A MODEL FOR IMPROVING ETHICS IN CONSTRUCTION MATERIALS AND PRODUCTS SUPPLY CHAIN USING BLOCKCHAIN

OLUWATOBI MODUPE KOLAWOLE

ORCiD: 0000-0002-7568-836X

A thesis submitted in partial fulfilment of the requirements of London South Bank University for the degree of Doctor of Philosophy

August 2022

Dedication

I would like to dedicate this thesis to my loving family, without whom I would never have reached this milestone at such an early stage in my life and career.

Declaration of Original Authorship

The researcher declares that work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

…………………………………………………………………… (Signed)

30th August, 2022
…………………………………………………………………… (Date)

Acknowledgements

I would like to express my deepest appreciation to God the Father, my Lord and Saviour Jesus Christ and the Sweet Holy Spirit of the only living God. I am what I am through Christ who strengthens me.

I find the African proverbial saying, "it takes the entire village to raise a child," to be very real and true in my case. I am one person who is blessed to have been helped by so many.

I am deeply indebted to my loving parents, Pastor Modupe Kolawole and Pastor (Mrs) Olufunke Kolawole, for their unparalleled love and support, without which the success I have enjoyed on many grounds would not have been possible. I would also like to extend my deepest gratitude to my exceptionally super-special siblings: Funmilayo Akah (ègbón mi olówó), Bukunmi Kolawole and Emmanuel Kolawole, for their unwavering love and support. In contrast to the stereotype, my extended family is one that is tightly knit in love. I am extremely grateful to Uncle Adeyanju Fujah, his wife, Auntie Yemisi Fujah and their children for the tremendous support, generosity and love they have shown me in the course of this journey, one that afforded me the liberty of focusing squarely on the research. I would like to extend my sincere thanks to my aunts, Mrs Racheal Kolawole and Mrs Bolaji Amonimo, and my uncle, Mr Olumurewa Kolawole, for their great love and support over the years. I very much appreciate my grandparents: (Late) Mrs Juliana Kolawole, Captain Olu Ojo (Rtd.) and (Late) Mrs Deborah Ojo for their profound belief in my abilities. I am also privileged to have the best cousins in the world, among whom are Deji and Deborah Arifalo, I am grateful to you all.

I would like to extend my sincere thanks to my supervisors, Dr Adamu Zulfikar and Mr Daniel Fong, for their insightful suggestions and invaluable guidance throughout the duration of this project. A special thanks to my mentor, Evangelist Emmanuel Jesutola, for his immeasurable impact on my life.

I am extremely grateful to my friends at Alive Church London and the leadership of Victory House London, for their love and fellowship, without which this journey would have been extremely lonely and bleak. Special thanks to my friends and other PhD colleagues who stepped in to offer support at different stages and in different ways in course of this research, you are the best!

Finally, I would like to extend my sincere appreciation to everyone who has been a part of my academic and life's journey, everyone who gave me a helping hand in my moments of insufficiency, and everyone who believed in me. Thank you very much! I hope I made you proud!

Abstract

There are countless materials and products that make up a building, including cladding, glazing, roofing, floors, ceilings, systems, etc., and the hidden and fragmented structure of the supply chain makes it highly vulnerable to several forms of ethical breaches at different tiers. Consumers also are increasingly concerned about where the products they are buying come from, highlighting important areas of concern that include the ethical, environmental, and social issues. Whereas current research identifies digitalization as a key part of providing transparency and increasing fairness in supply chains, and blockchain technology is lauded as having the potential to deliver this. However, while there has been a growing emphasis on ethics in construction in recent years, and an increase in studies around blockchain, there remains a paucity of studies related to how blockchain may help to improve the environmental and social dimensions of ethics in construction supply chains. A gap that this study fills through a holistic triple bottom line (TBL) approach.

To achieve this, the study aims to develop and validate a model for improving ethics in construction materials and products supply chains (CMPSC) following the TBL construct using blockchain technology. The study also explores the current state of ethics in the CMPSC and the implementations of blockchain for ethics and applies the learnings to develop a conceptual model to improve environmental, social and business ethics in the CMPSC using blockchain. The model was then refined and validated via a dual-phase validation protocol consisting of expert interviews and focus group discussions. A total of 30 participants participated in this study, this comprised of 16 construction industry supply chain professionals, 10 professionals in the ethics/sustainability in construction and 4 blockchain technology experts.

NVivo 12 was utilised to thematically analyse both the interviews and the focus group data. This approach was utilised to investigate the data from both a data-driven perspective (a perspective based on coding in an inductive way); and from the research question perspective (to check if the data is consistent with the research questions and if it provides sufficient information). The 30 interviews resulted in 4 high-level themes, 15 mid-level themes and 28 low-level themes, with the total number of codes within the themes being 721. The analysis of the focus group data resulted in 3 high-level themes and 10 mid-level themes, bringing the total number of codes within all themes to 74.

Results from this study revealed that the effectiveness of current ethical measures in the CMPSC has been limited due to weak implementation and compliance, the inability of the government to play its role, and the outright denial of unethical practises within supply chains. Results also show that even though greater emphasis is placed on the business component of ethics while the environmental or social component may only receive as much attention if it can be monetised or if it is demanded; nonetheless, the current state of ethics in the CMPSC remains weak across the three dimensions examined. Further results show that while blockchain may help improve ethics in the CMPSC, in addition to the transparency and digitization that technology provides, the need for education and the upholding of personal ethical values by supply chain players are key to the success of both current and new ethical supply chain initiatives. Individuals must first be made ethically aware in order to act ethically; only then may the implementation of a technological tool prosper.

The main contribution of this study to knowledge is the development of a model for improving ethics in the CMPSC within the TBL construct through blockchain technology. The model developed in this study provides practical clarity on how blockchain may be implemented within fragmented supply chains and a significant understanding of a socio-technical approach to addressing the issue of ethics within construction supply chains. It also has a vital role in helping the intended users and actors improve their knowledge of the technology and how blockchain can help to improve ethics in the CMPSC and also understand their roles and responsibilities on the network, thereby providing a framework and prerequisite guidance for the Blockchain-as-a-Service (BaaS) providers in the development of the computer model (blockchain network). The findings of this thesis demonstrate new insights and contribute to the existing body of knowledge by further advancing the discussion on the role of the blockchain in the construction industry.

