified as 0.75 and 0.25, corresponding to the null and alternative hypotheses, respectively. The null hypotheses ($H2_0$, $H3_0$, $H4_0$, and $H5_0$) were to be rejected only if the observed proportion was significantly different ($p < 0.05$) from the hypothesised proportion.

Literature suggested that binomial and Chi-square tests would be appropriate for testing the hypotheses H2, H3, H4, and H5 (Bryman and Cramer, 2011; Green and Salkind, 2005). However, though assumptions of both tests – random samples and independent observations (Pallant, 2013; Green and Salkind, 2005) – were satisfied by the data, the binomial test was discarded. This was because binomial tests are appropriate for relatively small sample sizes ($n < 25$) (Green and Salkind, 2005), yet the achieved sample size was large ($n > 30$). The alternative *z* test, which can accommodated larger samples, was also discarded since it only yields accurate results where the hypothesised proportion is close to 50% (Green and Salkind, 2005), yet the set hypothesised proportion was 75%. As such, the one-sample Chi-square test was most appropriate. To implement it, the hypothesised proportion of 0.75 was used and the effect size of the results noted. The effect size d was calculated using equation (5.3) (Green and Salkind, 2005, p.359):

$$d = \frac{x^2}{(n)(r-1)} \tag{5.3}$$

where: x^2 is the Chi-square value, n is the sample size, and r is the number of response options. The result was classified according to Cohen's criteria (Cohen, 1988).

5.4.2.2.2 Qualitative data analysis

Responses that generated qualitative data were optional (see Appendix B , section B.2.3): question 13 required respondents to give reasons for the option selected, and question 14 solicited general comments about the to-be system and the research. As such, qualitative data were not expected from all the respondents. Analysis of the collected qualitative data involved textual analyses with the aid of NVIVO 10 qualitative data analysis software (Bazeley and Jackson, 2013). These textual analyses were used in data triangulation to augment statistical analyses obtained from quantitative data. The procedure for analysing qualitative data followed directed content analysis explained earlier in section 5.4.1 although in this case, initial coding themes were based on the variables used in the quantitative analyses. The interview transcripts, which were transcribed verbatim, were scrutinised to identify text that directly or indirectly referred to the variables. Where such text was identified, it was coded to the respective variable or otherwise, a new theme was defined.

5.5 Chapter summary

This chapter has provided a detailed discussion on how the methods presented in Chapter 4 were applied. To achieve the first research objective, a process model of the as-is system for the development approval process of building projects in Uganda was created. To achieve the second research objective, the process model developed in the first objective was analysed to identify areas for improvement. To achieve the third research objective, a four-step mathematical modelling procedure consisting of problem formulation, assumptions, mathematical formulations, and verification, was executed. To implement this model into a software tool, a five-step software development cycle consisting of architectural design, model design, architectural building, prototyping, and verification, was effected. To achieve the fourth research objective, a process model of the to-be system was created by integrating the mathematical model into the as-is system. The to-be system was evaluated using semi-structured interviews with built environment professionals. The next chapter presents results and discussions pertaining to implementing the methods related to achieving the first and second research objectives.

Chapter 6
Integrating EC in the development approval process

Results from describing the existing practices related to the as-is system of the development approval process are presented; two process models which represent the status before and after verification are presented. Analysis of the described as-is system is provided, thereby highlighting gaps in the existing practice. Lastly, a chapter summary is presented.

6.1 The current development approval process

The outcomes from describing the current situation, so as to develop the as-is system, include process discovery, process mapping, and verification.

6.1.1 Process discovery

The aspects under process discovery, that is, process space, process topology and attributes, were identified as explained below.

6.1.1.1 Process space

Upon reviewing literature and relevant regulations, together with the author's experience and anecdotal evidence, the major subprocesses in the development approval process of buildings in Uganda were identified to be: environmental impact assessment subprocess, development permission subprocess, and building project subprocess.

6.1.1.2 Process topology and attributes

Process topology and attributes for each of the three subprocesses, as per information gathered through review of relevant regulations and author's experience, are given below.

6.1.1.2.1 Process topology and attributes for the environmental impact assessment subprocess

The developer prepares a project brief (PB) which contains various details as summarised in Table 6.1. The developer then submits the PB (in 10 copies) to the Executive Director (ED) of National Environment Management Authority (NEMA). If the ED deems the PB complete, he may send (within 7 working days of receiving the PB) a copy to the Lead Agency (LA) for comments. The LA is defined as "any Ministry, department, parastatal agency, local government system or public officer in which or in whom any law vests functions of control or management of any segment of the environment". For instance, if the project is related to construction of a housing estate, the LA can be the ministry in charge of housing. The LA makes comments and sends (with 14 working days of receiving) the PB back to the ED. If the LA does not respond (within 14 working days), the ED may proceed to consider the PB. The ED considers the PB together with comments made by the LA. If ED finds the project to be of significant environmental impact (with no appropriate mitigation measures stated in the PB), he/she requires the developer to undertake further actions of environmental impact assessment, which entail conducting an environmental impact study. If the ED is satisfied that there will be no environmental impacts (or mitigating measures are well stated in the PB), he/she may approve the project. Upon approval, the ED (on behalf of Authority) issues a certificate of approval. However, where an environmental impact study is required, the ED notifies the developer (within 21 days from PB submission to ED) accordingly.

Table 6.1 Contents of a project brief

Contents of the environmental impact assessment project brief
Nature of the project (as per Third schedule of National Environmental Management Act)
Land, air, and water affected
Activities to be undertaken
Design of the project
Construction materials to be used
Waste generation of the project
Number of people to be employed and benefits to community
Environmental effects and how to be eliminated/mitigated
Other issues deemed as necessary by the Authority

Source: Section 5 of the Environmental Impact Assessment regulations

An environmental impact study is conducted in accordance with terms of reference (ToR) developed by the developer in consultation with the Authority and LA. The ToRs include all issues required to be included in an environmental impact statement and those as may be required by ED. The developer, upon having the ToRs approved by the ED, submits to the ED the names of people to undertake the environmental impact study and the ED may approve or reject any of the submitted names. If the ED rejects a person, he/she requires a resubmission within a period to his discretion. During the environmental impact study, the developer seeks views of people who will be affected by the project. This is through publicising (for 14 days or more) the project and its effects/ benefits and after then, holding meetings (at appropriate time and place agreed by local council leaders) with the affected people to explain the project and its effects.

Upon completing the environmental impact study, the developer makes an environmental impact statement describing several issues as required by the law (Table 6.2), including an executive summary containing the main findings and recommendations. Meanwhile the environmental impact statement has to be signed by all those persons who conducted environmental impact study. The developer then submits (20 copies) environmental impact statement to the ED, who later transmits it to the LA for comments. The LA makes comments and sends (within 30 working days of receipt) the environmental impact statement back to the ED. If the LA does not respond (within 30 working days), the ED may proceed to make a decision about the environmental impact statement. Where the LA is the same as developer, it is not required to make comments on the environmental impact statement but rather, the LA submits the environmental impact statement to the ED to make comments. As such, the ED may consequently involve other neutral LAs to make comments.

Table 6.2 Contents of the environmental impact statement

Contents of the environmental impact assessment
Activities generated by the project
Proposed site and alternatives
Potentially affected environment
Material inputs and their environmental effects
Economic analysis
Technology and process to be used and alternatives
Products and by-product of the project
Environmental effects of the project (direct, indirect, cumulative, short-term and long-term effects)
Mitigating measures
Uncertainties in compiling the information
Indication of whether environment shall be affected
How information was generated
Any issues as required by the Executive Director

Source: Environmental impact assessment regulations, section 14

The ED, if satisfied that environmental impact statement is complete, invites (within 10 days of receiving comments from LA) the general public to make comments. Invitation, which contains several aspects about the project, is done through newspaper media of wider national/local circulation for a period deemed necessary by the ED. The ED receives the comments within 28 days from date of inviting the public. The ED also invites comments from the people who are most likely to be affected by the project. This invitation is done through newspaper of local circulation (i.e. where project is to be located), other mass media, and local governments for a period deemed necessary.

The ED upon considering all comments from LA, general public and the specifically affected people either makes a decision or calls for a public hearing (PH) especially where there is controversy. However, it can also be the ED's opinion that the PH will culminate into a just/fair decision and also the PH may be necessary for environmental protection and good governance. If a PH is necessary, the ED requests the LA to carry it out. The PH is carried out within a determined period (set upon ED in consulting with the LA) of not less than 30 days or more than 45 days from receiving comments on the environmental impact statement from LA, general public, and the specifically affected people. The PH is presided over by a presiding officer (PO) appointed by the LA in consultation with the ED. The date and venue of conducting PH is widely publicised to attract attention of those affected by the project and those who made comments. Upon completing the PH, the PO makes a report (within 30 days) to the ED and LA. Also, the LA then makes a report (within 21 days) to the ED presenting the findings and recommendations.

The ED makes a decision within less than 180 days from when the developer submitted the environmental impact statement. The ED may: approve whole or part of the project; require redesigning or relocation of project; refer back to developer for more information in order to make decision about project; reject project. The 'accept decision' contains the conditions deemed necessary and states period of validity of approval. Though the regulation does not explicitly guide on what the 'reject decision' contains, it can be inferred that it prohibits the development to be carried out. A decision is communicated to the developer within 14 days in form of a certificate of approval. However, the approval may be later revoked if: conditions are not complied with, project changes leading to adverse environmental impacts, emergence of substantive issues not prior considered at approval. When revoked, the developer stops the project until rectifications are made. Any person aggrieved by any decision made by the ED can appeal to the High Court.

6.1.1.2.2 Process topology and attributes for the development permission subprocess

Application for building permission is carried out using a prescribed format and it contains several requirements as stipulated by the regulations (Table 6.3). The application should also include a form (i.e. Form A) for approval of plans in relation to the Public Health (Buildings) rules (1951). On Form A, the applicant further describes details about the proposed construction such as materials, water fittings and supply, and cost of proposed works. In addition, details of the drainage plans are also included. The application for a building permit is made to the relevant authority (i.e. local government) and subsequently forwarded to the relevant committee within that authority for consideration. The committee could be the Physical Planning Committee or the Building Control Committee. The composition of the committees depends on the nature of local government/authority (i.e. whether district, urban authority, city etc.). For urban authorities, the committee is composed of the Town Clerk, Urban Physical Planner, City Engineer, Environmental Officer, Land Surveyor, Architect, and a private Physical Planner.

Table 6.3 Contents of a building permit application

Contents of the building permit application	
Building Control Act (Section 35)	**Physical Planning Act (Sixth Schedule)**
Name, physical address and postal address of applicant	Owner's/applicant's address
Proof of land ownership	Type of land ownership
Registration certificate of the Architect and/or Engineer	Details of the land (plot, district, size, etc.)
Copies of building plans	Purpose for which land is used
Letter from Chairperson of the Village council	Whether the development requires new road access
For multi-stored buildings, structural design and plans approved by Engineer	Methods for water, sewerage, surface water, and refuse disposal
For multi-stored buildings, geotechnical report	Whether the development involves building operations
For multi-stored buildings, designs of soil support in case of excavations	Drawings and specifications signed by Physical Planner

Where the application requires an EIA, the planning authority may grant temporally approval of the development subject to the developer obtaining an EIA certificate. The decision may be granted with conditions, without conditions, or not granted at all. Within 30 days of making the decision, the authority notifies the developer/applicant, specifying conditions if any, or reasons for refusal if the permission is not granted. The decision may also be deferred for a given period; the applicant is notified accordingly, including the reasons for deferment. An aggrieved applicant may appeal to higher authorities (i.e. planning committees of higher local government levels).

During construction, building control officers have a right to visit the site of building construction to confirm whether operations are proceeding as per regulation and consent. Upon completing the construction of the building, the developer notifies the committee, and subsequently applies for an occupation permit, which has to be granted before the building is commissioned. Within 14 days of receiving an application for occupation permit, the committee inspects the development and if satisfied, issues an occupation permit.

6.1.1.2.3 Process topology and attributes for the building project subprocess

Generally, building projects are unique and therefore, variations in projects' execution procedures, actors, type of construction contract, procurement route adopted, and so forth, are expected. British colonial legacy still reigns in Uganda since construction practices largely follow British Standards. Therefore, the widely acceptable major phases of a building project suggested by the Royal Institute of British Architects (RIBA, 2013) plan of work stages are usually followed. In each of the stages, the important aspects to appraise are usually building designs, costs, and fulfilment of regulatory requirements. With the help of the author's experience in the referenced context, the building project subprocess was described as follows.

a) Pre-construction

In the preconstruction phase, there are several stages, which mainly include inception (preparation of reports/ design briefs), preliminary designing, and detailed designing. Upon satisfactory completion of the design phase, construction of the building starts. However, there are regulatory requirements to fulfil before construction begins. Depending on the nature of project, EIA may be required. For instance, buildings that are generally out of character with their surroundings may require an EIA. Initial environmental assessments are done in the preliminary stages and, if required, detailed environmental assessments are done during the detailed design stage. The application for building permission has to be done as per the DP subprocess earlier elaborated in section 6.1.1.2.2.

b) Construction

Construction proceeds as per contractual requirements adopted and during this phase, periodic progress reports on designs and costs are made. Regulatory requirements also have to be fulfilled; environmental and planning authorities carry out impromptu visits to check how far the project conforms to the conditions of planning approval. Upon practical completion of the building, an application for occupation permit is made, before the building is commissioned.

6.1.2 Process mapping

Results obtained from the process mapping exercise included the process scope, high level map, high-level hierarchy diagram, and the process model of the as-is system.

6.1.2.1 Process scope

The process scope for each of the three subprocesses is presented below.

6.1.2.1.1 Process scope for the environmental impact assessment subprocess

It was deduced from the process discovery information that EIA subprocess started when there was a need to carry out an EIA. This was born by the fact that the project fell into a category for which EIA is mandatory. Thus the EIA process was started/triggered whenever there was a request to do an EIA of a project.

The EIA subprocess was complete when the developer was informed of the decision of approval, rejection, or deferring of the project. The activities of appealing the decision by developer or invoking of the decision later (if developer defaults) were considered to be outside the EIA subprocess, though could influence the process instance (i.e. EIA to be repeated or granted). The process instance was defined as an EIA of the concerned a project.

The EIA subprocess was found to have more than one way in which it could end. It could end by approval of project, rejection of the project, partial approval of project, and referring of the project back to the developer (i.e. to make amendments). Essentially, sending a decision to the developer determined that the EIA subprocess was complete.

6.1.2.1.2 Process scope for the development permission subprocess

Unlike the EIA requirement which only applied to particular types of building projects, the requirement for DP encumbered all types of building developments. Information from the process discovery phase showed that the need for permission to undertake a development triggered the DP subprocess. The activity of the applicant appealing any decision was considered not part of the DP subprocess though could influence the process instance (i.e. DP process to be repeated). The process instance was taken as a DP approval of the concerned development.

Sending the second decision (i.e. occupation permit) to the developer determined that the DP subprocess was complete. Like the EIA subprocess, the DP subprocess had more than one way in which it could end: approved conditionally, approved unconditionally, rejected, or deferred.

6.1.2.1.3 Process scope for the building project subprocess

The building project (BP) subprocess was envisaged to start when the client or developer solicited services of a consultant to work on a prospective building, and end when the building was commissioned. The process instance was therefore the construction of a building. Unless there were eventualities, there was only one end state, that is, ‘building commissioned’. Therefore, commissioning the building implied that the building project subprocess was complete.

6.1.2.2 Delineation of the high level map

The high-level map consisted of three subprocess of EIA, DP, and BP. For each of the subprocesses, their respective high-level activities are presented with their corresponding end states: Table 6.4 for the EIA subprocess, Table 6.5 for DP subprocess, and Table 6.6 for the BP subprocess. For most of the subprocesses, although regulations specified the developer/applicant/client, in reality, a consultant is usually hired to manage the processes on behalf of the developer.

Table 6.4 Top level map for the EIA subprocess

No.	Top level activity (Actor)	End state (s)	Conditions/remarks
1	Prepare project brief (PB) (Developer)	PB submitted	None
2	Assess Project Brief (ED)	PB sent to LA, PB sent back to developer, Project has impacts and mitigations are not okay, Project has no impacts, Project has impacts and mitigations are okay.	Considered further only if project is acceptable, if no LA response (14 days) proceed to consider, if EISd not required, approve project
3	Comment on Project Brief (LA)	PB comments sent to ED	None
4	Develop EISd ToRs (Developer)	ToRs approved, ToRs Rejected	Consult LA and ED, proceed only if TORs are approved
5	Conduct EISd (developer)	EISm submitted	Publicise for at least 14 days
6	Asses EISm (ED)	EISm sent back to developer, EISm sent to LA, Public hearing call, Public hearing not required	Considered further only if EISm is complete, if no LA response (30 days), proceed to consider, if public hearing is not required approve project
7	Comment on EISm (LA)	EISm comments send to ED	None
8	Conduct Public hearings (LA/PO)	PH report (s) submitted	None
9	Consider approval (ED)	Project differed, Project Rejected, Project Approved, Project partly approved,	None

Note: ToR – Terms of Reference; EISm – Environmental Impact Statement; EISd – Environmental Impact Study

Table 6.5 Top level map for the DP subprocess

No.	Top level activity (Actor)	End state (s)	Condition/remarks
1	Prepare documentation (developer/applicant)	Documentation submitted	If application for occupation permit then necessary documentation is prepared
2	Assess application (Authority)	Application sent back to developer, Application sent to PP committee	Processed further if deemed complete
3	Consider application (Authority)	Fees invoice, Permit fees received , Granted unconditionally, Granted conditionally, Deferred, Not granted	Regulation allows for granting permit on condition that EIA certificate is obtained

Note: PP – Physical Planning; EIA – Environmental Impact Assessment

Table 6.6 Top level map for the BP subprocess

No.	Top level activity (Actor)		End state (s)	Condition/remarks
1	Preconstruction			
	a	Prepare inception report/brief (consultant),	Inception report prepared	None
	b	Prepare preliminary designs (consultant),	Preliminary design report prepared	None
	c	Prepare detailed designs (consultant)	Apply for environmental permit, apply for building permit, final design report complete	Wait for approval (of building or environmental permit) to proceed
2	Construct building (contractor)		Apply for occupation permit, Building commissioned	Wait for approval (of occupation permit) to proceed

6.1.2.3 Presenting the as-is process model using BPMN

The general description of the process model diagram is given, followed by results from process mapping of the three subprocesses, and expansion of the subprocess.

6.1.2.3.1 General description of the process model diagram (s)

The high-level diagram before empirical verification consisted of activities for the three subprocesses, with each subprocess occupying its own pool, albeit connected by linkages (see Figure 6.1). Activities that had conditions attached on them were drawn following gateway(s) (i.e. the diamond shapes) or events (i.e. the circular shapes) that tested the condition of the preceding activity. If there were two end states (i.e. end state 1 and end state 2),

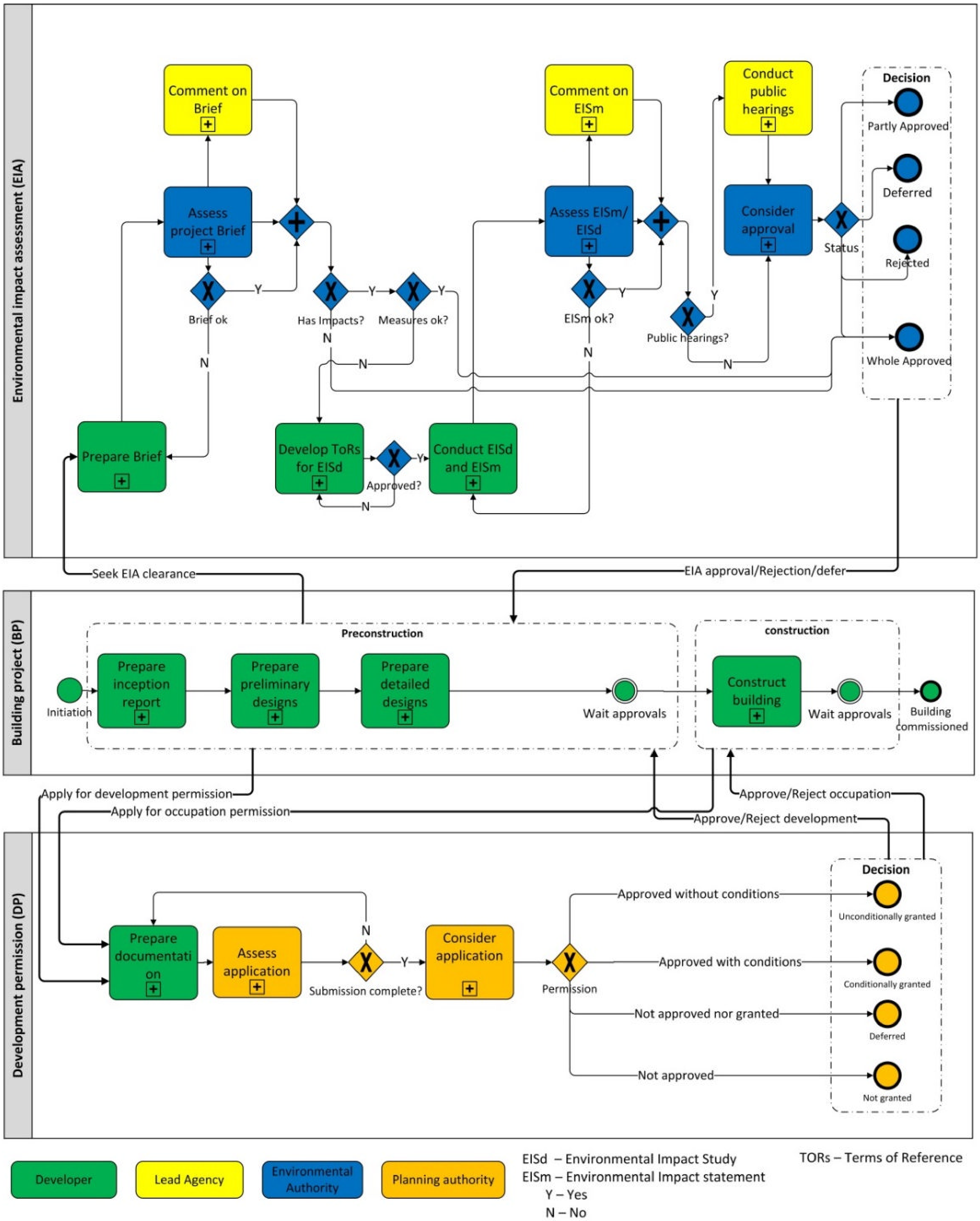


Figure 6.1 The as-is system before empirical verification

they were represented with an exclusive gateway, which was named after one of the end states. Such a gateway was labelled as a question (e.g. end state 1?), with the gates labelled Yes (Y) or No (N). If the endstates were more than two, the gates of the gateway were labelled with the respective end states (e.g. end state 1 for first gate, end state 2 for next gate, etc.). Activities done concurrently were preceded with a parallel gateway (i.e. for splitting into concurrent activities), while an activity that needed two or more activities to finish before it could begin, was preceded with a parallel gateway for joining the preceding concurrent activities.

6.1.2.3.2 EIA subprocess top level diagram

As listed in the top-level map (see Table 6.4), the EIA subprocess (see EIA pool in Figure 6.1) contains nine activities and starts with the activity of preparing the project brief which is triggered by the ‘seek EIA clearance’ link from BP. The EIA subprocess ended in four endstates each of which could affect the BP subprocess in various ways (e.g. begin or cancel construction, appeal etc.). This implies that activities in the BP subprocess that are dependent on EIA have to wait for any of the EIA’s end-states in order to initiate. Indeed the developer has to wait for the EIA approval decision in order initiate construction.

6.1.2.3.3 Building project subprocess top level diagram

The BP subprocess (see BP pool in Figure 6.1) was the focal subprocess of the process model because it was the reason for existence of all other subprocess. For that reason, the ‘start event’ and ‘end/terminate event’ for the overall process model resided in the BP subprocess. The BP subprocess was composed of four major activities structured into two phases: preconstruction (prepare inception report, prepare preliminary designs and prepare detailed designs) and construction (construct building). In the preconstruction phase, the consultant undertakes to fulfil the developer’s requirement of designing the building. If a project is one that requires environmental assessment, the EIA subprocess is triggered to begin within the preconstruction phase. Seeking environmental approval and obtaining a decision about the same are both modelled as two separate linkages connected between the EIA subprocess pool and the preconstruction phase. Application for building permission is also sought during preconstruction phase. Since a project cannot proceed without getting a building permit, this is represented by a “wait approvals’ intermediate event. In the same vein, a project for which EIA is required cannot proceed from this stage unless approved. The next activity, carried out by a contractor/builder, is that of construction which is shown by a ‘construct building’ activity, and only proceeds if requirements of development and environment regulations have been fulfilled. Although practical completion marks the end of the construction phase, developers have to apply (and wait) for approval of occupation permits. As such, commissioning of the building ends the building project subprocess, if the occupation permit is granted.

6.1.2.3.4 The DP subprocess top level diagram

As shown in the DP pool in Figure 6.1, the DP subprocess begins when the applicant seeks for a building permit or if it is at the end of construction, the occupation permit. The necessary documentation is prepared and submitted to the relevant authorities for assessment and upon confirming that it is complete, they proceed to consider the application. After considering the application, up to four outcomes are possible, as earlier highlighted in process discovery. Only when the ‘wait approvals’ events (within the preconstruction and construction phase of BP subprocess) receives a signal (‘approve/reject development’ and ‘approve/reject occupation’ linkages), does the developer react. Depending on the signal received (i.e. what the authority decides with the application), the developer then reacts accordingly (e.g. initiating construction). If the signal concerns occupation permit, and it has been granted, this ends the overall process model. The end is modelled with an end event labelled ‘building commissioned’.

6.1.2.3.5 Subprocess expansion

All the subprocesses’ activities of the top-level diagram shown in Figure 6.1 had no details since they were presented at an aggregate/collapsed level. For each collapsed activity of the subprocesses shown in the top-level diagram, the hierarchical process modelling approach prescribed that a separate child-level diagram had to be drawn. Therefore, child-level process diagrams were drawn for each collapsed activity of the ‘parent’ as-is top-level diagram. The various child-level diagrams are discussed in section 6.1.3.6, which presents the verified as-is system.

6.1.3 Verification of the as-is system

This section presents the outcomes from intra-design and empirical verification of the as-is system as per the methods explained in Chapter 5 section 5.4.1.3.

6.1.3.1 Intra-design verification

As can be observed in the description of the process model provided in section 6.1.2.3.1, the derived process models complied with various BPMN process modelling rules as listed in Appendix A section A.2. For instance, from Figure 6.1, it can be seen that all end events in a particular pool or lane had unique names, as per rule number 14. The recurrent reports produced upon checking compliance with the BPMN standard rules, using Microsoft Visio 2013, outlined issues that had to be addressed; an example is shown in Figure 6.2. At the bottom of figure are details about activities, gateways, events where a problem/issue had been identified. Upon addressing an issue, a compliance check was rerun until the report presented no issues requiring attention. Physical inspection of the process model to compare it with regulatory provisions showed that the relevant subprocesses and activities had been captured.

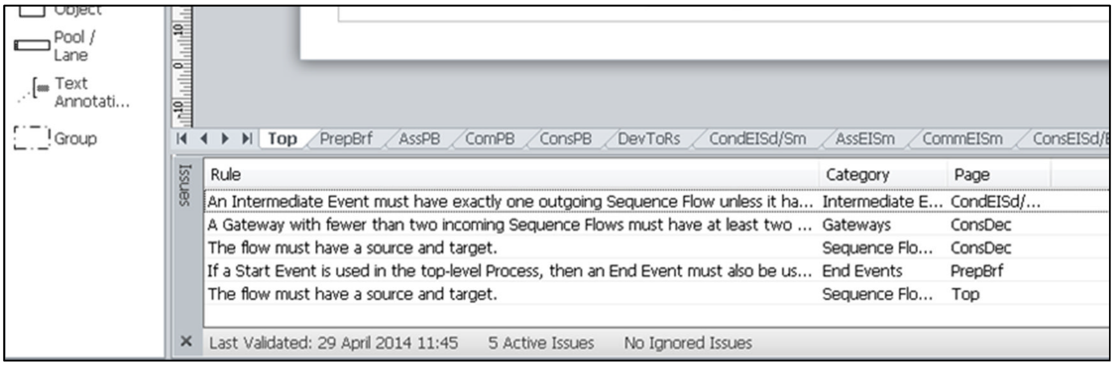


Figure 6.2 Compliance check of process model diagram

6.1.3.2 Empirical verification: data collection and preparation

At the end of the two-week data-collection period, seven interviews, each lasting for about thirty minutes, had successfully been conducted (see Table 6.7). Several attempts to make interview appointments with the Architect and Engineer for Kampala Capital City Authority proved futile. Meanwhile, it was learnt that although Kira Town Council had an established position for an

Architect, it was vacant. Equally, the position of Environmental Officer in Kira Town Council was vacant and the duties were carried out by the Physical Planner who thus doubled as an Environmental Officer. However, the Physical Planner was not counted twice although provided useful information on both the physical planning and environmental aspects. Since unsuccessful interview attempts were registered, some other members of the physical planning committees who were not on the initial SME list were considered. These included the Health Inspector for Kira Town Council, an environmentalist and a Land Surveyor, both from Kampala Capital City Authority.

Table 6.7 Summary of interviews conducted

Position as established by regulations	Physical planning committee	
	District (Kampala)	Urban area (Kira)
Physical planner	1	1
Architect	0	N/A
Engineer (Civil)	0	1
Environmental officer	1	N/A
Health Inspector	0	1
Environmentalist	1	0
Land Surveyor	1	0
Total	**4**	**3**

6.1.3.3 Empirical verification: overview of coding

The percentage distribution of comments/text coded per subprocess from the seven respondents is shown in Table 6.8. As can be observed, for each of the seven respondents, there was at least one subprocess from which no comments were coded. Verner noted that usually, “no single participant has a complete global view of the process from end to end” (Verner, 2004, p.3). It was therefore not surprising to find that some respondents’ narrations did not provide any pointers for coding in some subprocesses. Meanwhile, for each subprocess, its SMEs represented the most coding. The EIA subprocess received most coding from the environmental SMEs (69% from Environmentalist, 31% from Environmental Officer), while the BP (20% from Physical Planner A, 27% from Physical Planner B, and 20% from Engineer) and DP (29% from Physical Planner A, 36% from Physical Planner B) received most coding from the building and planning SMEs, respectively. Since each subprocess was largely identified by the respective SMEs, it can be argued that collection of new data (i.e. additional SMEs or local authorities) was unlikely to yield any new patterns. As such, the size and composition of the purposely selected sample was deemed to be sufficient.

Table 6.8 Percentage coding per subprocess

Subprocess	% coding from each of the seven respondents							Total
	a	b	c	d	e	f	g	
EIA	0.0	0.0	0.0	31.3	0.0	68.8	0.0	100
BP	20.0	26.7	20.0	0.0	6.7	13.3	13.3	100
DP	28.6	35.7	7.1	21.4	0.0	0.0	7.1	100

a = Physical Planner A, b = Physical Planner B, c = Engineer (Civil), d = Environmental Officer, e = Health Inspector, f = Environmentalist, g = Land Surveyor

6.1.3.4 Empirical verification: coding references with exemplars

Results regarding coding references with exemplars for the three subprocess and associated linkages are presented below.

6.1.3.4.1 Environmental impact assessment

The EIA subprocess, which contained most activities and actors, was verified to have been correctly represented by the process model. As can be seen (see Table 6.9), all activities, except ‘public hearings’, garnered coding references. Rival explanations were examined to understand why ‘public hearings’ did not register any coding or exemplars (see later section 6.1.3.5.1). It was also confirmed that EIA is not conducted for all kinds of projects. For instance, “a simple residential [building], which is not located in a fragile area, we do not require an EIA” (Environment Officer). The EIA subprocess was correctly described to begin with preparation of a brief by a consultant, assessment of the brief by the National Environment Management Authority (NEMA), commenting on the brief by stakeholders, development of terms of references by developer/consultant, conducting of impact study by developer/consultant, assessment of the environmental impact study by NEMA, commenting on impact study by stakeholders, holding public hearings if any, and consideration of approval by NEMA.

Table 6.9 Coding for the EIA subprocess

Top level activity		**Exemplars**
Theme description	**Coding reference**	
Prepare Brief (Developer/ Consultant)	2	"So, the way it all starts, you have to have a project brief" (Environmentalist)
Assess brief (NEMA)	1	"…you submit to NEMA. So depending on what you find out, if there are minimal impacts of the project, mitigation measure have been prescribed, the project may be approved there" (Environmentalist)
Comment on Brief (Lead agency)	1	"they will do what we call Environmental impact review and that is NEMA that does it and other stakeholders (Environmentalist)
Develop TORs (Developer/ Consultant)	3	"We have to review; actually, it is a big process because you have to get a consultant, do Terms of reference…"(Environment Officer)
Conduct Impact study and statement (Developer/ Consultant)	3	"…if the EIR process has not been able to identify proper mitigation measures and probably some impacts, then there they will ask you to go for a detailed Environmental Impact Assessment study" (Environmentalist)
Assess Impact study and statement (NEMA)	2	"So in this stage we do all the studies, the flora, fauna, air, soils, geotech etc, depending. Then you do the environmental impact statement then you submit to NEMA…" (Environmentalist)
Comment on impact statement (Lead Agency)	2	"That report is again sent to NEMA, NEMA then sends to these different stakeholders. Then these different stakeholders have to review it. After reviewing it, they send their comments back to NEMA" (Environment Officer)
Conduct public hearings (Lead Agency)	0	No exemplars registered
Consider approval (NEMA)	2	"That is where after submission, it is decision making, because the review goes on and on, and then NEMA will decide whether to approve the project or not to approve" (Environmentalist)

6.1.3.4.2 Building project subprocess

For the BP subprocess, the two major activities (the preconstruction phase and construction phase) and the three events (initiation of the project, end of preconstruction, and end of construction phase) all garnered exemplars (Table 6.10). Therefore, it sufficed to conclude that the BP subprocess and its corresponding actors had been appropriately reflected by the process model. It was noted that in order to construct a building, the building plans had to be first approved by the relevant authority. Meanwhile, an environmentalist clarified that environmental assessments are usually done during the feasibility stage. In addition, it was learnt that building projects' details (e.g. plans and specifications) are a crucial input into the EIA. This confirmed the existence of activities in the preconstruction phase. It was also noted that during construction, various checks are usually carried out by the local authority to confirm adherence to the relevant requirements. These checks can vary depending on the type of building. For instance, for high-rise developments, a supervising consultant is required. Meanwhile, at the end of the construction, an occupation permit is required before the building can be used. From these observations, it was concluded that the BP subprocess had been modelled adequately to reflect the formal practices.

Table 6.10 Coding for BP subprocess

Top level activity		Exemplars
Theme description	**Coding ref.**	
Phase 1 – Preconstruction (Developer/Consultant)	7	"Yeah an approval, especially, not only architectural, architectural and structural should be approved" (Engineer). "For big projects, we do EIA as part of feasibility, so they have their bit of designing" (Environmentalist). "…for a project that needs feasibility, I would go to the field, do my TORs, submit, wait for [EIA] approval, they give it to me, I still wait for the [construction] design" (Environmentalist).
Phase 2 – Construction (Developer/ Consultant)	8	"We don't have too much capacity to be everywhere at the right time, meaning, some construction can go on without being detected, yet they are building wrongly" (Health Inspector). "Then after approval, we have what we call a Job card, its yellow. It shows all the stages of construction of the building. So the building inspector is supposed to tick […] you call him, he signs […] so per stage you have to call him" (Physical Planner A). "If it is a storied building/ high-rise, vertical developments, there are other requirements that are needed, maybe supervision…" (Physical Planner B).

6.1.3.4.3 Application for development permission subprocess

As can be seen from the coding summary of the DP subprocess (see Table 6.11), all the high-level activities/themes registered coding references. This implied that these themes had at least been talked about by respondents.

Table 6.11 Coding for DP subprocess

Top level activity		Exemplars
Theme description	**Coding references**	
Prepare documentation (by developer/applicant)	2	"The approval process; ideally, there is a client, who is the owner the developer himself or the agent who is the architect" (Physical Planner B). "…clients bring in files through customer care, that is, we have a tent outside there…" (Physical Planner A).
Assess application (by Local authority)	8	"…when you submit the drawings, we make for you an assessment […] we have acknowledged that we have received the drawings" (Physical Planner B). "The physical planner looks through to see those that meet the basic requirements for assessment" (Physical Planner A). "My role there is to see adequacy of the plot, the proposed development. I check plot dimension, plot area and shape" (Land Surveyor).
Consider application (by Local authority)	4	"But in case everything is fine, it is presented now to the final committee, PPC, that is, the physical planning committee" (Physical Planner A). "So after that process of scrutinising the drawings and establishing a b c d, payments have been made, we then approve the drawings" (Physical Planner B). "…we do have conditional approvals depending on […], when we give you an approval letter, it has conditions on what you have to adhere to […] it stipulates exactly what you are requested to do before you commence construction" (Physical Planner B).

The process model had illustrated that the DP subprocess began when the applicant, who could be a developer or a consultant, required a building permit. From the exemplars presented in Table 6.11, it can be observed that the initiation of the DP subprocess and the associated actors had been modelled and identified correctly. Data suggested that the first activity of 'prepare documentation' had also been correctly modelled, and it was indeed a responsibility of the client or a nominated consultant to prepare documentation. As the process model had described, the 'consider application' activity was found to be handled by the physical planning committee, and conditional approvals were among its end-states.

6.1.3.4.4 Linkages

Data presented in Table 6.12 suggests that the initial six linkages were identified by the respondents, since each of these linkages garnered some coding references. Examples of interview excerpts in which these linkages were identified by the respondents are provided in Table 6.13. Overall, these data suggest that information documented in the process model was accurate.

Table 6.12 Coding reference for linkages

Linkage from	Linkage to	Description of linkage	Coding reference
Building project	Development permission	Apply for development permission	3
		Apply for occupation permit	3
Development permission	Building project	Approve/Reject development	3
		Approve/Reject occupation permit	3
Building project	Environmental impact assessment	Seek for EIA clearance	6
Environmental impact assessment	Building project	Approve EIA	2

Table 6.13 Exemplars for the linkages

Description of linkage	Exemplar
Apply for development permission	"clients bring in files through customer care, that is, we have a tent outside there" (Physical Planner A).
Apply for occupation permit	"…you've finished the structure; you [developer] have to apply for an occupation permit (Physical Planner A).
Approve/Reject development	"…we then approve the drawings and we give a client a copy, we also issue an approval letter (Physical Planner B).
Approve/Reject occupation permit	"…we are supposed to assess after the project is complete, more especially perhaps may be when we demand for an occupation permit (Physical Planner B).
Seek for EIA clearance	"we usually ask for […] NEMA report because of very high buildings, or in case you are in a swamp" (Physical Planner A).
Approve EIA	"…they [NEMA] will give you a certificate, an EIA certificate, with approval conditions, always" (Environmentalist).

6.1.3.5 Empirical verification: rival explanations

Upon inspection, rival explanations were identified in the DP and EIA subprocesses, and associated linkages, as presented below.

6.1.3.5.1 Application for development permission subprocess

In the DP subprocess, some rival explanations were identified in the 'assess application' and 'consider application' activities. The process model captured that 'assess application' had one child-level activity of 'screen documentation', with two end states of 'application not complete' and 'application submitted to physical planning committee'. In addition, only one flow depicting return of incomplete submissions to the developer had been described (i.e. resulting from the 'application not complete' end state). However, it was discovered from the interviews that upon checking the application for basic requirements, site visits are made, and if the development does not comply with requirement, it is referred back to the client. Upon confirming that the development complies with requirements, an assessment for the approval fees is made, and the developer is notified accordingly to make the necessary payments. At that time, the developer is also advised on whether an EIA will be required. When the developer returns after making necessary payments, an EIA certificate is also expected of him/her. This implied that there were additional flows to and from the 'prepare documentation' activity which had not been captured by the process model and therefore had to be considered in the revised process model. These aspects are summarised by the quotations below:

> *"after making for you the assessment, we organise for site inspection to see what you are going to put there with respect to our structure plan […] If it does not [comply], you refer back to the client to make the necessary alterations"* (Physical Planner B).

> *"… someone picks them from here then takes them to TRT [technical review team] […]; for them their first thing is to go to the field to basically verify; because if you told us there is nothing on ground, we go to see whether there is actually no development on ground"* (Physical Planner A).

> *"…the client gets that assessment form then goes to our revenue department then he is given a bank slip. He goes [to the bank], pays, then brings back the plan but this time it's for submission; the initial stage is for assessment, so plans are grouped in to assessment and submission* (Physical Planner A).

6.1.3.5.2 Environmental impact assessment process

As highlighted earlier in the EIA subprocess (section 6.1.3.4.1), all activities registered coding references with exemplars, except the activity of 'conduct public hearings'. However, although 'conduct public hearings' did not register any coding reference, no rival explanations were found. This implied that it was a formal activity, as required by law, though perhaps rarely executed. Meanwhile, interviewees clarified that the EIA subprocess is generally structured into three phases: screening, environmental impact study, and decision making. This was considered in the revised process model, as can be seen later in Figure 6.3.

6.1.3.5.3 Linkages

Although the initial six linkages documented by the process model had all been correctly verified, more linkages were unveiled between the BP and DP subprocesses. It was discovered that usually, the EIA is initiated in the DP subprocess but not in the BP subprocess, as earlier envisaged. Interviews revealed that it is rarely a developer's initiative to do an EIA.

> *"…once I request for an EIA, the client goes and gets a consultant who must be registered with NEMA"* (Environmental Officer)

Therefore, when an application for development permission is made to the local authority, the developer is advised whether an EIA is required. As such, there was a need to create a new linkage about EIA, between the BP and DP subprocesses.