Keywords: construction supply chain, ethics, blockchain, sustainability, responsible supply chain

Table of Content

List of Figures

List of Tables

List of Abbreviations

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
API	Application Programming Interface
BaaS	Blockchain-as-a-Service
BFT	Byzantine Faut Tolerant
BIM	Building Information Modelling
BLM	Black Lives Matter
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standard Institution
C-ID	Child - Unique Identifiers
CAD	Computer Aided Design
CBDC	Central Bank Digital Currency
CIOB	Chartered Institute of Building
CIPS	Chartered Institute of Procurement and Supply
CMN	Compliance Monitoring Nodes
CMPSC	Construction Materials and Products Supply Chain
CN	Customer Node
CON	Certifying Organisations Node
COP26	26th UN Climate Change Conference of the Parties Conference
COVID-19	Coronavirus Disease 2019
CSC	Concrete Sustainability Council
EBRD	European Bank for Reconstruction and Development
EPD	Environmental Product Declaration
ERP	Enterprise Resource Planning
ETI	Ethical Trading Initiative
GDPR	General Data Protection and Regulation
GHG	Greenhouse Gas
GIACC	Global Infrastructure Anti-Corruption Centre
HYBRIT	Hydrogen Breakthrough Ironmaking Technology
ICE	Institution of Civil Engineers
ILO	International Labour Organisation
IoT	Internet of Things
IRMA	Initiative for Responsible Mining Assurance
ISE	Institute of Structural Engineers
ISO	International Organization for Standardization
KYC	Know Your Customer
LCA	Life Cycle Assessment
NFC	Near Field Communication
OECD	Organization for Economic Cooperation and Development
P-ID	Parent- Unique Identifiers
P2P	Peer-to-Peer

PACS	Project Anti-Corruption System
PCL	Project Consortium Layer
PCR	Product Category Rules
PoA	Proof of Authority
PPN	Product - Player Nodes
RFID	Radio-Frequency Identification
RN	Registrar Nodes
RNLI	Royal National Lifeboat Institution
RUSI	Royal United Services Institute
SAI	Social Accountability International
SCM	Supply Chain Management
SDG	Sustainable Development Goals
SIT	Setup and Implementation Team
SMEs	Small-Medium Enterprises
SON	Standards Organisation Nodes
TBL	Triple Bottom Line
TI	Transparency International
WEF	World Economic Forum
WTO	World Trade Organization

Chapter 1 Introduction

This chapter discusses the background, problem statement and research justification in separate sections. The research aim, research questions and research objectives are also presented in the following sections. Furthermore, it highlights the significance of this current research and presents the structure of the thesis in the final section.

1.1 Background

The construction industry provides the foundation for infrastructure development by creating structures, oftentimes intricate and huge, with long supply chains involving a significant number of internal and external suppliers (Perera *et al.*, 2020). Construction projects involve intricate supply chains, numerous stakeholders and organisations, and a project's level of complexity leads to professional and organisational fragmentation. Such fragmentation, intricate contractual system, and uniqueness of construction projects are major reasons behind the sector's vulnerability to several forms of unethical practise (Transparency International, 2011). The construction materials and products supply chain (CMPSC) involve a network of interdependent activities, resources and actors that come together to turn a series of materials, products or services into a finished product before it is then passed to the end user. As such, it typically comprises a variety of resources, processes and actors involved in the production of materials and products from mine to market, and their activities and processes hugely impact the environment, people and the economy.

With an estimated 80% of global trade moving through supply chains, these networks remain one of the most crucial levers for businesses to have a positive effect on the world (United Nations Global Compact, 2017). Due to a rise in pressure from governmental and private-sector clients as well as general consumer awareness, responsible supply chain management is now on the rise. While the concept of an ethical and responsible supply chain is not new, the expansion of global sourcing opportunities has made maintaining an ethical and responsible supply chain a business and reputational necessity, as well as a legal obligation in some cases. As sourcing from unfamiliar locations is becoming more common due to cost saving pressures, project stakeholders are required to guarantee that it is not at the expense of people and the environment.

As earlier alluded to, the increasing emphasis on sustainability and the environment in construction in recent years further requires companies to apply ethical standards to their activities, giving more attention to corporate social responsibility, fair payments, procurement, moral judgements and other similar topics. Investors and activists are mounting increasing pressure on organisations to be more transparent about environmental, social, and governance aspects (CIOB, 2018a). Some contractors and clients are demanding more industry standards to boost product traceability in supply chains. In response to this, every organisation that seeks to improve ethics must identify risks and vulnerabilities in its supply chain, as well as prioritise efforts to improve social and environmental outcomes in addition to efforts to maximise business gains. Such organisations must ensure that beyond monitoring ethics within their organisation, they also maintain a supply network whose members respect and strive to integrate fundamentally fair social, environmental, and business standards within their supply-demand network, the achievement of which would help to meet the overall ethical goals of the industry.

With respect to environmental ethics, the construction industry has a shared goal of reducing emissions to net zero by 2050. However, buildings are not only responsible for emissions during their use phase but also for the emissions arising from manufacturing and processing of the building materials and products (Buildings Performance Institute Europe, 2021). The sector consumes 40% of the world's raw stones, gravel and sand and 25% of its virgin timber per year, with half of those resources being non-renewable (Karolina, 2021). As such, more concentrated efforts must be directed towards making the activities of the CMPSC more environmentally responsible if the environmental green goals of the construction industry are to be achieved. Also, regarding social ethics, Stronger Together (2019) reported that in 2016, around 40.3 million people were victims of modern slavery globally, and 61.7% of these people were in forced labour in sectors such as construction, manufacturing, mining, utilities, etc. At or below layers four and five of the supply chain, construction projects are regarded to be the most vulnerable to forced labour infiltration. Meanwhile, modern slavery is a threat not just to the labour force of the construction industry, but also to the supply chains of its raw materials and finished goods (Chartered Institute of Building, 2016). Supply chains are becoming more complex, hence, determining whether items are ethically sourced and produced becomes more difficult (O'Brien et al., 2008).

Furthermore, as regards business ethics, Transparency International (2006, 2008, 2011) revealed that the construction industry ranks among the most corrupt industries in the world. Several studies have also identified bribery and fraud as the most common forms of corruption in construction (OECD, 2015; Sohail and Cavill, 2006; Tl, 2011). CoST International (2016) predicts that if the current losses in the construction industry, which are thought to be between 10 and 30 percent, keep going, by 2030 more than $6 trillion will be lost every year around the world to corruption, bad management, and inefficiency. De Jong *et al.* (2009) suggests that improved openness and transparency of decision-making processes by all parties involved in a project is a major approach to improving business ethics in construction. Therefore, to improve ethics in the supply chain, there is a need for a holistic approach that not only focuses on addressing the business dimension of ethics but also seeks to address the environmental and social dimensions of ethics in the supply chain.

1.2 Problem statement and research justification

As BREEAM (2018) affirms, consumers are increasingly concerned about where the products they are buying come from. They highlight important areas of concern that include the following ethical, environmental, and social issues relating to: where the materials come from; whether they were extracted and processed in an environmentally responsible manner; if the highest levels of ethics have been demonstrated within the supply chain; whether the workforce involved in their extraction and production has been treated fairly; and whether communities local to the extraction and manufacture are adequately considered.

While numerous studies have investigated sustainability issues in the construction industry in general, a search of the literature revealed that despite the growing concerns earlier highlighted, up till now, far too little attention has been paid to evaluating and improving the ethical state of the CMPSC. Whereas the output of the CMPSC constitutes a major percentage of the industry's human resources and overall output, as every building is technically made up of its constituent materials and products. There are countless components that make up a building, including cladding, glazing, roofing, floors, ceilings, systems, and fitments and the hidden and fragmented structure of the supply chain make it highly vulnerable to several forms of ethical breaches at different tiers (CIOB, 2018a). Hence, efforts to improve ethics in construction must not be limited to monitoring and controlling only what happens on the construction site but means to ensure transparency and visibility in the CMPSC must also be given due consideration in designing a well-rounded approach to address ethics across the construction supply chain. As Werdmüller (2018) affirms, modern slavery in the construction sector affects more than just the labourers who work on construction sites. The materials and products used in construction each have their own supply chain and associated risk. Therefore, an approach to improving ethics in the construction industry must invariably include the very cogent but often neglected construction materials and products supply chain sector. Furthermore, such an approach must go beyond the usual narrow business-centric methodology, it must be one that is more holistic, considering environmental and social ethical matters in the CMPSC.

As multiple authors confirm, digitalization in the architecture, engineering and construction industry is considered as a key part of its development and holds high prospects to provide strategic solutions to the several established problems of the industry (Institute of Civil Engineers, 2018; Jacobsson *et al.*, 2017; Lavikka *et al.*, 2018; Linderoth, 2017); however, some challenges still exist. According to Aziz *et al.* (2009), connecting the many technological components of a digital system with the methodological, cultural, social, and organisational aspects unique to the construction industry presents a significant barrier in the development of digital applications for the sector. This is evidenced in the slow response of the industry to new technology when compared to other industries (ICE, 2018; Jacobsson *et al.*, 2017; Lavikka *et al.*, 2018). Nonetheless, digitisation in the construction industry remains promising as it will provide several possibilities that were not obtainable with the traditional manual systems of the past.

Blockchain, a technology which has been lauded as having the potential to have a greater impact than the internet (Bheemaiah, 2017), has the ability to increase productivity (IBM, 2020), improve ethics (Adams *et al.*, 2017; Boersma and Nolan, 2020), enhance efficiencies and lower costs (Leong *et al.*, 2018), as it has already demonstrated in a variety of industries. According to IBM (2020), blockchain is a distributed immutable ledger technology that facilitates the process of recording and tracing transactions between two or more parties, using cryptography, hashing and a consensus mechanism to maintain the integrity of the ledger. The workings of the blockchain technology are further explored in detail in Chapter 3 of this study.

Leong *et al.* (2018) claimed that a growing number of successful pilots reveal that blockchain can provide the network for registering, verifying, and tracking goods transferred between distant, and often mistrustful parties in a supply chain. Mehra and Dale (2020) affirm that it can also improve operational inefficiencies, reduce fraud, and even alleviate humanitarian challenges, like exploitative labour practises and environmental degradation, by enabling greater certainty, transparency, and accountability over the information shared between parties. Nevertheless, there is little clarity within the construction industry regarding how to achieve this (Smith and O'Rourke, 2019).

While several studies have focused on blockchain technology in general and its implementation in other sectors, such as finance, trade and supply chains, agriculture, shipping and logistics, etc., only a limited number of studies on blockchain in construction exist today, with the few use cases being mainly for BIM, as implemented by BIMCHAIN (Crunchbase, no date) and building data capture, as implemented by Briq (Williams *et al.*, 2019). This knowledge gap is further widened in the construction industry due to the usual resistance of the industry to new technologies. Hence, the potential impact of blockchain in the construction supply chain is currently understudied. Also, extant literature mainly focuses on how blockchain may impact the business dimension of the construction supply chain, but no study has investigated how blockchain may help to improve the environmental and social dimensions of ethics in the CMPSC, a gap that this study aims to fill by taking on a holistic triple bottom line (TBL) approach to improve ethics in the CMPSC through blockchain. As Smith and O'rourke (2019) posit, it is important for the construction industry to understand the potential that may be unlocked in time with this emerging blockchain technology.

As such, this research seeks to contribute to knowledge on improving ethics in CMPSC by developing and validating a blockchain model with the TBL construct. As earlier highlighted, the construction industry is a significant industry in all countries as it provides the foundation for infrastructure development, and the CMPSC constitutes a major percentage of the industry's human resources and overall outputs. However, the CMPSC is considered susceptible to breaching social ethical standards and impacting the environment hugely, whilst also impacting overall economic growth substantially. Therefore, there is an imperative need for a more holistic approach to improve ethics within the supply chain of construction materials and products, which makes this research highly unique and vital.

1.3 Research questions

In an attempt to fill the identified knowledge gaps, this research seeks to address the following fundamental research questions:

1. What is the current state of ethics in the CMPSC and how effective are the current measures on improving ethics in the CMPSC?
2. Is blockchain technology capable of impacting ethics in supply chains across the TBL construct?
3. How can blockchain help improve ethics in the CMPSC within the TBL construct?
4. What factors may affect the acceptance and implementation of blockchain technology in the construction industry?

1.4 Research aim and objectives

In order to address these research questions and to make contribution to knowledge which is necessary to address the research problem, the overall aim of this study is to develop and validate a model for improving ethics in construction materials and products supply chains (CMPSC) following the triple bottom line (TBL) construct using blockchain technology. To achieve the stated aim, the following objectives are pursued:

1. To evaluate the current state of ethics in the CMPSC following the TBL construct and how effective the current ethical measures have been.
2. To explore blockchain technology and its implementations for ethics following the TBL construct, in view of applying the learning to evaluate its feasibility to improve ethics in the CMPSC.
3. To establish how blockchain technology can help improve ethics in the CMPSC within the TBL construct.
4. To determine the factors that may affect the acceptance and implementation of blockchain technology in the CMPSC.
5. To develop and validate a model for improving ethics across the CMPSC following the TBL construct using blockchain technology.

1.5 Significance of the thesis

This research makes both theoretical and practical contributions to knowledge.

Practical Contribution

The main contribution of this thesis to knowledge is the development of a model for improving ethics in the CMPSC within the TBL construct through blockchain technology. This model provides practical understanding of a socio-technical approach to addressing the issue of ethics within construction supply chains. It also has a vital role in helping the intended users and actors improve their knowledge of the technology and how blockchain can help to improve ethics in the CMPSC and also understand their roles and responsibilities on the network.

In addition, the developed model provides a framework and prerequisite guidance for the Blockchain-as-a-Service (BaaS) providers for the development of the blockchain network, without which the comprehension of the expectations of the Setup and Implementation Team (SIT) will be limited and the resulting network unsatisfactory.

Theoretical Contributions

Firstly, while previous research mainly focused on the sustainability concerns ensuing from the activities of the construction industry (Akwada *et al.*, 2018; CIOB, 2018a; Ibrahim *et al.*, 2010; Omran and Schwarz-Herion, 2020; Stronger Together, 2019) and on blockchain technology in general and its implementation in other sectors (Boersma and Nolan, 2020; Hijazi *et al.*, 2019; Tezel *et al.*, 2019; Zheng *et al.*, 2017), this study takes an unconventional socio-technical approach to provide clarity on how ethics can be improved in the construction materials and products supply chain across the triple bottom line through blockchain technology and collective action theory.

Secondly, this research provides the knowledge required for understanding the effectiveness of current ethical measures, how their bottlenecks can be addressed, and it establishes 3 major routes to the improvement of ethics in the CMPSC, namely: through education, through blockchain technology and through the upholding of personal ethical values.

Finally, the findings of this thesis demonstrate new insights and contribute to the existing body of knowledge by further advancing the discussion on the role of the blockchain in the construction industry. It is also believed that the model developed for improving ethics in the CMPSC across the TBL forms a good basis for deepening the current body of knowledge on blockchain implementations for ethics in supply chains.