Another identified linkage was related to payments of permit fees. When the application is assessed, the developer is notified about the amount of fees. An official clarified that when "the clients come back, we call the clients, and they pick those plans, then they go and pay" (Physical Planner A). The developer/client, upon making the necessary payments, submits proof of payment. So when the developer resubmits the plans after making payments, the EIA approval, if required, is also part of the submission package. This information had not been captured like that by the process model and therefore, linkages demonstrating aspects of payments had to be included in the revised process model. However it was found that the permit fees and EIA requirement are usually addressed at the same time, as can be seen from evidence quoted below:

> *"But normally some people, not to waste their time, we tell you, when you are submitting, after we have assessed you, when you bring it back [after making payments], bring the NEMA certificate"* (Physical Planner A)

Therefore, the linkage for EIA (as described in the preceding paragraph) and that of permit fees were combined. This resulted into a new pair of linkages between the DP and BP subprocesses (i.e. need for EIA and/or fees, and submit EIA certificate and/or proof of payments) as can be seen in the verified as-is system discussed in the next section.

6.1.3.6 Verified as-is system

The verified existing practices regarding the development approval process were confirmed to be environmental impact assessment (EIA), building project (BP), and application for development permission (DP) (see Figure 6.3, and refer to Appendix D for the corresponding as-is child-level diagrams). Results from verification (refer to Table 6.9, Table 6.10, Table 6.11, Table 6.12, and Table 6.13) suggest that largely, there were minimal differences between what had been described by the process model and what was identified in formal practice.

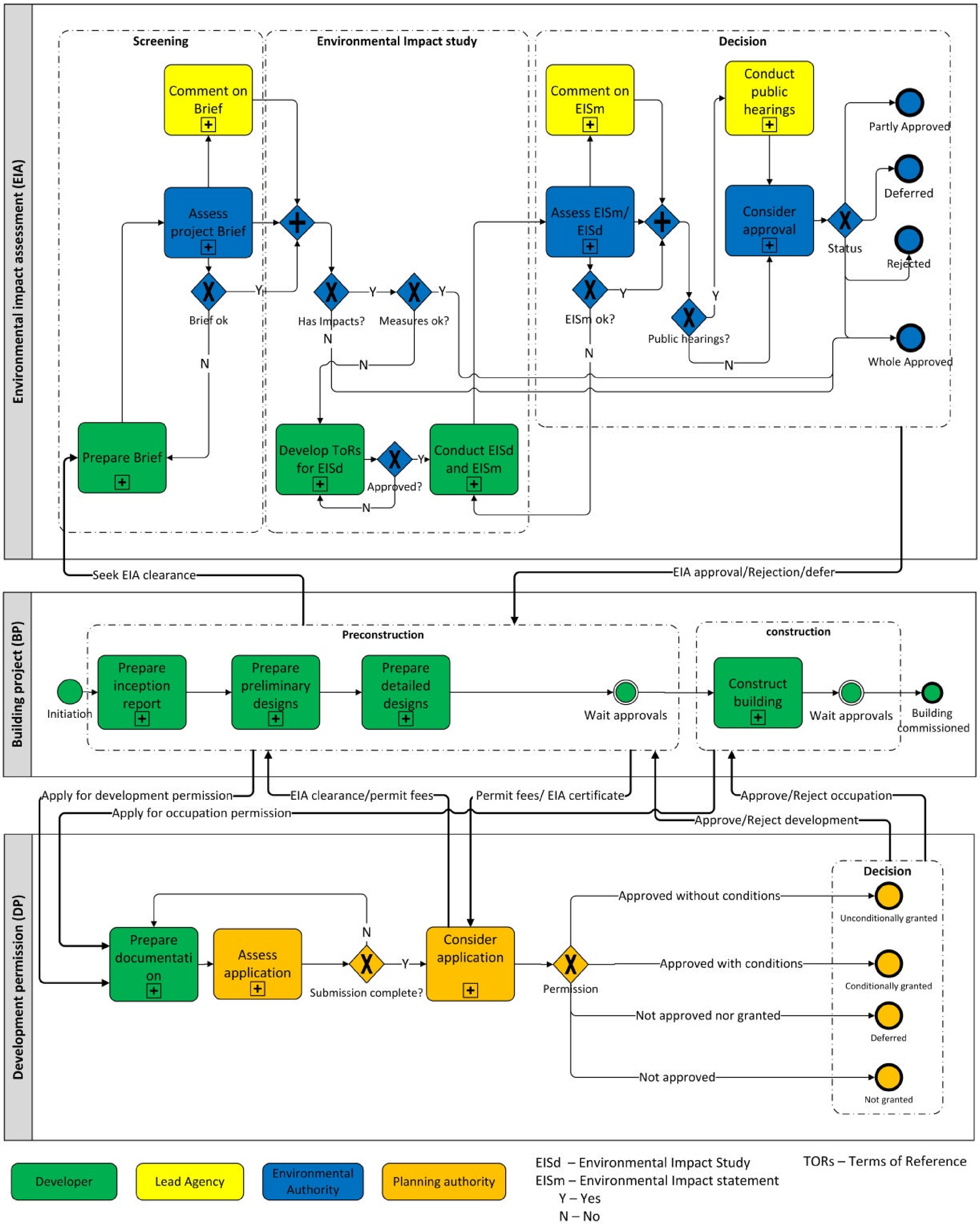


Figure 6.3 Verified as-is system

Having found minimal differences between what had been described by the process model and what was identified in formal practices, this implied that the existing practices had been correctly captured by the verified process model of the as-is system. The variations identified (see section 6.1.3.5) were not material enough to compromise the integrity of the process model but suggested that some activities had been captured at an aggregate level. This corroborates the argument that regulations do not necessarily have to be prescriptive, implying that there can be flexibility for the formal practice to prescribe how to comply with regulations (Penny et al., 2001).

6.2 The possibility of integrating EC in the as-is system

Results from analysing the as-is system show that the regulatory framework that governs the construction of buildings in Uganda (Building Control Act; Physical Planning Act; National Environmental Act) is silent on matters related to energy efficiency and EC from buildings. No reference was found on consideration of energy consumption and/or efficiency of prospective buildings. In addition, none of the SMEs referred to energy efficiency as a prerequisite for assessing building permit applications. This finding confirms assertions in Cheng et al. (2008 p.33), that “many developing countries don’t yet have adequate building codes, let alone regulations for energy efficiency in buildings”. In the case of the current practice in Uganda, this finding suggests that environmental impacts, such as EC, that are associated with energy consumption of buildings, are overlooked.

Upon exploring the possibility of integrating EC accounting in the current development approval process, it was found that the only opportunity to assess the potential environmental impacts of buildings is during the EIA subprocess. However, not all building projects are subjected to EIA. The National Environment Act stipulates that generally, projects subjected to EIA are those that include: “an activity out of character with its surroundings”, “any structure of a scale not in keeping with its surroundings”, and “major changes in land use”. This suggests that most building projects, especially those related to residential buildings, are usually exempted from EIA, as highlighted by respondents’ interview excerpts below:

> *Then we also look at, basically the area, the surrounding area. There are certain places that the soils we know are suspect. Then we also look at the length of the building. But usually, if it is a bungalow, even if it is 200 meters, we shall not ask you for NEMA. Even if say it's one more story, we shall not ask you* (Physical Planner A).

> *For example a simple residential [building], which is not located in a fragile area, we do not require an EIA* (Environmental Officer).

The findings regarding the contents of a typical building permit application suggest that assessment of EC is not a requirement. The contents of a project brief (see Table 6.1), environmental impact statement (see Table 6.2), and building permit application (see Table 6.3) do not provide for explicit consideration of carbon emissions associated with buildings, let alone EC. This suggests that currently, there are no formal initiatives related to accounting for EC emissions in the development approval process of building projects in Uganda. The absence of EC accounting in the development approval process of buildings suggests that Uganda is not up to date with advances in promoting low-carbon buildings. Literature discussed in Chapter 2 (section 2.2.3) suggested that in other countries like UK (Brighton and Hove, 2013), Hong Kong (Yuan and Ng, 2015), Australia (Teh et al., 2015), and Singapore (Yeo et al., 2016), EC is considered as an assessment criteria for the environmental sustainability performance assessment of buildings. Since these initiatives from elsewhere show that quantification of EC is fundamental, improvement of the practice in Uganda necessitates an approach to facilitate quantitative assessment of EC in the EIA of building projects, during the development approval process. This approach, the author posits, should be in form of a mathematical model.

6.3 Chapter summary

This chapter has presented findings from addressing objective one and two. The current practices related to the development approval process have been described to be EIA subprocess, DP subprocess, and the BP subprocess. These subprocesses have been presented as an as-is system, in form of a process model, based on BPMN. Findings from analysing the as-is system suggested that accounting for EC is not considered in the development approval process of buildings in Uganda, yet recent advances in other countries suggested otherwise. In order to improve the current practice in Uganda, the author argued, incorporation of EC accounting in the development approval process of building projects is necessary, and this can be undertaken during EIA. To achieve this, the author argued, requires developing an approach for quantifying EC. The next chapter, which presents outputs from the third research objective, presents the approach in form of a model to facilitate the integration of EC accounting in the development approval process of building projects.

Chapter 7
An approach to facilitate the integration of EC

The previous chapter concluded with a suggestion that there is need to develop a model for quantifying EC, so as to facilitate the integration of EC accounting in the development approval process of building projects in Uganda. As such, this chapter presents a mathematical model and tool for quantifying EC, based on the methods explained in Chapter 4 section 4.4 and Chapter 5 section 5.3.

7.1 The mathematical model

Upon executing the methods described in Chapter 4 section 4.4.1, the equations defining emissions from construction materials, emissions from plant, emissions from workforce, constraints, and the final model are presented hereunder. The uniqueness of the mathematical model and verification of each of its equations, are also presented.

7.1.1 Emissions from construction materials

Emissions from manufacturing and transporting n construction materials, using e different sources of energy are given by Equations (7.1) and (7.2) below, respectively. Three options A, B, and C, were considered in Equation (7.2). Option A is applicable where the weight of materials is significant and known, and the distance of transportation can be estimated. Option B is applicable where the weight of materials is insignificant (whether known or unknown) and the quantity of energy used is known. Option C is suitable where weight of materials is insignificant (whether known or unknown) and the distance of transportation can be estimated:

$$EC_{m1} = \sum_i^n \rho_i \left(\sum_j^e V_{ij}\, C_j^a \theta_j^a + S_i\right) \tag{7.1}$$

$$EC_{m2} = \begin{bmatrix} \sum_i^n \rho_i \left(\sum_j^e W_{ij}\, X_j^a C_j^a \alpha_j^a\right); \mathit{If\ option\ A\ conditions\ apply} \\ \sum_i^n \sum_j^e W_{ij}^a\, C_j^a\, \alpha_j^a; \mathit{If\ option\ B\ conditions\ apply} \\ \sum_i^n X_j^a \left(\sum_j^e C_j^b\, \alpha_j^a\right); \mathit{If\ option\ C\ conditions\ apply} \end{bmatrix} \tag{7.2}$$

where: EC_{m1} is the total emissions from manufacturing materials (in $kgCO_2$); ρ_i is the quantity of material type i (in kg); V_{ij} is the quantity of energy j to manufacture a unit of material i (in kWh/kg) (see Table 7.1); C_j^a is the carbon emission factor (in $kgCO_2$/kWh) per unit energy j used (see Table 7.2); θ_j^a is a disaggregation factor in manufacturing material i; S_i is a constant for process emissions per unit of material i (in $kgCO_2$/kg) (see Table 7.1); EC_{m2} is the total emissions from transporting materials (in $kgCO_2$); W_{ij} is the quantity of energy j to transport a unit of material i per unit distance (in kWh/kgkm); X_j^a is the transport distance for material i (in km); α_j^a is a disaggregation factor in transporting materials; C_j^b is the carbon emission factor per unit distance (in $kgCO_2$/km) with respect to the corresponding transportation energy j (see Table 7.3); W_{ij}^a is the quantity of energy j to transport material i (in kWh).

Table 7.1 Energy constants for various energy sources

Material type	**V_{ij} (kWh/kg)**	**Remarks**
Cement	1.253 (general)	Process emissions (S_i) of 0.52$kgCO_2$/kg clinker, 23% cementitious additions on average
	1.528 (Portland)	CEM I Portland 94% Clinker
Sand	0.023 (general)	Gravel or Crushed Rock
Aggregates	0.023 (general)	
Steel	5.583 (general)	Recycled Content ~ 59%
	9.833 (virgin)	
	2.611 (recycled)	
Glass	4.167	Primary glass, process emissions (S_i) of 0.185$kgCO_2$/kg
Brick (common brick)	0.833 (general)	6MJ per brick

Source: adapted from Hammond and Jones (2011)

Table 7.2 Emission constants

Fuel/energy source	C_j^a **(kgCO2/kWh)**	
	Direct	**Indirect**
Natural gas	0.20421	0.03118
Diesel (100% mineral diesel)	0.26757	0.05688
	0.68 (Uganda)	
Petrol (100% mineral petrol)	0.25343	0.05076
Fuel oil	0.28594	0.05382
	0.71 (Uganda)	
Coal (industrial)	0.32893	0.05527
Coal (electricity generation)	0.33792	0.05527
Electricity	0.44548 (UK grid for 2013)	
	0.14 (Uganda grid)	
Solar (Photovoltaic)	0.075	
Solar (Concentrating Solar Power)	0.089	
Hydropower	0.043	
Wind	0.081	

Source: Defra/DECC (2013); IPCC (2011); UNFCCC (2010)

Table 7.3 Emission constants for transportation

Fuel	C_j^b **(kgCO2/ Km)**		**Remarks**
	Direct	Indirect	
Petrol	0.21485	0.04126	Average: up to 3.5t (vehicle reference weight), 40% laden, light commercial vehicles
Diesel	0.25190	0.04837	
LPG	0.26533	0.03330	
CNG	0.24126	0.03561	
Diesel	0.83098	0.15942	Average (>3.5t), rigid heavy goods vehicles, 50% laden.
	0.98252	0.18850	Average (>3.5t) , articulated heavy goods vehicles, 60% laden

Source: Defra/DECC (2012); Tables 7b,c, d and e

7.1.2 Emissions from plant

Emissions from operation and transportation of p plant, using e different sources of energy are given by Equation (7.3) and (7.4) respectively:

$$EC_{q1} = \sum_q^p \varphi_q \left(\sum_j^e U_{qj}\, C_j^a \theta_j^b\right) \quad (7.3)$$

$$EC_{q2} = \sum_q^p \varphi_q^b \left(\sum_j^e Y_{qj}\, X_j^b C_j^a \alpha_j^b\right) \quad (7.4)$$

where: EC_{q1} is the total emissions from operating plant (in kgCO2); φ_q is the number of plant type q; U_{qj} the quantity of energy j used for operating plant q (in kWh); C_j^a is the carbon emission factor (in kgCO2/kWh) per unit energy j

used (see Table 7.2); θ_j^b is a disaggregation factor in operating the equipment; EC_{q2} are the total emissions from transporting plant; φ_q^b is the weight of plant q (in kg); Y_{qj} is the quantity of energy j to transport a given weight of plant q per unit distance (in. kWh/kgkm); X_j^b is the transport distance for plant q (in km); α_j^b is a disaggregation factor in transporting the plant. Options mentioned in Equation (7.2) about material transportation can equally apply to transportation of plant in Equation (7.4).

7.1.3 Emissions from workforce

Emissions from transporting workforce for duration r, using e different sources of energy were given by Equation (7.5) considering two options A and B. Option A is applicable where the duration of transporting the workforce and the quantity of energy used per unit duration are known. Option B is applicable where the duration of transporting the workforce, the quantity of workforce, the distance travelled, and the modes of transport used are all known.

$$EC_l = \begin{bmatrix} \sum_f^r \beta_f \left(\sum_j^e Z_{fj}\, C_j^c \alpha_j^c\right);\ If\ option\ A\ conditions\ apply \\ \sum_f^r \beta_f\, L_f X_j^c \left(\sum_j^e C_j^d\, \alpha_j^d\right);\ If\ option\ B\ conditions\ apply \end{bmatrix} \quad (7.5)$$

where: EC_l is the total emissions from transporting workforce (in $kgCO_2$); β_f is the duration f workforce is transported (in days); Z_{fj} is the quantity of energy j to transport workforce per duration (in kWh/day); C_j^c is the carbon emission factor of the transport energy used (in $kgCO_2$/kWh) (see Table 7.2); α_j^c is a disaggregation factor for transporting workforce; L_f is the number of people in the workforce required; X_j^c is the distance travelled by a person per duration (in km/day); C_j^d is the carbon emission factor per person per unit distance depending on the mode (e.g. bus, train, cycle) of transport used (in $kgCO_2$/personkm) (see Table 7.4); α_j^d is a disaggregation factor for the mode used in transportation.

Table 7.4 Emission constants per transportation mode

Mode	C_j^c **(kgCO2per Km)**[a]	
	Direct	**Indirect**
Average petrol car	0.20864	0.03707
Average diesel car	0.19354	0.03680
	0.545 (Uganda)	
Average petrol hybrid car	0.13900	0.02465
Average LPG car	0.21306	0.02649
Average CNG car	0.19001	0.02757
Average petrol motorbike	0.11912	0.02072

[a] Emissions per person per km (C_j^d) are obtained by dividing the respective figure in the table with the number of passengers in that vehicle. Source: Defra/DECC (2012); UNFCCC (2010)

7.1.4 Conditions subjected to the model

The direct and indirect emissions (defined as per Defra/DECC, 2013) fulfil Equation (7.6), whereas the disaggregation factors for all the different sources of energy e sum to unity, as expressed by Equations (7.7) and (7.8):

$$C_j^{a,b,c,d} = D_j + I_j \qquad (7.6)$$

$$\sum_j^e \theta_j^{a,b} = 1\,;\ 0 \leq \theta_j^{a,b} \leq 1 \qquad (7.7)$$

$$\sum_j^e \alpha_j^{a,b,c,d} = 1\,;\ 0 \leq \alpha_j^{a,b,c,d} \leq 1 \qquad (7.8)$$

where: D_j and I_j are the direct and indirect emissions resulting from energy source j, respectively.

7.1.5 The final model

The final derived consolidated model for the total EC (EC_T) of a building project is given by Equation (7.9) below.

$$EC_T = (EC_{m1} + EC_{m2}) + (EC_{q1} + EC_{q2}) + EC_l \qquad (7.9)$$

7.1.6 Uniqueness of the mathematical model

As can be seen, the mathematical model caters for emissions from construction materials, emissions from plant, and emissions from workforce. This implies that the model uses the cradle to construction completion boundary which, as argued earlier (Chapter 2 section 2.3.2), adequately accommodates the entire building projects' boundary. To address the prevalent problem of quantifying emissions in an aggregated manner (refer to earlier discussions in Chapter 2 section 2.3.3.1), disaggregation factors (θ_j^a, α_j^a, θ_j^b, α_j^b, α_j^c, and α_j^d) were introduced in the model to allow for disaggregation. This enables the specific sources of energy to bear on the quantification, in a manner that allows differentiating the contribution of the different sources of energy to the resulting EC.

The relevance of disaggregation, as embedded in this mathematical model, is that it can facilitate making second-order decisions based on value judgement. For instance, if two bricks have the same EC (i.e. kgCO_2 per brick), a first-order decision based on the quantity of EC might be irrelevant as both bricks will have the same environmental impacts related to emissions. However, applying disaggregation could for instance reveal that one of the bricks was manufactured using biomass, whereas the other was manufactured using hydro-electricity. Based on this information, value judgements can be made regarding which brick to use in light of the circumstances surrounding the energy sources. In addition, as has been demonstrated (see Equation 7.5, option B), disaggregation can extend to other components of the model that are not related to energy, for example, the modes of transporting materials. In that way, disaggregation can facilitate achieving emission reductions through trade-offs by varying transport modes. Such aspects of value judgement, and emission trade-offs, which are all facilitated by disaggregation, are potential drivers for sustainable construction.

7.1.7 Verification of the mathematical model

All derived equations were satisfactorily checked for dimensional homogeneity. Table 7.5 shows a list of all the terms used in the equations, their units, and the corresponding derived dimensions based on the fundamental dimensions (mass (*M*), length (*L*), and time (*T*)) that were used in dimension analysis. A step by step example of assessing dimensional homogeneity for Equation (7.1) is illustrated below in six steps:

Step 1 involves stating the equation: $EC_{m1} = \sum_i^n \rho_i \left(\sum_j^e V_{ij}\, C_j^a \theta_j^a + S_i\right)$

Step 2 involves breaking down the equation into constituent terms and deducing their dimensions; from inspection, the above equation can be broken down into three terms:

EC_{m1}, $\rho_i V_{ij} C_j^a \theta_j^a$, and $\rho_i S_i$

The dimensions for the above three terms can be deduced as follows:

EC_{m1} was measured in kgCO2 (i.e. mass) and thus $[EC_{m1}] = M$

ρ_i was measured in kg and thus $[\rho_i] = M;$

V_{ij} was measured in kwh/kg and thus $[V_{ij}] = (ML^2T^{-2})/M;$

C_j^a was measured in kgCO2/kWh and thus $[C_j^a] = M/(ML^2T^{-2});$

θ_j^a was a dimensionless constant and thus $[\theta_j^a] = 1;$

S_i was measured in kgCO2/kg and thus $[S_i] = M/M.$

Step 3 and 4 involve substituting the deduced dimensions into each of the terms of the equation and solving the powers:

$[EC_{m1}] = M,$

$[\rho_i V_{ij} C_j^a \theta_j^a] = (M \times (ML^2T^{-2})/M \times M/(ML^2T^{-2}) \times 1) = M,$ *and*

$[\rho_i S_i] = (M \times M/M) = M.$

Step 5 involves inspecting the dimensions on either sides of the equation to check whether they are similar.

Step 6 involves confirmation: it can be confirmed that Equation (1) is dimensionally consistent.

Verification of other equations is presented as follows: Table 7.6 for Equation (7.2), Table 7.7 for Equation (7.3), Table 7.8 for Equation (7.4), Table 7.9 for Equation (7.5), Table 7.10 for Equation (7.6), Table 7.11 for Equation (7.7), Table 7.12 for Equation (7.8), and Table 7.13 for Equation (7.9). As can be observed from step number six in each of the tables, all the equations were verified to be dimensionally consistent. Peer review provided extra scrutiny of the mathematical model as any other inconsistences or incompleteness were addressed by attending to the reviewers' comments. Since the model was accepted for publication, this was suggestive evidence that it was a correct model (Kibwami and Tutesigensi, 2014).

Table 7.5 Terms and their dimensions

Symbol	Representation	Units	Dimensions
EC_{m1}	Emissions from manufacture of materials	$KgCO_2$	M
EC_{m2}	Emissions from transportation of materials	$KgCO_2$	M
EC_{q1}	Emissions from operation of construction equipment	$KgCO_2$	M
EC_{q2}	Emissions from transportation of construction equipment	$KgCO_2$	M
EC_l	Emissions from workforce transport	$KgCO_2$	M
ρ_i	Quantity of material	kg	M
V_{ij}	Energy use per unit of material	Kwh/kg	$(ML^2T^{-2})/M$
C_j^a	Emissions per unit of energy	$kgCO_2$/Kwh	$M/(ML^2T^{-2})$
θ_j^a	Disaggregation factor in material manufacture	dimensionless	1
S_i	Emissions per unit of material	$kgCO_2$/kg	M/M
W_{ij}	Energy used per unit of material per unit distance	Kwh/kgkm	$(ML^2T^{-2})/ML$
X_j^a	Transport distance for material	Km	L
α_j^a	Disaggregation factor in material transportation	dimensionless	1
W_{ij}^a	Energy used to transport material	Kwh	ML^2T^{-2}
C_j^b	Emissions per unit distance	$kgCO_2$/km	M/L
φ_q	Number of equipment	No.	1
U_{qj}	Energy to operate equipment	Kwh	ML^2T^{-2}
φ_q^b	Weight of equipment	Kg	M
θ_j^b	Disaggregation factor in operating equipment	dimensionless	1
Y_{qj}	Energy used per weight of plant per unit distance	Kwh/kgkm	$(ML^2T^{-2})/ML$
X_j^b	Transport distance of plant	Km	L
α_j^b	Disaggregation factor in transporting equipment	dimensionless	1
β_f	Duration of using workforce	days	T
Z_{fj}	Energy used to transport workforce per day	Kwh/day	$(ML^2T^{-2})/T$
C_j^c	Emissions per unit of energy for transporting	$kgCO_2$/Kwh	$M/(ML^2T^{-2})$
α_j^c	Disaggregation factor in transporting workforce	dimensionless	1
L_f	Number of people in the workforce	No.	1
X_j^c	Distance per person per day	Km/day	L/T
C_j^d	Emissions per person per unit distance	$kgCO_2$/personkm	M/L
α_j^d	Disaggregation factor for transport mode	dimensionless	1
D_j	Direct emissions	$kgCO_2$	M
I_j	Indirect emissions	$kgCO_2$	M

Table 7.6 Dimension analysis for Equation 7.2

Steps		Left hand side	Right hand side		
			Option A	Option B	Option C
1	State equation	EC_{m2}	$\sum_{i}^{n} \rho_i \left(\sum_{j}^{e} W_{ij} X_j^a C_j^a \alpha_j^a \right)$	$\sum_{i}^{n} \sum_{j}^{e} W_{ij}^a C_j^a \alpha_j^a$	$\sum_{i}^{n} X_j^a \left(\sum_{j}^{e} C_j^b \alpha_j^a \right)$
2	Break equation into constituent terms	EC_{m2}	$\rho_i W_{ij} X_j^a C_j^a \alpha_j^a$	$W_{ij}^a C_j^a \alpha_j^a$	$X_j^a C_j^b \alpha_j^a$
3	Substitute dimensions	M	M x (ML^2T^{-2})/ML x L x $M/(ML^2T^{-2})$ x 1	ML^2T^{-2} x $M/(ML^2T^{-2})$ x 1	L x M/L x 1
4	Reduce and solve powers	M	$MML^2T^{-2}M^{-1}$ $L^{-1}LMM^{-1}L^{-2}T^2$	ML^2T^{-2} M $M^{-1}L^{-2}T^2$	LML^{-1}
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	M	M	M	M
6	Confirm	Dimensionally consistent			

Table 7.7 Dimension analysis for Equation 7.3

Steps		Left hand side	Right hand side
1	State equation	EC_{q1}	$\sum_{q}^{p} \varphi_q \left(\sum_{j}^{e} U_{qj} C_j^a \theta_j^b \right)$
2	Break equation into constituent terms	EC_{q1}	$\varphi_q U_{qj} C_j^a \theta_j^b$
3	Substitute dimensions	M	1 x ML^2T^{-2} x 1 x $M/(ML^2T^{-2})$ x 1
4	Reduce and solve powers	M	ML^2T^{-2} $MM^{-1}L^{-2}$ T^2
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	M	M
6	Confirm	Dimensionally consistent	

Table 7.8 Dimension analysis for Equation 7.4

Steps		Left hand side	Right hand side
1	State equation	EC_{q2}	$\sum_{q}^{p} \varphi_q^b \left(\sum_{j}^{e} Y_{qj}\, X_j^b\, C_j^a\, \alpha_j^b \right)$
2	Break equation into constituent terms	EC_{q2}	$\varphi_q^b Y_{qj} X_j^b C_j^a \alpha_j^b$
3	Substitute dimensions	M	M x (ML^2T^{-2})/ML x L x M/(ML^2T^{-2}) x 1
4	Reduce and solve powers	M	$MML^2T^{-2}M^{-1}\ L^{-1}LMM^{-1}L^{-2}T^2$
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	M	M
6	Confirm	Dimensionally consistent	

Table 7.9 Dimension analysis for Equation 7.5

Steps		Left hand side	Right hand side	
			Option A	**Option B**
1	State equation	EC_l	$\sum_{f}^{r} \beta_f \left(\sum_{j}^{e} Z_{fj}\, C_j^c \alpha_j^c \right)$	$\sum_{f}^{r} \beta_f\, L_f X_j^c \left(\sum_{j}^{e} C_j^d\, \alpha_j^d \right)$
2	Break equation into constituent terms	EC_l	$\beta_f Z_{fj} C_j^c \alpha_j^c$	$\beta_f L_f X_j^c C_j^d \alpha_j^d$
3	Substitute dimensions	M	T x (ML^2T^{-2})/T x M/(ML^2T^{-2}) x 1	T x 1 x L/T x M/L x 1
4	Reduce and solve powers	M	$TML^2T^{-2}\ T^{-1}MM^{-1}L^{-2}T^2$	$T\ LT^{-1}ML^{-1}$
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	M	M	M
6	Confirm	Dimensionally consistent		

Table 7.10 Dimension analysis for Equation 7.6

Steps		Left hand side	Right hand side
1	State equation	$C_j^{a,b,c,d}$	$D_j + I_j$
2	Break equation into constituent terms	C_j	term 1 = D_j ; term 2 = I_j
3	Substitute dimensions	m	term 1 = m; term 2 = m
4	Reduce and solve powers	m	term 1 = m; term 2 = m
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	m	term 1 = m; term 2 = m
6	Confirm	Dimensionally consistent	

Table 7.11 Dimension analysis for Equation 7.7

Steps		Left hand side	Right hand side
1	State equation	$\sum_{j}^{e} \theta_j^{a,b}$	1
2	Break equation into constituent terms	1	1
3	Substitute dimensions	1	1
4	Reduce and solve powers	1	1
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	1	1
6	Confirm	Dimensionally consistent	

Table 7.12 Dimension analysis for Equation 7.8

Steps		Left hand side	Right hand side
1	State equation	$\sum_{j}^{e} \alpha_j^{a,b,c,d}$	1
2	Break equation into constituent terms	1	1
3	Substitute dimensions	1	1
4	Reduce and solve powers	1	1
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	1	1
6	Confirm	Dimensionally consistent	

Table 7.13 Dimension analysis for Equation 7.9

Steps		Left hand side	Right hand side
1	State equation	EC_T	$(EC_{m1} + EC_{m2}) + (EC_{q1} + EC_{q2}) + EC_l$
2	Break equation into constituent terms	M	Term 1 = EC_{m1}; Term 2 = EC_{m2}; Term 3 = EC_{q1}; Term 4 = EC_{q2}; Term 5 = EC_l
3	Substitute dimensions	M	Term 1 = M; Term 2 = M; Term 3 = M; Term 4 = M; Term 5 = M
4	Reduce and solve powers	M	Term 1 = M; Term 2 = M; Term 3 = M; Term 4 = M; Term 5 = M
5	Inspect remaining dimension (s) on either sides of the equation whether they are similar	M	Term 1 = M; Term 2 = M; Term 3 = M; Term 4 = M; Term 5 = M
6	Confirm	Dimensionally consistent	

7.2 Carbon Measurement Tool (CaMeT)

This section presents results derived from the methods explained in Chapter 4 (section 4.4.2), regarding implementing the mathematical model into a software tool.

7.2.1 Structure of CaMeT after time box 2

The architecture of the second CaMeT prototype, which was an output of time box 2, is shown in Figure 7.1. The second prototype had no functionality but revealed the general structure of the envisaged tool and functionalities. It consisted of nine elements and as can be seen from the figure, the major inputs from the mathematical model (Equations 7.1 to 7.5) were captured by elements labelled 5, 6, and 7.

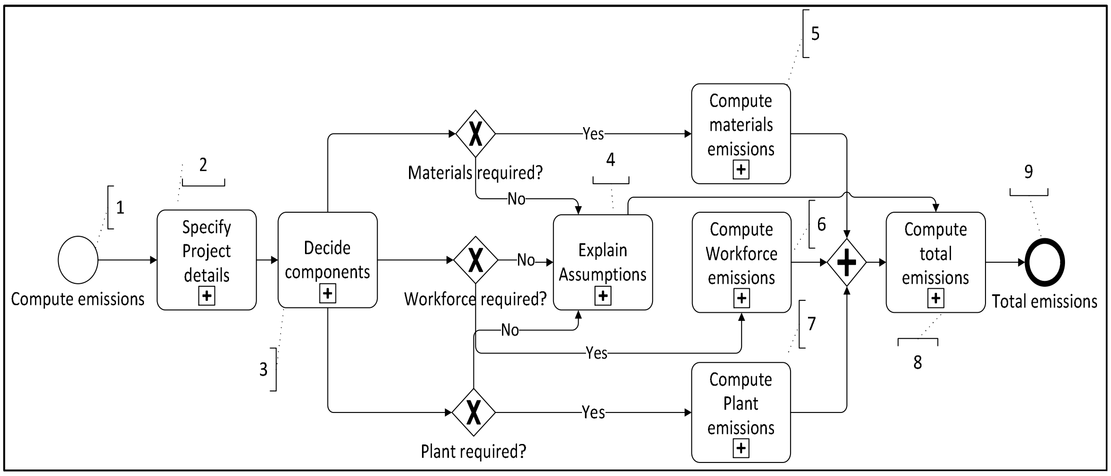


Figure 7.1 Architecture of the second prototype

7.2.2 Structure of CaMeT after time box 3

The overall structure of the third and final CaMeT prototype is presented and explained in this section.

7.2.2.1 Overview of the structure

The third and final CaMeT prototype is similar to its predecessor but possesses several design features that facilitate usability (see Figure 7.2). The architectural layout is similar to traditional workflow diagrams which have left to right flow logic. This makes it easier for users to logically follow what is required. Intuitively, the tool enables users to effortlessly move from one step to another or alternatively, click the button/element of choice as long as appropriate information has been input. Generally, it is expected that this tool will be easy to use in Uganda since it is based on Excel, which is ubiquitously used. Unsurprisingly, most software tools related to computing carbon emissions are country specific in order to suitably incorporate national circumstances (see

Greenhouse Gas Protocol, 2014; Joint Research Center, 2014). CaMeT is similarly country-specific, since it accommodates Ugandan circumstances, such as specification of a geographical region (e.g. district) in which the building project is located.

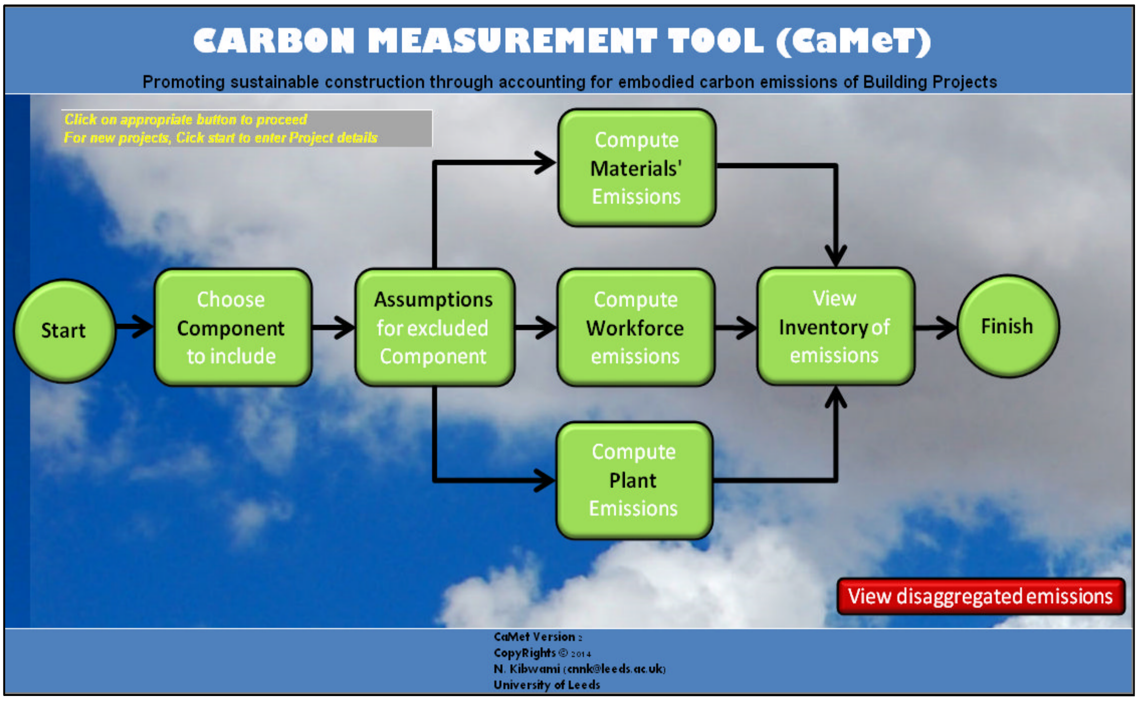


Figure 7.2 Structure of the final prototype of CaMeT

7.2.2.2 Results from verification of CaMeT

Results from verification of CaMeT (i.e. module and integrated testing) suggested that its individual and integrated components worked correctly. The various errors identified during coding were appropriately addressed. It was ascertained that information entered into the various user forms of the graphical user interface was correctly transferred to the data access/storage spreadsheets when the relevant command buttons were clicked. The inbuilt ‘error handling’ options, which can warn the user in case required information is not entered (or incorrectly entered) ensured correctness of the outputs. Meanwhile, answers obtained from manually solved EC quantification problems matched those of using CaMeT, thereby confirming that the software had been built correctly.

7.2.2.3 Functionality of CaMeT

The graphical user interface basically consists of nine elements (see Figure 7.2) denoted by buttons which are fully functional upon clicking on them. The functions of each of these buttons, and therefore the overall operation of CaMeT, are explained below.

7.2.2.3.1 Starting

CaMeT is started by double clicking on the relevant Excel application file. Since macros were used, a security warning appears requiring Macros to be enabled for the Excel file. Upon 'enabling macros', the tool is then ready to be used. Clicking the 'start' button opens up a copyrights message which can be dismissed by clicking OK (see an example of VBA programing code in Figure 7.3). A form (see Figure 7.4) then appears for the user to enter some descriptive information (e.g. type of building such as commercial or residential, geographical location like district, etc.) of the project.

```
Sub Oval1_Click()

MsgBox "CaMet Version 1.2" & vbCr & "PROTOYPE VERSION" & _
vbCr & " " & vbCr & "CopyRights-Nathan Kibwami (PG Researcher)" & _
vbCr & "University of Leeds (2014)" & vbCr & "   " & _
vbCr & "CLICK OK TO CONTINUE", vbOKOnly, "CopyRights Message" 'this m

frmProjectDetails.Show 'opens the project details form

End Sub
```

Figure 7.3 VBA code for starting CaMeT

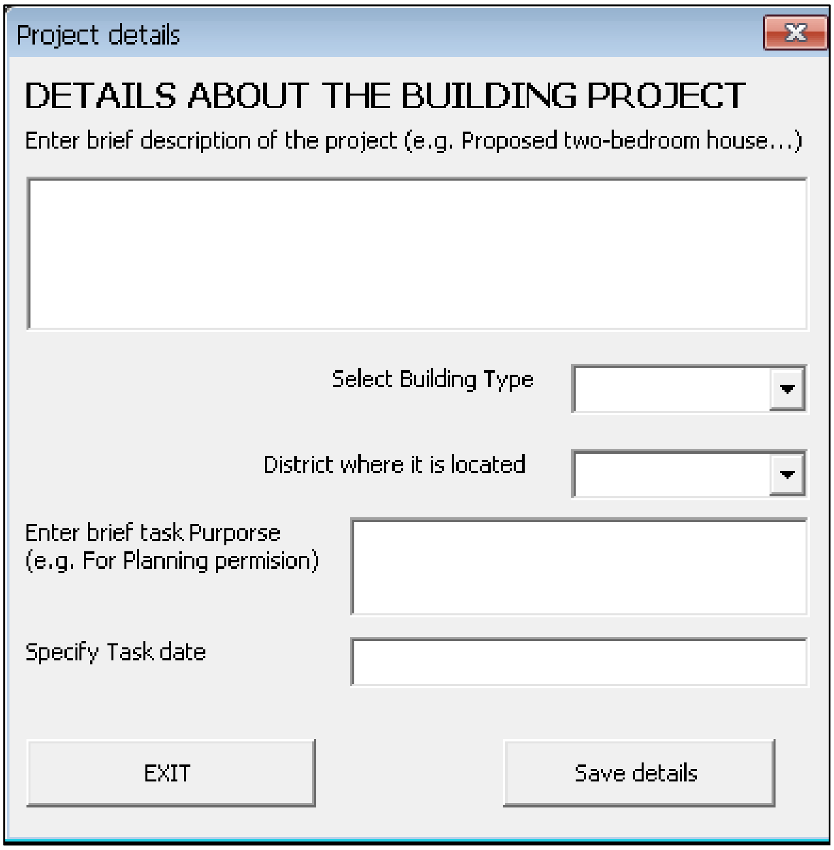


Figure 7.4 Entering project details in CaMeT

7.2.2.3.2 Choosing the component to include

Decisions on what emissions to compute (whether materials, plant, workforce, or all) are made at this stage. This offers options and flexibility to users regarding which emissions to compute. Clicking on the 'component' button opens a form (see Figure 7.5). Required options are selected by clicking on the relevant form's check boxes. The form also has other buttons to offer users on-screen help information, for instance, about what CaMeT considers to be included in material emissions. If one of the three components is not checked and 'SAVE&CONTINUE' button is clicked, the user is reminded to enter any assumptions he/she has considered in excluding the component. Assumptions are entered by clicking the 'assumptions' button, which then opens another relevant form.