1.6 Research scope

The fundamental goal of this research is to develop and validate a conceptual model for improving ethics in construction materials and products supply chains (CMPSC) following the triple bottom line (TBL) construct using blockchain technology. Therefore, it involves the process of creating a graphical representation (or model) of the real world that gives an easily understood depiction of the system under study. As such the model would seek to provide practical clarity on how blockchain may be implemented to address the issue of ethics within construction supply chains. The model would also help the intended users and actors understand their roles and responsibilities on the network.

To achieve this, at the initial stage of the research, a substantial review of literature was conducted to gain knowledge in the fields of blockchain, ethics and the construction supply chain and subsequently to identify the research gaps, form the research aim and objectives as well as the research methodology required to achieve them. Following this, a more detailed literature review was conducted to further develop knowledge of the subject matter and to develop the initial version of the conceptual model. Afterwards, expert interviews were held to gain further understanding of the subject matter and to refine and validate the developed model. Having refined the model based on feedback from the interview participants, the model was then validated in a focus group discussion.

However, the scope of this work does not include the development of a computer model for any simulation purposes. Although, the developed model provides a framework and prerequisite guidance for the Blockchain-as-a-Service (BaaS) providers in the development of the computer model (blockchain network) for simulation and implementation purposes.

1.7 Structure of the research thesis

This research seeks to improve ethics in CMPSC through blockchain and develops a model for the improvement of ethics through blockchain technology. It adopts an inductive approach to answer the research questions and achieve the objectives of this study. An inductive reasoning through its explorative approach is used to gain a deeper understanding of ethics within the CMPSC and how blockchain technology can impact it, based on learnings of its impact within the supply chain of other industries. The research design adopted in this research, along with the corresponding phases involved, is shown in Figure 1.1.

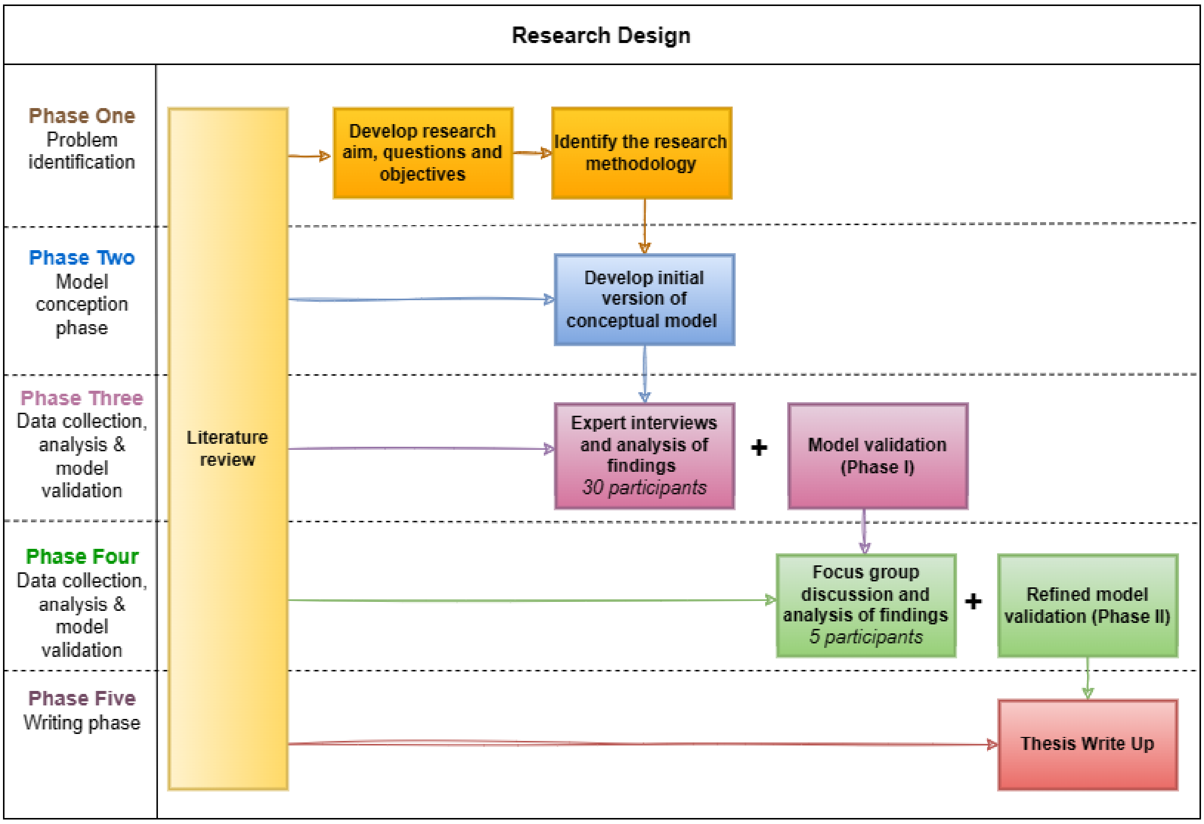

Figure 1.1: Schematic representation of the research design

Chapter 1

The chapter introduces and provides an overview of the entire research process, it explains the background, problem statement and justification for the study. Then it identifies the research aim, research questions and objectives. It also highlights the significance of this study and gives a brief overview of the other chapters.

Chapter 2

Following the introduction, the second chapter reviews the relevant literature regarding the construction industry and ethics within the construction materials and products supply chain. It presents an overview on literature regarding the current state of ethics in the CMPSC within the TBL construct and the current measures in place to uphold ethics in the supply chain.

Chapter 3

This chapter reviews literature on blockchain technology, to study its workings and impacts in supply chains. The core features of the technology, its underlying elements, its applications across some industries and factors affecting its implementation were reviewed in this chapter, with the aim of applying the learning to evaluate its feasibility to improve ethics in the CMPSC.

Chapter 4

In this chapter, the theoretical framework underpinning the model and the conceptual model developed are discussed. It reveals the study's utilisation of the theory of collective action as the theoretical framework that underpins the conceptual model built on blockchain to improve ethics in the CMPSC following the TBL construct. This chapter goes further to discuss the rationale for the theoretical framework, conceptual model and the rationale for blockchain as the underlying technology. This chapter also provides insights into the development of the model and its workings and clearly outlines how it proposes to improve environmental, social and business ethics within the CMPSC.

Chapter 5

This chapter discusses the research approach adopted for this research, it also reveals the technique utilised for the gathering and analysis of data in order to achieve the research objectives. In addition, it presents the research paradigm regarding what can be known and how it can be known from the perspective of the researcher. It also discusses the range of research philosophies, research approaches, research strategies, research choices, data collection techniques and procedures to gather the appropriate primary data required for the achievement of the objectives of the research.

Chapter 6

This chapter presents the results and analysis of the data which was systematically and rigorously collected from the expert interviews and focus group discussion. Following the thematic analysis of the data set using NVIVO 12, it presents the new insights on the subject area based on the unique perspectives shared by the participants. Furthermore, in this chapter, the results of both phases of the validation of the developed conceptual model are also presented.

Chapter 7

This chapter presents an interpretation and explanation of the findings from both the interviews and focus group as presented in the Chapter 6, highlighting their relationship with the existing literature and how they address the research questions and objectives of this study. This chapter also goes on to present arguments to support the entire discussion and to explain the insights that emerged from the study.

Chapter 8

This chapter provides concluding remarks with an overview of the main research findings. It also presents the theoretical and practical contributions of this research, as well as the limitations and directions for future research. The structure of this research thesis and the flow of the chapters is illustrated in Figure 1.2.

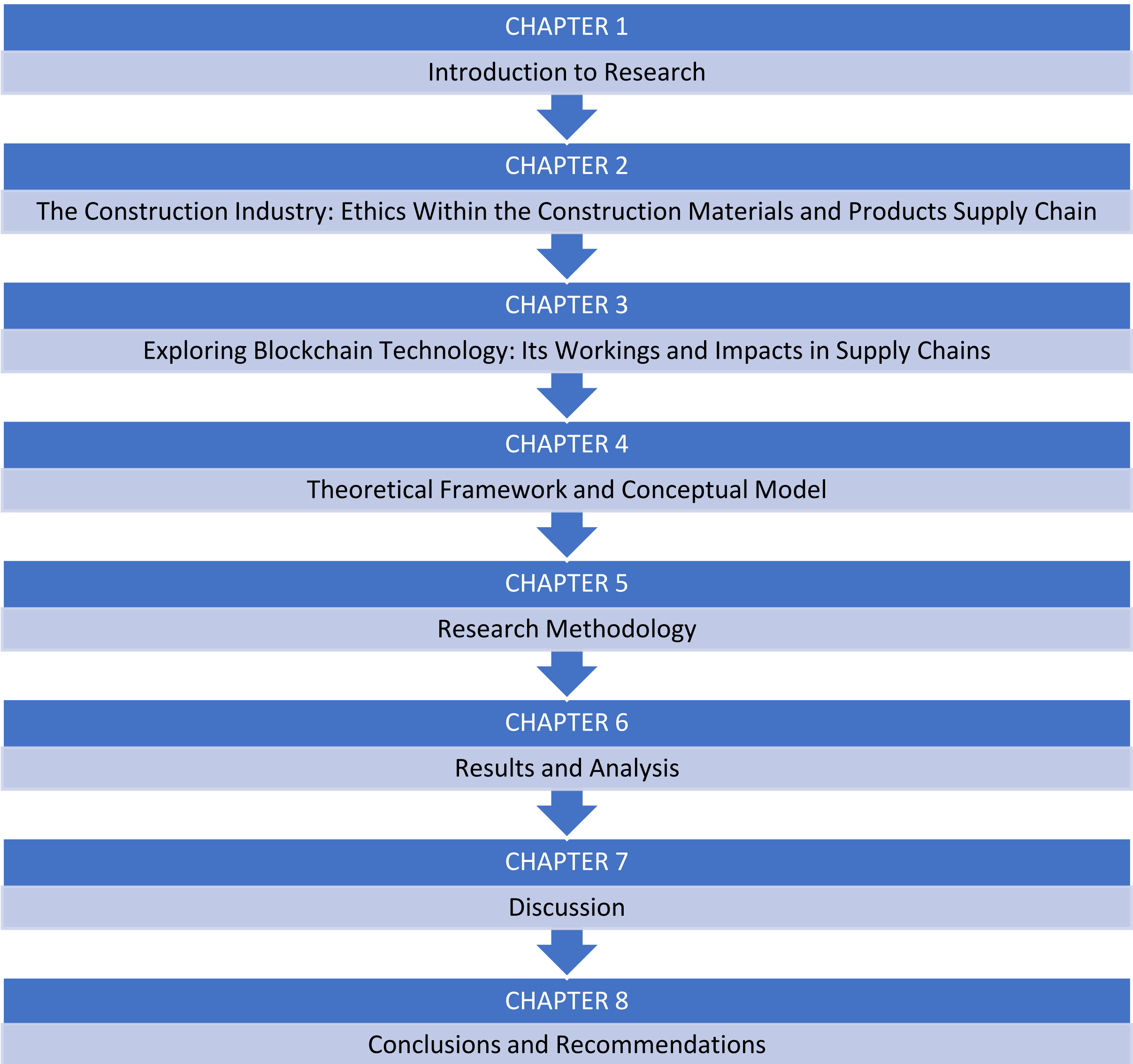

Figure 1.2 An outline of the structure of the research thesis

Chapter 2 Ethics within construction materials and products supply chain

2.1 Introduction

In the supply chain of construction materials and products, a network of interdependent activities, resources and actors come together and offer services to turn a series of materials and products into a finished product before it is then passed to the end user. It typically comprises a variety of resources, processes and players involved in the production of materials and products, including raw material extractors, component suppliers, manufacturers, distributors, etc; and other players within a typical construction project who procure the materials and products such as client, consultants, contractors etc. These activities and processes hugely impact the environment, people and the economy. Hence, the need to maintain a supply network whose members respect and strive to integrate fundamental international environmental, social, and business standards within its supply-demand network. This section therefore describes the nature of the construction industry and takes a holistic TBL approach to evaluate the current ethical state of its materials and products supply chain and to help understand how effective the current ethical measures have been.

2.2 The construction supply chain and its management

Historically, a supply chain was thought of as a series of flows: a material flow downstream, a transaction flow upstream, and a bidirectional flow of information (Christopher, 1992). Later, a supply chain was deemed a network rather than a - linear – chain per se (Pryke, 2009), because the numerous organisations that make up the network simultaneously generate diverse and multiple information streams (Christopher, 2005). As a result, a supply chain can be defined as a "supply-demand network," or a complex and dispersed network of organisations (Christopher, 2011). Construction Excellence (2004) classifies all construction companies as part of a supply chain, including clients, main contractors, designers, surveyors, subcontractors, and suppliers, it posits that the term is used to describe the chain of companies that transform a series of basic materials, products, or services into a finished product for the client. SDG (2018) define the supply chain as the passage of materials from a company involved in production to a final consumer. It can be direct, involving only a focal organisation, a supplier and a consumer, or extended to involve the focal organisation, its suppliers and consumers as well as other parts of the chain, involving intermediate actors, such as financial resource providers, government agencies and research institutions. A supply chain, according to the Committee on Supply Chain Integration, is an association of customers and suppliers who buy, convert, distribute, and sell goods and services among themselves, resulting in the creation of a specific end product, while working together but in their own best interests (National Research Council, 2000). Other scholars simply define it as a network of suppliers, factories, warehouses, distribution centres, and retailers (Xiaoning and Papadonikolaki, 2019).

For this study, supply chain will be defined as a network of interdependent activities, resources and actors involved in turning a series of materials, products or services into a finished product and its passage to the end user. As such, a typical construction supply chain goes beyond the often-acknowledged construction actors such as architects, engineers, surveyors, contractors, etc., to include other actors involved in a variety of other stages, including raw material extractors, component suppliers, manufacturers, distributors, and customers. At each level, one or more geographically distant organisations may be engaged; for example, a manufacturer may obtain material from multiple suppliers and subsequently supply multiple distributors (O'Brien *et al.*, 2008).