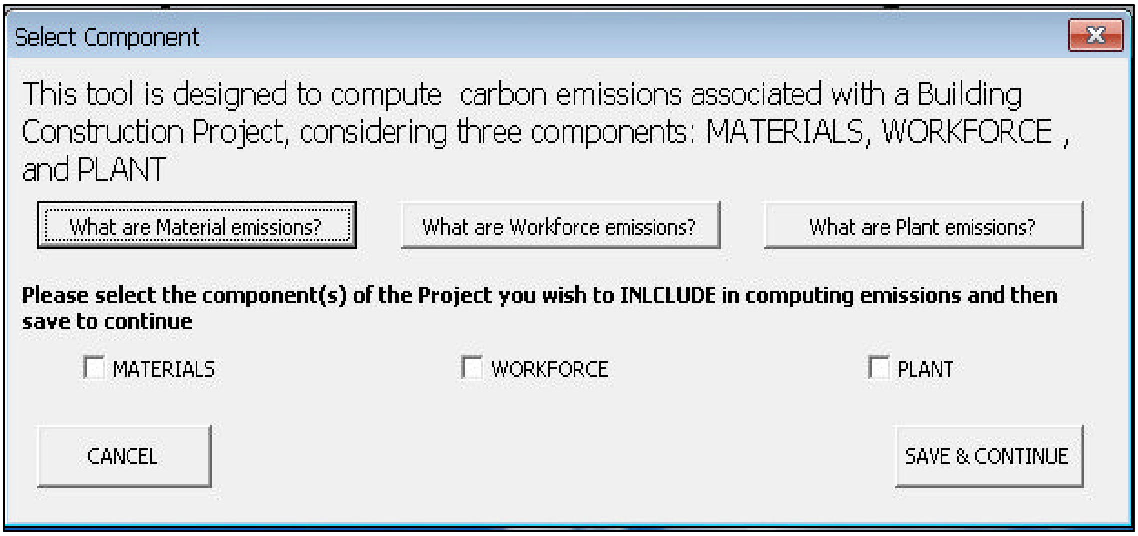


Figure 7.5 Select component in CaMeT

7.2.2.3.3 Computing materials' emissions

Emissions from materials are computed by clicking on the materials' button, which then opens a form (see Figure 7.6) for the user to enter relevant information. A database can be selected, upon which emissions computations can be based. The database is based on the tables of emission/energy constants earlier presented with the mathematical model (see section 7.1). Six material entries were considered based on the most carbon-intensive materials elaborated earlier (see Chapter 2 section 2.3.3.2). From the drop-down menu, the user can select the relevant material(s). The quantity of material can also be entered in the adjacent input box. Upon entering required data, clicking on the 'compute emissions' button invokes the mathematical model's equation that was built in Excel spreadsheets in order to compute emissions. The result is indirectly stored for later recall. If emissions from transporting materials are also required, the relevant button can be clicked to open up the relevant form (see Figure 7.7). From Figure 7.7, it can be seen that the three options (A, B, and C) of computing emissions that were elaborated in the mathematical model are also reflected in the tool. In Figure 7.7, option C is active, showing that five transportation modes can be considered for each material.

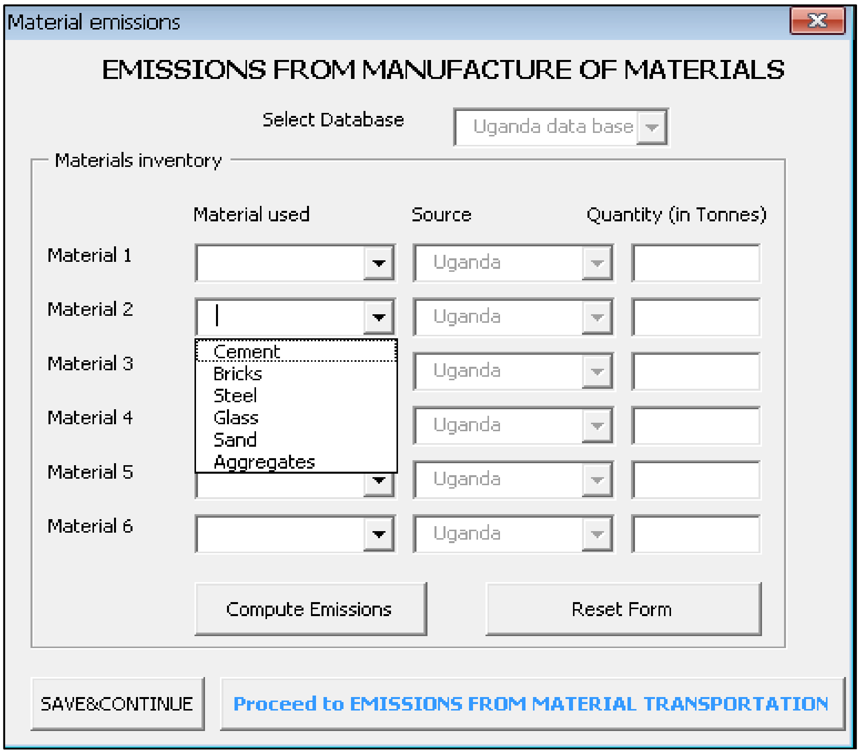


Figure 7.6 Materials manufacturing emissions in CaMeT

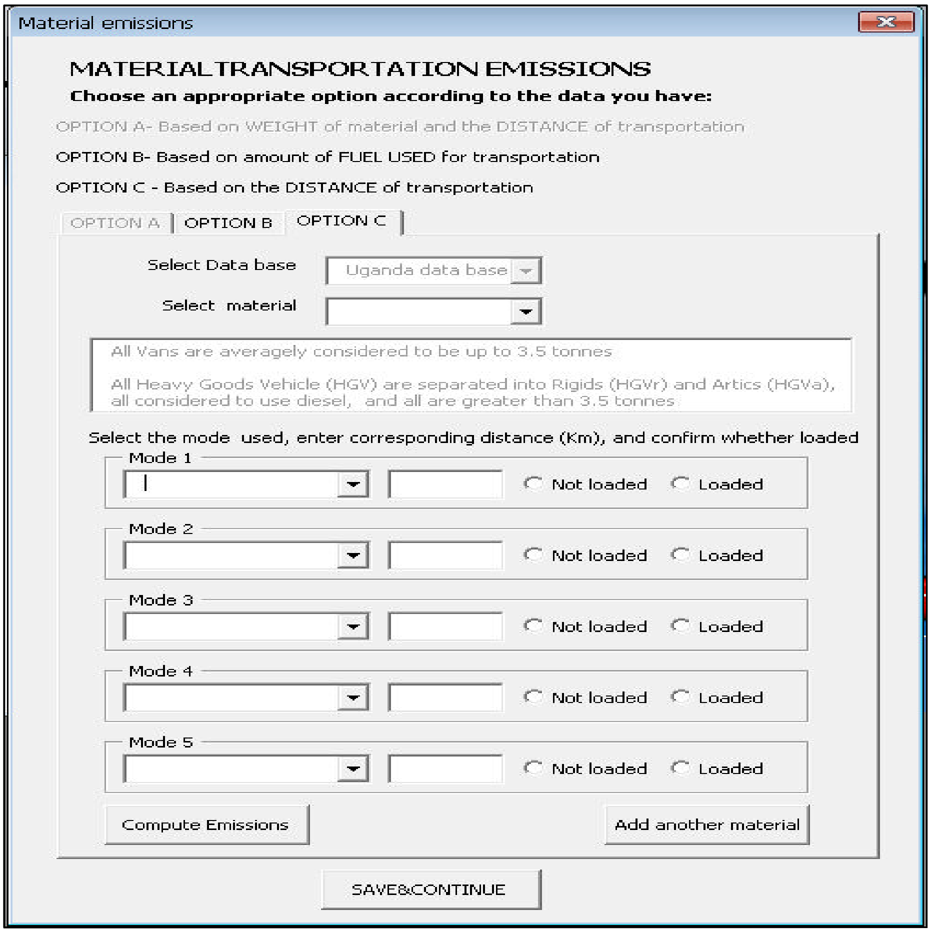


Figure 7.7 Material transport emissions in CaMeT

7.2.2.3.4 Computing workforce emissions

If emissions from transporting workforce are to be computed, the user clicks on the 'workforce' button, which then opens a form (see Figure 7.8). The two options, A and B, highlighted in the mathematical model are similarly reflected by two tabs on the form (i.e. Option A and Option B). The active tab of option B in Figure 7.8 shows details of computing emissions from workforce considering six modes of transport, which can be selected from the drop-down menu. Other required details, such as duration, distance per person per day, and number of people using a particular mode, can also be entered as appropriate.

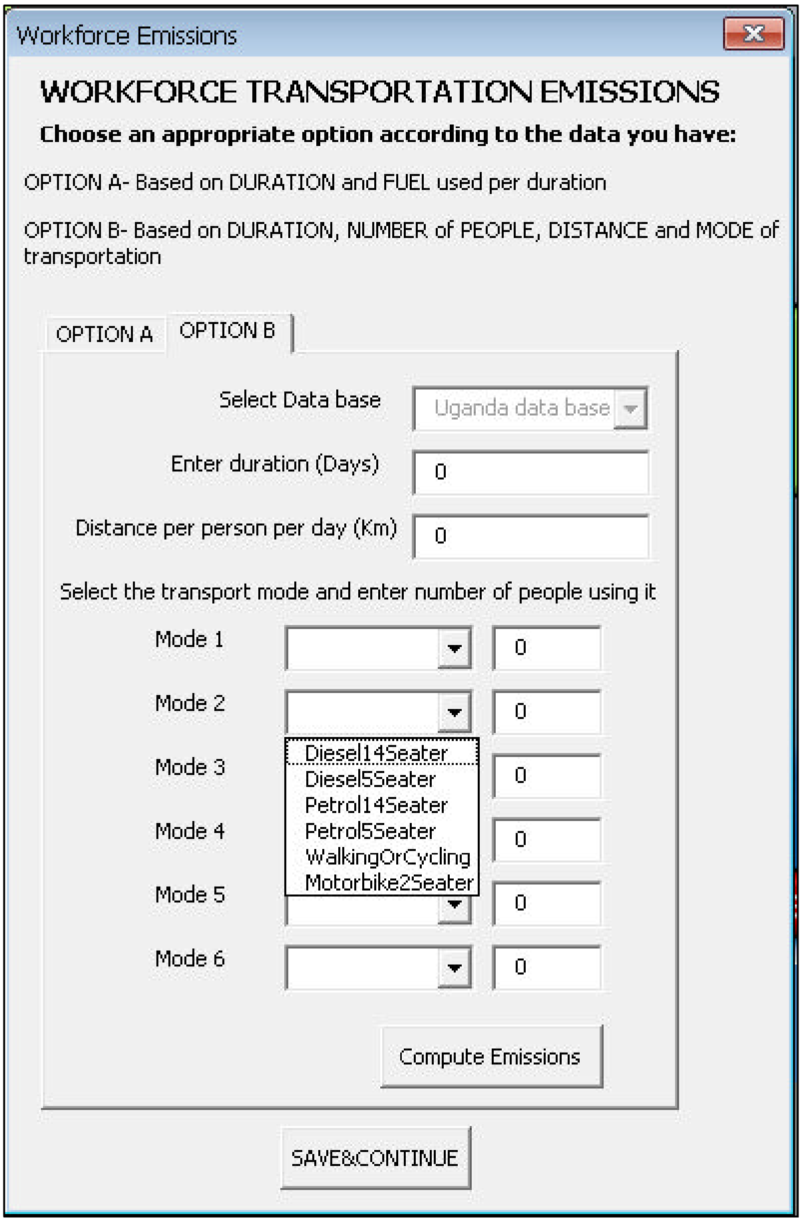


Figure 7.8 Workforce transport emissions in CaMeT

7.2.2.3.5 Computing plant emissions

For emissions from operating plant, the user clicks on the ‘plant’ button, which then opens a form (see Figure 7.9). Up to four types of fuel – diesel, petrol, biodiesel and electricity – can be specified for each plant. The user is required to enter the type of plant (and specify its name), the number of plant, and the amount of fuel/energy used. If emissions from transporting plant are required, the relevant button is clicked, which opens up a form similar to that of calculating emissions from material transportation.

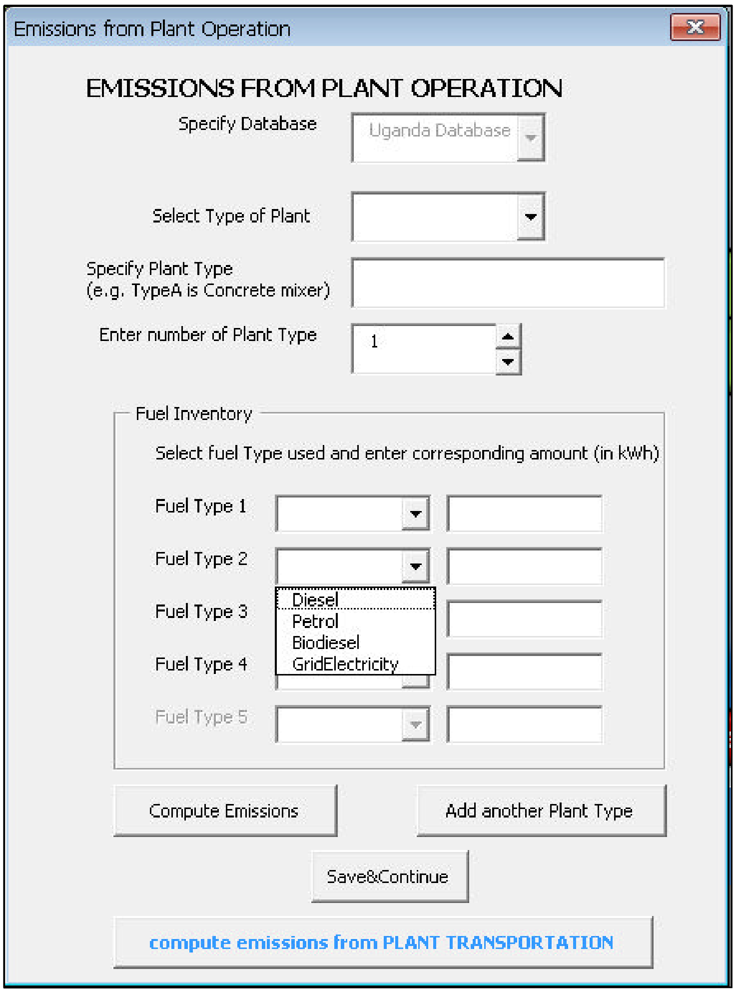


Figure 7.9 Plant operation emissions in CaMeT

7.2.2.3.6 Viewing inventory of emissions

The inventory of all the emissions computed is provided when the button of ‘inventory’ is clicked. This opens up a form (see Figure 7.10) which has a bar graph to show the project’s composition of emissions from materials, workforce and plant. Clicking on the ‘view carbon report’ opens a report (see example in

Appendix E), which is similar to traditional bills of quantities used in Uganda, to summarise all the emissions computed and relevant descriptive information which the user entered. A procedure was added to automatically convert the report into a PDF document for ease of circulation and avoidance of accidental alteration of reports. The report is the major output from the CaMeT and serves the interests of various stakeholders depending on the reason for carrying out EC computation. For instance, for the case of development approval, the report is attached to the documents that are submitted in applying for a building or occupation permit as elaborated later (Chapter 8, section 8.1) in the to-be system.

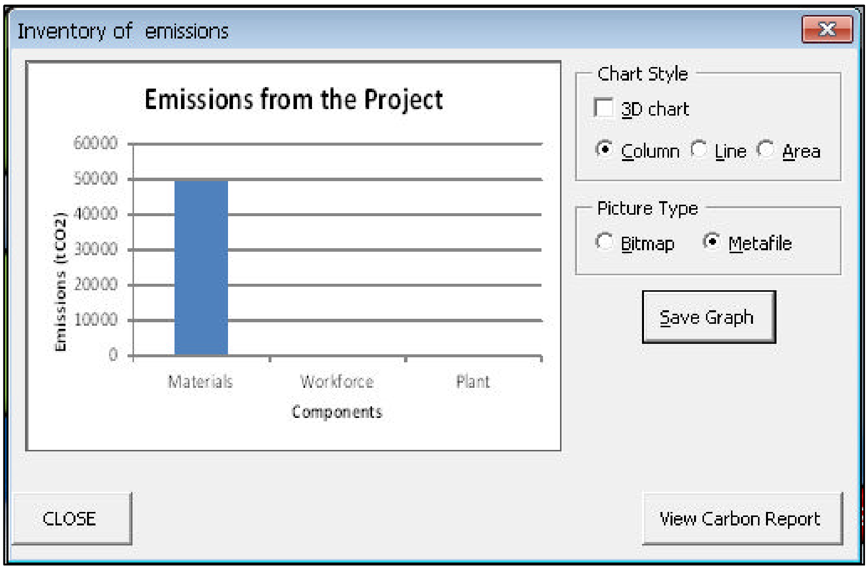


Figure 7.10 Inventory of emissions in CaMeT

7.2.2.3.7 Viewing disaggregated emissions

The disaggregation concept which was described in the mathematical model (see section 7.1.6) was also implemented in the tool. The user can view disaggregated emissions by clicking the 'view disaggregated emissions' button. From the output, it is possible to assess the contribution of the various energy sources to the resulting EC. An example of how disaggregated emissions resulting from transporting workforce is shown in Figure 7.11. If users want to make some scenarios, they can save the report and then back-track through the steps/buttons of CaMeT to a point where changes in the inputs are required. Another output/report can then be generated and compared with the earlier one.

In that way, it is possible to generate scenarios about emissions associated with various types of energy used in accomplishing the same task.

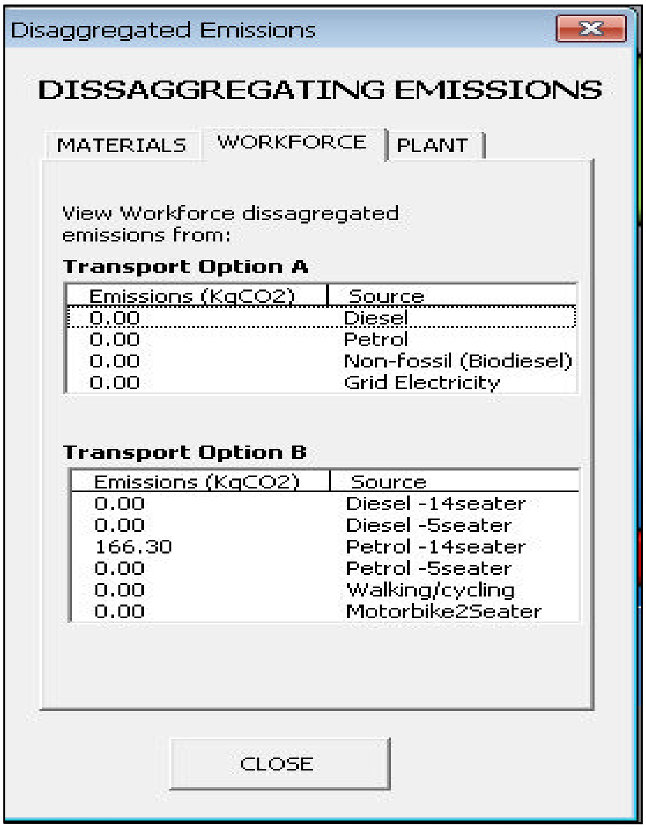


Figure 7.11 Disaggregated workforce emissions in CaMeT

7.3 Chapter summary

This chapter has presented results and findings pertaining to the third research objective, which was about developing an approach to facilitate the integration of EC accounting in the development approval process of building projects. A mathematical model consisting of nine equations has been presented and verified. Contrary to the prevailing EC accounting initiatives, the model can accommodate disaggregation and also considers the cradle-to-construction completion boundary. The model was implemented by a software tool known as CaMeT, whose structure and operation has also been presented. This tool, which is tailored to the building sector in Uganda, is the first of its kind. The mathematical model (and tool) presented in this chapter and the as-is system presented in Chapter 6 provided a basis to create the new (to-be) system of development approval in Uganda. The next chapter (Chapter 8), which relates to objective four, presents the to-be system.

Chapter 8
The to-be system

This chapter presents the outcomes related to objective four which was about proposing and evaluating a to-be system of enhancing sustainable construction. Firstly, the structure of the to-be system is presented, followed by results from evaluating the to-be system, based on testing the five hypotheses (H1, H2, H3, H4, and H5) set in this study. The chapter ends with a summary of the key aspects discussed in the chapter.

8.1 Structure of the to-be system

The to-be system is a culmination of the findings from objective one (Chapter 6 section 6.1), objective two (Chapter 6 section 6.2), and objective three (Chapter 7). The findings presented in Chapter 6 suggested that there is a need to introduce EC accounting in the current development approval process of buildings (i.e. as-is system), since EC accounting was found to be missing in the existing formal practices. However, introducing EC accounting required quantifying EC of building projects. Consequently, having developed a mathematical model (Chapter 7 section 7.1) and software tool (Chapter 7 section 7.2) for quantifying EC, the missing piece of the puzzle – the carbon accounting subprocess – had been discovered. As such, the carbon accounting subprocess was integrated in the as-is system to create the to-be system as elaborated hereunder.

8.1.1 Process discovery

The process space, process topology and attributes of the to-be system are described hereunder.

8.1.1.1 Process space

The to-be system consists of the following subprocesses: carbon accounting subprocess, environmental impact assessment subprocess, development permission subprocess, and building project subprocess. Whereas the subprocess of carbon accounting was new, the rest were modified from the as-is system.

8.1.1.2 Process topology and attributes

Process topology and attributes for each of the four subprocesses of the to-be system are explained below.

8.1.1.2.1 Process topology and attributes for the carbon accounting subprocess

The carbon accounting subprocess was a totally new subprocess in the to-be system and it prescribed computation of EC. Since the carbon accounting subprocess was conceived from the mathematical model, its sub-activities included the following: decide components to include, explain assumptions, compute materials' emissions (i.e. Equations 7.1 and 7.2), compute plant emissions (i.e. Equations 7.3 and 7.4), compute workforce emissions (i.e. Equation 7.5), and compute total emissions (i.e. Equation 7.9). These activities are carried out by the developer/consultant in two instances – building permit application and occupation permit application – and the resulting two types of carbon emissions were denoted as 'Carbon 1' and 'Carbon 2', respectively.

8.1.1.2.2 Process topology and attributes for the environmental impact assessment subprocess

Changes to the as-is EIA subprocess manifested in the activities of prepare brief, conduct EISd/EISm, and assess EISd/EISm. When the developer /consultant is preparing the brief, a carbon report is also included. In the case of environmental impact study, the projects' emissions are also included in the environmental impact statement. Meanwhile, when the environmental management authority (i.e. NEMA) is assessing the EISm submitted to it by the developer, opinions about the project's emissions are also included.

8.1.1.2.3 Process topology and attributes for the development permission subprocess

Activities that changed in the as-is DP subprocess included prepare documentation, assess application, and consider application. In the new 'prepare documentation' activity, a carbon report is among the documents submitted when applying for a building permit or occupation permit. When the authority is assessing applications, it requires estimates on the carbon emissions of the building project and also, at the end of the building project (i.e. before occupation), the emissions caused are required to be documented. Equally, in considering the decision to grant the building or occupation permit, authorities include the implication of the project's emissions with regard to the planning requirements.

8.1.1.2.4 Process topology and attributes for the building project subprocess

a) Pre-construction

Two activities in the preliminary phase of the BP subprocess were revised: prepare preliminary designs and prepare detailed designs. During preparation of preliminary cost estimates and detailed cost estimates, preliminary carbon estimates and detailed carbon estimates are also provided, respectively. This resulted into the new linkage of 'account for carbon 1', connecting the BP subprocess to the new 'carbon accounting subprocess'. Therefore, before applying for building permit, the estimated carbon emissions of the project (i.e. Carbon 1) have to be assessed.

b) Construction

During the construction phase, periodic progress reports also include carbon emissions to date. Therefore upon practical completion of construction, final progress reports also include the final carbon emissions caused by the building project. This is what results into the new linkage of 'account for carbon 2' (between the BP and carbon accounting subprocesses), implying that assessment of the final carbon emissions of the building projects (i.e. Carbon 2) is needed before applying for an occupation permit.

8.1.2 Process mapping

Results obtained from the process mapping exercise included the process scope, high level map, and the process model of the to-be system.

8.1.2.1 Process scope

With the exception of the new carbon accounting subprocess, the process scope for the environmental impact assessment subprocess, building project subprocess, and development permission, were similar to those of the as-is system (see section 6.1.2.1) and therefore not repeated herein. For the carbon accounting subprocess, it is initiated in two circumstances: when accounting for carbon 1 is required and when accounting for carbon 2 is required. It similarly ends in two end states: 'building permission applied for', and 'occupation permission applied for'.

8.1.2.2 Delineation of the high level map

The high-level map of the to-be system consisted of four subprocess: EIA, DP, BP, and carbon accounting. Since the process space for the EIA, DP, and BP subprocess of the to-be system was the same as that of the as-is system, the high level map was also the same (see section 6.1.2.2), and thus not repeated herein. For the carbon accounting subprocess, it had only one high level activity called 'compute project's emissions'.

8.1.2.3 Process model of the to-be system

The general description of the process model diagram of the to-be system is given, followed by results from process mapping of the four subprocesses.

8.1.2.3.1 General description of the to-be process model diagram

The overall structure of the to-be system is shown in Figure 8.1, and the corresponding 'to-be' child level process diagrams of the carbon accounting subprocess are presented in Appendix F. Results from intra-design verification suggested that the to-be system adhered to the process modelling rules.

8.1.2.3.2 The Carbon accounting subprocess

The carbon accounting subprocess (see Carbon accounting pool in Figure 8.1) is detailed in Figure 8.2. A quick inspection of the carbon accounting subprocess confirms that it is augmented by the mathematical model and software tool which were presented in the previous Chapter 7. As can be seen, computation of project's emissions is composed of sub activities (e.g. compute materials emissions, explain assumptions, etc.) that are representative of the mathematical model's equations and components of CaMeT.

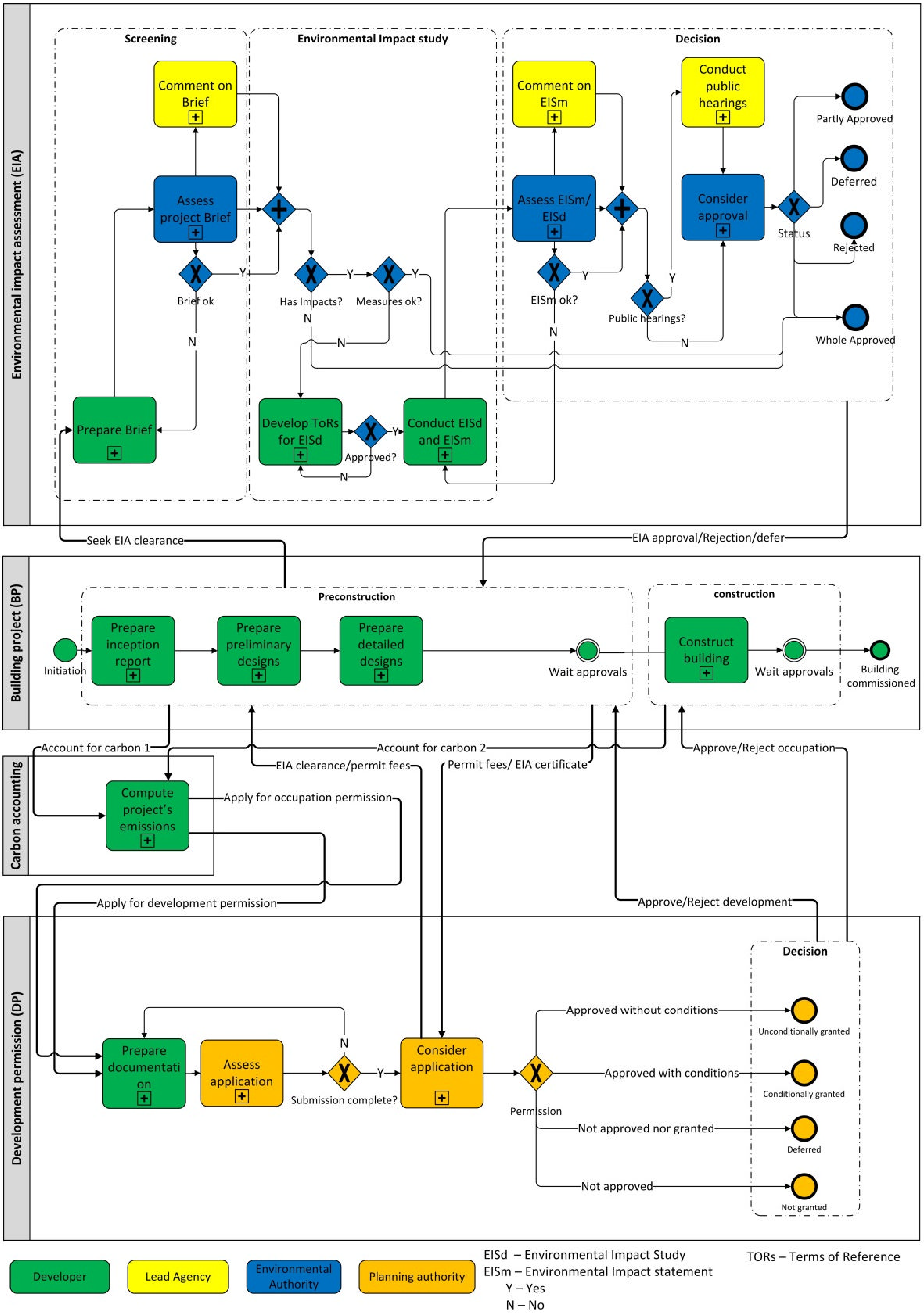


Figure 8.1 The to-be system

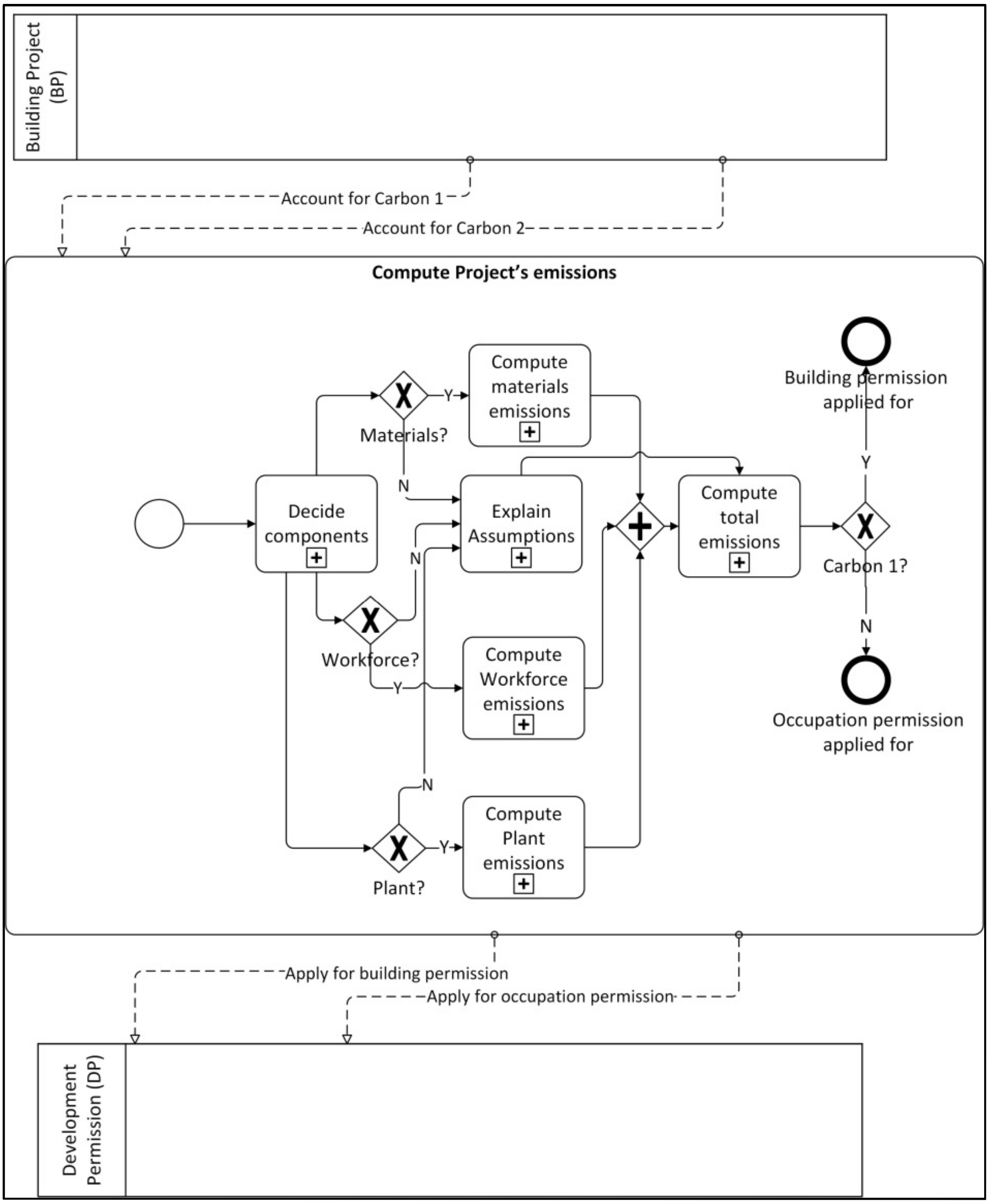


Figure 8.2 Subprocess for computing project's emissions

It is evident from Figure 8.2 that the carbon accounting subprocess is initiated by two linkages ('account for carbon 1' and 'account for carbon 2') which emanate from the BP subprocess. It similarly ends in two end states ('building permission applied for' and 'occupation permission applied for'). These two end states inform the two linkages emanating from the carbon accounting subprocess to the DP subprocess; this logic can be traced in Figure 8.2. The details (i.e. child-level diagrams) for each of the activities of the carbon accounting subprocess are presented in Appendix F.

8.1.2.3.3 The modified EIA subprocess

In the EIA subprocess, introduction of the carbon accounting subprocess affected the activities of prepare brief, conduct EISd/EISm, and assess EISd/EISm. This implied that: in preparing the brief (see Figure 8.3), a carbon report is also included; when making an EISm (see Figure 8.4), the projects' emissions are also included; and when NEMA is assessing the EISm (see Figure 8.5), opinions about the project's emissions are also included.

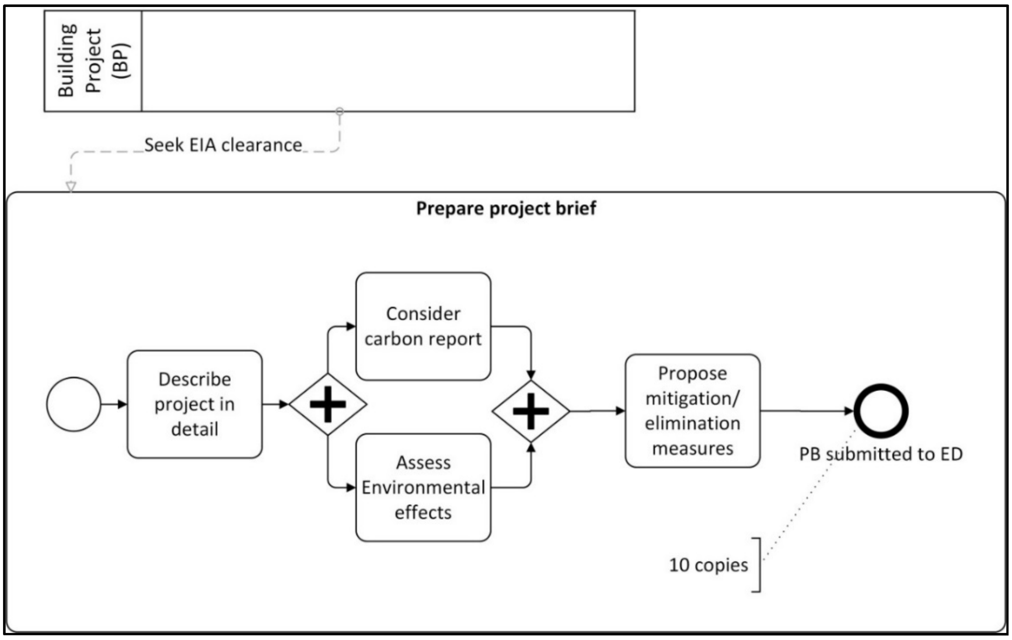


Figure 8.3 Preparing project brief in the to-be system

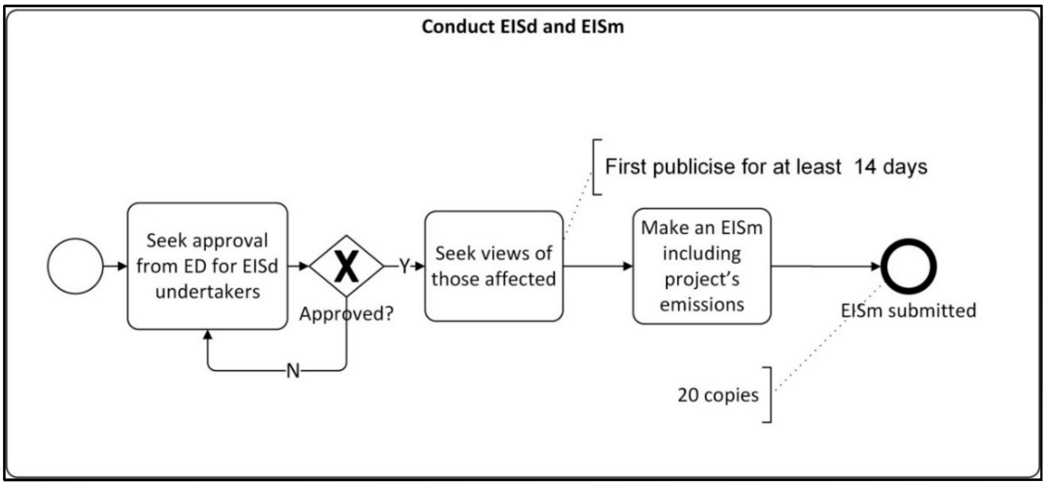


Figure 8.4 Conducting EI study/statement in the to-be system

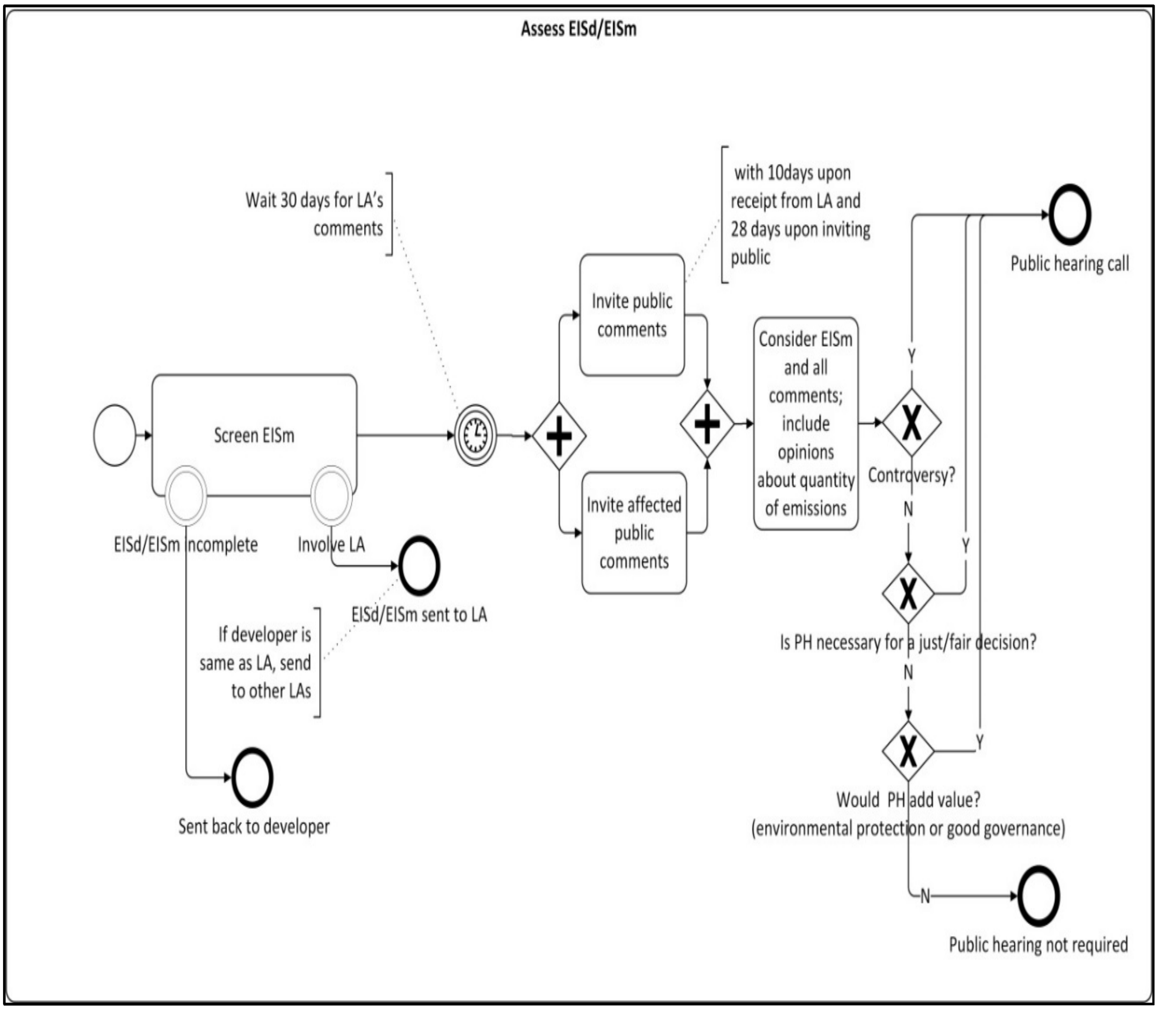


Figure 8.5 Assessing EI study/statement in the to-be system

8.1.2.3.4 The modified BP subprocess

Introduction of the carbon accounting subprocess affected three activities of the BP subprocess: prepare preliminary designs, prepare detailed designs, and construct building. The carbon accounting procedures are in many ways similar (and also in alignment) with the existing practices of accounting for building projects' costs. During preparation of preliminary cost estimates and detailed cost estimates, preliminary carbon estimates (see Figure 8.6) and detailed carbon estimates (see Figure 8.7) are also provided, respectively. This is what resulted into the new linkage of 'account for carbon 1' as seen in Figure 8.1. Therefore, before applying for building permit, carbon emissions of the project have to be assessed as depicted in the to-be system's activity of 'prepare detailed designs' (see Figure 8.7). During construction (see Figure 8.8), periodic progress reports also include appraising carbon emissions which are again considered in the final progress reports at the end of construction. Upon practical completion of construction, the previous practice (see figure in Appendix D, section D.2.4) was to apply for an occupation permit. The proposed practice shown in Figure 8.8 introduces accounting for carbon emissions before applying for an occupation permit and this is what results into the new linkage of 'account for carbon 2', which can also be seen in Figure 8.1.