The construction industry creates intricate and huge structures, with long supply chains involving a significant number of internal and external suppliers (Perera *et al.*, 2020). Construction projects involve a large number of stakeholders and organisations, and the project's complexity leads to professional and organisational fragmentation. Modelling of construction supply chains has been studied extensively since the early 1990s, with the goal of determining how manufacturing concepts can be applied to the fragmented construction supply chain in order to optimise activities across its various tiers (O'Brien et al., 2008). This has resulted in a surge in interest in the field of supply chain management (SCM). In addition, increasing global competition, cost pressure and market uncertainty have contributed to the pursuit of SCM based on the premise that potential exists to improve customer service, reduce costs and achieve sustainable competitive advantage through upstream and downstream collaboration throughout the value chain (Adetunji *et al.*, 2008).

As research and execution draw from varied disciplines such as manufacturing and operations management, organisational configurations, and information technology, a variety of perspectives on supply chain management exist. As a result, no one definition of SCM exists, and no single dominant paradigm exists (O'Brien et al., 2008). SCM, according to Stadtler (2005), is defined as the integration of organisational units along the supply chain, as well as the coordination of materials, information, and financial flows in order to meet consumer needs. SCM is defined by Litke et al. (2019) as the management of the progress path of goods and services, which includes the transfer and deposit of natural resources (raw materials), the backlog of ongoing processes, and completed products from genesis to use. According to (Adetunji et al., 2008), SCM can be characterised from three perspectives. Firstly, it is defined as the integrated management of materials, information, and financial flows from raw material extraction to end-user in the manufacturing industry perspective. Secondly, it encompasses the management of an organization's interaction with its direct suppliers and numerous departments and agencies in the public sector, emphasising that 'procurement management' is the preferred term in the public sector. Finally, they define SCM from the perspective of the construction sector as collaboration between the primary contractor, subcontractors, and suppliers, as well as the growth of these relationships inside the supply chain system toward the formation of lean supply chain partnerships.

With an estimated 80% of global trade moving through supply chains, supply networks remain one of the most crucial levers for businesses to make a positive effect in the world (United Nations Global Compact, 2017). As pressure from governmental and private-sector clients, as well as general consumer awareness develops, responsible supply chain management is constantly improving. Although, there are a number of factors that contribute to ineffective and inefficient supply chain performance in the construction industry. Nevertheless, it is stated that the openness and traceability of products should be stressed as the basis for ongoing improvement (Abeyratne and Monfared, 2016). Also, the management of information in the supply chain, including information sharing, information content, and information quality, is critical (Zhou and Jr. Benton, 2007). Information asymmetry has weakened trust within the supply chain as customers and buyers have no reliable way to verify and validate the true value of the products they purchase because of the lack of transparency and traceability (Wang *et al.*, 2017). While many studies focus on the use of advanced IT applications for supply chain management, such programmes typically require a centralised organisation to record and manage the data, which other partners may not be willing to provide. The Institution of Civil Engineers (ICE) states in its 2018 Shaping a Digital World report that the sector is rapidly transitioning into "a world of connection, automation, and data abundance," and that blockchain is possibly the most "exciting" technical breakthrough (ICE, 2018)

According to Consortium (2020), there are numerous stakeholder parties involved throughout the supply chain in a typical project-level structure of a construction project, including sponsors: client, funders, etc.; consultants: architects, engineers, etc.; contractors: main contractor, sub-contractors; supply chain actors: manufacturers and product suppliers; operations: management agent, facilities management; and users: tenants, residents, customer. The construction industry's supply chain is highly fragmented, with over 99 percent of companies classified as Small-Medium Enterprises (SMEs)

(White, 2015). A construction project supply chain, according to O'Brien et al. (2008), is a human system that is set up with the goal of delivering a construction project and is organised into a network of multiple enterprises linked together by economic ties. Although emergent properties and layers of hierarchy are usually a natural result of the economic ties that bind each firm to the construction project, this is not always the case when it comes to aligning interests and effectively coordinating actions among its members.

One of the major (and possibly the most occurring) frequently activity within construction supply chain is procurement, as materials, products and services are regularly being procured before, during and after construction. The value of materials and products that are required to be purchased and used for any construction contract makes up a large proportion of a project’s total contract sum, typically up to 40–45% of the cost of all construction work (Andrew et al., 1998). Contractors must maintain an ethical supply chain as well as procure products at the right price, quality, and on time to remain competitive in today's market. Most of the vendors and subcontractors are chosen during the procurement process which increasingly overlaps with the design and construction phase. Price, safety, quality, and schedule performance are common selection criteria (O'Brien et al., 2008). According to GIACC (2020), the term "procurement" refers to the process by which the project owner requests suppliers to submit offers to the project owner to supply works, equipment, materials, products, services, or finance for the project; evaluates the submitted offers; and awards contracts to the suppliers whose offers are judged to be the most favourable to the project owner.

Public procurement is one of the most corrupted government functions (Anthony Bowen et al., 2012). According to OECD (2015), an estimated 20-25 percent of national procurement budget are lost to corruption globally each year. Public procurement accounts for 13% of GDP in OECD countries and one-third of total government spending, making it one of the most corrupted government activities. Governments all across the world have begun to employ innovative technology to improve procurement process integrity, efficiency, and value for money. Among these, blockchain is considered to have a lot of promise in terms of fighting corruption and inefficiency (Yang, 2019).

2.3 Ethical supply chain for construction materials and products

Ethics is a branch of moral philosophy that deals with the principles that should be used to guide and promote certain behaviours and actions. Ethics is focused on the core concerns of “what is the best way for people to live?” and “what behaviours are right or bad in given circumstances?” (Bowen *et al.*, 2007). It dates back to ancient Greek thinkers and there is much debate in the philosophical arena about the definition of ethics. Ethical concerns are those that revolve around what we should do, and ethical claims are prescriptive rather than descriptive or predictive. They are typically normative and aspirational, describing the behaviours, practises, and character traits that we should aspire for, even if they are difficult to attain. The increasing emphasis on sustainability and the environment in construction further requires companies to apply ethical standards to their activities, giving more traction to conversations around corporate social responsibility, fair payments, procurement, moral judgements and other similar topics.

Understanding the impact of our sourcing and purchasing actions is highly crucial in today's world (CIPS, 2013). While the concept of an ethical and responsible supply chain is not new, the expansion of global sourcing opportunities has brought to light certain important procurement challenges that must be addressed. Maintaining an ethical and responsible supply chain is now a business and reputational necessity, as well as a legal duty in some cases. Furthermore, a track record of sustainable and ethical procurement can promote investment, boost staff morale, and go above and beyond legal obligations. As a result, every company must identify risks and vulnerabilities in its supply chain, as well as prioritise efforts to improve social and environmental outcomes.

Hence, for this study, ethical supply chain will be framed as a supply network whose members respect and strive to integrate fundamentally fair social, environmental, and business standards within its supply-demand network. Related key words used in existing literature to illustrate ethical supply chains include sustainable supply chain, green supply chain, responsible supply chain, corporate social responsibility, etc. It takes a holistic view and incorporates net benefits for both the producer, buyer and the wider world by considering the impact of environmental, economic and social factors along with price and quality (CIPS, 2013).