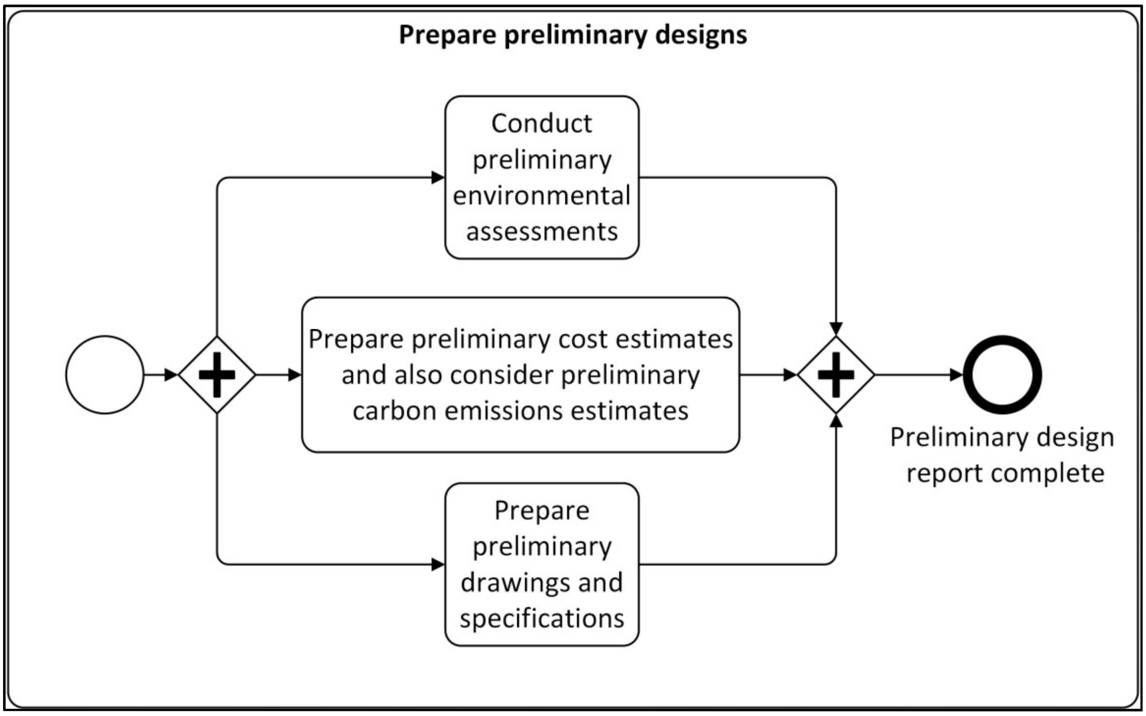


Figure 8.6 Preparing preliminary designs in the to-be system

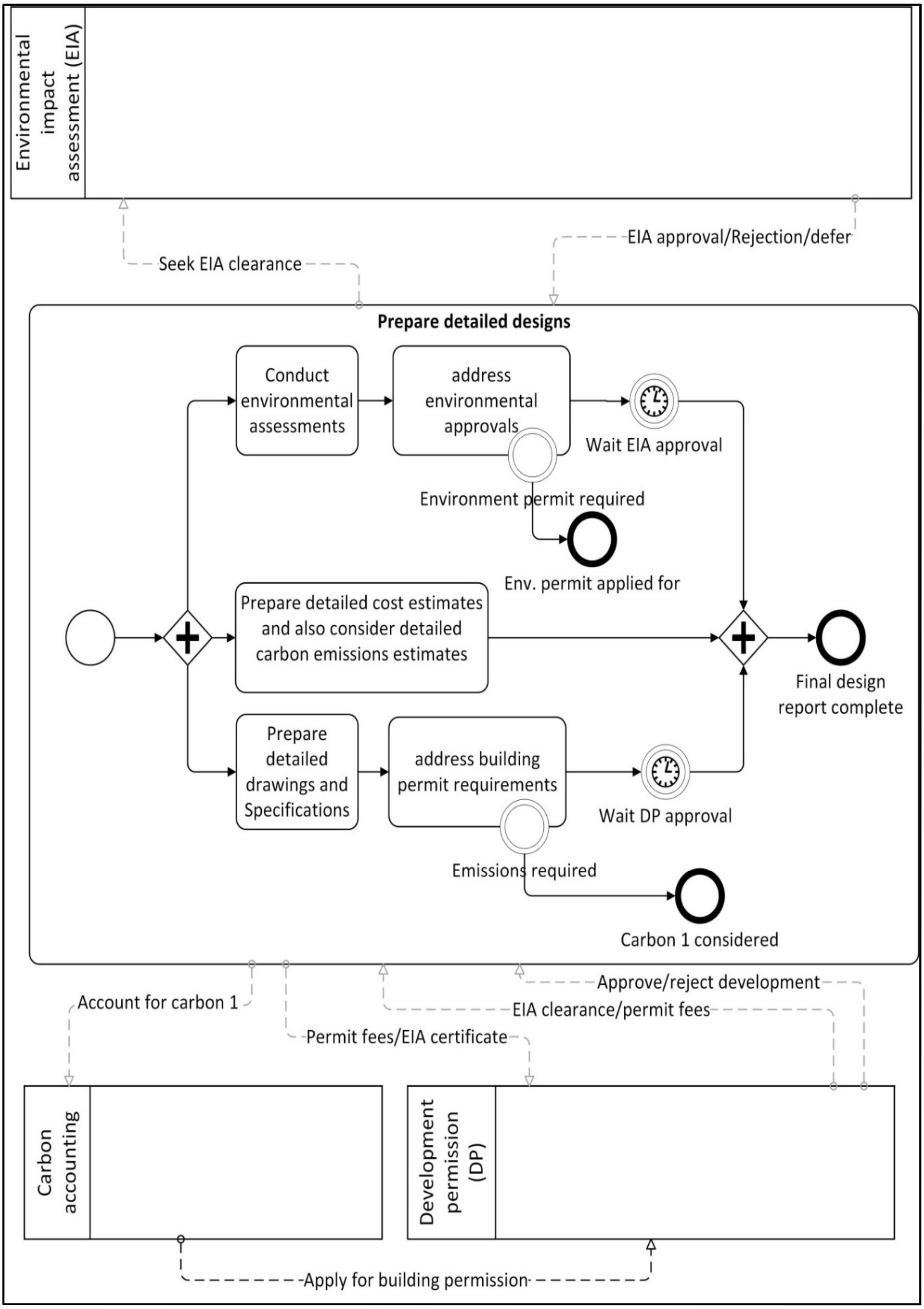


Figure 8.7 Preparing detailed designs in the to-be system

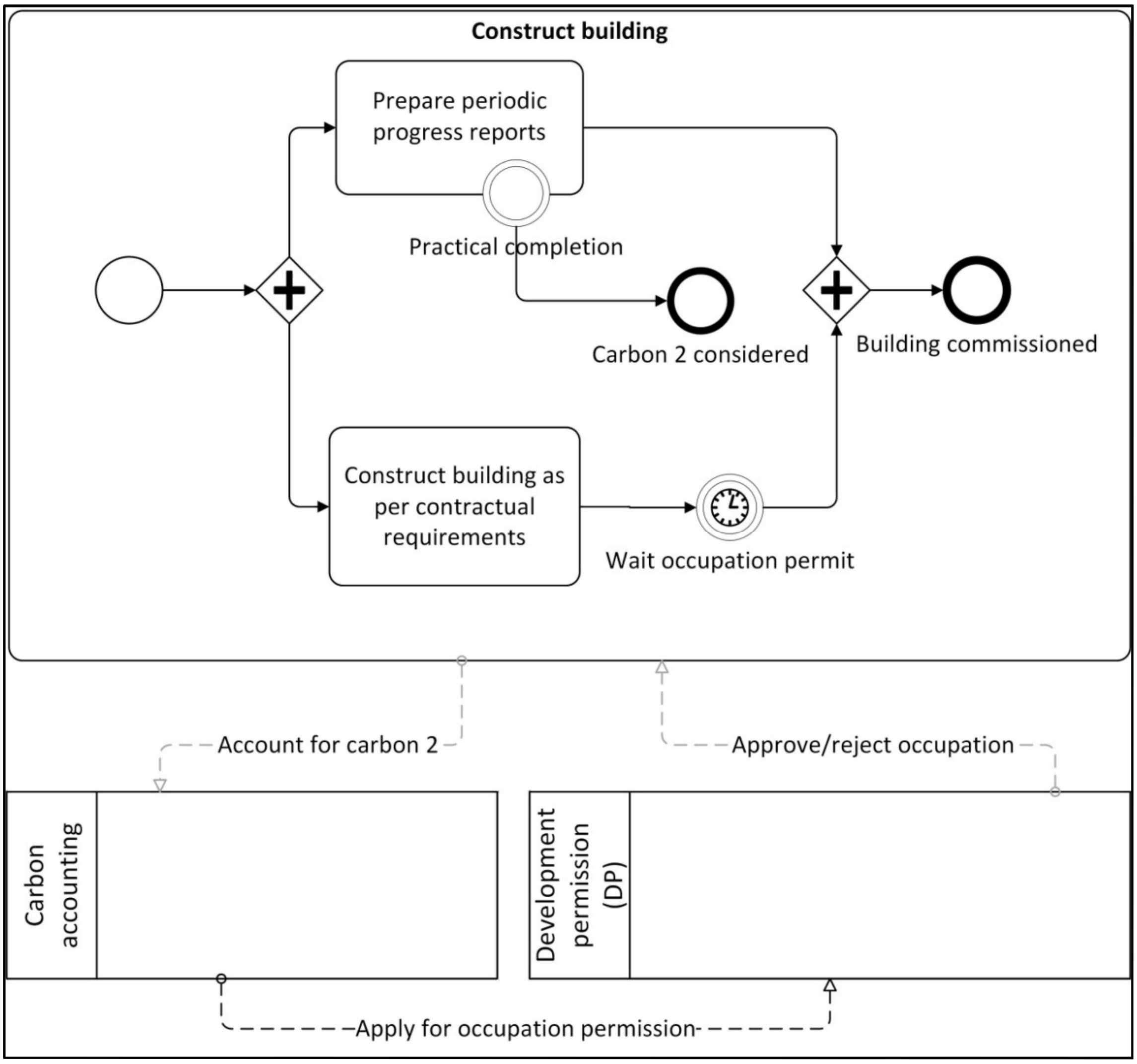


Figure 8.8 Construct building in the to-be system

8.1.2.3.5 The modified DP subprocess

Due to the introduction of the carbon accounting subprocess, some prevailing procedures within the three activities (prepare documentation, assess application, and consider application) of the DP subprocess were revised. The proposed 'prepare documentation' activity (see Figure 8.9) demands for inclusion of a carbon report among the documents submitted for building/occupation permit. In assessing applications, authorities can check if emissions of the building project are required and if so, whether included in the application submitted by the developer (see Figure 8.10). In considering the application (see Figure 8.11) authorities also check the implication of the project's emissions with regard to the planning requirements.

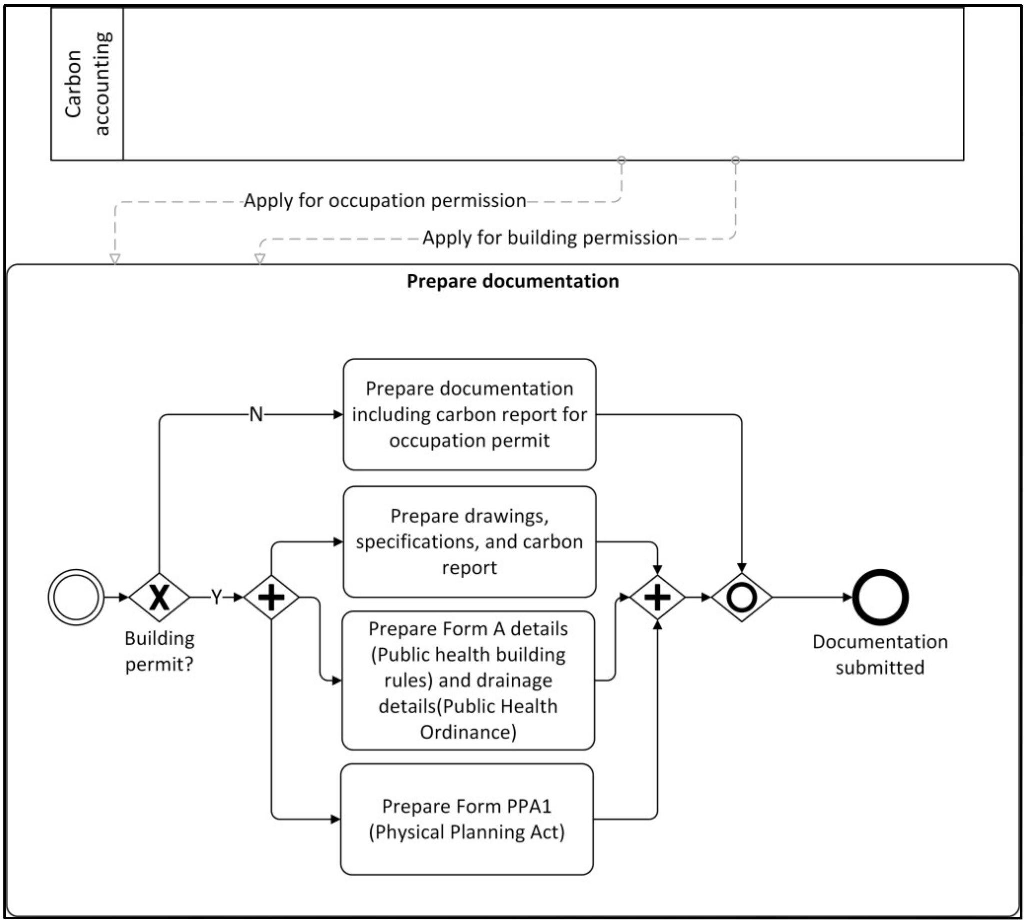


Figure 8.9 Preparing documentation in the to-be system

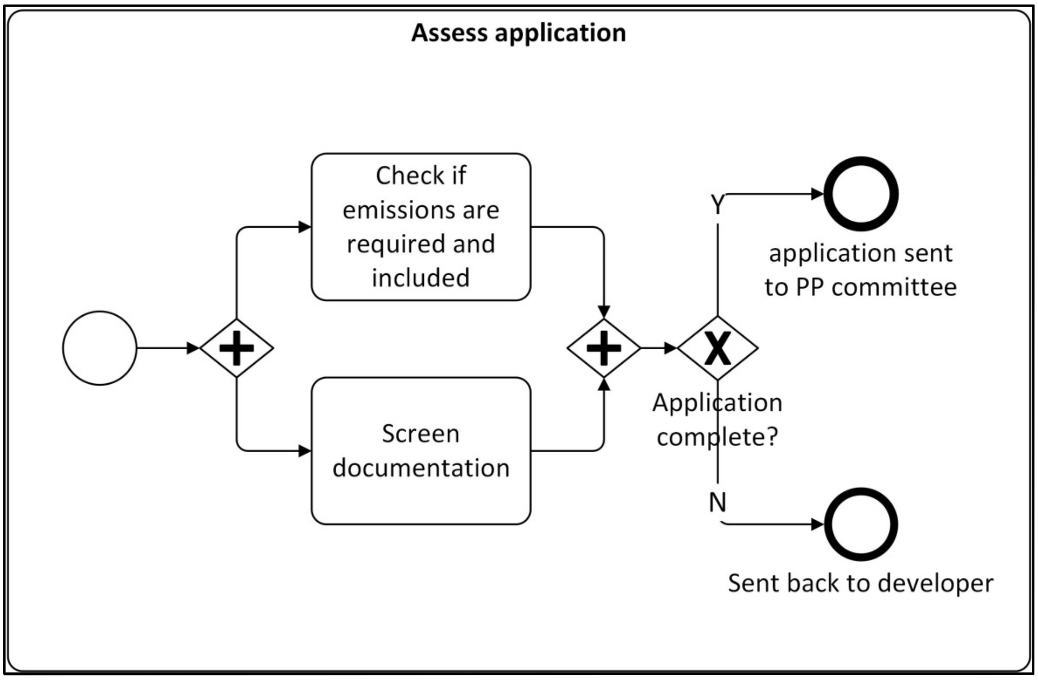


Figure 8.10 Assessing application in the to-be system

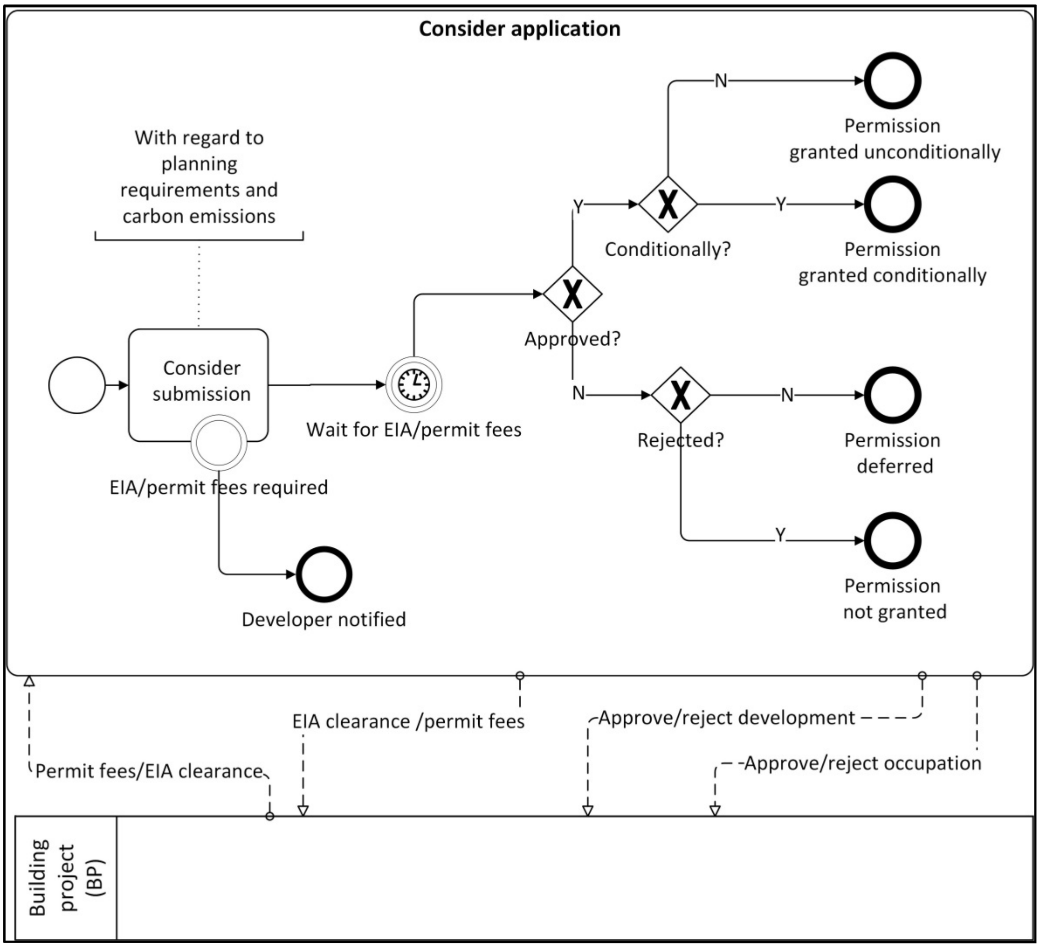


Figure 8.11 Considering application in the to-be system

8.2 Evaluation of the to-be system

This section presents results and discussions regarding evaluation of the to-be system, based on the methods explained in Chapter 5 section 5.4.2. The following are presented: preliminary analysis, effectiveness, cost-effectiveness, distributional considerations, institutional feasibility, format of introducing, kind of buildings to consider, professionals suitable, and findings from qualitative analyses.

8.2.1 Preliminary analysis

This section establishes validity of collected data by presenting the following: response rate, assumptions of statistical tests, response bias, reliability of the scale, and validity of responses.

8.2.1.1 Response rate

By the end of the data collection process, which lasted for 9 weeks, all the potential respondents in the initial sample of 120 (16% of the research population) individuals had been contacted, indicating a contact rate of 100%. However, of the 120 potential respondents, data were successfully collected from 85 of them, indicating a response rate of 71% (see Table 8.1). All individuals contacted were capable of performing the tasks required of them since they were literate and there was no language barrier. For the 29% of the initial sample from whom data were not collected, three major causes were noted:

- some respondents were not in the country or approved study area (i.e. Kampala and Wakiso districts) and were to return when the data collection period had lapsed;
- some respondents showed interest and interview appointments were made but they failed to fulfil the appointments even after successive rescheduling throughout the entire 9-week data collection period; and
- other respondents had no interest in participating in the study.

Table 8.1 Response rates

Professionals	**Population size (No.)**	**Initial sample size (No.)**	**Response**		**Non response**	
			Achieved sample (No.)	**%**	**Not achieved (No.)**	**%**
Architects	163	30	20	67	10	33
Engineers	405	30	21	70	9	30
Quantity Surveyors	42	30	21	70	9	30
Environmentalists	144	30	23	77	7	23
Overall	**754**	**120**	**85**	**71**	**35**	**29**

The achieved response rate was acceptable based on evidence gathered from literature. Baruch explored what could be a reasonable response rate in academic studies and found an average response rate of 55.6% in the 175 cases examined (Baruch, 1999). However, that study excluded administered research instruments like structured interviews used in this study. For administered instruments, high response rates are usually guaranteed – rates as high as 80% are not unusual (Owen and Jones, 1994). Meanwhile, Kervin observed that general response rates for personal interviews are usually around

70% (Kervin, 1992, p.422). Therefore, in the evaluation exercise, the achieved response rate of 71% was acceptable.

8.2.1.2 Assessing assumptions for statistical tests

Each of the three assumptions considered in selecting the appropriate statistical tests is examined hereunder.

8.2.1.2.1 Random sampling and independent observations

The sampling procedure used in evaluation was based on random sampling techniques which involved stratification of the research population into strata from which participants were randomly picked. The participants selected in the sample were independent of each other. This meant that each data collection instance (i.e. an interview) involved one person, who was interviewed without interaction with others. As such, all collected data fulfilled the assumption of random sampling and independent observations.

8.2.1.2.2 Level of measurement

As can be seen from the identification of variables and data analysis procedures (Chapter 5 section 5.4.2), the level of measurement for the variables was not based on the same measure. Whereas the variables of ‘Years of experience’ and ‘perception of effectiveness’ were based on a continuous measure, the rest of the variables were based on categorical measures which involved either a dichotomous (e.g. Yes or No) or Likert scale.

8.2.1.2.3 Normal distribution

Since normal distribution applies to data that are based on continuous level of measurement, the composite variable of ‘perception of effectiveness’ was assessed for normality. It was not necessary to assess the variable of ‘Years of experience’ since no further analyses were to be performed with it, apart from descriptive statistics. Results for the Kolmogorov-Smirnov test for normality indicated that data related to ‘perception of effectiveness’ did not significantly deviate from a normal distribution (p = 0.85). This was further supported by the Normal Q-Q plot where it can be seen that most data points are reasonably placed in a straight line (see Figure 8.12). As such, parametric statistics were applicable on the ‘perception of effectiveness’ variable.

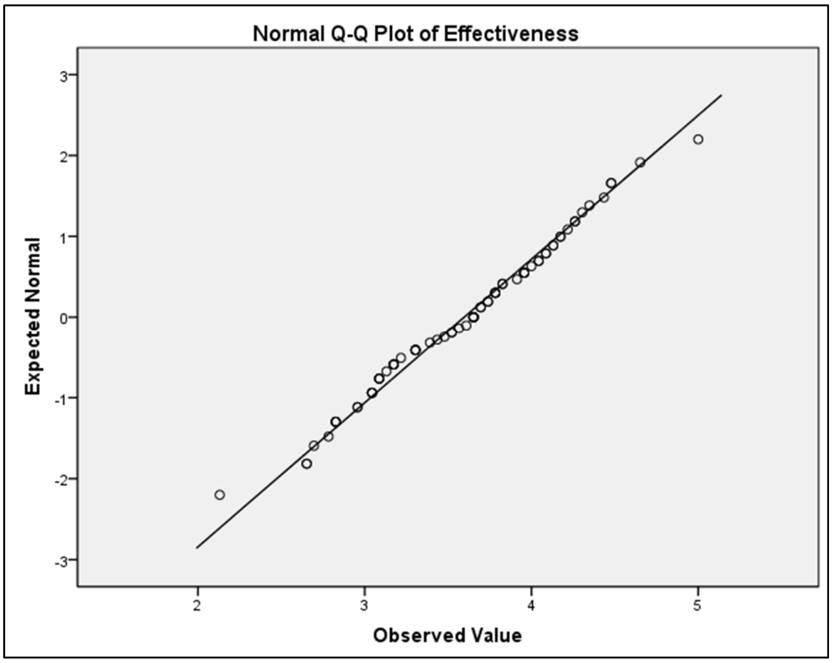


Figure 8.12 Assessing normality with Q-Q plot

8.2.1.3 Response bias

Having obtained a response rate less than 100%, response bias was assessed to check whether the non-responses (29%) had different opinions. Regarding the continuous variable (perception of effectiveness), for the three waves used in assessing response bias, wave1 contained 30 respondents (35%), wave 2 contained 29 respondents (34%), and wave 3 contained 26 respondents (31%). Results from one way between-groups ANOVA showed that there was no statistically significant difference at the $p < 0.05$ level in the scores of the perception of effectiveness across the three waves: F (2, 68) = 1.48, $p = 0.24$. Multiple wave comparisons revealed that for: Wave 1 vs Wave 2, $p = 0.61$; Wave 1 vs Wave 3, $p = 0.65$; and Wave 2 vs Wave 3, $p = 0.21$. Meanwhile for the categorical variables (see Table 8.2), except 'fairness' ($p < 0.05$), there were no significant differences across the three waves ($p > 0.05$). This was confirmed by the *phi* coefficient (see the last column in Table 8.2) which showed no strong association (*phi* ≈ 0) between the categorical variables and the three waves. It was therefore inferred that even if a fourth wave containing the remaining 29% of the participants who did not respond was to be included, there would not have been significant changes in the results. As such, it was safely concluded that the effect of non-responses on evaluation of the to-be system was negligible. The differences in opinions regarding the 'Fairness' of the to-be system were not very surprising since distributional considerations related to fairness are notoriously subjective (Gupta et al., 2007).

Table 8.2 Chi-square test for non-response

Variable	% of respondents			x^2	*n*	*p*	*Phi*[a]
	Wave 1	Wave 2	Wave 3				
Institutional feasibility							
Relevance	35	34	31	N/A[b]	85	N/A[b]	N/A[b]
Legal acceptance	32	37	31	3.47	78	0.18	0.21
Compatibility	37	33	30	1.87[c]	79	0.40	0.15
Persistence	33	38	29	5.00	72	0.08	0.26
Predictability	34	34	32	1.22[c]	82	0.54	0.11
Cost implications							
Benefits	37	33	30	1.43[c]	75	0.49	0.13
Understanding	35	35	30	0.41[c]	81	0.82	0.07
Implementation	36	34	30	1.34	84	0.51	0.13
Distributional considerations							
Legitimacy	35	34	31	3.01[c]	83	0.22	0.17
Fairness	32	32	36	7.17[c]	62	0.03	0.35
Transparency	36	32	32	0.59[c]	81	0.75	0.09

[a] Values closer to 0 and 1 demonstrate a weak and strong correlation, respectively.

[b] All respondents belonged to one category (i.e. all selected ‘Yes’) thus no Chi-Square test was necessary

[c] Likelihood Ratio was used instead of Pearson Chi-square since the assumption of minimum expected cell frequency was violated

8.2.1.4 Reliability of the effectiveness scale

The Cronbach coefficient alpha obtained was 0.85, which was greater than 0.7, suggesting that the ‘perception of effectiveness’ scale exhibited good internal consistency and therefore, was reliable. Opinions expressed in DeVellis (1991, p.85) show that alpha values between 0.8 and 0.9 are “very good”. With such a ‘very good’ Cronbach alpha value obtained, moreover from a scale composed of relatively a large number of items ($n > 10$), it was not necessary to investigate the scale’s inter-item correlation statistics (see Pallant, 2013).

8.2.1.5 Assessing response validity

To assess response validity, the following are presented and discussed: nature of practice, years of experience, awareness of sustainable construction, and understanding sustainable construction.

8.2.1.5.1 Nature of practice

The different types of professionals with their corresponding nature of practice are shown in Table 8.3. Majority (74 out of 85) were engaged in private consultancies. Since the initial examination of the sampling frame revealed similar results (see section 5.4.2.1.2(a)), this suggested that the achieved sample was a reliable representation of the study population.

Table 8.3 Professionals and practice

Professional	Nature of practice [a]					Total	Percent
	a	b	c	d	e		
Architect	18	2	0	0	0	20	23.5
Engineer	19	0	0	2	0	21	24.7
Quantity Surveyor	17	0	4	0	0	21	24.7
Environmentalist	20	0	1	1	1	23	27.1
Total	**74**	**2**	**5**	**3**	**1**	**85**	**100.0**

[a] a = Private consultancy firm, b = Private-non consulting firm, c = Government, d = Construction firm, e = Other

8.2.1.5.2 The years of experience

The years of experience ranged from 5 to 51 years, with a mean of 15.35, and standard deviation of 8.76. Majority of respondents (40%) had 5 to 10 years of experience. These results offer two suggestions. Firstly, it can be inferred that responses were reliable since no respondent had below 5 years of experience (Majdalani et al., 2006). This enhanced internal validity. Secondly, in a Ghanaian based study (Ametepey et al., 2015), most (47%) of professionals surveyed had 6 to 10 years of experience, implying that the profile of professionals' experience in other developing countries is not so different from that of Uganda.

8.2.1.5.3 Awareness of sustainable construction

Responses about the level of awareness indicated that 53% of respondents were 'moderately aware' and 26% 'extremely aware' of sustainable construction (see Figure 8.13). Literature suggests that the high level of awareness of sustainable construction amongst built environment professionals is not unique to Uganda. In James and Matipa (2004), it was discovered that 60% of the 'construction professionals' (Architectural, Engineering, and Quantity Surveying) in Zambia were aware of sustainable construction, whereas in Ghana, 83% of the 'practitioners' (Architects, Quantity Surveyors, and Structural Engineers) indicated to be aware of sustainable construction (Ametepey et al., 2015). A

Lebanese study also concluded that Architects and Engineers were most aware of sustainability amongst various construction stakeholders (Majdalani et al., 2006). Two implications can be deduced from these findings. Firstly, internal validity was boosted since the high level of awareness of sustainable construction implied that the surveyed respondents were largely informed about various concepts they were asked about, during the evaluation exercise. Secondly, the level of awareness of sustainable construction in Uganda is comparable to that of other countries.

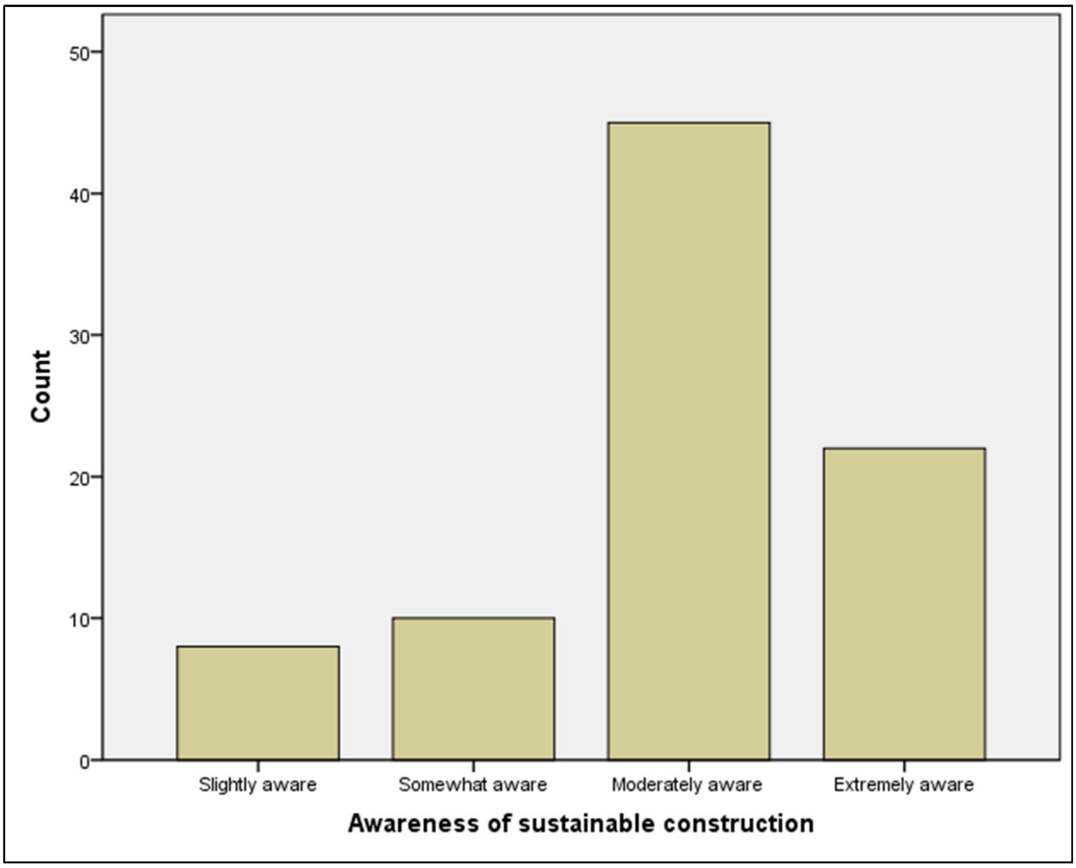


Figure 8.13 Awareness of sustainable construction

Although it was found that generally, all respondents were highly aware of sustainable construction, a Chi-square test for independence (with Likelihood Ratio) indicated a significant difference in the level of awareness among the four types of professionals, x^2 (9, n = 85) = 25.32, p = 0.003. The percentage distribution of responses suggests that generally, Architects are most aware whereas Quantity Surveyors are least aware (see Table 8.4). Therefore, there is need to increase awareness for some professionals, especially Quantity Surveyors.

Table 8.4 Responses on awareness of sustainable construction

Awareness of sustainable construction	Architects	Engineers	Quantity Surveyors	Environmentalists
Not at all aware	0%	0%	0%	0%
Slightly aware	0%	10%	14%	13%
Somewhat aware	10%	5%	33%	0%
Moderately aware	50%	62%	48%	48%
Extremely aware	40%	24%	5%	39%
Total	**100%**	**100%**	**100%**	**100%**

8.2.1.5.4 Understanding of sustainable construction

Visual impressions from Figure 8.14 show that the perception of sustainable construction varied. A Chi-square test for independence (with Likelihood Ratio) indicated no significant difference in the selection of statements among the four professionals, x^2 (15, *n* = 85) = 20.26, *p* = 0.16. This implied that perception of sustainable construction was not related to the type of profession. However, out of the six statements, a statement describing sustainable construction as ‘practices that do not harm the environment’ was most selected (86%). On the whole, statements that relate sustainable construction to environmental sustainability were most selected, followed by those related to economic sustainability, and lastly, social sustainability. This suggests that sustainable construction is understood as synonymous with environmental sustainability. This means that the first order state of sustainability in Uganda is environmental sustainability. However, Uganda’s perception of sustainability is no different from other contexts. In Zainul Abidin (2010, p.424), “all respondents associated environmental aspects with sustainable construction”. Similar findings are reported in Majdalani et al. (2006) wherein it was discovered that Architects and Engineers placed a greater importance on environmental concerns. This suggested responses from built environment professionals in Uganda could be relied upon since their interpretation of sustainable construction was similar to that of professionals in other countries.

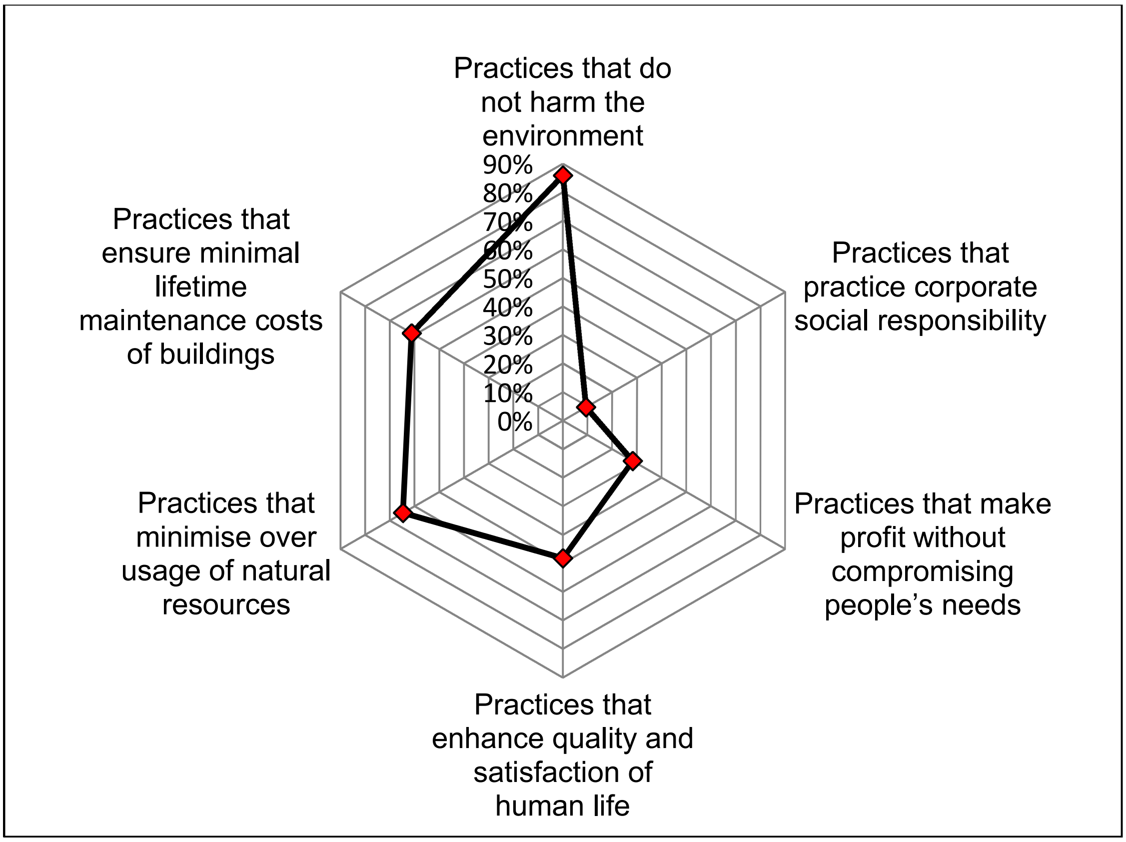


Figure 8.14 Perception of sustainable construction

Further analysis showed that most (43%) selected two environmental statements and one economic statement (i.e. 2Env&1Eco), followed by 26% who selected one environmental, one social, and one economic statement (i.e.1Env&1Soc&1Eco) (see Figure 8.15). Other resulting combinations were as follows: 2Env&1Soc (14%), 2Soc&1Env (6%), 2Eco&1Env (8%), and 2Eco&1Soc (2%); no respondent chose 2Soc&1Eco. A further 'like-with-like' clustering of responses (e.g. 2Env&1Soc with 2Soc&1Env) revealed that environment and economic statements (i.e. Env&Eco) were selected most (51%), followed by Env&Soc (22%), and lastly, Eco&Soc (2%). This suggested that the second order state of sustainability in Uganda relates to environmental and economic sustainability. In addition, it was revealed that social sustainability was least considered. These findings have previously been reported elsewhere (Shen et al., 2010; Edum-Fotwe and Price, 2009; Lehtonen, 2004).

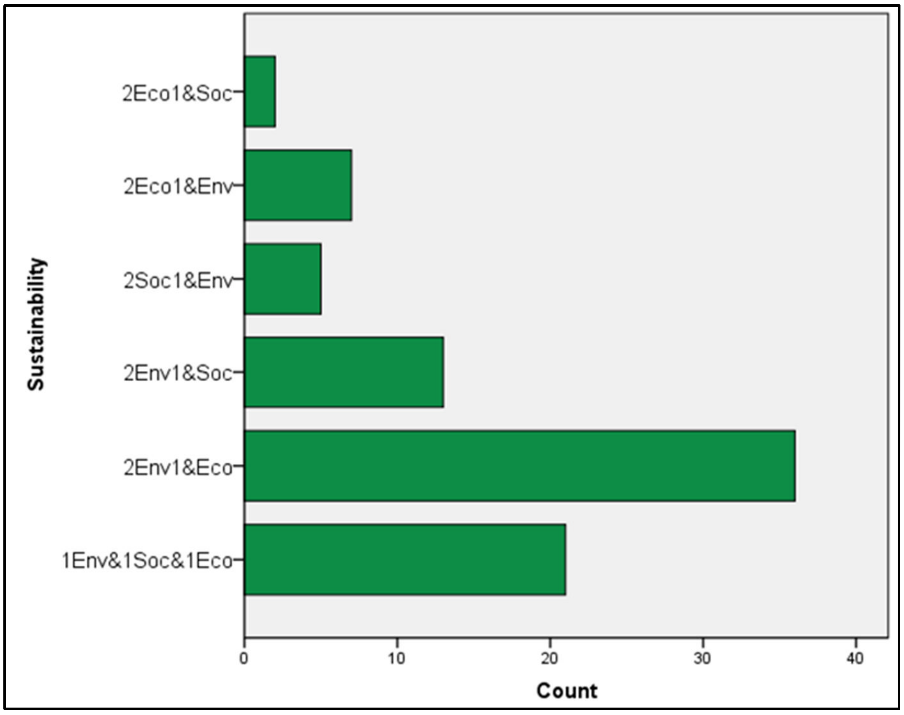


Figure 8.15 Multiple selection analysis of statements

8.2.2 Effectiveness: testing hypothesis H1

The effectiveness in facilitating sustainable construction, which was the main contribution of the to-be system, was scored highly and all professionals shared similar opinions. Resulting scores ranged from 2.13 to 5, with an average score of 3.60. This showed that the to-be system was not scored 1 (the minimum) and that there was at least an instance in which it was scored 5 (the maximum possible score). Results from the one-way between groups ANOVA showed that there was no statistically significant difference at the $p < 0.05$ level in the scores of the four professions: F (3, 67) = 1.53, $p = 0.22$. Levene's test for homogeneity of variance returned a value of 0.23 ($p > 0.05$), confirming that the variance in scores for the four types of professionals was insignificant.