Due to lower labour costs, sourcing from unfamiliar locations is becoming more common. It is therefore the responsibility of project stakeholders to guarantee that these cost savings do not come at the expense of people and the environment. In some regions of the world, many workers and subcontractors, including children, are not protected by law, and many are subjected to criminal behaviour, poor pay, and working conditions, with little concern for health and safety. Workers are frequently subjected to harassment and abuse, and in some cases, they may be coerced to labour (CIPS, 2013). Procurement professionals should seek to conduct business with responsible suppliers that respect the rule of law and human rights, understand the nature of the products and materials they are supplying, and recognize their responsibility to protect the environment (WEF, 2020), with the end goal of creating an environment intolerant to criminal conduct, such as any form of modern slavery, corruption or bribery, and minimising or eradicating harmful environmental and social impacts. They must ensure that workers in their supply chain have good working conditions and that their human rights are protected. The larger picture is to assure a better outcome for everyone, including higher business returns for buyers, suppliers, and employees (CIPS, 2013).

Transparency in the supply chain is critical to developing an ethical supply chain because the supply chain is no longer a back-office operation that few people are aware of. Today, it has evolved into a competitive differentiator and part of the corporate business model. Buyers should look beyond the first, second, and even third tiers of their supply chain, according to the Chartered Institute of Procurement and Supply (CIPS), because workers at the bottom of the supply chain, or on the branches of the supply chain, such as migrant workers hired through labour hire intermediaries, are often the most vulnerable to exploitation (CIPS, 2013).

This current research assessed ethics within the construction supply chain under the triple bottom line: environmental ethics, social ethics and business ethics. The notion of "the triple bottom line" was used for the first time in 1994 by John Elkington, his argument was that companies should be preparing three separate bottom lines. One to measure of corporate profit; the second is the bottom line of a company's "people account", to measure how socially responsible an organization has been throughout its operations; the third is the bottom line of the company's "planet" account, which is a measure of how environmentally responsible it has been (Żak, 2015). This approach has since then been widely adopted and adapted in the study of ethics and sustainability in supply chains by several researchers, international bodies, governmental organizations and non-governmental organizations (CIOB, 2018; CIPS, 2013; SDGs, 2018; United Nations Global Compact, 2017). Many topics touch across all three dimensions unavoidably. For example, attaining gender equality will have a significant impact on economic growth as well as social costs (SDGs, 2018). Climate change, likewise, is already incurring substantial social, environmental, and economic costs all around the world (United Nations Global Compact, 2017). Nevertheless, in the following section, the assessment is divided into these three dimensions, well aware of the complicated and intricate links between the various themes. The tenets of the TBL concept are illustrated in Figure 2.1.

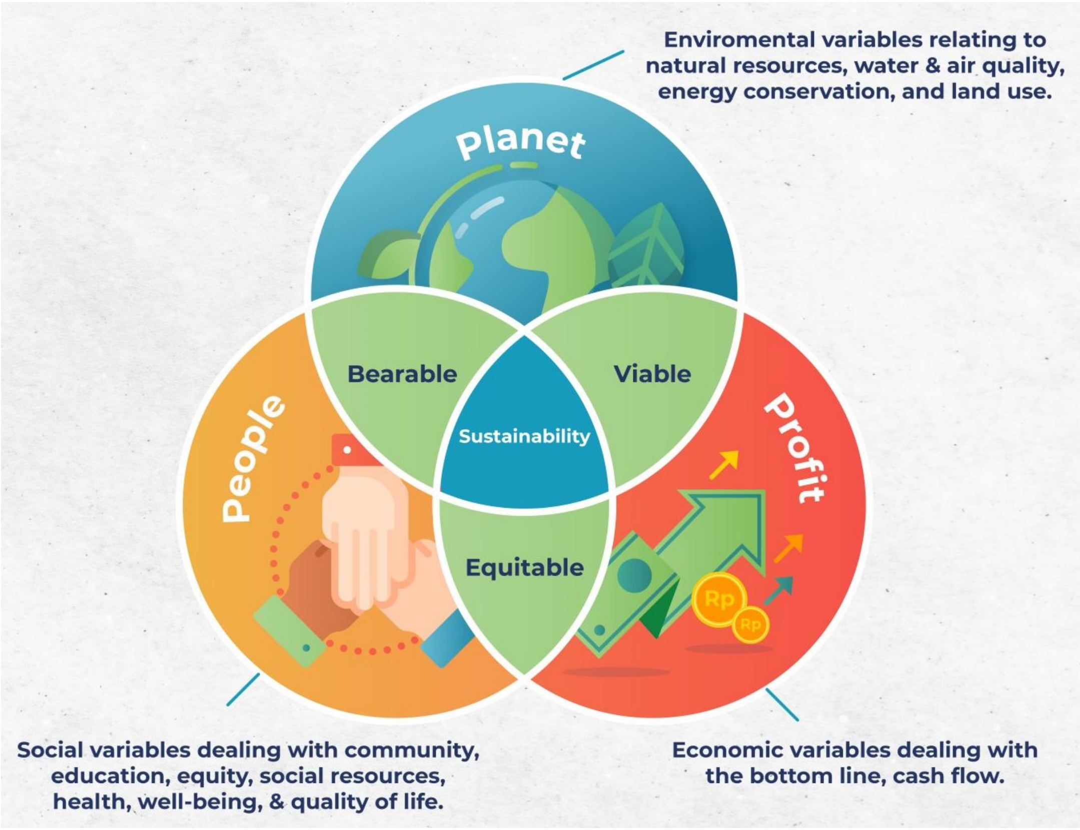

Figure 2.1 The tenets of the triple bottom line concept. (Source: Waste4change (2021))

2.4 Current state of ethics in construction materials and product supply chain

Construction and its products use a lot of energy and water, and they pollute the air, ground, and aquatic habitats (Ibrahim *et al.*, 2010; Morledge and Jackson, 2001; Mustow, 2006). People-related issues are known to have a poor record in construction, particularly for health and safety (Boersma and Nolan, 2020; CIOB, 2018a, 2018b; Stronger Together, 2019; Werdmüller, 2016). The construction sector and its clients have also been accused of operating unethically, such as obtaining timber from unsustainable sources and extracting minerals in a way that results in human rights violations (Akwada *et al.*, 2018; Chimeli *et al.*, 2011; Omran and Schwarz-Herion, 2020; Palmer *et al.*, 2014; Palmer, 2001). In this section, the current state of ethics in construction supply chain is further discussed in reference to the triple bottom line: environmental ethics, social ethics, and business ethics.

2.4.1 *Environmental ethics*

Environmental ethics is the study of ethical questions raised by human relationships with the nonhuman environment. Ethical reflection on human relations with the nonhuman world is not new; concern about the environmental impacts of human practices and human treatment of animals dates back to ancient Greece (Palmer *et al.*, 2014). Environmental ethics emerged as a distinct field of philosophy during the 1970s, and its scope has since expanded significantly (Palmer *et al.*, 2014). Environmental ethics is concerned with environmental justice. The US Environmental Protection Agency defines it as the equitable treatment and meaningful participation of all individuals, regardless of race, colour, national origin, or income, in the creation, implementation, and enforcement of environmental laws, regulations, and policies. Furthermore, environmental risks are not limited by geography or time, our existing activities, lifestyles, and policies have an impact on the ecological situations of people who have not yet been born.