Discussions in Chapter 3 (section 3.2.3.2.1) suggested that effectiveness is the extent to which a measure achieves its intended goal. In line with the aim of this research, the main goal of the to-be system was that of enhancing sustainable construction. Therefore, effectiveness was judged upon the extent to which the to-be system was perceived to facilitate sustainable construction. As such, in setting the hypothesis about the effectiveness of the to-be system, the null hypothesis ($H1_0$) and the counter alternative hypotheses ($H1_1$) were as follows:

- $H1_0$: The to-be system is perceived as not effective in facilitating sustainable construction

- $H1_1$: The to-be system is perceived to be effective in facilitating sustainable construction

A one-sample *t* test was conducted on the 'effectiveness' scores to further evaluate whether their mean score of 3.6 was significantly different from the set cut-off score of 3. From the results of the *t* test with alpha set at 0.05, the sample mean of 3.60 (*Sd* = 0.56) was found significantly different from 3.0, $t(70) = 8.94$, $p = 0.000$ ($p < 0.0005$). Such level of significance implied that the observed scores reflected a pattern, rather than chance. Therefore, there was compelling evidence to reject the null hypothesis in favour of the alternative hypothesis which stated that the to-be system was perceived as effective. The 95% confidence interval ranged from 3.46 to 3.73. The effect size *d* of 1.06 obtained indicated a large effect. This implied that the difference between the cut-off score of 3.0 (i.e. where > 3 is effective) and the to-be system's mean score of 3.6 was reliably large enough to warrant perception of the to-be system as effective. These findings corroborate the assertions made in several works that the primary purpose of accounting for carbon emissions is improving sustainability (RICS, 2012; Knight and Addis, 2011). Based on this evidence, the author argues that in order to improve sustainable construction in Uganda, EC accounting should be integrated into the existing development approval process.

Descriptive statistics show that for all the three pillars, the effectiveness of the to-be system was scored above average. The mean scores were as follows: environmental pillar (*Mean* = 3.76, *Sd* = 0.59), economic pillar (*Mean* = 3.18, *Sd* = 0.72), and social pillar (*Mean* = 3.74, *Sd* = 0.68). This implied that, even when disaggregated into the three pillars, the effectiveness of the to-be system in facilitating sustainable construction was still substantial. Since there is an intimate relationship between construction activities and economic development (Giang and Sui Pheng, 2011; Wells, 1985), yet developing countries are encouraged to follow a low carbon path to development, implementation of the to-be system could facilitate sustainable development. Therefore, if Uganda's policymakers were to take this finding seriously, the building sector could follow a more sustainable path towards meeting the needs of the country.

A comparison of the effectiveness scores across the three pillars revealed interesting findings. According to the Kolmogorov-Smirnov test for normality, only the scores related to the environmental pillar were normally distributed (p = 0.2). In order to compare the three pillars' scores using the same test, a decision was taken to use the Friedman test which is a non-parametric test with less strict statistical assumptions. The Friedman test indicated that there was a statistically significant difference in the effectiveness scores across the three pillars (environmental, economic, social x^2 (2, n = 71) = 49.68, p < 0.0005). This suggested that the effectiveness of the to-be system in facilitating environmental, economic, and social sustainability, was not the same. Inspection of the median values − which were unsurprisingly different from the mean values because of the skewed distribution − showed that: social (*Md* = 3.83), environmental (*Md* = 3.73), and economic (*Md* = 3.17). As can be seen, social aspects were most scored, despite having been least understood (see 8.2.1.5.4) with regard to understanding sustainable construction. This finding confirms that EC accounting can promote socially responsible construction practices. In the case of Uganda, the to-be system contributes to socially sustainable practices which are currently least appreciated.

8.2.3 Cost effectiveness: testing hypotheses H2 and H3

In assessing the cost effectiveness of the to-be system, the cost implications and benefits associated with it were considered.

8.2.3.1 Cost implications of the system: hypothesis H2

Hypothesis H2 emanated from discussions presented in Chapter 3 (section 3.2.3.2.2). Firstly, it was hypothesised that if a policy is to be perceived as having little or no cost implications, there would not be need for new institutions to implement the policy. Secondly, such a policy would be easy to understand. Based on these arguments, the null hypothesis ($H2_0$) and the counter alternative hypothesis ($H2_1$) related to cost implications of the to-be system were as follows:

- $H2_0$: The to-be system has cost implications
- $H2_1$: The to-be system has no cost implications

As far as cost implications of the to-be system in relation to its implementation are concerned, 55% the respondents felt that significant modification to existing institutions is required, 22% suggested that minor modification of existing institutions is required, 17% suggested that new institutions are required, and 5% suggested that existing institutions can suffice. A Chi-square test for independence indicated no significant differences in the responses among the professionals, x^2 (3, *n* = 84) = 6.23, *p* = 0.10. In terms of how easy it was to understand the to-be system's processes and procedures, 51% of the respondents felt that it was somewhat easy, followed by 29% who indicated that it was very easy, 15% suggesting that it was not easy, and lastly 2% were undecided; none felt that the to-be system was 'not easy at all'. A Chi-square test for independence (with Likelihood Ratio) indicated no significant differences, x^2 (3, *n* = 81) = 1.17, *p* = 0.76, implying that the professionals sampled shared similar perceptions on how hard or easy the to-be system was.

The dichotomised results from descriptive statistics show that 27% of the responses thought new institutions are not required, whereas 72% indicated new institutions are required. This implies that majority of the respondents considered the to-be system to have high cost implications with regard to implementation, since significant modification or need for creating new institutions was envisaged. A one-sample Chi-square test confirmed that the difference between the observed 72% and hypothesised 75% was not significant, x^2 (1, *n* = 84) = 0.25, *p* = 0.61. The effect size of 0.003 obtained was classified as small. As such, the null hypothesis ($H2_0$) was accepted, suggesting that the to-be system could have high cost implications. It is stated in IPCC (2007a), that cost implications broadly manifest as direct and indirect costs. Whereas direct costs are associated with implementation, indirect costs result from intended or unintended effects of implementation. Therefore, the to-be system was envisaged to have high direct costs. Perhaps this explains why results presented in section 8.2.2 showed that the to-be system's ability to facilitate sustainable construction was least in regard to economic sustainability.

The dichotomised results showed that 15% found the to-be system difficult, whereas 81% considered it to be easy. A one-sample Chi-square test confirmed that the difference between the observed 15% and hypothesised 75% was significant, x^2 (1, *n* = 81) = 150.13, *p* < 0.0005. The effect size of 1.85 obtained was classified as large. As such, the null hypothesis ($H2_0$) was rejected in favour for the alternative hypothesis ($H2_1$) which suggested that the cost implications with regard to ease of understanding are low. One of the ways in which cost implications of a measure can be kept low is by ensuring that implementation procedures are simple (Gupta et al., 2007). Therefore, it will be necessary to strike a balance between the high cost implications associated with the need for new institutions and the low cost implications associated with the ease of understanding, such that the overall cost implications can be offset.

8.2.3.2 Benefits: hypothesis H3

Discussions on cost implications of environmental policy suggested that benefits associated with an environmental policy should also be assessed in order to understand its cost-effectiveness (see Chapter 3 section 3.2.3.2.2). As such, for the to-be system, it was necessary to ascertain whether it could contribute to other benefits such as carbon trading. Therefore, in assessing the benefits associated with the to-be system, the null hypothesis ($H3_0$) and the counter alternative hypothesis ($H3_1$) were as follows:

- $H3_0$: The to-be system has no benefits
- $H3_1$: The to-be system has benefits

Regarding whether the to-be system could contribute to other benefits such as carbon trading, the extent of agreement was as follows: Strongly disagree (4%), Disagree (4%), Undecided (3%), Agree (52%), Strongly agree (29%). A Chi-square test for independence (with Likelihood Ratio) indicated no significant differences in the responses among the professionals, x^2 (3, *n* = 75) = 4.13, *p* = 0.25, implying that all professionals shared similar opinions.

Upon dichotomising the responses, results showed that 8% disagreed, whereas 81% agreed that the to-be system can contribute to other benefits. A one-sample Chi-square test confirmed that the difference between the observed 8%

and hypothesised 75% was significant, x^2 (1, *n* = 75) = 179.56, *p* < 0.0005. The effect size of 2.39 obtained was classified as large. As such, the null hypothesis ($H3_0$) was rejected in favour for the alternative hypothesis ($H3_1$), inferring that the to-be system can contribute to benefits such as carbon trading. This finding corroborates claims, such as those made by UK's Embodied Carbon Industry Task Force (2014), that EC accounting can contribute to several benefits. Therefore, cost effectiveness of the to-be system can be realised if the to-be system's benefits are exploited in order to offset its cost implications.

8.2.4 Distributional considerations: hypothesis H4

It was argued that a policy perceived to be legitimate, fair, and transparent would address distributional considerations (see Chapter 3 section 3.2.3.2.3). This led to hypothesising about distributional considerations of the to-be system whereby the null hypothesis ($H4_0$) and the counter alternative hypothesis ($H4_1$) related to the three aspects (legitimacy, fairness, and transparency) of distributional considerations were set as follows:

- $H4_0$: The to-be system does not address distributional considerations
- $H4_1$: The to-be system addresses distributional considerations

Responses to the three aspects under distributional considerations of the to-be system are shown in Table 8.5. A Chi-square test for independence (with Likelihood Ratio) indicated no significant differences in responses among the professionals: legitimacy, x^2 (3, *n* = 83) = 1.69, *p* = 0.64; fairness, x^2 (3, *n* = 62) = 1.01, *p* = 0.80; and transparency, x^2 (3, *n* = 81) = 2.67, *p* = 0.45. In relation to each of the three aspects (legitimacy, fairness, and transparency) of distributional considerations, the hypothesis (H4) was analysed as follows.

Table 8.5 Distributional considerations for the to-be system

Item	Responses				
	1	2	3	4	5
Willingness to use – Legitimacy [a]	0%	4%	2%	51%	43%
Fairness [b]	4%	6%	20%	47%	17%
Intentions being clear – Transparency [c]	0%	5%	4%	67%	24%

[a] 1 = Extremely unlikely, 2 = Unlikely, 3 = Undecided, 4 = Likely, 5 = Extremely likely
[b] 1 = Very unfair, 2 = Unfair, 3 = Undecided, 4 = Fair, 5 = Very fair
[c] 1 = Very unclear, 2 = Unclear, 3 = Undecided, 4 = Clear, 5 = Very clear

8.2.4.1 Legitimacy

According to Mickwitz (2003), in assessing legitimacy, there is need to assess the degree to which a measure is accepted by those it is intended for. In other words, “does the public accept”? (Huitema et al., 2011, p.184). Upon dichotomising the responses about willingness to use the to-be system, 95% of the respondents were willing to accept it in comparison with 4% who were not. A one-sample Chi-square test confirmed that the difference between the observed 4% and hypothesised 75% was indeed significant, x^2 (1, *n* = 83) = 225.58, $p < 0.0005$. The effect size of 2.72 obtained was classified as large. The null hypothesis ($H4_0$) was rejected in favour for the alternative hypothesis ($H4_1$). Therefore, the findings suggested that the to-be system can address distributional considerations related to legitimacy.

8.2.4.2 Fairness

Since fairness concerns how the outcomes of a measure are distributed (Huitema et al., 2011; Mickwitz, 2003), the to-be system’s outcomes were envisaged to be fairly distributed in Uganda. Upon dichotomising responses into ‘generally fair’ and ‘generally unfair’, 64% considered the to-be system to be generally fair, whereas 10% thought it was generally unfair. A one-sample Chi-square test confirmed that the difference between the observed 10% and hypothesised 75% was significant, x^2 (1, *n* = 62) = 127.51, $p < 0.0005$. The obtained effect size of 2.06 was classified as large. The null hypothesis ($H4_0$) was rejected in favour of the alternative hypothesis ($H4_1$).

8.2.4.3 Transparency

On the whole, the dichotomised responses revealed that 91% considered the to-be system’s intentions as clear, compared with 5% who indicated that the intentions were not clear. A one-sample Chi-square test confirmed that the difference between the observed 5% and hypothesised 75% was significant, x^2 (1, *n* = 81) = 212.05, $p < 0.0005$. The effect size of 2.62 obtained was classified as large. As such, the null hypothesis ($H4_0$) was rejected in favour for the alternative hypothesis ($H4_1$). Therefore, the to-be system was perceived to address distributional considerations in regard to transparency. Since transparency is one of the criteria for democratic accountability (Huitema et al., 2011), this finding suggests that the to-be system upholds principles of democratic accountability.

8.2.5 Institutional feasibility: testing hypothesis H5

The major aspects in assessing institutional feasibility of a policy were identified as relevance, legal acceptance, compatibility, persistence, and predictability (see Chapter 3 section 3.2.3.2.4). A policy that fulfils these five aspects was envisaged as institutionally feasible. As such, the hypothesis (H5) about the institutional feasibility of the to-be system involved setting the null hypothesis ($H5_0$) and the counter alternative hypothesis ($H5_1$) as follows:

- $H5_0$: The to-be system is not institutionally feasible
- $H5_1$: The to-be system is institutionally feasible

The five aspects considered for assessing the institutional feasibility of the to-be system are presented in Table 8.6. All professionals unanimously agreed about the relevance of the to-be system. A Chi-square test for independence indicated that agreement about legal acceptance significantly varied, x^2 (3, *n* = 78) = 9.18, *p* = 0.03. Also, the Chi-square test for independence (with Likelihood Ratio) indicated that opinions about the compatibility of the to-be system with national priorities significantly varied, x^2 (3, *n* = 79) = 9.55, *p* = 0.02. Mostly, Architects (35%) and Quantity Surveyors (24%) were more inclined to the opinion that the to-be system is not compatible, compared to Engineers (5%) and Environmentalists (4%). However, there were no significant differences (Chi-square test for independence with Likelihood Ratio) in responses among the professionals regarding the to-be system's persistence, x^2 (3, *n* = 72) = 5.36, *p* = 0.15 and predictability, x^2 (3, *n* = 82) = 4.33, *p* = 0.23. Therefore, for further analyses involving hypothesis tests, it was appropriate to combine the professionals' responses on relevance, persistence, and predictability. For the hypothesis tests regarding legal acceptance (section 8.2.5.2) and compatibility (section 8.2.5.3), results were presented per type of profession. In relation to each of the five aspects (relevance, legal acceptance, compatibility, persistence, and predictability) of institutional feasibility, the hypothesis (H5) was analysed as follows.

Table 8.6 Institutional feasibility of the to-be system

Item	Responses (%)	
	No [a]	Yes
Relevance	0	100
Legal acceptance	35	57
Compatibility	15	78
Persistence	25	60
Predictability	8	88

[a] Responses in the ‘No’ category represent the observed percentages.

8.2.5.1 Relevance

According to the European Environment Agency (2001), ‘relevance’ is the extent to which the measure’s objective is justifiable in relation to the needs of the context. All (100%) respondents acknowledged that there was a need for pursuing sustainable construction and as such, there was no need to test the corresponding null ($H5_0$) and alternative hypotheses ($H5_1$). Not only did this overwhelming response underscore the relevance of the to-be system but it also underscored the relevance of this research to Uganda. Therefore, it can be argued that promoting sustainable construction is justified in relation to the needs of Uganda.

8.2.5.2 Legal acceptance

In assessing legal acceptance, the extent to which the to-be system was compliant to the laws and regulations of Uganda was probed. A one-sample Chi-square test per profession returned the following results:

- Architects: Observed = 53%, x^2 (1, n = 19) = 5.07, p = 0.024, effect size = 0.27;
- Engineers: Observed = 44%, x^2 (1, n = 18) = 8.96, p = 0.003, effect size = 0.50;
- Quantity Surveyors: Observed = 50%, x^2 (1, n = 18) = 6.00, p = 0.014, effect size = 0.33;
- Environmentalists: Observed = 13%, x^2 (1, n = 23) = 8.96, p = 0.0005, effect size = 2.05.

These results show that for each professional type, the differences between the observed percentages (i.e. those saying that the to-be system does not fit into existing regulatory framework) and hypothesised (75%) percentage were significant (p < 0.05). The corresponding effect sizes were also large and as such, the null hypothesis ($H5_0$) was rejected in favour for the alternative hypothesis ($H5_1$). Therefore, the to-be system was perceived as institutionally feasible with regard to legal acceptance.

8.2.5.3 Compatibility

Regarding whether the to-be system is compatible with national priorities, a one-sample Chi-square test conducted per profession revealed the following:

- Architects: Observed = 35%, x^2 (1, n = 17) = 14.29, p = 0.0005, effect size = 0.84;
- Engineers: Observed = 5%, x^2 (1, n = 19) = 49.28, p = 0.0005, effect size = 2.59;
- Quantity Surveyors: Observed = 25%, x^2 (1, n = 21) = 29.35, p = 0.0005, effect size = 1.4;
- Environmentalists: Observed = 4%, x^2 (1, n = 22) = 58.24, p = 0.0005, effect size = 2.65.

These results show that for each professional type, the differences between the observed percentages and hypothesised (75%) percentage were significant ($p < 0.05$). The corresponding effect sizes were also large and as such, the null hypothesis ($H5_0$) was rejected in favour for the alternative hypothesis ($H5_1$). This implied that the to-be system is compatible with Uganda's priorities. Since it is crucial in Uganda that any proposed measure, especially in the context of addressing climate change, is compatible with Uganda's priorities (Olsen, 2006; Bwango et al., 2000), the to-be system demonstrates how national priorities can be reconciled with the mitigation of climate change.

8.2.5.4 Persistence

With regard to whether the to-be system is persistent, a one-sample Chi-square test confirmed that the difference between the observed 24% and hypothesised 75% was significant, x^2 (1, n = 72) = 85.63, $p < 0.0005$. The effect size of 1.19 obtained was classified as large. As such, the null hypothesis ($H5_0$) was rejected in favour for the alternative hypothesis ($H5_1$). Therefore, the to-be system was perceived to be institutionally feasible in regard to persistence. Mickwitz suggests that for a measure to be persistent, its impacts (intended or unintended) are long lasting (Mickwitz, 2003). Therefore, the to-be system could provide lasting solutions to minimising carbon emissions from the building sector.

8.2.5.5 Predictability

Regarding predictability of the impacts resulting from implementation of the to-be system, a one-sample Chi-square test confirmed that the difference between the observed 8% and hypothesised 75% was significant, x^2 (1, n = 82) = 193.19, p < 0.0005. The effect size of 2.36 obtained was classified as large. As such, the null hypothesis ($H5_0$) was rejected in favour for the alternative hypothesis ($H5_1$). It was therefore confirmed that the to-be system is institutionally feasible in regard to predictability. For a measure whose effects are predictable, its outcomes can be foreseen and thus it is possible for those affected to prepare in advance and take into account the implications (Mickwitz, 2003). Therefore, for the to-be system, policy makers will have foresight ahead of its implementation because its impacts are predictable.

8.2.6 Format of introducing the to-be system

Fifty one percent (51%) of the respondents suggested that the to-be system should be introduced as a regulation, followed by those who preferred it as an economic instrument (32%), and lastly as an information instrument (17%). A Chi-square test for independence (with Likelihood Ratio) indicated no significant differences in responses among the professionals, x^2 (6, n = 85) = 2.98, p = 0.81. Therefore, the to-be system was largely preferred as a regulatory tool.

Preference for the to-be system as a regulatory tool was not a surprising finding since regulations are quoted to be the most widely used environmental policy instruments (Mickwitz, 2003; OECD, 1994). Several studies suggest that changes in the regulatory framework are an effective way of causing a positive behavioural change towards sustainable construction (Serpell et al., 2013; Zainul Abidin, 2010; Majdalani et al., 2006; Manoliadis et al., 2006). Du Plessis argues that promoting sustainable construction in developing countries requires developing or updating regulatory mechanisms (Du Plessis, 2007). It was also noted in James and Matipa (2004) that the low consideration of wider aspects of sustainable construction in Zambia was because such aspects were not prescribed to be mandatory. These findings suggest that if the intentions of the to-be system are to be greatly realised, it should be introduced as a mandatory requirement.

8.2.7 Kind of buildings considered in the to-be system

Results regarding the kind of buildings to which the to-be system should apply were as follows: non-residential buildings (48%), 'All' kinds of buildings (48%), and residential buildings (4%). A Chi-square test for independence (with Likelihood Ratio) indicated significant differences in the opinions among the professionals, x^2 (6, n = 85) = 13.32, p = 0.04. Results in Table 8.7 suggest that Architects and Environmentalists were mostly responsible for these significant differences since none of them preferred the to-be system to apply to residential buildings.

Table 8.7 Kind of buildings to apply

Professional	Choice of building type to apply (%)		
	Residential	Non-residential	All kinds
Architects	0	30	70
Engineers	5	62	33
Quantity surveyors	10	33	57
Environmentalists	0	65	35

8.2.8 Professionals suitable for carbon accounting

Regarding the professions suitable for role of EC accounting, results were as follows: Architects (37%), Engineers (11%), Quantity surveyors (17%), Environmentalists (17%), All professionals (15%), and others (3%). These results were surprising because previous studies suggest that Quantity Surveyors are most suitable for EC accounting (RICS, 2012; Zuo et al., 2012; Knight and Addis, 2011). Meanwhile, a Chi-square test for independence (with Likelihood Ratio) indicated significant differences in the opinions among the professionals, x^2 (21, n = 85) = 49.35, p < 0.0005. These differences were further confirmed by the *phi* coefficient (*Phi* = 0.77) which suggested a strong correlation between the type of profession and choice of answer.

The percentage distribution of responses confirmed that there was a high tendency for the professionals to select their corresponding profession (see Table 8.8). For instance, Architects most preferred Architects (75%). However, this tendency was minimal for Engineers. Overall, these findings concur with literature (see earlier discussions in section 5.4.2.1.2 b)(vii)) suggesting a lack of consensus regarding who should be responsible for EC accounting. Therefore, it would be useful in building projects to define the responsibilities of the built environment professionals in regard to carbon accounting.

Table 8.8 Professionals suitable for carbon accounting

Professional	Choice of who to account for carbon (%)					
	Arch	Eng	QS	Env	All	Other
Architects	75	0	10	5	10	0
Engineers	38	24	5	5	28	0
Quantity surveyors	33	10	33	10	10	4
Environmentalists	9	9	17	44	13	8

Note: Arch – Architects, Eng – Engineers, QS – Quantity Surveyors, Env – Environmentalists

8.2.9 Findings from qualitative analyses

In form of data triangulation, qualitative data augmented quantitative data as discussed below.

8.2.9.1 Effectiveness of the to-be system

Responses coded under the effectiveness theme revealed that "[the to-be system] would also be very good for sustainable development" (Environmentalist) and "…actually, nice when it comes to contributing to sustainable environment" (Engineer). This suggests that the to-be system was perceived to be an enabler of sustainable development and a sustainable environment. These findings agree with those from quantitative analyses (see section 8.2.2), confirming that the to-be system indeed facilitates sustainability.

8.2.9.2 Cost implications of the to-be system

Findings from the theme about cost implications of the to-be system show that the to-be system might increase indirect costs. Various supporting exemplars from interview transcripts are given below:

> *"…the cost implications of doing this, is that the cost of construction is going to increase* (Quantity Surveyor).

> *"Of course, if you are going to, sometimes if you are going to reduce the carbon footprint, then you probably are going to spend a little more money on the job"* (Architect).

> *"For the system, I am just worried, you are just going to increase our costs of doing business"* (Environmentalist).

The finding that the to-be system might have high cost implications with regard to the indirect costs was not very surprising. As documented in BRE and Cyril Sweett (2005), sustainable construction is largely perceived to have high cost implications. In Ametepey et al. (2015, p.113), the "fear of high investment costs" was noted as one of the major challenges of implementing sustainable construction. Khalfan also reported that the "high cost that is involved in the whole construction process" inhibits sustainability initiatives (Khalfan, 2015, p.943). However, BRE and Cyril Sweett (2005) documented that there are many sustainability measures that can be implemented at little cost, especially if the earliest stages of the building's life cycle are utilised. Since the to-be system is based on the earliest possible stages of a building (i.e. during the development approval process), there is a chance to keep the indirect costs low.

8.2.9.3 Distributional considerations

The theme for distributional considerations only registered coding with regard to legitimacy. Findings showed that the to-be system was indeed acceptable, as several interviewees opined below:

> *"I think it is okay and very very welcome, and we are waiting for it, for us we play other environmental roles, so we are waiting for it* (Architect).

> *"This is long overdue and I just don't know why our Government, our Ministry of Education... I mean I was in the UK in the late 90's, 98, the topic was environment, and people, I mean were just so sensitive"* (Quantity Surveyor).

> *"That is a welcome system. You should make an effort to have a workshop to run us through this and we get to know where you are heading…"* (Environmentalist).

8.2.9.4 Institutional feasibility

Findings from word cloud-analysis of the responses from the open ended question underpinned the institutional feasibility of the to-be system with regard to its relevance (see Figure 8.16). Most respondents "think" of the "system", "research", and the general "idea" to be "good" in relation to the "environment" and "construction". As can be further gleaned from the summary of excerpts shown in Table 8.9, the to-be system, and this overall research, is considered to be unique, new, valid, innovative, and timely.

Figure 8.16 Word frequency cloud analysis

Table 8.9 Comments demonstrating relevance of the to-be system

SN	Comment	Source
1	But it's quite good, it is quite unique, even if there is carbon trading already, but nobody has come up with such a project like this.	Environmentalist, 13 years of experience
2	Well I think it is a good research, a new one, interesting.	Quantity Surveyor, 10 Years of experience
3	Having something quantifiable is good and this research is valid.	Architect, 6 years of experience
4	My comment would be it is an existing approach but new, the concept is still new in Uganda.	Engineer, 12 years of experience
5	I can only say it is a very good innovation.	Architect, 9 years of experience
6	I think it is a unique and innovative research; it is timely, actually me I had not even thought of it in terms of construction. My idea was in crops, anyway, the things that we have been looking at.	Environmentalist, 6 years of experience
7	Integrating carbon emissions in the construction industry is going to be a new field in the country.	Environmentalist, 10 years of experience

The predictability of the to-be system's impacts was also confirmed by several respondents' opinions as extracted below:

> *"… they [donors] will be now having something that is working on the ground, and this side [Uganda], it will also be good for the environment basically"* (Quantity surveyor).

> *"[the to-be system] would put pressures on the manufacturers to modify their processes...they have to go back to the table and design products that can suit"* (Engineer).

> *"… very good in the long term, and I think if it is implemented it will have some effect"* (Engineer).

8.2.9.5 Format of introducing the to-be system

Similar to quantitative results presented in section 8.2.6, results from qualitative data suggested that most respondents preferred the to-be system to be introduced either as a regulation, or as an amendment to existing relevant regulations:

> *"…there has to be a strong legal basis for its implementation, because from my experience in EIA, which is also mandatory, is that it has to be the law, because that is what people most people respond to […] it could be a regulation for instance, or an amendment to an existing regulation"* (Environmentalist).
>
> *"I see two key things for it to work: one is legislation, very important"* (Architect).
>
> *"Then the other thing is, there is nothing that drives good innovations like legislations. If something is legislated for, people will have no option"* (Quantity Surveyor).

It is worth mentioning that although regulations are largely considered effective, they have some drawbacks. For instance, regulation instruments are easily subject to "bargaining and negotiations" which can potentially lead to corruption (OECD, 1994, p.8). Some respondent was of the view that legislations in Uganda have hitherto faced a challenge of corruption. Proponents of economic instruments (e.g. taxes) were of the view that legislations have some challenges and thus cannot work independently. These opinions suggested that the to-be system should not be introduced in a sole instrument. Indeed some commentators suggest that regulations should be used in combination with economic and information instruments (Weber et al., 2013; OECD, 1994). Economic instruments have several advantages which include: creation of incentives to comply, flexibility of modification, and a source of revenue (e.g. though levying environmental taxes, emissions trading, etc.) (Gupta et al., 2007; Mickwitz, 2003; Vedun and van-der-Doelen, 1998 p.104). Meanwhile, information instruments are usually the cheapest to introduce and manage (Vedun and van-der-Doelen, 1998 pp.107-114). According to Vedun and van-der-Doelen (1998 pp.107-114), the information instrument can be used as an initial action to pave way for a regulatory tool. Therefore, although results suggested that regulations are the most preferred way of implementing the system, it will be useful to incorporate economic and information tools as can be gleaned from an interview excerpt below:

> *"… one of the most important things to do here is that in implementing this system, we do not need to force people. If you force or impose a cost in implementing this it will be very difficult. It would rather be better that you create rapport; you teach people the importance of these things, of what value it is to them, such that a person knows that what is going to be implemented is not of use may be to government or some parastatals, but it is even of use to me as an individual"* (Engineer).

8.2.9.6 Kind of buildings to be considered

Quantitative data regarding which kind of buildings the to-be system should apply to showed that 48% of the respondents chose 'All' kinds of buildings, 48% chose non-residential buildings, and 4% residential buildings. The corresponding reasons for choice are summarised in qualitative data of interview excerpts presented in Table 8.10.

Table 8.10 Reasons for kind of building to consider

Kind of building	Reason
Non-residential buildings	"the reason I chose non-residential is because big buildings...it is the volumes" (Quantity Surveyor).
Residential buildings	"…because they are not subjected to EIA [...] then again if you talk about residential, it is broad [...] because as I was saying, apartments are subjected to EIA [...] what makes apartments come into the environment is that they are projects which are out with its natural settings (Environmentalist) "And then the question is, at the end of the day, these small residential areas, there are so many, cumulatively" (Environmentalist)
All types	I think the system is a good system but the need.., from what our market and regulations..., it can only apply to the big structures" (Quantity Surveyor). But this for now should be tied to multi-million projects […] we should have the element of the magnitude of the project (Environmentalist)

It was realised that respondents selected 'non-residential' because they associated non-residential projects to "big developments", "big structures", and "multi-million projects. Respondents suggested that the magnitude of the project should be considered since residential buildings can also involve large-scale developments which can contribute to substantial emissions. Therefore, although ‘All’ kinds of buildings and non-residential buildings were equally selected, this study proposes that ‘All’ kinds should be considered albeit with a further criterion of project magnitude.

8.2.9.7 Suitable professions to account for carbon

Reasons that were given for choosing the suitable professionals to conduct EC accounting are summarised in the excerpts presented in Table 8.11. Quantitative results suggested that Architects are the most preferred professionals (section 8.2.8), contrary to literature (RICS, 2012; Zuo et al., 2012; Knight and Addis, 2011) which suggested Quantity Surveyors. Explanations for this contradiction can be traced in the reasons given by respondents.

Firstly, Architects were thought to be the best professionals to conduct carbon accounting because of their primary role of team leadership. Respondents argued that Architects are usually the team leaders, projects managers, lead professionals, and in most cases, they are at the fore front of building projects. An Architect, it was argued, has to take the primary role of the cause (i.e. carbon accounting) before it can be enforced to other professionals. Secondly, Architects were selected because of the nature of their responsibilities. Among their responsibilities include application for building permits and certification of payments for completed works, all which are fundamental to the to-be system. In addition, Architects interface directly with the developer and thus have an opportunity to influence the developer’s buy-in. Moreover, since Architects specify materials, they are in position to advise the developer about alternative options like greener options. Therefore, it can be argued that the major reason as to why Quantity Surveyors were not seen as suitable for the role is because in Uganda, the Quantity Surveying profession is not (yet) greatly empowered in lead-management of projects.

Table 8.11 Reasons for suitability of professional

Professional suitable	Supporting excerpt
Architect	"…most contracts used empower Architects as lead consultants…they deal with the overall management of the project and as such, they are appropriate for this [carbon accounting] role..." (Architect). "…when the client wants to put up a building like this, you do not go to the Structural Engineer, you go to the Architect…these [Architects] are the guys who come up with the design concept; the other ones, the Engineers, give it a life". (Engineer).
Quantity Surveyor	"…since they [Quantity Surveyors] are the ones who make Bills of Quantities for the entire construction, may be they are conversant with determining carbon emissions, they can also come up with Bills of Carbon" (Environmentalist). "It is easy to monitor if Quantity Surveyors take it on because they are involved in similar processes like valuations" (Quantity Surveyor).
Environmentalist	"[by professional; training] this is what they do" (environmentalist). "they [environmentalists] are the ones involved in environmental aspects and thus best placed" (Quantity Surveyor). "[Environmentalists] fully understand the modalities involved in carbon accounting" (Environmentalist). "other professionals will not have enough information on the environmental side and the mainstream environmental like some of us" (Environmentalist).
All professionals	"They [professionals] enter projects at different stages, e.g. Architect at design, Engineers as design, Quantity Surveyors at Costing. All parties should be involved for this to work (Engineer). "Each profession has got a different input. The architect will design and specify materials, same applies to Engineer, then the Quantity Surveyor is normally there to compute the Carbon footprint. Therefore it is ALL, since each of them has a different role to play (Quantity Surveyor). "It is a multi-disciplinary thing. You will need a skill of a certain expert to enable you move these aspects, not only one. Somebody in transport, somebody who is good in social, somebody who is good in communication to communicate this…". (Environmentalist). "In some projects Architects are not involved, in others Engineers are not involved. All have to be involved". (Architect).
Engineers	"The system cuts across mechanical and process engineers. For example like cement footprint, one has to trace the beginning of the processes" (Engineer). "They know where the emissions come from, especially with regard to machines" (Quantity Surveyor).

Respondents that argued for Quantity Surveyors as the best professionals to conduct carbon accounting posed several reasons. Firstly, Quantity Surveyors were considered to possess the relevant technical ability since their primary role involves scrutiny of quantities for various projects' components such as materials, plant, and workforce. This, it was argued, would enable them to quickly conceptualise what is required of the EC accounting practice. Secondly, one respondent argued that since Quantity Surveyors would already have bills of quantities, they could easily break down the components into emissions. This implies that Quantity Surveyors possess relevant information required for carbon accounting. Indeed some respondents argued that Quantity Surveyors normally prepare specifications, material schedules, bills of quantities, valuation of completed works, and collect various data from the different members of the project team. Moreover, as noted by one Quantity Surveyor, "[EC accounting] is a cost aspect, and the country is a cost driven economy, thus anyone who concerns costs will be the best one". This is in agreement with literature since it is recommend in Knight and Addis (2011) that Quantity Surveyors are suitable because inputs into EC accounting are similar to those of cost accounting and therefore, both activities can be done concurrently. It is also argued in RICS (2012) that Quantity Surveyors are usually involved in computing material quantities and thus are best placed to account for EC.

Based on the evidence from the quantitative data, qualitative data, and literature, it can be inferred that Architects and Quantity Surveyors are perhaps the best placed professionals. Since the to-be system is limited to buildings, yet Architects primarily design buildings, for every building constructed, there would be at least an Architect associated with it. This may not be the case for Engineers or Environmentalists. Similarly, for every building constructed, there would be at least a Quantity Surveyor. Indeed, one environmentalist emphasized that, "…not all constructions will use an EIA specialist, Architect or Engineer, but all will use a Quantity Surveyor", since all constructions involve costs. Therefore, if carbon accounting is to appeal to most projects, Quantity Surveyors should take the lead role. Nevertheless, because the prevailing practice in Uganda does not greatly empower Quantity Surveyors, they should work together with the Architects.

8.2.9.8 Challenges of implementing the to-be system

The challenges of implementing the to-be system are summarised in Table 8.12 and discussed in detail hereunder.

Table 8.12 Challenges of implementation

Challenge	Supporting excerpt (s)
Hindrance of development	“the fact of the matter is that as a country is going through a development process, truth be told, it is going to be a bad emitter” (Engineer). “Africa has contributed less to emissions otherwise, it will kick people like manufacturers out of business” (Quantity Surveyor).
Lack of priority	“Uganda as a developing country has its own unique challenges. Usually a developing country has limited choices sometimes and preference is never given to environmental issues” (Engineer). “NEMA [as] the lead institution to enforce but they seem not to be having the moral character to enforce”(Engineer).
Lack of buy-in	“The only challenge is 'buy-in'. Buy-in from the professionals themselves and then the public, and then developers”(Architect). “…for someone to buy in, if it is not a person who is really passionate about environment, they might not really buy into it” (Architect).
Monitoring compliance	“…so how does the authority enforce that I am going to use this diesel size track and that's what happens? It is kind of hard for that side” (Quantity Surveyor). “You need to have a way to enforce it. If you cannot enforce it, can you fix it in? For example if you are giving a permit or something”(Environmentalist).
Low level of awareness	“…my worry is that people are not aware. So I am sure there will be a lot of resistance in case it has to be implemented” (Engineer). “…professionals do understand, here a b c, but Ugandans, the majority might not understand it” (Engineer).
Lack of emissions standards	“I don't know what standards it would refer to, because in the case of Uganda, they are still in draft” (Environmentalist).
Need for databases	“I am concerned on the data base. I think in order for this to be practical, it would need to be a huge amount of things” (Architect). “So I see a problem there because this is just one tiny example, if you look at more complex structures in a commercial setting […] the amount of different materials” (Architect).
Reliability of information	“If someone knows that I am going to be charged for carbon emissions in construction, I will give you lesser that I have to use during construction” (Environmentalist). “…but the challenge is, how reliable the information will be” (Quantity Surveyor).

8.2.9.8.1 Hindrance to development

There is a belief that imposing emission reduction commitments to developing countries is unfair and curtails development. Indeed, some interviewees asserted that as a country goes through a development process such as industrialisation, it is likely to emit more carbon emissions. Other responses supported the idea that the more the country becomes developed, the more it is likely to consider environmental issues. This, to some respondents, implied that the to-be system is premature for Uganda. However, this was not surprising since, as earlier discussed in the literature (Chapter 3), there is a longstanding debate concerning the extent of countries' responsibilities in reducing emissions. Developing countries often oppose limiting their emissions on a premise that it is not their responsibility since developed countries are hitherto the culprits to high emissions (Sathaye and Ravindranath, 1998). While such arguments are valid, it is widely accepted that mitigating climate change requires efforts from all countries (Nath and Behera, 2010). The overall implication is that the to-be system should be implemented in a way that does not hinder but supplement development.

8.2.9.8.2 Lack of prioritisation

Some responses suggested that a developing country like Uganda faces unique challenges which often leave it with no options of prioritising the environment. In many developing countries, policy makers are fully aware of the need to preserve the environment but dilemmas often arise when there is a need to choose between economic development and environmental sustainability (Cao, 2003). For instance, needs like energy security and poverty alleviation may be prioritised over conservation of the environment. Mukwaya noted that as Uganda's oil mining prospects steadily take shape, environmental regulatory bodies are increasingly facing pressure to contravene laws (Mukwaya, 2007). Therefore, as posited in several studies (Olsen, 2006; Bwango et al., 2000; Halsnæs, 1996), successful implementation of the to-be system requires adapting it to national priorities.

8.2.9.8.3 Lack of buy-in

Respondents felt that the buy-in from the professionals, public, and the developers is likely to be a challenge especially for those who are not passionate about the environment. On the demand side, it was noted that if developers/clients do not require sustainability performance, it is less likely for the professionals or contractors to incorporate the same in implementation of building projects. A certain study in Zambia found that few consultants had worked on projects where clients demanded sustainability practices and moreover, clients were only interested in economic sustainability (James and Matipa, 2004). Similarly, another study in Malaysia found that developers were mostly interested in economic but not environmental or social sustainability (Zainul Abidin, 2010). Other commentators suggest that the extent of sustainability of projects is greatly influenced by the clients' buy-in (Shen et al., 2010). Therefore the economic aspects of sustainable construction, that the to-be system can facilitate, will have to be emphasised to the developers/clients in order to influence their buy-in.

8.2.9.8.4 Monitoring compliance

Respondents argued that enforcing compliance might not be easy since it may not be possible to monitor whether what is prescribed is actually followed during the construction process. One respondent noted that it is commonplace for developers to state what they are going to do to address environmental issues, but once given approvals, they proceed to do the opposite. This kind of challenge seems to be common with regard to prevailing environmental management mechanisms such as EIA. Akello noted that in Uganda, challenges of enforcing compliance are exacerbated by insufficient capacity in terms of expertise and facilitation of the enforcement agencies (Akello, 2007). Since the to-be system was found to be compatible with the existing regulatory framework, the prevailing mechanisms of enforcing compliance can equally apply. Meanwhile, Cao suggests that public awareness is important in promoting self-regulating mechanisms especially in such developing countries where capacity and resources are chronically insufficient (Cao, 2003).

8.2.9.8.5 Low level of awareness

The construction industry is composed of various stakeholders such as clients, contractors, and regulatory bodies, who play various roles in execution of building projects. Although the level of awareness of sustainable construction was found to be relatively high, it was only related to the built environment professionals. Respondents suggested that although professionals might be knowledgeable, the level of awareness among other stakeholders such as clients might be low. Indeed, 90% of the clients surveyed in Zambia, according to James and Matipa (2004), had no knowledge on sustainable construction.

Although studies suggest that awareness of sustainability issues with regard professionals is most critical since they are the ones who can encourage other stakeholders (Ametepey et al., 2015), improving awareness among other stakeholders is also crucial. Indeed, one Architect said that it is easier for designers to implement sustainable practices if clients are in support of the same.

8.2.9.8.6 Lack of emissions standards

Some respondents suggested that the absence of emissions standards with regard to the building sector may pose some challenges. Although the prevailing regulations regarding environmental issues in Uganda provide for development of emissions standards in various sectors, many sectors still lack these emission standards (Mukwaya, 2007). However, the lack of emission benchmarks with regard to buildings is not a challenge that is unique to Uganda. Even in developed countries, these benchmarks are not yet set since EC accounting is relatively new and thus it is expected that emission-standards of buildings might be tenable over time (RICS, 2012). Practices in developed countries suggest that addressing this challenge involves implementation of EC accounting such that over time, emissions benchmarks can be established. It is therefore safe to assume that if the to-be system is implemented, overtime, emissions standards could be established.

8.2.9.8.7 Need for databases

Respondents were of the view that practical implementation of the to-be system will require data bases yet these are not available at the moment. Interviewees argued that data bases (e.g. of embodied energy of materials) will be important especially for complex construction projects which entail a variety of inputs. Indeed, according to Du Plessis (2007), databases are potential enablers of sustainability practices. Since evaluation of the to-be system showed that it could enable development of comprehensive databases, over time, databases can be developed if the to-be system is implemented.

8.2.9.8.8 Reliability of information

Some respondents argued that fostering transparency and reliability of information is likely to be a challenge. This was premised on the idea that if one knows that they are likely to face penalties, they will under-declare or give inaccurate information about the proposed project. However, in Uganda, this kind of challenge is not new since other sectors such as taxation face similar challenges (see Kangave, 2005). Addressing this challenge therefore requires monitoring and compliance, especially if the to-be system is introduced as a regulation or economic instrument.

8.3 Chapter summary

This chapter has presented results and discussions pertaining to objective four – proposing and evaluating a to-be system for enhancing sustainable construction. The structure of the to-be system has been presented and discussed. A major component of the to-be system is carbon accounting. This component affects the existing development approval process of buildings in such a way that EC of building projects should be considered when applying for a building permit and also when applying for an occupation permit. Upon testing the five hypotheses (H1, H2, H3, H4, and H5) set in this study, the to-be system was found effective in facilitating sustainable construction (H1), has benefits (H3), addresses distributional considerations (H4), and is institutionally feasible (H5). However, its cost implications (H2) with regard to the need for establishing new institutions to implement it were found to be relatively high. Other aspects that were considered as important in the implementation of the to-be system have also been discussed. These include the appropriate format of introducing the to-be system, which was found to be regulations, and professionals suitable for the role of EC accounting, who were identified to be Architects and Quantity Surveyors. In addition, some challenges of implementing the to-be system were also noted although for most challenges (e.g. lack of data bases, lack of awareness), it was only through implementation of the to-be system that they could be mitigated. If the overall findings presented in this chapter were to be summarised into one sentence, it would state that integrating EC accounting in the development approval process of building projects, in the form proposed in this research, can enable Uganda’s building sector to follow a sustainable path towards development. The next chapter (Chapter 9), which is the last, presents conclusions and recommendations from the entire thesis.

Chapter 9
Conclusions and Recommendations

This chapter, which concludes this thesis, begins by providing conclusions in which a general overview of the overall research is presented together with the strategic and tactical levels contribution. This is followed by a discussion of conclusions per each of the four research objectives, highlighting what this research set out to do, what was found, significance, contributions to knowledge, and the limitations that apply. Lastly, recommendations are presented.

9.1 Conclusions

The general overview of the research and the conclusions per each of the four research objectives are presented in this section.

9.1.1 General overview of the research

This research was broadly motivated by scientific evidence which suggests that the increased concentration of GHGs in the atmosphere has led to warming of the climate. Literature suggested that the building sector accounts for a significant proportion of the GHG emissions. Tackling these emissions, the author argued, is crucial since it is a potential way in which the building sector contributes to the overall agenda of promoting sustainable development and sustainable construction. However, the focus on the operation phase of buildings, as the case has widely been, cannot effectively deliver the sustainability agenda of the building sector.

As buildings are continuously designed to stricter operation energy efficiency standards, OC emissions will gradually reduce, shifting the relative importance and magnitude of buildings' emissions to EC emissions. EC emissions have been documented to emanate from activities like material manufacture, transportation, and equipment use associated with creating buildings. Prevailing deficiencies in accounting for EC were documented and it was argued that accounting for EC should be in a disaggregated manner and also expand boundaries from the predominant cradle-to-gate, to cradle-to-construction completion. In that way, the author posited, wider aspects of the development approval process of building projects can be catered for so as to enhance sustainable construction. However, this kind of EC accounting was found to require significant contextualisation of procedures. Contextualising EC accounting procedures has been demonstrated in this research by proposing and evaluating a to-be system for the development approval process of building projects in Uganda. The to-be system integrates EC accounting into the existing development approval procedures in Uganda. The main contribution of the to-be system, as this work has demonstrated, is its ability to enhance sustainable construction.

Work presented in this thesis has been scrutinised through peer review assessment, a consequence of which has been various publications, thereby demonstrating evidence of original contribution to knowledge (Kibwami and Tutesigensi, 2016b; Kibwami and Tutesigensi, 2016a; Kibwami and Tutesigensi, 2015a; Kibwami and Tutesigensi, 2014). This research therefore makes a contribution to the body of knowledge in a number of ways which can be distinguished into strategic and tactical levels of contribution.

a) At the strategic level, it has been empirically demonstrated in this research that integrating EC accounting in the development approval process of building projects can enhance sustainable construction. In addition, a robust method of process modelling, which was used in addressing the first and third research objective, is original in both conception and execution. This research therefore has a strong consideration for contributing to research methodology in terms of using process mapping techniques that are supported by a verification procedure of semi-structured interviews. Meanwhile, the mathematical model presented in addressing the third research objective is unique in design (i.e. use of disaggregation) and scope (i.e. use of cradle to construction completion boundary). This potentially contributes to improving quantification and accounting for EC emissions worldwide.

b) At the tactical level, a previously unexplored Ugandan context has been investigated. Before this research started, there was nothing known about the procedures and/or usefulness of integrating EC accounting in the development approval process of buildings in Uganda. This study has empirically demonstrated the need for quantifying EC in building projects, thereby identifying what is lacking in Uganda and how the desired improvements could be attained. A robust to-be system that integrates EC accounting in the development approval process of building projects in Uganda has been proposed and evaluated. Results from the evaluation of the to-be system provide environmental policy makers with first-hand information that can be used to optimise resource allocation when considering implementation of competing environmental policies in Uganda.

9.1.2 Description of the existing development approval process

The first research objective, which sought to describe the existing development approval process of building projects in Uganda, was fulfilled in Chapter 6. A method of process modelling was used and it consisted of the following steps: process discovery, process mapping, and verification.

It was found that the development approval process (i.e. the as-is system) entails three major subprocesses: building project (BP), application for development permission (DP), and environmental impact assessment (EIA). The BP subprocess begins when the developer recruits consultants for the building project and ends when an occupation permit is issued. The DP subprocess begins with applying for a building permit and ends when an occupation permit is granted. The EIA subprocess begins with preparation of a project brief by the developer or their agent, and ends when an EIA certificate has been granted by the relevant authority (NEMA). Largely, findings suggested that there were minimal differences between what had been modelled and what was identified in formal practice. A potential limitation to these findings emanates from the empirical verification exercise, since the informants who were interviewed were limited to subject matter experts (SMEs) from only two local planning authorities in Uganda. As such, the representativeness of the findings as far as the whole country is concerned can be questioned. However, this limitation does not seriously constrain the findings for two reasons. Being

SMEs, the informants possessed more knowledge about the development approval process than any other stakeholders in the building sector. Secondly, given that the development approval process is prescribed by regulations, and thus it is the same for the whole country, focussing on only two of the local authorities in Uganda does not greatly affect the representativeness of the findings.

9.1.3 Possibility of integrating EC

The second research objective, which sought to explore the possibility of integrating EC accounting in the development approval process of building projects in Uganda, was fulfilled in Chapter 6. The development approval process of building projects in Uganda was analysed in order to identify areas of improvement. The analysis was an extension to the process modelling method used in achieving the first research objective.

It was found out that in the three subprocesses that formed the current development approval process (i.e. environmental impact assessment, development permission, and building project), there were no activities related to accounting for EC emissions. This finding had several implications. Firstly, this corroborated assertions in literature that there is lack of research and practice on carbon emissions in developing countries, especially in Africa. Since success in addressing climate change demands joint global efforts, developing countries like Uganda need to consider accounting for carbon emissions in buildings. Secondly, because literature suggests that EC accounting can facilitate sustainable construction, absence of EC accounting indicated that the building sector in Uganda was missing out on opportunities of promoting sustainable construction practices.

Absence of EC accounting in Uganda demonstrated a theoretical contribution to knowledge in form of being the first confirmatory empirical evidence to suggest that the prevailing practices of development approval process do not consider accounting for EC emissions in building projects. However, there were some limitations identified. As the analysis focussed only on the formal practices associated with the development approval process of buildings, the findings do not account for the informal practices or any other voluntary practices which are not prescribed by the regulations related to the development approval process.

Although there were no activities related to EC accounting, the possibility of integrating EC accounting lies in two activities related to the environmental impact assessment subprocess – preparation of a project brief and conducting an environmental impact study. In each of these two activities, current practice requires inclusion of the likely environmental effects of prospective building projects, although EC is not among the requirements. Therefore, expansion of these two activities in order to include EC emissions among the environmental effects that are required to be reported was identified as a potential way forward to integrate EC accounting in the current development approval process of building projects in Uganda. Therefore, it was necessary to develop an approach that can facilitate integrating EC accounting in the development approval process of buildings in Uganda.

9.1.4 An approach to facilitate integration of EC

The third research objective, which sought to develop an approach to facilitate integration of EC accounting in the development approval process of building projects, was fulfilled in Chapter 7. A mathematical model for quantifying EC was developed and implemented as a software tool.

9.1.4.1 Model for quantifying carbon emissions

The researcher undertook to develop a model that could be used to compute EC emissions in a disaggregated manner, considering the cradle to construction completion boundary of building projects. Mathematical modelling was the method used to achieve this and involved problem formulation, stating assumptions, assembling mathematical formations, and verification.

A quantitative-deterministic-static-algebraic mathematical model composed of nine equations was developed. Equations (7.1) and Equations (7.2) represented emissions from manufacturing and transporting construction materials; Equation (7.3) and (7.4) represented emissions from operation and transportation of plant; Equation (7.5) represented emissions from transporting workforce; Equation (7.6) represented direct and indirect emissions; Equations (7.7) and

(7.8) represented constraints subjected to the model; and Equation (7.9) represented the consolidated model.

The mathematical model provides new insights into the emerging practice of EC accounting for buildings. Firstly, the accounting boundary that was considered accommodates cradle to construction completion. This boundary adequately addresses the entire development approval process, unlike the predominant boundaries that are limited to cradle-to-gate. Secondly, the model's ability to allow for disaggregation enables the specific sources of energy to bear on the quantification of emissions. In that way, it is possible to make second-order decisions in reducing EC, based on value judgements. Computationally, if disaggregation factors can be varied, disaggregation can facilitate achieving emission reductions by trade-offs. Practically, this facilitates considering alternative less carbon-intensive energy sources. All these features that were embedded in the mathematical model were identified to be potential enhancers of sustainable construction in the building sector, irrespective of country.

The mathematical model makes a contribution to the body of knowledge about quantification of EC emissions. For instance, the model could be used as a 'methodology' for developing Clean Development Mechanism projects that are associated with buildings, as demonstrated in Kibwami and Tutesigensi (2015b) and Kibwami and Tutesigensi (2016b). Therefore, the proposed mathematical model has wider applications that are not limited to Uganda. In that way, the model makes a contribution to the general body knowledge on EC accounting. However, there were some limitations to the mathematical model. The type of model was limited to a quantitative-deterministic-static-algebraic model; the boundary was limited to cradle-to-construction completion boundary; the modelling technique was limited to process-based lifecycle energy analysis; and the emissions computed were limited to those emanating from materials (manufacture and transportation); plant (operation and transportation); and workforce transportation.

9.1.4.2 Software tool for quantifying carbon emissions

Against the background that quantification of carbon emissions is computationally intense, a software tool (CaMeT) was developed to implement the mathematical model. An agile software development method involving Rapid Application Development (RAD) was used.

The resulting CaMeT software was in form of a module housed by third-party software, Excel. CaMeT consists of nine elements denoted by buttons which are fully functional upon clicking on them. Among several factors that facilitate usability of the CaMeT is its architectural layout and embedded error handling options. The layout of CaMeT is similar to traditional workflow diagrams whereas its error handling options can warn users in case of missing or incorrect data.

CaMeT received constructive feedback which underscored its relevance in the context of Uganda wherein it represents a pioneering initiative. Some interviewees who participated in the evaluation of the to-be system proposed that CaMeT could be developed into the first “carbon sustainability” rating tool for buildings in Uganda and Eastern Africa. Such opinions suggest that CaMeT makes a contribution to knowledge, especially in terms of addressing the growing need for software tools that address carbon accounting for particular country-contexts. Nonetheless, there were some limitations identified. As it currently stands, the graphical user interface (GUI) for CaMeT is generic and thus not specific to any user yet there might be different kinds of users (e.g. local authorities, clients, professionals, etc.) with different interests in using the tool. In addition, CaMeT is limited to operating within Excel, implying that a computer without this program cannot be used to run CaMeT.

9.1.5 Proposing and evaluating the to-be system

The fourth research objective sought to propose and evaluate a system for enhancing sustainable construction, based on integrating EC in the development approval process of building projects in Uganda. This objective was fulfilled in Chapter 8 whereby a to-be system, which integrates EC accounting in the existing development approval practice, was developed and evaluated as explained below.

9.1.5.1 Structure of the to-be system

The intention of the researcher was to propose a new development approval process of buildings (i.e. to-be system) that incorporates accounting for EC. The to-be system was presented as a process model. The required inputs were obtained from the outputs of the first research objective (i.e. as-is system) and third research objective (i.e. quantifying EC emissions). The to-be system was therefore developed by integrating a component of EC accounting (based on the mathematical model that was implemented as a software tool) into the as-is system, using process modelling.

A major contribution of the to-be system is that it integrates a carbon metric in environmental assessment of building projects in a disaggregated manner that spans the whole development approval process. This widens the available options for enhancing sustainable construction in the building sector. Since the prevailing EC accounting practices such as those emerging in the UK are limited to cradle-to-gate, for the first time, this thesis has provided insights into EC accounting based on the entire development approval process of buildings. As such, the built environment, policy makers, and other relevant stake holders of the building construction sector in Uganda have access to a state-of-the-art novel strategy for integrating EC accounting in construction practices. Meanwhile, a major limitation of the to-be system is its applicability – it is limited to the geographical context of Uganda.

9.1.5.2 Evaluation of the to-be system

The main purpose of evaluation was to ascertain the value of introducing EC accounting in the development approval process of buildings in Uganda, in light of promoting sustainable construction. In that way, it was possible to ascertain whether the ‘right to-be system’ had been proposed. Structured interviews with built environment professionals in Uganda were used in the evaluation exercise.

Results from evaluating the to-be system were quantitatively and qualitatively interpreted. Results from the variables for assessing response validity confirmed that responses collected were valid. Demographic data showed that most professionals were engaged in private consultancies, as it had earlier been anticipated. The overall practicing experience ranged from 5 to 51 years, implying the respondents had significant experience to provide valid answers. Majority of the professionals were aware of sustainable construction although sustainable construction was most appreciated in relation to environmental sustainability. Literature confirmed that these findings were not unique. Upon testing various hypotheses, it was found that the to-be system was perceived to: be effective in promoting sustainable construction; have significant cost implications regarding its implementation; have insignificant cost implications regarding ease of understanding it; have benefits; address distributional considerations (in terms of acceptability, fairness, and transparency); and institutionally feasible (in terms of relevance, compliance, compatibility, persistence, and predictability). Most respondents preferred the to-be system to be implemented as a regulation, applying to all kinds of buildings. Architects and Quantity Surveyors emerged as best suitable for spearheading EC accounting. Qualitative results, such as themes and word cloud analysis which were gleaned from the qualitative data, supported the findings from quantitative analyses. Respondents commended the to-be system as unique, new, valid, innovative, and timely.

Several implications emerged upon evaluating the to-be system. Since it was confirmed that the to-be system is effective in facilitating sustainable construction, work in this thesis presents new evidence to corroborate the assertion that EC accounting can improve sustainability (see Kibwami and Tutesigensi, 2016a). The to-be system fulfils the aim of this research by contributing to the understanding and possible enhancement of sustainable construction in Uganda. Having found that it could address distributional considerations and institutional feasibility, this was evidence that a right system had been proposed for Uganda. Since sustainable construction was understood in terms of environmental and economic sustainability, yet the to-be system scored highly with regard to social sustainability, the to-be system was envisaged to facilitate a third order state of understanding sustainable construction. Meanwhile, having discovered that the to-be system could highly promote social aspects of sustainability, yet literature suggested that social aspects are the least understood, this work offers new suggestive evidence linking EC accounting to social sustainability. Moreover, the to-be system also had policy implications. Since the goal of Uganda’s renewable energy policy is to increase dependence on renewable energy to 61% by 2017 (The Republic of Uganda, 2007), if the to-be system is implemented, stakeholders in the building sector will be encouraged to seek low-carbon alternatives such as utilising renewable energy. This suggests that, for the first time, this work has provided an enabling framework for the building sector to contribute to the goal of renewable energy policy.

The to-be system makes significant contributions to knowledge. In some publications arising from this thesis that underscored the original contributions related to application of the to-be system, it was demonstrated that the to-be system could support a market-based mechanism which boosts sustainable construction in developing countries (Kibwami and Tutesigensi, 2016b; Kibwami and Tutesigensi, 2015b). Regarding wider applications, findings from evaluating the to-be system open the way for Uganda to take forward the recent global agreement on sustainable development. This agreement, titled “Transforming our world: the 2030 Agenda for sustainable development”, prescribes 17 sustainable development goals to be achieved (United Nations, 2015). The to-be system potentially contributes to sustainable development goal number 12 (sustainable consumption) and 13 (combating climate change).

Despite the contributions of the to-be system argued in this research, there were some limitations identified. Firstly, application of the to-be system was limited to Uganda. Secondly, the approach of assessing cost implications and benefits of the to-be system was based on nonmonetary considerations and thus excluded cost benefit analyses. Cost-benefit analysis would require attaching monetary values to the system’s cost implications and benefits, an aspect that was beyond the scope of this work. Thirdly, opinions from evaluating the to-be system were based on those of built environment professionals only (i.e. Architects, Engineers, Quantity Surveyors, and Environmental Impact Assessors). Although literature suggested that built environment professionals are usually the most knowledgeable in this regard, their opinions may not reflect those of other stakeholders in the building sector in Uganda. Therefore, the findings of this research provide a foundation to initiate future inquiries.

9.2 Recommendations

The recommendations, which include piloting and potential future research in relation to improvement of the to-be system, are presented in this section.

9.2.1 Piloting the to-be system

This work has established a valid argument to justify the uptake of EC accounting in building projects in Uganda. It was found that integrating EC accounting in the development approval process of building projects can enhance sustainable construction. To this end, the author argues, policy makers must act now by considering implementation of the to-be system, before it is too late. Implementation can be first undertaken as a pilot initiative in Kampala Capital City Authority and/or Kira Town Council since the jurisdiction of these two local authorities covers geographical areas that have the highest number of construction activities in Uganda. That said, successful implementation of the to-be system will greatly depend on whether the government of Uganda is proactive and supportive. In a Ghanaian study, the "lack of government commitment" was identified as the second most challenge of implementing policies related to sustainable construction (Ametepey et al., 2015, p.113). This, among other things, implies that the Ugandan government should spearhead by adopting the to-be system on government-funded projects.

9.2.2 Future work

Since implementation of the to-be system was beyond the scope of this study, it was not possible to evaluate the long-time impacts of the to-be system. Instead, evaluation was based on the forecasted/perceived impacts or changes to the status quo if the to-be system was to be implemented. Therefore, it would be interesting to conduct longitudinal research, preferably during piloting the to-be system, whereby it is first implemented and then after some time, evaluated. In such efforts, it would be possible to assess the cost benefit analysis of the to-be system where by monetary values are attached to the likely benefits of the to-be system. Also, opinions of other stakeholders in the building sector (e.g. external funders, developers, contractors, manufacturers, and construction material suppliers) can be captured in such a longitudinal pilot study.

Several improvements are also envisaged regarding CaMeT, the tool which was developed to implement the mathematical model embedded in the to-be system. These improvements, as outlined below, are potential areas for future research.

- Since CaMeT was limited to operating within Microsoft Excel 2010, the tool will have to be occasionally upgraded to suit latest versions of Microsoft Excel.
- The tool could benefit from some improvements regarding its outputs in order to increase its utility. Although CaMeT was intended for computational purposes (i.e. quantifying carbon emissions) only, some opinions from respondents suggested that it would be useful for the tool to provide alternatives for mitigation, such as how many trees can someone plant to offset the emissions caused, or which materials can be used in lieu of carbon intensive options.
- Improvements in the GUI are also necessary since there is a need to vary the GUI in order to cater for various user-needs. This might culminate into a CaMeT version for each of the users. Of importance will be the need to maintain the interoperability of various user-versions such that outputs from one version are compatible with the other.
- The scope of developing CaMeT did not entail commercial application. Some respondents, especially Architects, posited that CaMeT presents a great potential to provide the first carbon rating standards for buildings in Uganda. Therefore, a commercial version of CaMeT can be developed, an aspect that might entail addressing costs of development, distribution of the software, and maintenance.
- The need for databases was identified as a major enabler for the proposed initiatives in this work. With scarcity of data in Uganda, it is likely that in some cases, databases might be borrowed from other sources outside Uganda. This may require improving on the compatibility of databases imported into the tool. Similar efforts of improvement can be observed in several commercially available carbon software tools such as SimaPro, GaBi, and Athena in relation to compatibility with the widely used Ecoinvent database. Therefore, CaMeT will benefit from further improvements relating to database storage capabilities.

Generally, there is a need to educate the society about the concepts of the to-be system such as EC accounting and its benefits. This should begin from the young generation up to the practitioners in the construction industry. A possible way of achieving this is by integrating the to-be system's concepts into the education programs through reviewing the current curricula of primary, secondary, and university education in Uganda. In that way, the culture of sustainability shall be widely inculcated in the construction industry and society at large. For the case of the current practitioners, there is need to incorporate the concepts of the to-be system into continuous professional development (CPD). Regarding other stakeholders such as developers, there is need for deliberate awareness campaigns. On the whole, educating the society will demand developing various packages of the to-be system to fit various levels of training needs. All these initiatives are not only avenues for future research but potential industrial applications of this research's outputs.

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Appendix A BPMN elements and rules

A.1 BPMN Elements

In BPMN, the combination of the graphical elements defines a process diagram, which is based on flow charting techniques (White, 2004), albeit with a plethora of graphical elements which are used to define process logic (Silver, 2011). Graphical elements are generally grouped into flow objects, connecting objects, swim lanes, and artifacts (OMG, 2011).

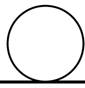
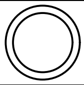
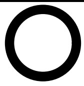
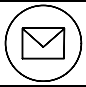
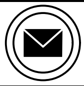
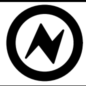
A.1.1 Flow objects

As can be seen in Appendix A, BPMN uses a variety of flow objects to model simple and more complex behaviours; the three major flow objects are Event, Activity, and Gateway.

a) Event

An event is something that can happen in the process, consequently affecting process flow. A variety of event-shapes are used to define distinctive varying happenings within the process model. Represented by circular shapes, events can manifest in mainly three categories: *starting*, *intermediate* and *end* events as labelled 1, 2 and 3 respectively, in Table A.1. If the circle is empty, as seen in labels 1 to 3, the event is referred to as an empty or none event (i.e. empty/none start, empty intermediate and empty end). To distinguish between event behaviours, a marker is placed inside the circle to represent a trigger (e.g. an envelope marker represents a message) and this can be done for all the three categories of Events. BPMN provides several triggers for events (e.g. Message, Error, Timer, Terminate etc.). For instance, from Table A.1, label 4 is a Message start event, label 5 is a Message intermediate event, and label 6 is an Error end event. Further, the behaviours are classified into throwing/sending and catching/receiving. An event with a 'filled' marker (e.g. label 5 and label 6) is a throwing/sending event, whereas that with an unfilled marker (e.g. label 4) is a catching/receiving event. For example, label 4 represents an event that is triggered upon receiving/catching a message whereas label 5 represents an intermediate event that sends/throws a message (Debevoise and Geneva, 2011; OMG, 2011; Silver, 2011; White, 2004).

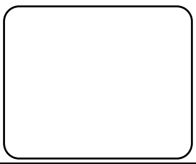
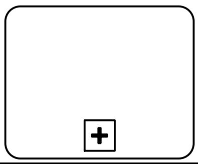
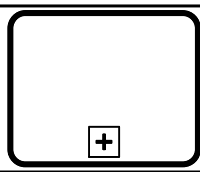
Table A.1 Examples of Event flow objects

Label	1	2	3	4	5	6
Graphical representation						

b) Activity

An activity, which is represented by a rectangle with rounded edges, denotes work performed in the process and it defines a step in the process. An activity (refer to Table A.2) can be either a task, which is represented by an empty box (see label 7), a subprocess, which is represented by a box with a plus (or minus) sign (see label 8) or a call activity (formerly known as a re-usable subprocess in earlier BPMN versions) which is represented by a thick bordered box (see label 9). The plus and minus signs represent collapsed and expanded subprocesses respectively. Tasks are referred to as atomic since they have no internal subparts or rather, cannot be further broken down, whereas subprocesses are non-atomic (i.e. compound), since they contain subparts (i.e. child-level processes).

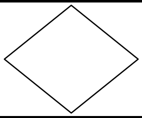
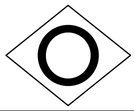
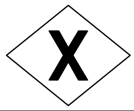
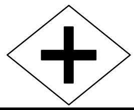
Table A.2 Examples of Activity flow objects

Label	7	8	9
Graphical representation			

c) Gateways

Gateways, which are represented by a diamond shape (see Table A.3), represent the decisions taken during process flow. By providing explicit control in the process, gateways can prescribe split, merge or parallel flows. A marker placed inside a gateway denotes the behaviour of the gateway. For the exclusive gateway (see label 12), only one path from it can be followed. For a parallel gateway (see label 13), all paths from, or to it, have to be fulfilled. The inclusive gateway (see label 11) combines both the behaviours of exclusive and parallel gateways i.e. all or some of the paths from it may have to be fulfilled, though one path should at least be designated as a default one. In BPMN, a gateway without a marker (i.e. label 10) is equivalent to an exclusive gateway.

Table A.3 Examples of Gateway flow objects

Label	10	11	12	13
Graphical representation				

A.1.2 Connecting objects

To create a structure of the process, flow objects have to be connected together using connecting objects. BPMN provides three kinds of connecting objects which are Sequence flow, Message flow, and Association (See Table A.4). Sequence flows show the order in which activities are performed in a process (White, 2004). It is implied in a sequence flow that when the tail-end completes, the head-end is enabled (Silver, 2011). A message flow is represented by a dashed line and is used to show communication between a process and an external entity (Silver, 2011). An association, as the name suggests, is used to associate data, text and other annotations, to flow objects (White, 2004).

Table A.4 BPMN Connecting objects

Object name	Sequence flow	Message flow	Association
Graphical representation			

A.1.3 Swim lanes

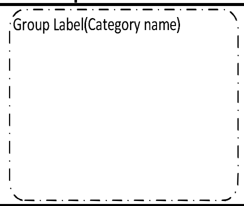
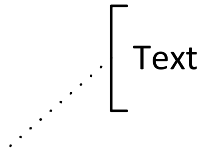
Swim lanes present a mechanism of organising activities and processes into categories. This helps to distinguish responsibilities or functions of various actors within a process model (White, 2004). The swim lane objects in BPMN are Pools and Lanes (see Figure A.1). A pool is a rectangular box shape functioning as a container of the whole process, whereas lanes are the subdivisions within the pool (White, 2004). In BPMN process modelling, an empty pool is called a black-box pool whereas one with internal details is a white-box pool (Silver, 2011; OMG, 2011). The process modelling method and style advocated for by Silver – and also used in this work – suggests that pools should be labelled with the name of the process (but not the name of the organisation), whereas lanes should be labelled as the different actors or departments (Silver, 2011). This approach allows the name of the process (es) to bear on the process model and minimises unnecessary splitting of single process into multiple processes. For instance, where Process A (see Figure A.1) is represented by one pool with two Actors each in a lane, the pool is named Process A and rather not the name of the organisation in which Process A happens. Pools and lanes can be drawn either horizontally (which is most common) or vertically. Given that a pool represents a single process, a modelling exercise with only one process, without distinguished actors/functions, would not require a pool.

Figure A.1 BPMN Pool and Lanes.

A.1.4 Artifacts

BPMN offers artifacts (see Table A.5) to enable a modeller communicate better in a way of showing additional information in a process model. Though there are two standard Artifacts (i.e. group and text annotation), modellers are free to add more as deemed fit (OMG, 2011). A group artefact is a kind of visual highlighter in form of a dotted-dash box which is drawn around elements (e.g. subprocesses) in a process model to show some association or purpose (Debevoise and Geneva, 2011; Silver, 2011). One of such associations could be that the grouped objects fall into some similar category (OMG, 2011). The other artefact, text annotations, is used to provide some additional information for readers to easily comprehend the process model (OMG, 2011).

Table A. 5 Example of artifacts

Artifact name	Group	Text Annotation
Graphical representation		

A.2 Rules for process modelling

Mendling and colleagues suggested seven process modelling guidelines that they considered to be simple and easily understood by modellers (Mendling et al., 2010). These are: use of fewer elements, minimising routing paths, using one start and one end event, modelling as structured, avoiding inclusive gateways, use of verb-object labelling and decomposing models that have more than 50 elements. Silver (Silver, 2011) documented twenty styles that can be used to derive a process model. The BPMN standard (OMG, 2011) also specifies several rules although most of are not explicitly but rather tacitly referred to; the standard is flexible in a way that modellers can devise customised rules and styles in cases where the standard is silent. Table A.6 summarises rules/styles that were used, derived from Silver (2011, pp. 71-84), Mendling et al. (2010), and BPMN rules (OMG, 2011), Rules no. 21 to 25 are BPMN specific rules which are important for intra-design verification of process model.

Table A.6 BPMN rules and styles

No.	**Rule/style**
1	Label all elements of the process model clearly to make process logic clear
2	Adopt a hierarchical modelling, fitting one process level per page
3	Use black-box pools to represent external actors or maintaining process logic
4	Request-instantiated processes should be modelled with a message start event
5	Internal units of an organisation should be represented as lanes not pools
6	Process pools are labelled with process name, black box pools with entity name
7	Success and exception end states should be indicated with separate end events, well labelled to indicate the end states.
8	Activities should be labelled VERB-NOUN e.g. *compute total* not *total computed*
9	For top level process, use triggers (e.g. time and message) for start event
10	For a subprocesses preceding a gateway labelled with a question, it should have multiple end events one of which should be named after the gateway’s label.
11	For all message events, they should equally have message flows
12	‘Message’ flows between a parent and its child level diagram should match (i.e. should be replicated in quantity and labelling).
13	Message flows should be labelled with name of message

14	In a process level, end events should have unique names.
15	In a process model, activities should have unique names.
16	In a subprocess, there should be only one start event and it should be a 'none' type (i.e. without a trigger)
17	Nested process pools should have the same label as the top level process pools
18	For hierarchical modelling, child-level diagrams should not contain any top-level processes
19	Exclusive gateways should not merge alternative flows unless into another gateway. The alternative flows should directly connect to the activity
20	Parallel gateway should not join into none (non-triggered) end event.
21	Sequence flows should not cross a pool's boundary
22	Sequence flows should not cross a subprocess' boundary
23	Message flows cannot connect elements in the same pool
24	Sequence flows only connect to activity, gateway or event; both tail and head ends should be properly connected
25	Message flows may only connect to activity, message event or black box pool; both tail and head ends should be properly connected

Appendix B Research instruments

B.1 Verification of the system

B.1.1 Consent form

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Consent to take part in stage 1 of a research project titled "Promoting Sustainable Construction: accounting for carbon in construction projects"

Stage 1 of the research	Add your initials next to the statement if you agree
I confirm that I have read and understand the information sheet dated [date to be inserted later] explaining the above research project and I have had the opportunity to ask questions about the project and the questions I have asked have been answered to my satisfaction.	
I understand that my participation is voluntary and that I am free to withdraw at any time before or during participation without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. I understand that my responses will be kept strictly confidential.	
I agree for the data collected from me to be used in relevant future research in an anonymised form.	
I agree to take part in the above research project and will inform the principal researcher should my contact details change.	

Name of participant	
Participant's signature	
Date	

Name of principal researcher	Nathan Kibwami
Signature	
Date	
Contact details	Principal Researcher: Nathan Kibwami UK address: School of Civil Engineering, University of Leeds, Leeds. LS2 9JT UK telephone: +44 (0) 7766576749 UK email: cnnk@leeds.ac.uk Uganda address: P.O.BOX 7062 Kampala Uganda telephone: +256 (0) 782 204932 Uganda email: knathan@cedat.mak.ac.ug

Project title	*Document type*	*Version#*	*Date*
Promoting Sustainable Construction: accounting for carbon in construction projects	Consent form for Verification (stage 1)	3	Aug 2014

B.1.2 Information sheet

School of Civil Engineering
Faculty of Engineering

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Promoting sustainable construction: accounting for carbon in construction projects
Stage 1 of the research

INFORMATION SHEET

You are being invited to take part in this research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask the researcher if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Background and aim of the project
This research project is a 3 to 4 year PhD research study being undertaken at University of Leeds, funded by the Commonwealth Scholarship Commission the UK. The research aims at addressing greenhouse gases like carbon dioxide emitted during processes associated with constructing buildings in Uganda. In fulfilling this aim, data will be collected in two stages, 1 and 2; this information sheet pertains to stage 1. Procedures of building permit application, environmental impact assessment, and construction processes in Uganda, as prescribed by relevant regulations, have been documented. Before proposing anything to improve current practices, it is important to first find out how the documented information reflects the reality in practice. Therefore the purpose of this particular study-stage is to compare the documented information with the reality in practice.

Why you have been chosen
A total of nine participants are expected to be recruited for this study-stage. You have been purposely selected because you possess the relevant information this study needs to collect and therefore, your participation is important to the success of this study.

Taking part in this study
It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep, and also be asked to sign a consent form a copy of which you can also keep. You can withdraw from the study at any time before or during the interviews without it affecting any benefits that you are entitled to in any way, and you do not have to give a reason.

What will be required of you
Information will be collected using interviews. Although the time for interviewing will vary, it is anticipated that no more than one hour will be necessary. Using flow chart diagrams, the researcher will explain to you the steps he has documented in the three processes mentioned above. You will then be given a chance to give your opinions regarding the various steps presented in each process, regarding how it compares with what is actually done in practice.

Recording interviews

Project title	*Document type*	*Version#*	*Date*
Promoting Sustainable Construction: accounting for carbon in construction projects	Information sheet for Verification (stage 1)	2	Aug 2014

School of Civil Engineering
Faculty of Engineering

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It is hoped that the discussion sessions can be audio-recorded. The researcher will first obtain permission from you in order to proceed with any audio-recordings. During discussions, you will be allowed to request pausing the recording, if there any discussions you would not like to be recorded. Recordings made will be used only for purposes of this study. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

Benefits for taking part
Whilst there are no immediate benefits for participating in the project, it is hoped that this work will generally contribute to promoting sustainable construction in Uganda.

Confidentiality
All information given will be treated as confidential. You will not be able to be identified in any reports or publications arising from this study. You will have a chance, if you wish, to get a copy of the results/publications. Contact the researcher via details below.

Contact for further information

Principal Researcher:	Nathan Kibwami
UK address:	School of Civil Engineering, University of Leeds, Leeds. LS2 9JT
UK telephone:	+44 (0) 7766576749
UK email:	cnnk@leeds.ac.uk
Uganda address:	P. O. Box 7062, Kampala
Uganda telephone:	+256 (0) 782 204932
Uganda email:	knathan@cedat.mak.ac.ug

Research Supervisor:	Apollo Tutesigensi
Address:	School of Civil Engineering, University of Leeds, Leeds. LS2 9JT
Telephone:	+44 (0) 113 343 4678
Email:	a.tutesigensi@leeds.ac.uk

Thank you for taking the time to read through this information.

We hope you are happy to take part.

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Project title	*Document type*	*Version#*	*Date*
Promoting Sustainable Construction: accounting for carbon in construction projects	Information sheet for Verification (stage 1)	2	Aug 2014

B.1.3 Semi structured interview

Semi structured interview

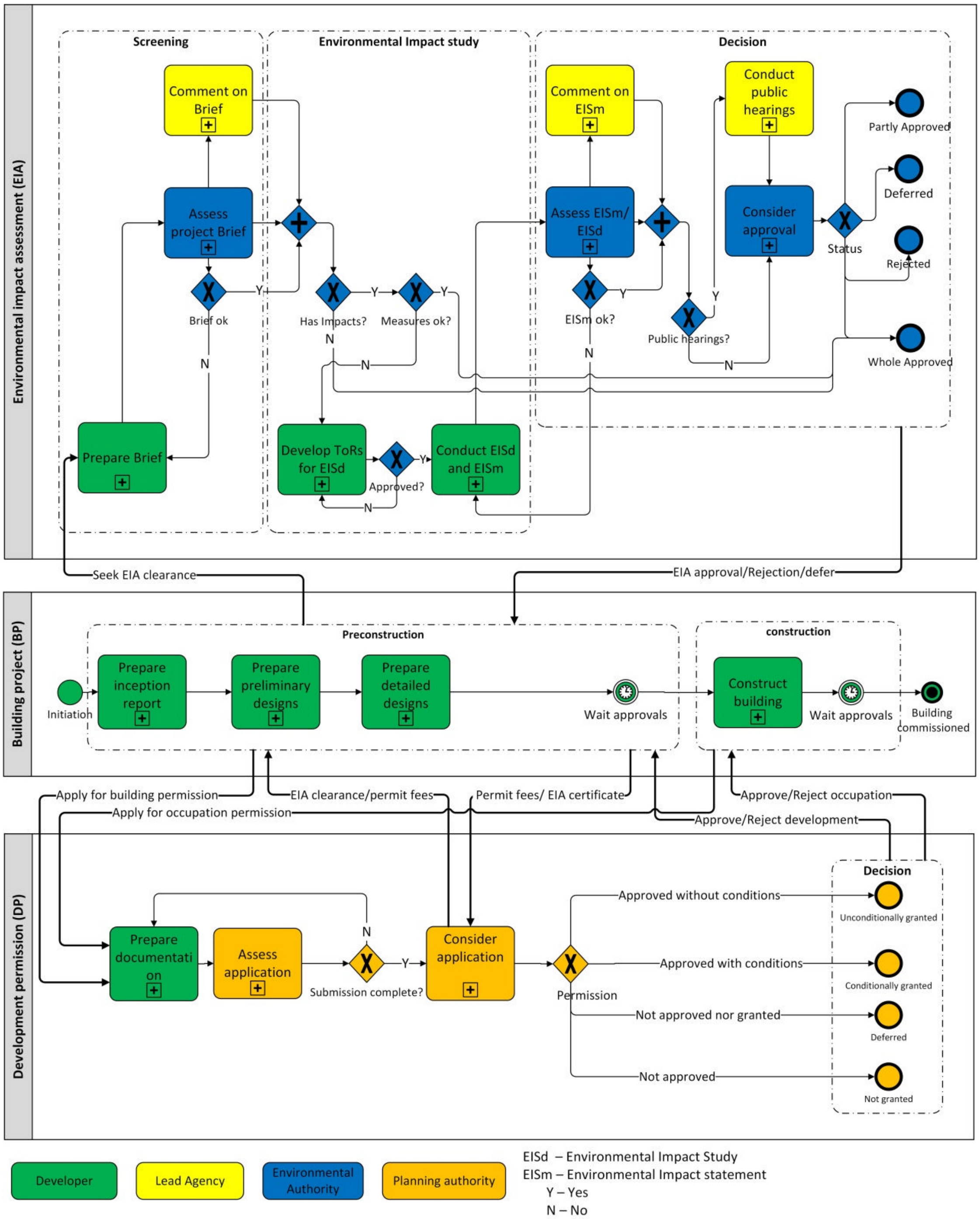
Explain to the informants how the as-is system is (as process modelled), using chart 1, and probe (using the table below as a guidance) whether it matches with the 'real' existing practices.

Project title	*Document type*	*Version #*	*Date*
Promoting sustainable construction	Semi structured interview	3	07/14

N	Comparison of system's model components, activity, linkages with those of systems' reality					
	Model Component	**Reality Component**	**Model Activity**	**Reality Activity**	**Model linkages**	**Reality linkages**
a	Construction project process	?	**Project Team** Prepare inception report Prepare preliminary designs Prepare detailed designs Construct building	? ? ? ?	Seek EIA clearance Seek development permission/construction permit	? ?
b	Environmental impact assessment process	?	**Developer:** Prepare brief Develop ToRs Conduct impact study and impact statement **Authority (NEMA)** Assess brief Assess impact statement Consider Approval **Lead Agency** Comment on brief Comment on impact statement Conduct public hearings	 ? ? ? ? ? ? ? ? ?	EIA approval/Rejection	?
c	Application for development permission process	?	**Developer:** Prepare documentation **Authority (Local government)** Assess application Approve project	 ? ? ?	Development/construction Permission	?

Project title	*Document type*	*Version #*	*Date*
Promoting sustainable construction	Semi structured interview	3	07/14

B.1.4 Chart 1


Environmental impact assessment (EIA)
Screening
Environmental Impact study
Decision
Comment on Brief
Assess project Brief
Brief ok
Prepare Brief
Has Impacts?
Measures ok?
Develop ToRs for EISd
Approved?
Conduct EISd and EISm
Comment on EISm
Assess EISm/ EISd
EISm ok?
Public hearings?
Conduct public hearings
Consider approval
Status
Partly Approved
Deferred
Rejected
Whole Approved
Y
N
Seek EIA clearance
EIA approval/Rejection/defer
Building project (BP)
Preconstruction
construction
Initiation
Prepare inception report
Prepare preliminary designs
Prepare detailed designs
Wait approvals
Construct building
Wait approvals
Building commissioned
Apply for building permission
EIA clearance/permit fees
Permit fees/ EIA certificate
Approve/Reject occupation
Apply for occupation permission
Approve/Reject development
Development permission (DP)
Prepare documentation
Assess application
Submission complete?
Consider application
Permission
Decision
Approved without conditions
Unconditionally granted
Approved with conditions
Conditionally granted
Not approved nor granted
Deferred
Not approved
Not granted
Developer
Lead Agency
Environmental Authority
Planning authority
EISd – Environmental Impact Study
EISm – Environmental Impact statement
Y – Yes
N – No

B.2 Evaluation of the to-be system

B.2.1 Consent form

School of Civil Engineering
Faculty of Engineering

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Consent to take part in stage 1 of a research project titled "Promoting Sustainable Construction: accounting for carbon in construction projects"

Stage 2 of the research	Add your initials next to the statement if you agree
I confirm that I have read and understand the information sheet dated [date to be inserted later] explaining the above research project and I have had the opportunity to ask questions about the project and the questions I have asked have been answered to my satisfaction.	
I understand that my participation is voluntary and that I am free to withdraw at any time before or during participation without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. I understand that my responses will be kept strictly confidential.	
I agree for the data collected from me to be used in relevant future research in an anonymised form.	
I agree to take part in the above research project and will inform the principal researcher should my contact details change.	

Name of participant	
Participant's signature	
Date	

Name of principal researcher	Nathan Kibwami
Signature	
Date	
Contact details	Principal Researcher: Nathan Kibwami UK address: School of Civil Engineering, University of Leeds, Leeds. LS2 9JT UK telephone: +44 (0) 7766576749 UK email: cnnk@leeds.ac.uk Uganda address: P.O.BOX 7062 Kampala Uganda telephone: +256 (0) 782 204932 Uganda email: knathan@cedat.mak.ac.ug

Project title	*Document type*	*Version#*	*Date*
Promoting Sustainable Construction: accounting for carbon in construction projects	Consent form for Validation (stage 2)	3	Aug 2014

B.2.2 Information sheet

School of Civil Engineering
Faculty of Engineering

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Promoting sustainable construction: accounting for carbon in construction projects
Stage 2 of the research

INFORMATION SHEET

You are being invited to take part in this research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask the researcher if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Background and aim of the project

This research project is a 3 to 4 year PhD research study being undertaken at University of Leeds, funded by the Commonwealth Scholarship Commission the UK. The research aims at addressing greenhouse gases like carbon dioxide emitted during processes associated with constructing buildings in Uganda. This information sheet pertains to stage 2 of this research in which a system of accounting for carbon emissions has been developed, based on modifying existing construction practices, which were studied in an earlier stage 1 of this research. The purpose of this particular study-stage is to evaluate whether the developed system can promote sustainable construction.

Why you have been chosen

A total of 50 to 100 participants are expected to be recruited for this study-stage. You have been randomly selected as a built environment professional in Uganda because you possess the relevant information this study needs to collect and therefore, your participation is important to the success of this study. You were identified from the publicly available list of certified members registered in your profession.

Taking part in this study

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep, and also be asked to sign a consent form a copy of which you can also keep. You can withdraw from the study at any time before or during the interviews without it affecting any benefits that you are entitled to in any way, and you do not have to give a reason.

What will be required of you

Information will be collected using interviews. Although the time for interviewing will vary, it is anticipated that no more than one hour will be necessary. The researcher will explain to you how the proposed system of accounting for carbon emissions in construction projects is to work. You will then be given a series of questions with multiple answers for you to choose the most appropriate as regards the relevance of the proposed system in promoting sustainable construction in Uganda. The researcher will be around to address any clarifications that you may require.

Recording interviews

Project title	*Document type*	*Version#*	*Date*
Promoting Sustainable Construction: accounting for carbon in construction projects	Information sheet for Validation (stage 2)	2	Aug 2014

School of Civil Engineering
Faculty of Engineering

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It is hoped that the discussion sessions can be audio-recorded. The researcher will first obtain permission from you in order to proceed with any audio-recordings. During discussions, you will be allowed to request pausing the recording, if there any discussions you would not like to be recorded. Recordings made will be used only for purposes of this study. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

Benefits for taking part
Whilst there are no immediate benefits for participating in the project, it is hoped that this work will generally contribute to promoting sustainable construction in Uganda. In addition, the researcher plans to disseminate findings in one of the continuous professional development (CPD) workshops held by your profession association if he is given an opportunity to.

Confidentiality
All information given will be treated as confidential. You will not be able to be identified in any reports or publications arising from this study. You will have a chance, if you wish, to get a copy of the results/publications. Contact the researcher via details below.

Contact details for further information

Principal Researcher:	Nathan Kibwami
UK address:	School of Civil Engineering, University of Leeds, Leeds. LS2 9JT
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Research Supervisor:	Apollo Tutesigensi
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Telephone:	+44 (0) 113 343 4678
Email:	a.tutesigensi@leeds.ac.uk

Thank you for taking the time to read through this information.

We hope you are happy to take part.

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B.2.3 Structured interview

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INTERVIEW SCHEDULE

PART ONE

Demographic profile

1) Which profession do you belong to (**choose one**)
   a) Architect
   b) Engineer (civil, structural, mechanical)
   c) Quantity Surveyor
   d) Other (please specify)______________________
2) How many years of experience do you have in relation to the profession selected above?

   ____

3) How would you best describe the nature of practice you are employed in? (**choose one**)
   a) Private consultancy firm (e.g. Architectural, Quantity Surveying, Engineering, Environmental)
   b) Private-non consulting firm (e.g. Real estate developer, NGO)
   c) Government (e.g. Local Government, Ministry, Parastatal)
   d) Construction firm (e.g. Contractor)
   e) Other (please specify)______________________
4) How would you rate your general level of awareness of Sustainable Construction? (**choose one**)
   a) Not at all aware
   b) Slightly aware
   c) Somewhat aware
   d) Moderately aware
   e) Extremely aware
5) In your opinion, what best describes the term Sustainable Construction? (**choose only Three** you consider most applicable)
   a) Construction practices that do not harm the environment (e.g. avoiding constructing in wet lands)
   b) Construction practices that practice corporate social responsibility (CSR)
   c) Construction practices that make profit without compromising people's needs
   d) Construction practices that enhance quality and satisfaction of human life (e.g. safety at workplace)
   e) Construction practices that minimise over usage of natural resources like water and sand
   f) Construction practices that ensure minimal lifetime maintenance costs of buildings

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PART TWO

A brief description of the system developed (Refer to Chart 2 and software Tool)

This research has developed a 'new' system of accounting for carbon emissions (i.e. greenhouse gases like carbon dioxide) resulting from construction project activities. The system is in many ways similar to the existing practices of accounting for construction costs i.e. preliminary cost estimates during early designs, detailed costs estimates during detailed designs, and certificates of payments during construction. The difference is that in this system, costs are substituted with carbon emissions. The system is composed of four major processes: construction process, application for building permit, environmental impact assessment, and **a new process of carbon accounting.**

Like costs, carbon estimates are computed from quantities of materials, labour/workforce, and plant/equipment used. Carbon from materials includes that arising from their manufacture and transportation to construction site. Carbon from workforce arises from the transportation used to and from the construction site. Carbon from plant/equipment arises from their transportation and use on site.

According to the system, when submitting plans for building permits or environment assessment approvals to the local authorities, a 'Bill of Carbon' is also included. During construction, the interim certificates of payments will also detail how much carbon has been emitted to date, corresponding with the costs and quantities expended. At the end of construction, similar to costs, the final account of carbon emissions shall include how much emissions the project caused, in comparison with the earlier estimates.

A tool has also been developed to assist in calculating carbon. The tool is simple to use as it is based on Microsoft Excel. It avails several options for one to calculate carbon. For instance: for materials, you enter the type and quantity of material (e.g. tons, square meters) and it calculates the emissions. For transport-related carbon, you enter the amount of fuel used and type. For onsite carbon from equipment, you specify the number and type of equipment, plus the quantity and type of fuel used

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6) Is the need for sustainable construction (i.e. reducing emissions) worthwhile to pursue?

   a) Yes
   b) No
   c) Don't know

7) Effectiveness: If the proposed system is implemented, to what extent will it contribute to each? *Next to each statement, use the scale provided to write a number (**No.**) that best indicates decision.*

1 = not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely
0 = don't know

	Statement	No.
a	Minimising over usage of resources like energy and materials during construction	
b	Improving on the overall energy consumption profile of buildings	
c	Promoting use of waste to manufacture new products	
d	Encouraging reuse of a product several times before discarding it	
e	Encouraging use of renewables like biodiesel instead of non-renewables like diesel	
f	Minimising pollution like emissions of carbon dioxide emissions	
g	Promoting environmental labelling and rating systems (e.g. LEED)	
h	Encourage considering environmental issues during the construction stage	
I	Facilitation of decisions to consider materials that are sustainably produced	
J	Enabling development of comprehensive data bases related to emissions	
k	Enhance enforcement and compliance with environmental regulations	
l	Lead to financially affordable options like walking instead of driving	
m	Creation of more employment opportunities like using people instead of diesel-equipment	
n	Enhancing competitiveness in construction through advancing sustainability practices	
o	Enable choosing suppliers or contractors who demonstrate environmental performance	
q	Creation of financial incentives for those using it and disincentives for those not using it	
r	Encourage using local materials and workforce	
s	Generation of income like for those producing sustainable materials and energy	
t	Making construction operations more compatible with local needs	
u	Increase awareness about carbon emissions in construction	
v	Promoting corporate social responsibility (CSR)	
w	Promoting health and safety at workplace	
x	Developing capacity and skills regarding matters of carbon emissions accounting	

8) Cost related aspects:

i. To what extent do you agree that the system can contribute to other benefits such as carbon trading

Strongly agree

Agree

Undecided

Disagree

Strongly disagree

Don't know

ii. **Choose one statement** below which you consider most applicable with regard to implementing the proposed system

a) It will require establishing new institutions
b) It will require significant modification of existing institutions
c) It will require minor modification of existing institutions
d) Existing institutions can suffice without any modifications
e) Don't know

iii. Are the processes of the system easy to understand?

a) Very easy
b) Somewhat easy
c) Undecided
d) Not easy
e) Not easy at all
f) Don't know

9) Distributional considerations:

i. How likely would you be willing to accept using the system?

a) Extremely unlikely
b) Unlikely
c) Neither likely nor unlikely
d) Likely
e) Extremely likely
f) Don't know

ii. To what extent is the system fair to the various stakeholders involved (e.g. Clients, Manufacturers/suppliers, Consultants, Regulators and Contractors)?

a) Very fair
b) Fair
c) Neither fair nor unfair
d) Unfair
e) Very unfair
f) Don't know

iii. To what extent do you consider the intentions of the system clear?

a) Very clear
b) clear
c) Neither clear nor unclear
d) Unclear
e) Very unclear
f) Don't know

10) Institutional feasibility:

i. Does the system fit into existing regulatory framework?

Yes

No

Don't know

ii. Is the system compatible with political or national priorities such as promotion of renewable energy?

a) Yes
b) No
c) Don't know

iii. Would you consider the system a lasting solution to minimising emissions?

a) Yes
b) No
c) Don't know

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iv. Are the impacts resulting from implementation of the system foreseeable?
   a) Yes
   b) No
   c) Don't know

11) What would be the most appropriate format in which the system should be introduced? (Choose **one**)

a) As a regulation (i.e. assessing emissions from building projects should be mandatory)
b) As an economic instrument (i.e. levying taxes to those who do not account for emissions from building projects and financial incentives to those who do)
c) As an information tool (i.e. as a form of public awareness campaign about emissions associated with building projects)

12) Which kinds of buildings are most appropriate for the system to apply to? (Choose **one**)

a) Residential (e.g. houses)
b) Non-residential (e.g. shopping centres, office blocks, factories)
c) All kinds

13) Which professionals do you think are most suitable for conducting the role of carbon accounting? (Choose **one**)

a) Architects
b) Engineers
c) Quantity surveyors
d) Other (please specify…………………………………..)

What is the reason for your choice above? (Optional)

……………………………………………………………………………………………………

14) Please feel free to provide any other comments on the system and this research in general if you have any (Optional)

……………………………………………………………………………………………………

Thank you for your time and opinions

B.2.4 Show card

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INTERVIEWEE SHOW CARD

PART ONE

1) Your profession (Please **choose one)**
   a) Architect
   b) Engineer (civil, structural, mechanical)
   c) Quantity Surveyor
   d) Other (please specify)_____________________
2) Years of experience
3) Nature of practice (Please **choose one**)
   a) Private consultancy firm (e.g. Architectural, Quantity Surveying, Engineering, Environmental)
   b) Private-non consulting firm (e.g. Real estate developer, NGO)
   c) Government (e.g. Local Government, Ministry, Parastatal)
   d) Construction firm (e.g. Contractor)
   e) Other (please specify)_____________________
4) Awareness of Sustainable Construction (Please **choose one**)
   a) Not at all aware
   b) Slightly aware
   c) Somewhat aware
   d) Moderately aware
   e) Extremely aware
5) Sustainable Construction (please **choose only Three** you consider most applicable)
   a) Construction practices that do not harm the environment (e.g. avoiding constructing in wet lands)
   b) Construction practices that practice corporate social responsibility (CSR)
   c) Construction practices that make profit without compromising people's needs
   d) Construction practices that enhance quality and satisfaction of human life (e.g. safety at workplace)
   e) Construction practices that minimise over usage of natural resources like water and sand
   f) Construction practices that ensure minimal lifetime maintenance costs of buildings

6) Need for sustainable construction

a) Yes
b) No
c) Don't know

7) Contribution of the system

1 = not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely

0 = don't know

Statement	
a	Minimising over usage of resources like energy and materials during construction
b	Improving on the overall buildings' energy consumption
c	Promoting use of waste to manufacture new products
d	Encouraging reuse of a product several times before discarding it
e	Encouraging use of renewables like biodiesel instead of non-renewables like diesel
f	Minimising pollution like emissions of carbon dioxide emissions
g	Promoting environmental labelling and rating systems (e.g. LEED in USA, BREAM in UK)
h	Encourage considering environmental issues during the construction stage
I	Facilitation of decisions to consider materials that are sustainably produced
J	Enabling development of comprehensive data bases related to emissions
k	Enhance enforcement and compliance with environmental regulations
l	Lead to financially affordable options like walking instead of driving
m	Creation of more employment opportunities like using people instead of diesel-equipment
n	Enhancing competitiveness in construction through advancing sustainability practices
o	Enable choosing suppliers or contractors who demonstrate environmental performance
q	Creation of financial incentives for those using it and disincentives for those not using it
r	Encourage using local materials and workforce
s	Generation of income like for those producing sustainable materials and energy
t	Making construction operations more compatible with local needs
u	Increase awareness about carbon emissions in construction
v	Promoting corporate social responsibility (CSR)
w	Promoting health and safety at workplace
x	Developing capacity and skills regarding matters of carbon emissions accounting

8) Cost related aspects:

i. Contribution to other benefits such as carbon trading

a) Strongly agree
b) Agree
c) Undecided
d) Disagree
e) Strongly disagree
f) Don't know

ii. Implementing the proposed system (**choose one** statement)

a) It will require establishing new institutions
b) It will require significant modification of existing institutions
c) It will require minor modification of existing institutions
d) Existing institutions can suffice without any modifications
e) Don't know

iii. Ease of understanding the processes of the system

a) Very easy
b) Somewhat easy
c) Undecided
d) Not easy
e) Not easy at all
f) Don't know

9) Distributional considerations:

i. Willingness to use the system

a) Extremely unlikely
b) Unlikely
c) Neither likely nor unlikely
d) Likely
e) Extremely likely

f) Don't know

ii. Fairness of the system

a) Very fair
b) Fair
c) Neither fair nor unfair
d) Unfair
e) Very unfair
f) Don't know

iii. Clearness of the system

a) Very clear
b) clear
c) Neither clear nor unclear
d) Unclear
e) Very unclear
f) Don't know

10) Institutional feasibility:

i. Fitting into existing regulatory framework

a) Yes
b) No
c) Don't know

ii. Compatibility

a) Yes
b) No
c) Don't know

iii. Lasting solution

a) Yes
b) No

c) Don't know

iv. Impacts foreseeable

a) Yes

b) No

c) Don't know

11)Most appropriate format (Choose **one**)

a) As a regulation (i.e. assessing emissions from building projects should be mandatory)
b) As an economic instrument (i.e. levying taxes to those who do not account for emissions from building projects and financial incentives to those who do)
c) As an information tool (i.e. as a form of public awareness campaign about emissions associated with building projects)

12) Kinds of buildings (Choose **one**)

a) Residential (e.g. houses)

b) Non-residential (e.g. shopping centres, office blocks, factories)

c) All kinds

13) Professionals suitable (Choose **one**)

a) Architects

b) Engineers

c) Quantity surveyors

d) Other (please specify……………………………………..)

Reason (Optional)

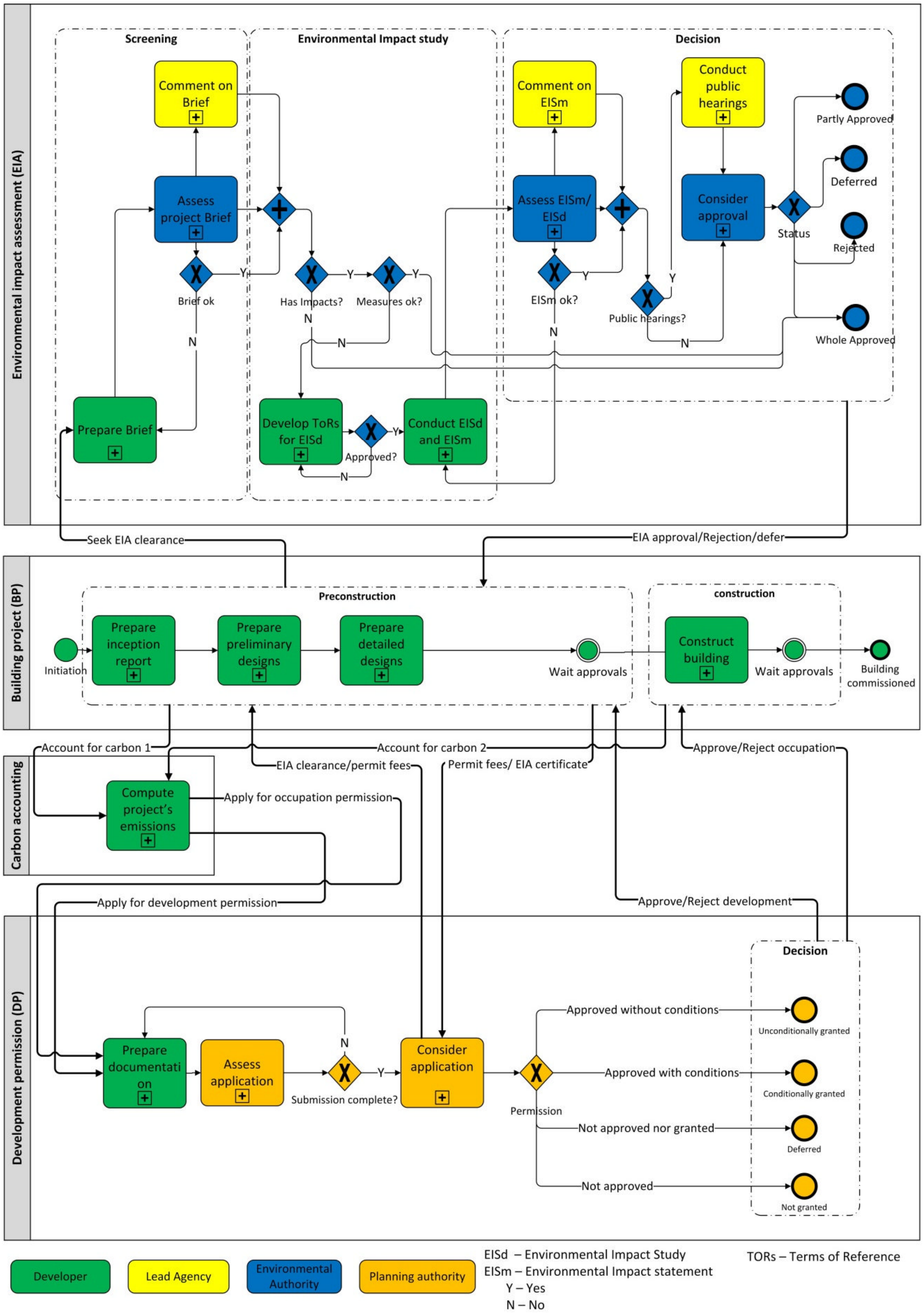
……………………………………………………………………………………………………

14) Any other comments (Optional)

a) ……………………………………………………………………………………………………

Thank you for your time and opinions

B.2.5 Chart 2


Environmental impact assessment (EIA)
Screening
Environmental Impact study
Decision
Comment on Brief
Assess project Brief
Brief ok
Prepare Brief
Has Impacts?
Measures ok?
Develop ToRs for EISd
Approved?
Conduct EISd and EISm
Comment on EISm
Assess EISm/ EISd
EISm ok?
Public hearings?
Conduct public hearings
Consider approval
Status
Partly Approved
Deferred
Rejected
Whole Approved
Seek EIA clearance
EIA approval/Rejection/defer
Building project (BP)
Preconstruction
construction
Initiation
Prepare inception report
Prepare preliminary designs
Prepare detailed designs
Wait approvals
Construct building
Wait approvals
Building commissioned
Account for carbon 1
Account for carbon 2
EIA clearance/permit fees
Permit fees/ EIA certificate
Approve/Reject occupation
Carbon accounting
Compute project's emissions
Apply for occupation permission
Apply for development permission
Approve/Reject development
Development permission (DP)
Decision
Prepare documentation
Assess application
Submission complete?
Consider application
Permission
Approved without conditions
Unconditionally granted
Approved with conditions
Conditionally granted
Not approved nor granted
Deferred
Not approved
Not granted
Developer
Lead Agency
Environmental Authority
Planning authority
EISd – Environmental Impact Study
EISm – Environmental Impact statement
Y – Yes
N – No
TORs – Terms of Reference

Appendix C Research ethics approval

C.1 Ethics application Form (excerpts of key questions and answers)

Note: cross-references in this section do not refer to other sections in this thesis but rather the application document which was submitted to seek for ethics approval

What are the main ethical issues with the research and how will these be addressed?

The research is to be carried out in Uganda, which is the researcher's native country. This calls for several actions since it is outside UK. Firstly, there is need to fulfil the ethical requirements in Uganda; this been addressed under section C.4. Secondly, there is also a need for risk assessment, which has been dealt with in section C.18. The methods to collect data (e.g. interviews) will involve interaction with human participants and there is need to seek for consent from participants (see section C.7 and C.11), ensure anonymity, and data protection (see section C.20).

The researcher has taken necessary steps to prepare for the field work and be able to address underlying ethical issues. The following workshops have been attended:

Data Protection and Research (Nov 13 2012)
Ethics and Ethical Review (Nov 15 2012)
Ethical Issues in Online Research (April 24 2013)
Responsible Authorship (June 5 2013)
Research with Human Participants (Mar 21 2014)
Ethical Issues in Research Overseas (April 12 2014)

What will participants be asked to do in the study?

<u>Stage 1: verification of the system (19th September to 10th October 2014)</u>

Through a semi structured interview arrangement, participants will be presented with the process model of the as-is system using a flow diagrams drawn on a chart (see Appendix C1) The chart is a simplified version of what was actually developed in this research; there is a need to make it easier to comprehend by lay people. For instance, it does not contain complex routings and considers only major activities. The major advantage with a chart is that it offers an opportunity for the respondents to easily visualise the end-to-end view of processes, unlike verbal or written prose. The researcher will proceed to explain the system and participants will then be asked for their views regarding the system as presented, and how it matches what is actually done in practice (see Appendix A1 for interview schedule). Their responses will also be audio recorded upon gaining permission to do so.

<u>Stage 2: validation of the system (11th October to 19th December 2014)</u>

Through a structured interview arrangement, participants will be presented with a simplified process model of the proposed (To-be) system through explanations aided by a chart (See Appendix C2), similar to stage 1 above. The researcher will proceed to explain the system and afterwards, participants will be presented with a series of structured questions to give their views regarding the system See Appendix B1). The questions, which are based on measures of sustainable construction derived from literature review, will be presented through paper-based medium with coded responses for the informants to select appropriate choices. The researcher will still be present during completing the questions just in case there are any further clarifications required by informants.

How will potential participants in the study be:
(i) identified?

Verification stage
The researcher will identify the physical addresses and telephone numbers of gatekeepers (e.g. reception desks) for the two cases of data collection under this stage, which are Kampala capital city authority and Kira town council; the researcher is aware of where these places are located. The researcher will then physically visit these places in order to identify which individuals constitute the physical planning committees, using the guidance list of positions (e.g. district engineer, environmental officer, etc.) established under the physical planning regulation. Not all individuals on the physical planning committees will be included in the study but rather, a purposely selected few (see section C.9 for sampling).
Validation stage
The participants under this stage will be identified through their respective professional association bodies, i.e. Architects Registration Board (ARB) for Architects, Engineers Registration Board (ERB) for engineers, Surveyors Registration Board (SRB) for surveyors, and National Environment Management Authority (NEMA) for the environmental impact assessors. These bodies annually publish members registered with them and these lists are publicly accessible via media agencies or secretariats of the boards. The lists, which will be used as the sampling frame, contain physical addresses and telephone numbers of the informants.
(ii) approached?
Verification stage
In the initial visit to identify potential participants, the researcher will introduce himself to the appropriate gatekeepers or if directly possible, informants, with aid of the introductory letters and the research permit. For the case of meeting gatekeepers, subsequent access to the appropriate informants will then be sought. The research permit granted from the NCST and documentation from Makerere university (refer to section C.4), will contain introductory letters to local governments where the research is to be carried out. Upon meeting the informants sought for, the researcher shall explain the purpose of carrying out the research, and subsequently solicit their participation.
Validation stage
The researcher will physically introduce himself to the respective secretariats of the professionals and will ask the secretariats to make aware of his intentions to all the 'potential' participants on the lists. This will be used as the initial form of entrée, before contacting the participants directly. The researcher will then select participants by random sampling (see also section C.9) from the lists. The researcher will then physically visit the addresses of the informants selected. In this initial encounter, the researcher will introduce himself to the informants and also explain the purpose of carrying out the research, following-on the communication made earlier by their secretariats. Informants will be briefed on the consent process, clearly clarifying that the participation is voluntary. Where for one reason or the other it is not possible to initially visit the informants' physical addresses, they will be contacted through telephone calls. The same information (i.e. researcher introducing himself, purpose of research, and consent process) will be passed-on through the telephone-conversations.
(iii) recruited?
Verification stage
Solicitation of participation will be preceded by giving participants the information sheet for this phase (See Appendix A3), followed with the consent process (Appendix A2), clearly clarifying that the participation is voluntary. Where it is possible to make the interview appointment within the same initial visit highlighted above in C.7 (i)&(ii), the interview process shall consequently proceed. Where not possible, arrangements for a later time for the interview meeting will be made. In that case, the informant will be taken through the consent process again in the next appointment. If the appointment turns out unsuccessful, another one will be arranged. Successive attempts for unsuccessful appointments will be made throughout the first two weeks in the duration of stage 1

Validation stage
Like in verification stage above, solicitation of participation will be preceded by giving participants the information sheet for this phase (See Appendix B3), followed with the consent process (Appendix B2), clearly clarifying that the participation is voluntary. Where it is possible to make the interview appointment in the same initial encounter highlighted in C.7(ii) above, the interview process shall consequently proceed, otherwise, arrangements for the another meeting will be made, whereby if successful, the informant will be taken through the consent process again, before interview. If this second attempt is unsuccessful, another one will be arranged. Successive attempts for unsuccessful appointments will be made throughout the duration of stage 2 data collection.

Will informed consent be obtained from the research participants?
Verification stage
This stage involves semi-structured interviews with potential participants and informed consent will be sought before this is done. Before beginning the interview, the interviewee will be given an information sheet to read (see Appendix A3), followed with the informed consent form (see Appendix A2) containing information about the consent process. The researcher will have copies of the same and will go through them with the informants, highlighting important aspects. The information sheet gives a brief introduction of the research, highlighting the background and purpose of the study/verification. It stresses data protection and confidentiality. It also specifies that participants will be free to with draw from the study before or during the interview process, without any penalty. The informants will be given a chance to ask any questions regarding the information sheet and consent process. Contact details of the researcher and his supervisor are included on the information sheet just in case the informants require more clarifications afterwards. Those who are happy to participate in the study will sign two copies of the consent form, one for keeps, and another for the researcher. They will also keep a copy of the information sheet.
Validation stage
This stage involves structured interviews with potential participants and informed consent will also be sought before this is done. The procedure and documentation of informed consent shall be as the same as that described in the verification stage above except that the background and the purpose of the study-stage (i.e. validation) will differ. See Appendix B3 and Appendix B2 for the information sheet and informed consent forms, respectively.

How will the research team ensure confidentiality and security of personal data?
The researcher has undertaken necessary training to this effect (see section A.10). All research activities in both stages 1 and 2 shall comply with the University's Code of Practice on Data Protection.
Verification stage
At the end of a semi-structured interview, audio files will be downloaded from the recording device, encrypted, and stored on the M drive. Upon transcription, interviews will also be stored on M drive. The data shall be anonymised and kept away from the consent forms. The laptop used and the portable devices shall be adequately encrypted using recommended University Encryption Service software. The laptop will not be left unattended unless locked with an adequate password protection. All operations with the laptop will be via desktop anywhere, through Citrix receiver which is recommended by the University. The researcher has arranged to acquire reliable portable internet services to this effect. In report writing, any direct quotations, where used, shall not identify the participants. Phrases such as "…an official from a local government council mentions that…" shall be used.
Validation stage
Like in the above stage, at the end of a structured interview, audio files will be downloaded from the recording device, encrypted, and stored on the M drive. Information on paper questionnaires will be immediately inputted into the appropriate

software (e.g. Excel and SPSS) in raw form in pre-prepared schedules. The data will be anonymised and kept away from the consent forms. Paper questionnaires will be securely transported and stored in a lockable case at the research base. The researcher has arranged to acquire an office at his workplace (Makerere University) which shall be used as the research base for the overall duration of fieldwork.

C.2 Approval from University of Leeds

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Nathan Kibwami
Civil Engineering
University of Leeds
Leeds, LS2 9JT

MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC)
University of Leeds

22 August 2014

Dear Nathan

Title of study	**Promoting Sustainable Construction: accounting for carbon in construction projects**
Ethics reference	**MEEC 13-028**

I am pleased to inform you that the application listed above has been reviewed by the MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC) and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
MEEC 13-028 Ethical_Review_Application_NKibwami.pdf	2	20/08//14
MEEC 13-028 Appendix 1_Procedures for research application Uganda_UNCST.pdf	1	25/07/14
MEEC 13-028 Appendix 2_uncst_rc1_application_form.doc	1	25/07/14
MEEC 13-028 Appendix 3_uncst_rs6_application_form.doc	1	25/07/14
MEEC 13-028 Appendix 4_ Approved Fieldwork RiskAssessment_243627.pdf	1	25/07/14
MEEC 13-028 Appendix A1_SemiStrInterview_Verification_Stage 1 V3 .docx	1	25/07/14
MEEC 13-028 Appendix A3_Information sheet_Verification_Stage 1 V2.doc	1	20/08//14
MEEC 13-028 Appendix A2_Consent form Verification_ stage 1.docx	2	20/08//14
MEEC 13-028 Appendix B1_StrInterview_Validation_Stage 2 V3 .docx	1	25/07/14
MEEC 13-028 Appendix B3_Information sheet_Validation_Stage 2 V2.doc	1	20/08//14
MEEC 13-028 Appendix B2_Consent form Validation_ stage 2.docx	2	20/08//14
MEEC 13-028 Appendix C1_Chart1_As-Is system for verification_.pdf	1	25/07/14
MEEC 13-028 Appendix C1_Chart2_To-Be system for validation_.pdf	1	25/07/14

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

J Blaikie

Jennifer Blaikie
Senior Research Ethics Administrator, Research & Innovation Service
On behalf of Professor Gary Williamson, Chair, MEEC FREC

CC: Student's supervisor(s)

C.3 Approval from Uganda: Makerere University

Makerere University

P.O. Box 7062 Kampala, Uganda
Website: http://www.mak.ac.ug/cedat

TEL: 256-414-545029 Fax: 256-414-532780
Email: principal@cedat.mak.ac.ug

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY (CEDAT)

4th August 2014

TO WHOM IT MAY CONCERN

RECOMMENDATION FOR MR. N. KIBWAMI WHO IS CURRENTLY PURSUING PhD RESEARCH

The purpose of this letter is to formally introduce to you a PhD student, Mr. Nathan Kibwami, who is a member of staff of Makerere University in the College of Engineering Design, Art and technology.

Nathan works in the department of Construction Economics and Management. He is currently pursuing a PhD research titled ***"Promoting Sustainable Construction: accounting for carbon emissionsof construction projects in Uganda"*** at University of Leeds in the UK. Presently, he is at a stage of data collection.

Any assistance rendered to him will be highly appreciated.

Yours faithfully,

A/Prof. Henry Alinaitwe (PhD)
Principal

C.4 Approval from Uganda: UNCST

Uganda National Council for Science and Technology
(Established by Act of Parliament of the Republic of Uganda)

UNCST

Our Ref: SS 3586 17/11/2014

Mr. Nathan Kibwami
Makerere University
Uganda

Re: Research Approval: **Promoting Sustainable Construction: Accounting for Carbon Emissions of Construction Projects in Uganda**

I am pleased to inform you that on **1/9/2014**, the Uganda National Council for Science and Technology (UNCST) approved the above referenced research project. The Approval of the research project is for the period of **1/9/2014** to **9/9/2015**.

Your research registration number with the UNCST is **SS 3586.** Please, cite this number in all your future correspondences with UNCST in respect of the above research project.

As Principal Investigator of the research project, you are responsible for fulfilling the following requirements of approval:

1. All co-investigators must be kept informed of the status of the research.
2. Changes, amendments, and addenda to the research protocol or the consent form (where applicable) must be submitted to the designated local Institutional Review Committee (IRC) or Lead Agency for re-review and approval **prior** to the activation of the changes. UNCST must be notified of the approved changes within five working days.
3. For clinical trials, all serious adverse events must be reported promptly to the designated local IRC for review with copies to the National Drug Authority.
4. Unanticipated problems involving risks to research subjects/participants or other must be reported promptly to the UNCST. New information that becomes available which could change the risk/benefit ratio must be submitted promptly for UNCST review.
5. Only approved study procedures are to be implemented. The UNCST may conduct impromptu audits of all study records.
6. A progress report must be submitted electronically to UNCST within four weeks after every 12 months. Failure to do so may result in termination of the research project.

Below is a list of documents approved with this application:

	Document Title	Language	Version	Version Date
1	Research Proposal and Appendices	English	N/A	N/A

Yours sincerely,

Winfred Badanga
for: Executive Secretary
UGANDA NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY

LOCATION/CORRESPONDENCE

Plot 6 Kimera Road, Ntinda
P. O. Box 6884
KAMPALA, UGANDA

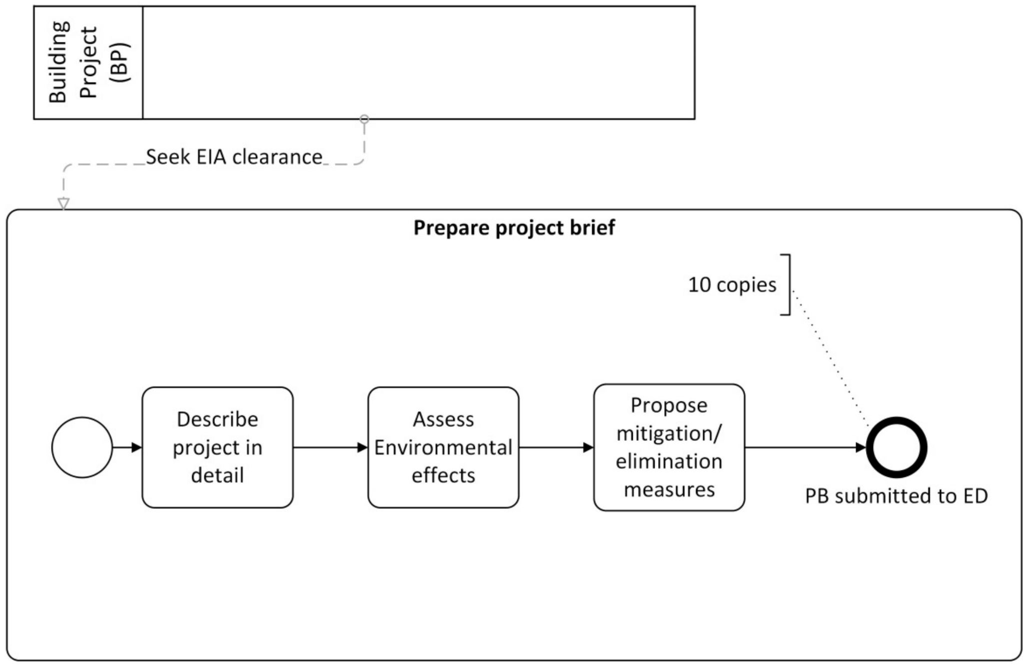
COMMUNICATION

TEL: (256) 414 705500
FAX: (256) 414-234579
EMAIL: info@uncst.go.ug
WEBSITE: http://www.uncst.go.ug

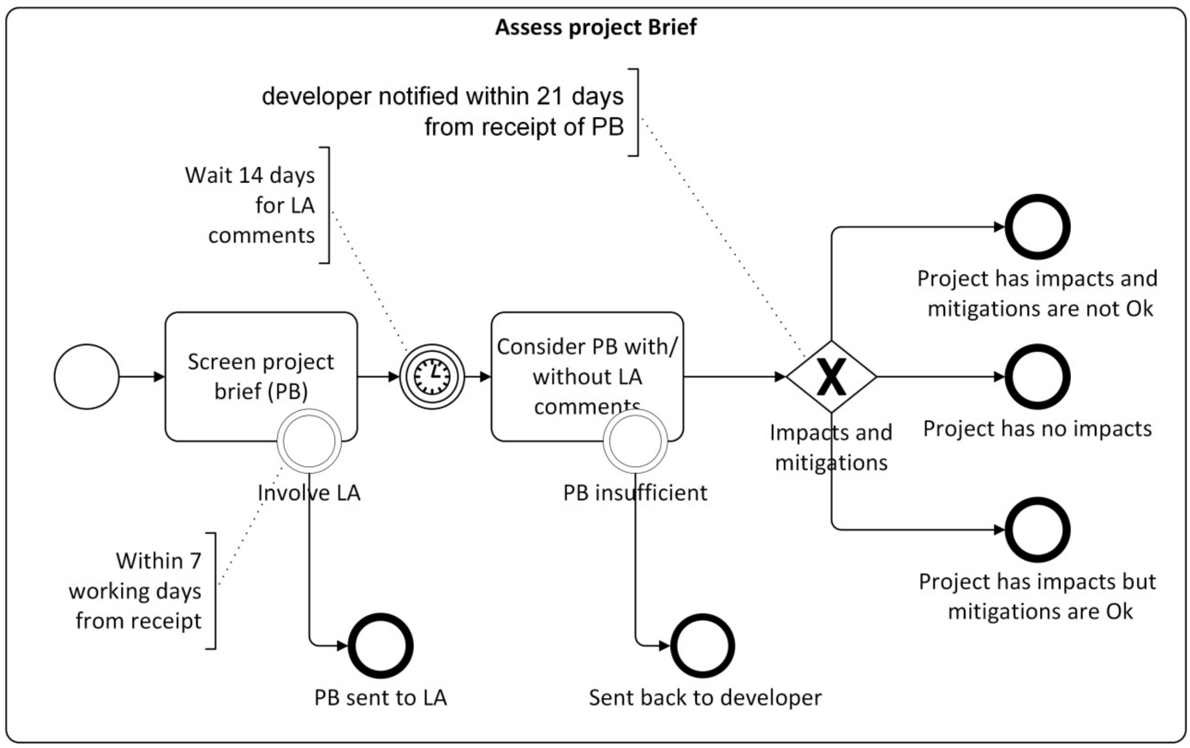
Appendix D Child-level process models (as-is)

D.1 Environmental impact assessment subprocess

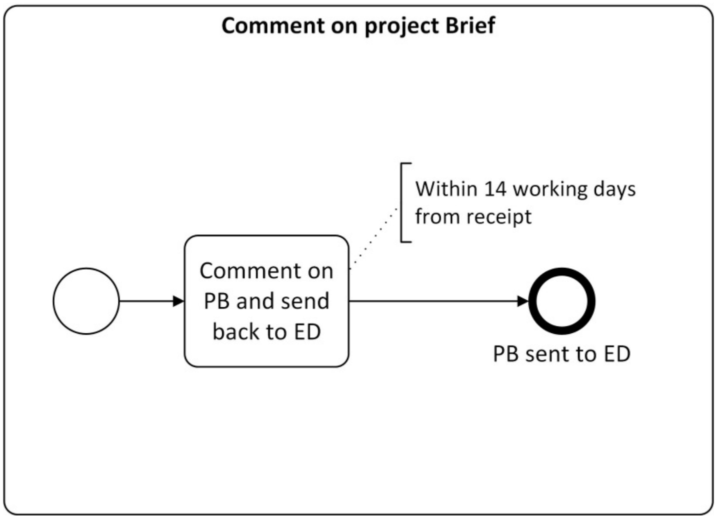
D.1.1 Prepare project brief



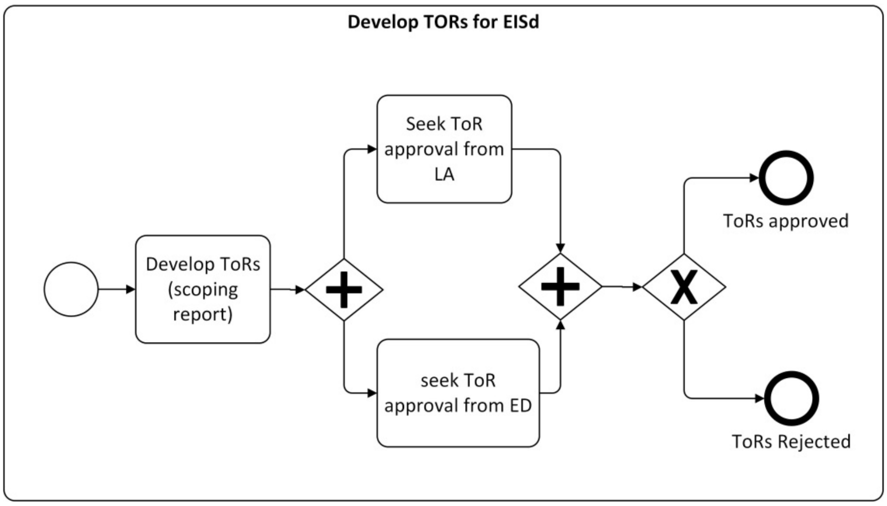
D.1.2 Assess project brief



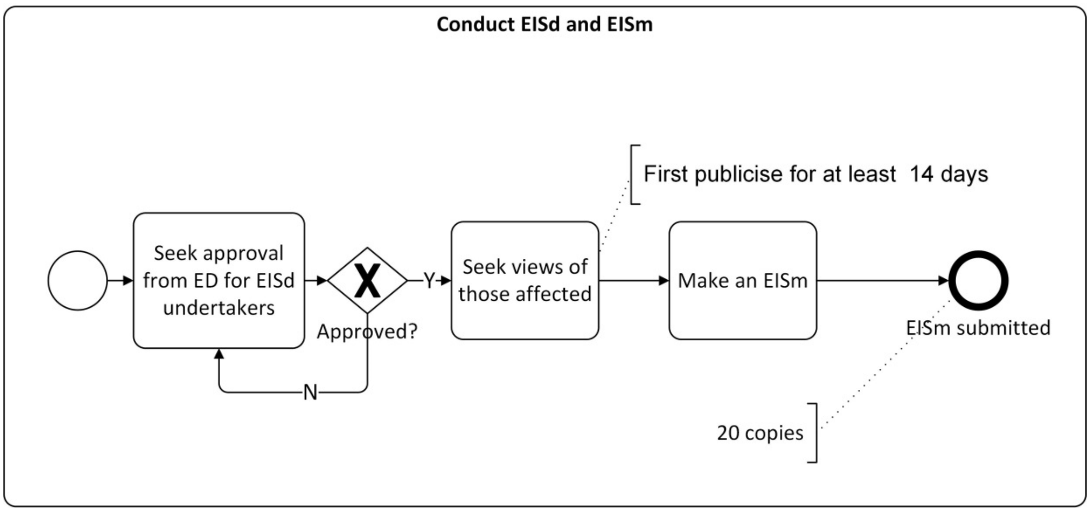
D.1.3 Comment on project brief



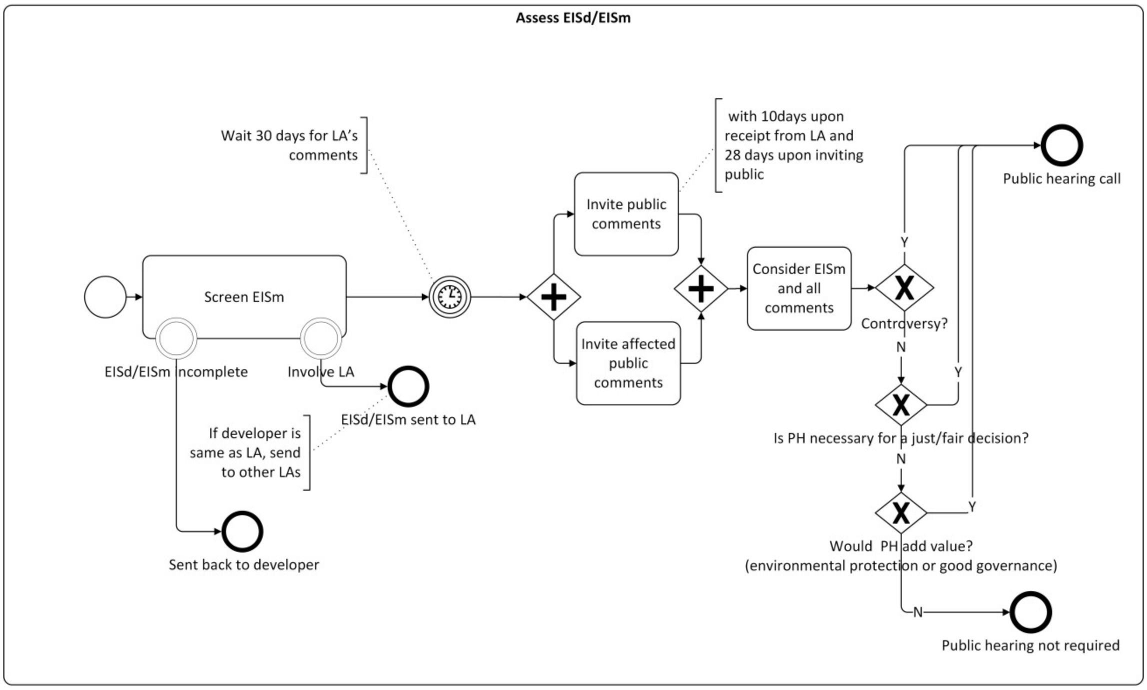
D.1.4 Develop Terms of reference



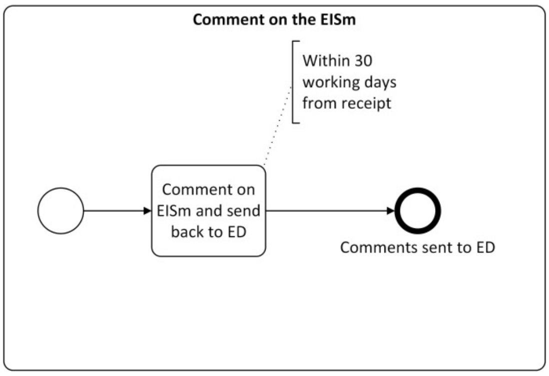
D.1.5 Conduct Environmental Impact study



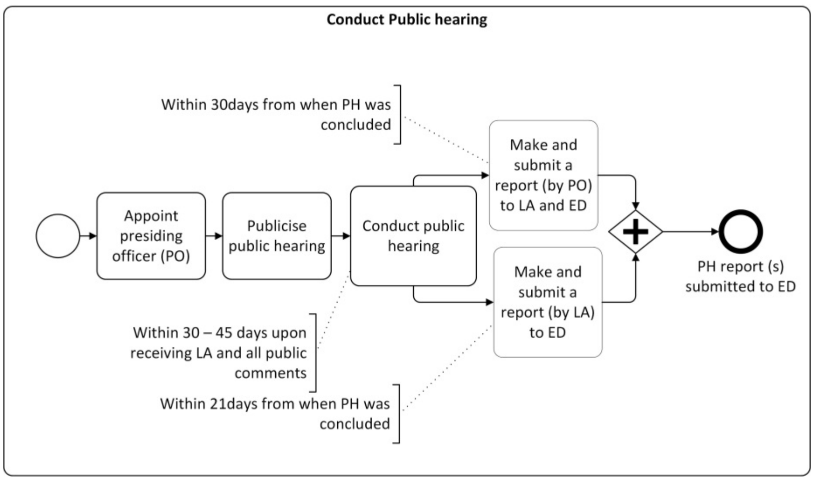
D.1.6 Assess environmental impact statement (EISm)



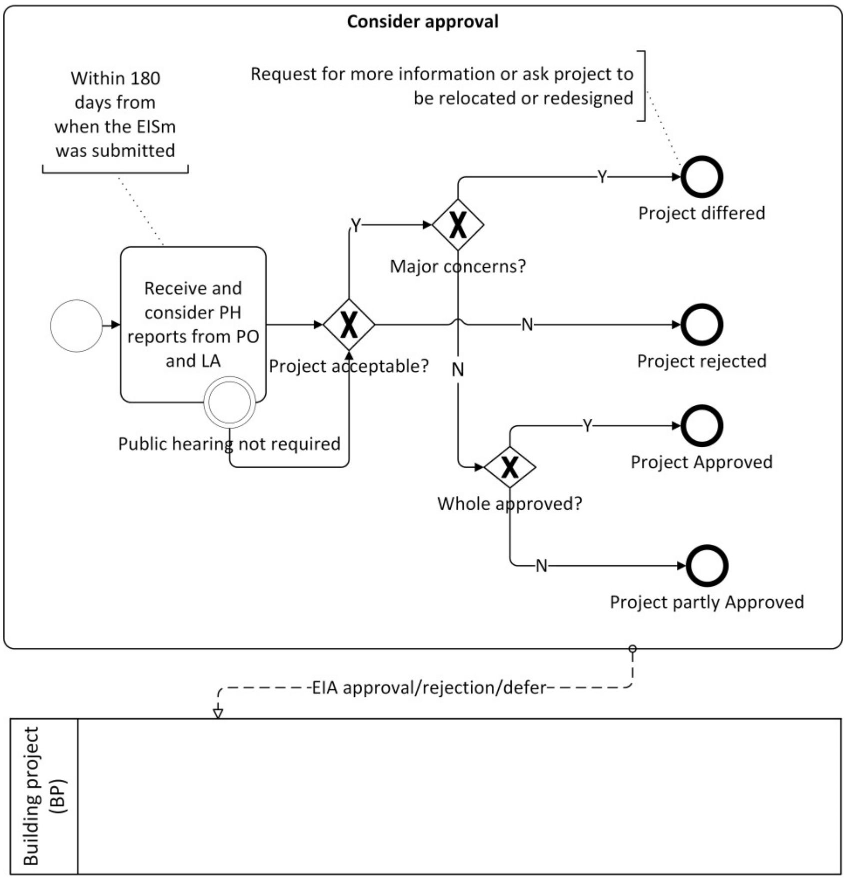
D.1.7 Comment on environmental impact statement



D.1.8 Conduct public hearing

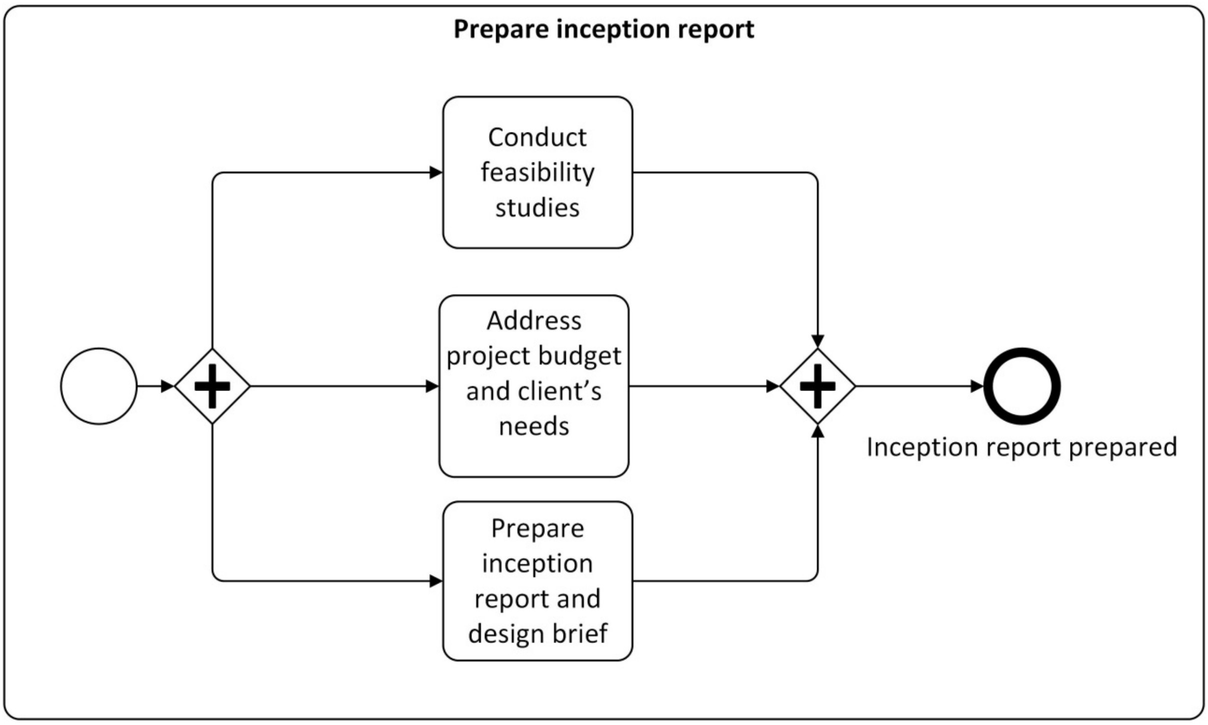


D.1.9 Consider approval

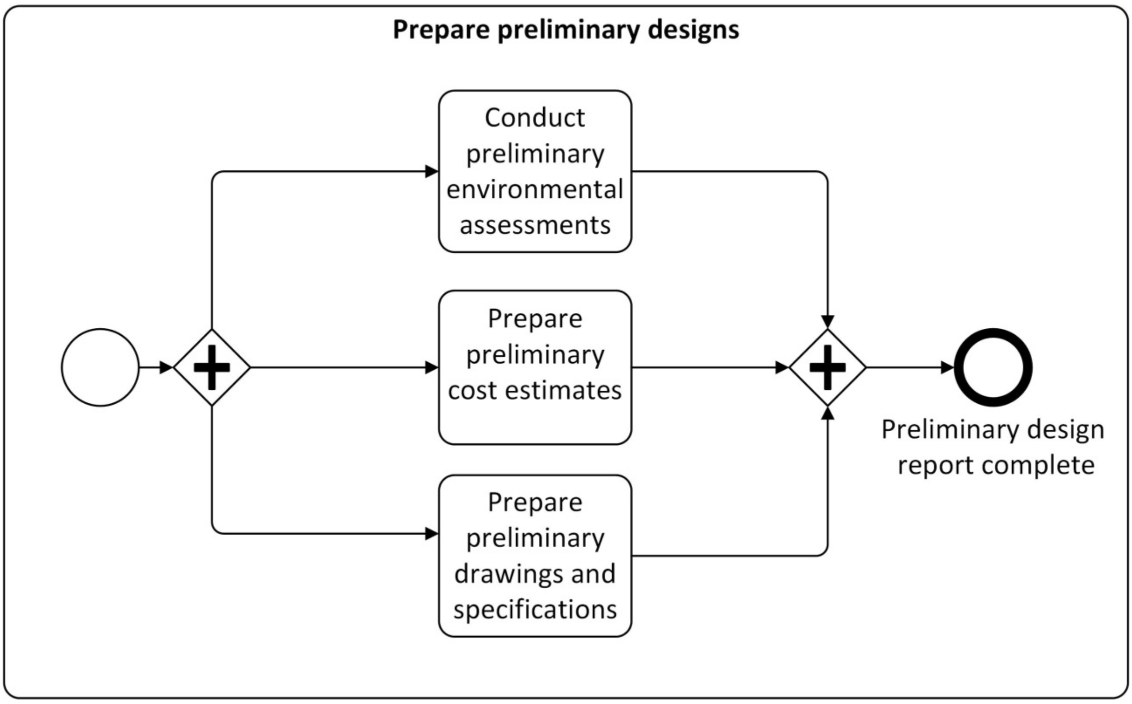


D.2 Building project subprocess

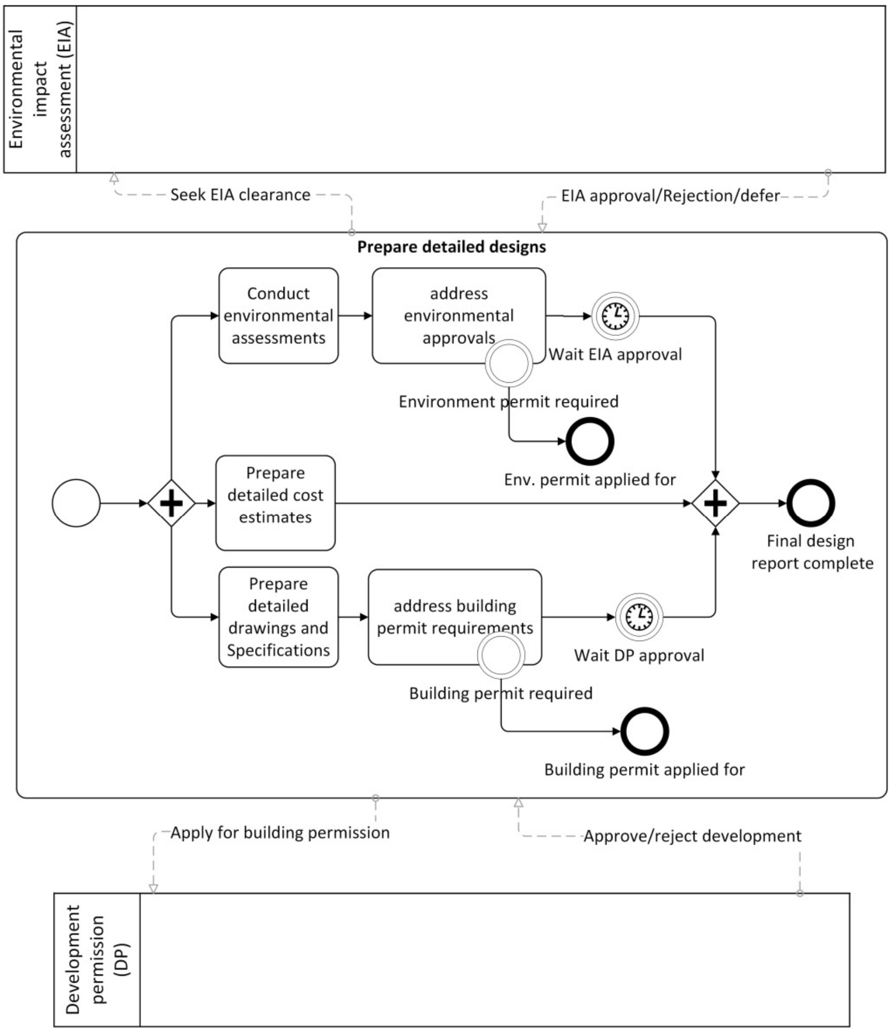
D.2.1 Prepare inception report/brief



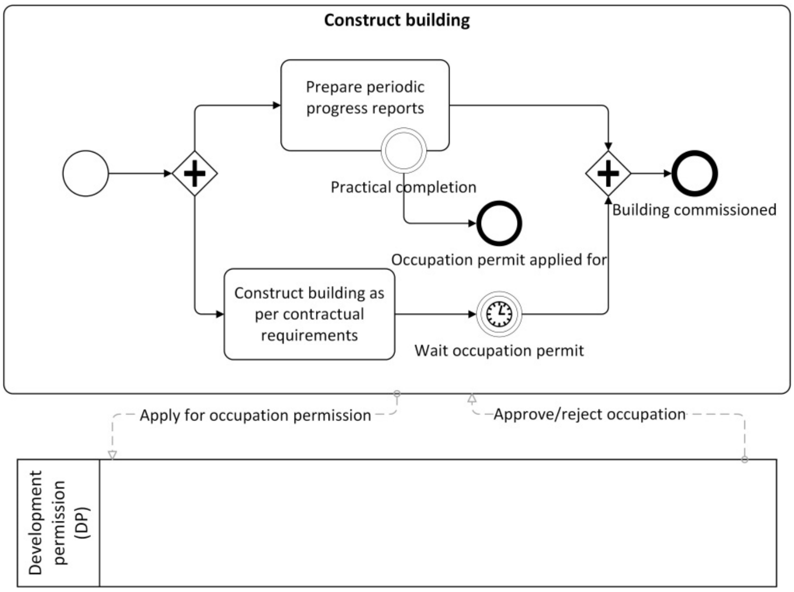
D.2.2 Prepare preliminary designs



D.2.3 Prepare detailed designs

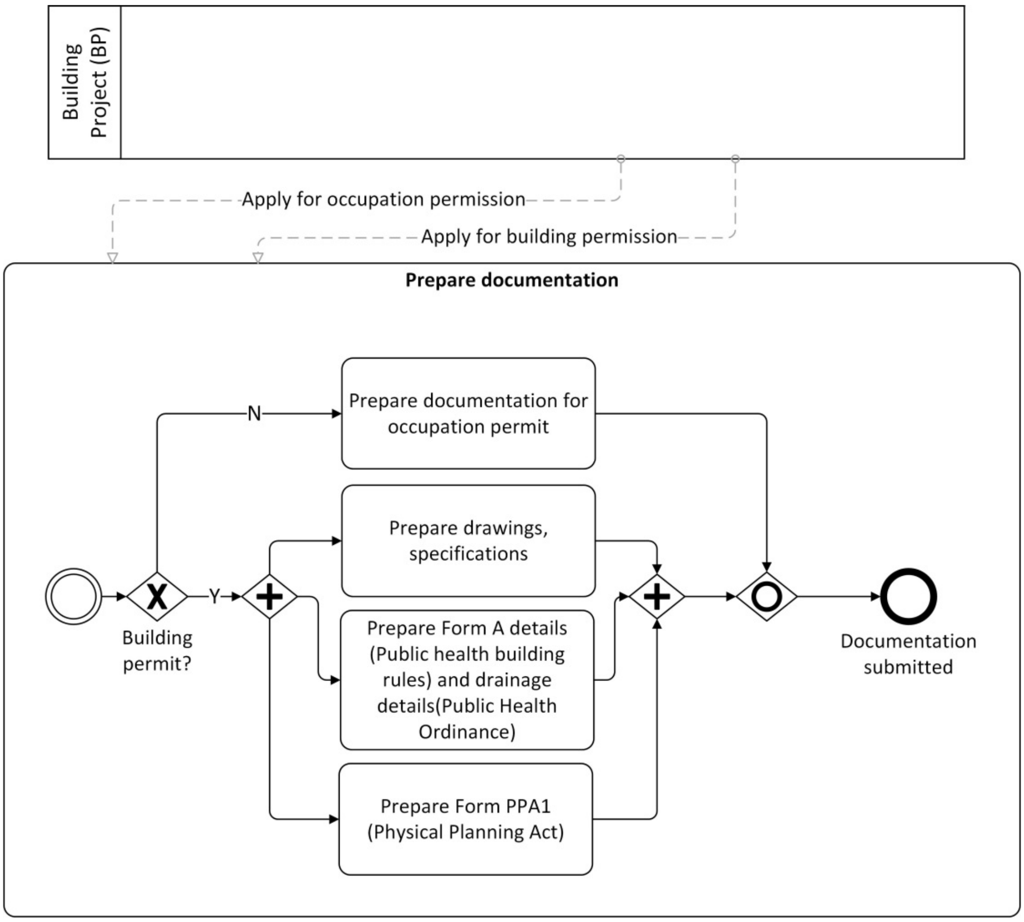


D.2.4 Construct building

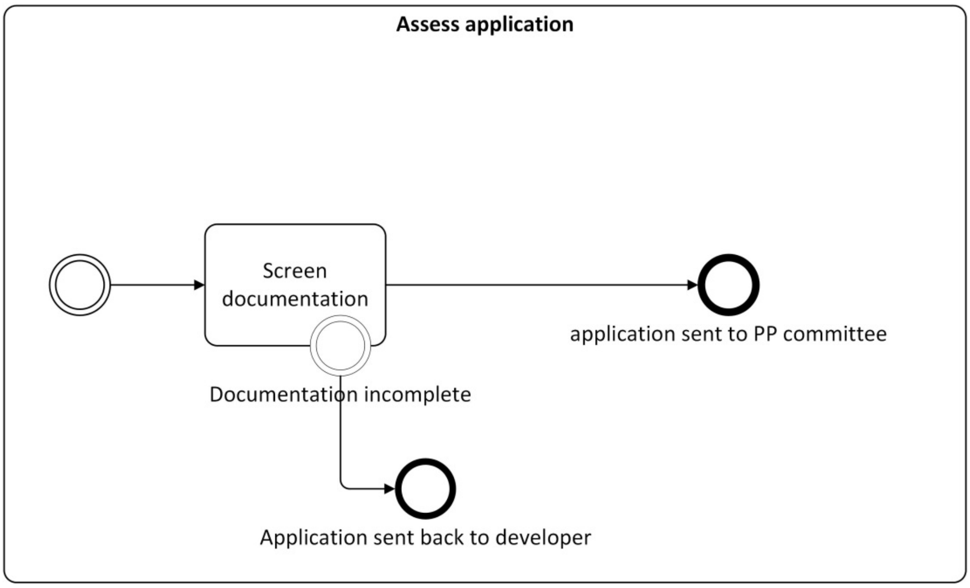


D.3 Development permission subprocess

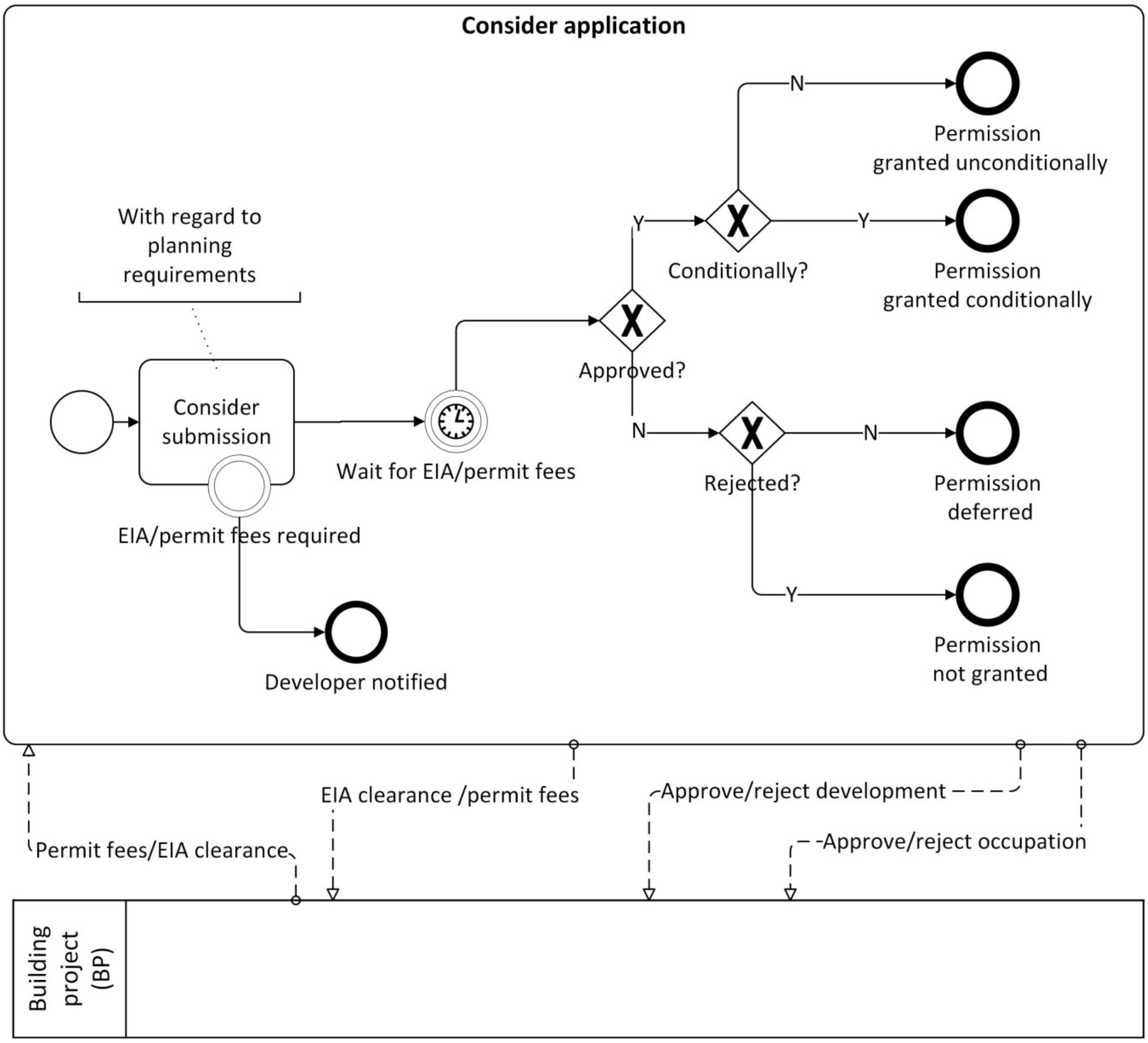
D.3.1 Prepare documentation



D.3.2 Assess application



D.3.3 Consider application



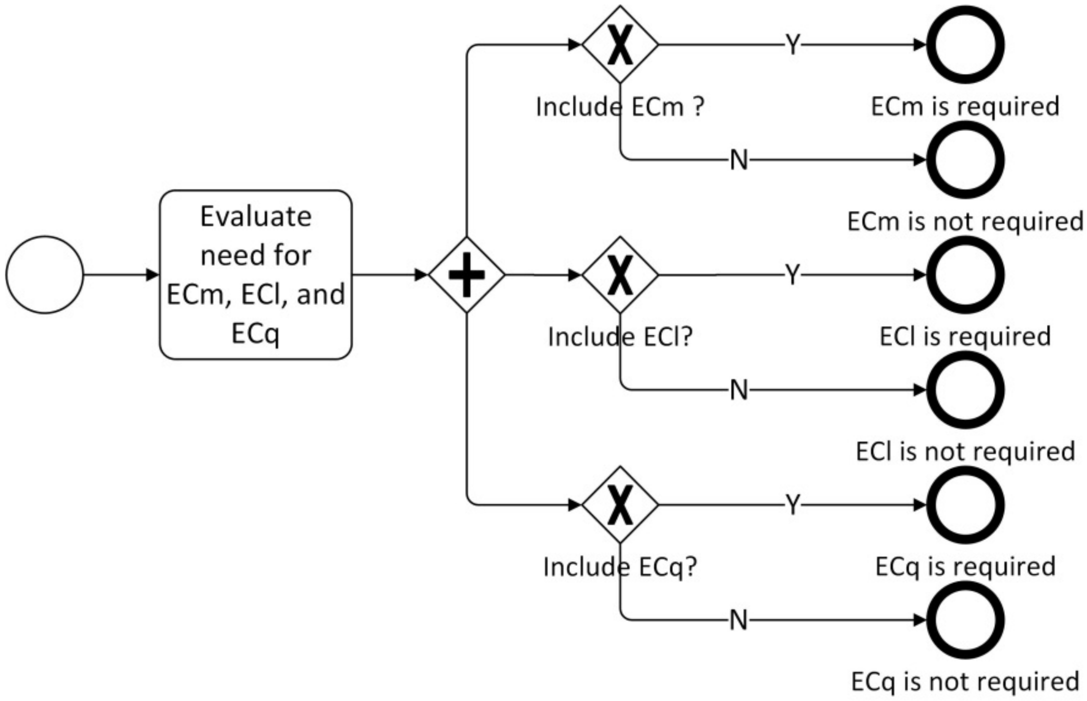
Appendix E Carbon Measurement Tool (CaMeT)

E.1 Example page from a CaMeT's carbon report

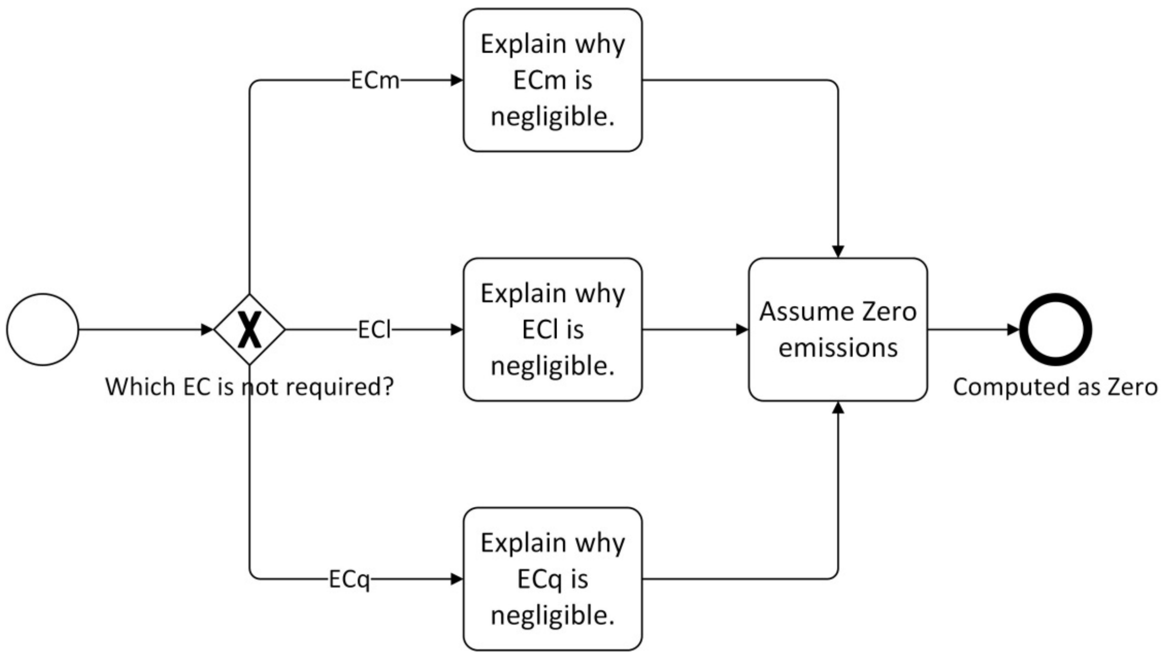
EMBODIED CARBON EMISSIONS OF THE PROJECT				
Sno	**Description**	**Details**	**Quantities**	**Remarks**
	COMPONENT NO.1: EMISSIONS FROM MATERIALS			
	General comments:			
	<u>ELEMENT NO.1: CEMENT</u>			
	EMISSIONS FROM MANUFACTURE			
A	Total carbon emissions associated with manufacture of Cement			
	Data base	Uganda		
	Source of material	Uganda		
	Quantity of material	Kg	888	
	Amount of emissions	tCo2	829	
	EMISSIONS FROM TRANSPORTATION			
B	Total carbon emissions associated with transporting cement from factory gate to construction site			
	Data base	Uganda		
	Source of material	Uganda		
	Quantity (OptionA)	Kg	0	
	Quantity (OptionB)	kWh	0	
	Quantity (OptionC)	Km	100	
	Amount of emissions (Option A)	tCo2	0	
	Amount of emissions (Option B)	tCo2	0	
	Amount of emissions (Option C)	tCo2	230	
	Total carried to Summary of component 1		1,059	

Appendix F Child-level process models (to-be)

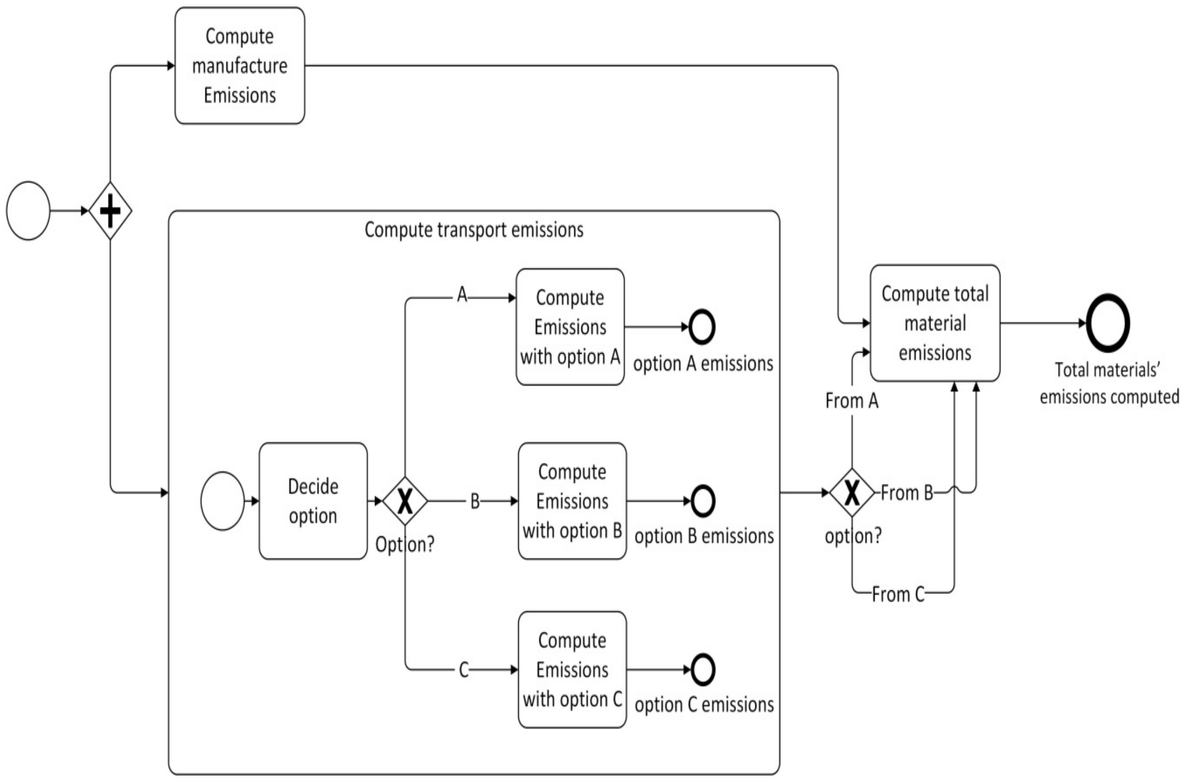
F.1 Decide components/emissions to include



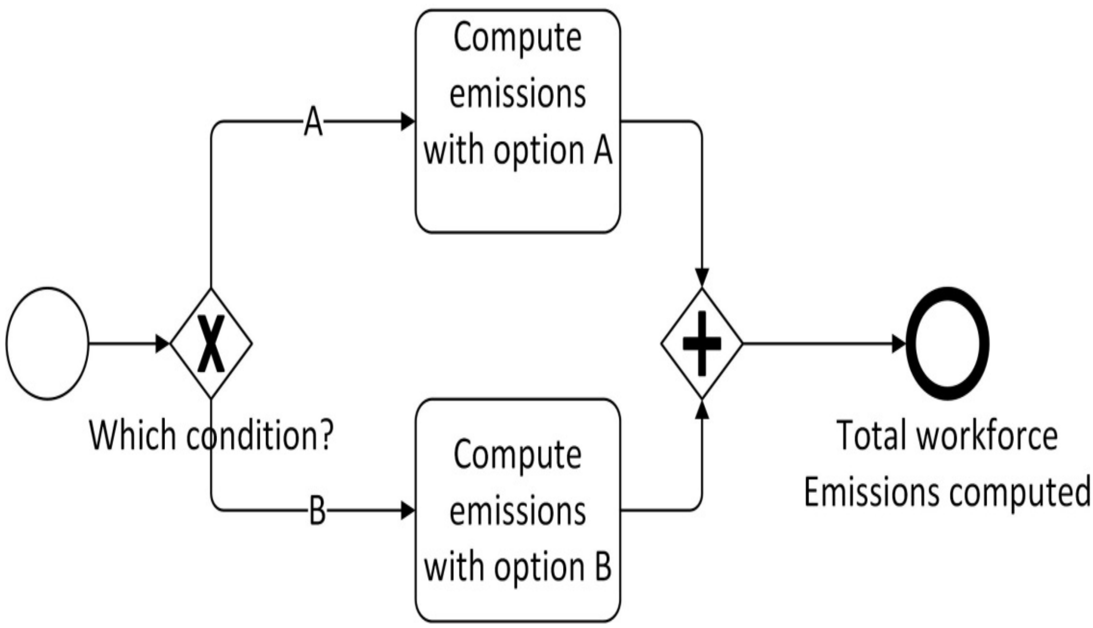
F.2 Explain assumptions



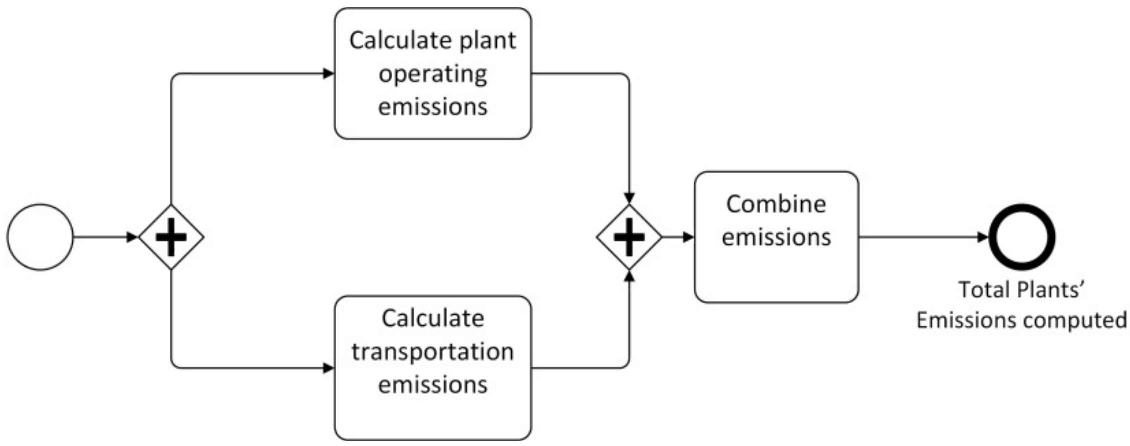
F.3 Compute materials' emissions



F.4 Compute workforce emissions



F.5 Compute plant emissions



F.6 Compute total emissions