Every single construction action has an impact on the environment. Construction is unquestionably one of the most resource-intensive and environmentally harmful businesses on the planet (Earth Watch Institute, no date). The materials chosen, the technology used, and the development of the building site all produce carbon dioxide, which contributes to global warming. Though some claim that the climate is not changing and that their businesses have no environmental impact, but this is untrue, because in reality, the construction industry is responsible for 23% of air pollution, 40% of drinking water contamination, and 50% of landfill waste (Morledge and Jackson, 2001). Actions on the construction site, transportation, and the fabrication of building supplies all contribute to this high percentage. The sector consumes 40% of the world's raw stones, gravel and sand and 25% of its virgin timber per year, with half of those resources being non-renewable (Karolina, 2021).

As a result, climate change is becoming a more pressing concern in construction, particularly following the 2021 United Nations Climate Change Conference (COP26), as both governments and private firms strive to attain their own net-zero goals. “Green” or "net zero" clauses in construction contracts are encouraged, as are green construction practises such as analysing and lowering greenhouse gas emissions related with building construction processes and material production (Werdmüller, 2016). However, the environmental implications of building products go beyond greenhouse gases, energy, and resources; they also include water extraction, eutrophication, land use, pollution, and waste. These variables have a huge impact on animals, causing them to change their ways of living and thus decrease their population. These types of consequences are frequently overlooked by decision-makers since the problems may not become apparent for a long time.

Moreover, all other dimensions of sustainability rely on a safe and life-sustaining environment, yet forecasts indicate that the environmental dimension of sustainability will have the most worrisome future. By 2050, it is anticipated that 60% of the world's primary ecosystems, on which mankind depends for survival, will be severely strained, and 15-40% of species will be gone (United Nations Global Compact, 2017). As a result, climate change is indeed a human rights issue, with many of the most severe consequences falling on those already disadvantaged, such as women, children, and the impoverished and all sectors of society have critical roles to play in combating climate change and adapting to its effects.

Instead of being careless environmental trustees, construction professionals should be responsible stewards who endeavour to balance their environmental impact with conscious measures aimed at pollution prevention and remediation. One way to accomplish this is to incorporate sustainability into the procurement of products and services, with a focus on environmental attributes as well as other social and ethical criteria as appropriate and applied to the value chain, rather than the common pervasive goal of economic benefit that often drives procurement (World Economic Forum, 2020).

Concrete, steel, and timber are the most widely used construction materials and products worldwide (Monteiro *et al.*, 2017; World Steel Association, 2018); however, concrete and steel production have huge impacts on the environment (Jonathan Watts, 2019; Kjesbu *et al.*, 2017), and many criticize the construction industry as chief culprits of deforestation (Akwada *et al.*, 2018; Chimeli *et al.*, 2011). The following section further discusses their environmental impact and current initiatives to reduce their adverse impact on the environment.

The concrete factor

The construction industry is infamous for consuming a lot of resources and energy. The use of Portland cement in concrete, for example, accounts for more than 6% of human-caused carbon emissions. Among materials, only coal, oil and gas are greater sources of greenhouse gases. Furthermore, it uses nearly a tenth of all industrial water used worldwide and exacerbates the problem of silicosis and other respiratory ailments. Wind-blown dust from stocks and mixers contributes up to 10% of the coarse particulate matter that chokes Delhi (Sarkar *et al.*, 2019), where experts discovered that the air pollution index at some building sites was at least three times higher than permissible values (Clement *et al.*, 2021; SHAZLY *et al.*, 2021).

According to a study by Elhacham et al., (2020), we may have already passed the threshold where the carbon mass of every tree, bush, and shrub on the earth is outweighed by concrete. According to the study, the mass of everything humans have built and created, from concrete sidewalks and glass-and-metal buildings to plastic bottles, clothing, and computers, is now roughly equal to the mass of all living species on Earth and could soon surpass it. The McKinsey Global Institute (2019) reports that China has poured more cement every three years since 2003 than the United States did in the whole twentieth century. Cement output was equivalent to steel production in 1950; it has increased 25-fold since then, more than three times as quickly as its metallic building counterpart.

Concrete is the most frequently utilised substance on the planet, second only to water. With up to 2.8 billion tonnes of CO2, the cement sector would be the world's third greatest carbon dioxide emitter, trailing only China and the United States (Jonathan Watts, 2019). Urbanisation, population expansion, and economic development, according to Chatham House, will drive global cement production from 4 to 5 billion tonnes per year. According to the World Commission on the Economy and Climate, if emerging nations build their infrastructure to present global average levels, the construction sector will produce 470 gigatonnes of carbon dioxide by 2050. This is in violation of the Paris Climate Agreement, which requires every nation in the world to reduce yearly carbon emissions from the cement industry by at least 16 percent by 2030 if the world is to stay within 1.5°C to 2°C of warming. Concrete is beautiful and adaptable, but it regrettably checks all the environmental degradation boxes. As a result, developers must consider all of the materials they use and their overall impact, but many engineers say that there is no feasible alternative to concrete (Skocek *et al.*, 2020).

There is a lot of interest in finding new sources of supplemental cementitious materials that can be scaled up globally due to the rising demand to mitigate the environmental impacts of concrete and the fact that the majority of CO2 emissions come from limestone, the main raw material used, and initiatives are being developed to cut carbon dioxide emissions by 25% by 2030 and to reach zero net emissions by mid-century. Skocek et al. (2020) in their study found that a carbon capture and utilisation (CCU) technology based on mineralization of concrete fines proves to be a potential solution for reducing these emissions, saving 30% more CO2 than merely replacing clinker with limestone. Monteiro et al. (2017) affirms that industrial by-products such as coal fly ash and iron blast-furnace slag, which can improve a variety of concrete properties, can partially replace Portland cement. Another initiative to lessen the negative impact of concrete on the environment is CarbonCure, CarbonCure uses a technology that infuses recycled CO2 into fresh concrete to lower its carbon footprint while maintaining performance. CO2 undergoes a mineralization process and is permanently incorporated into concrete after injection, providing concrete producers with both economic and environmental benefits (Skocek *et al.*, 2020).

The steel factor

Steel is an iron alloy in which the majority of the carbon has been reduced to as little as 1.7 percent to improve its strength and fracture resistance when compared to other types of iron. Steel is made from 98 percent of all iron ore mined, accounting for about 95 percent of all metals produced; 51 percent of world steel is used in building (World Steel Association, 2018). Steel, like concrete, is produced in large quantities around the world, according to World Counts (2022), the world produces enough steel to build an Eiffel Tower every 3 minutes, which equates to 180,000 Eiffel Towers in one year, totalling around 1800 million tonnes. Steel production emits an average of 1.83 tonnes of CO2 per tonne of steel produced, making it a major contributor to global warming, accounting for over 3.3 million tonnes of CO2 annually (World Steel Association, 2018) and its production is one of the most energy-consuming and CO2 emitting industrial activities in the world (Luo *et al.*, 2019). Steel requires about 20 gigajoules of energy per ton produced and three quarters of that energy comes from burning coal (World Counts, 2021). Also, steel production requires large inputs of coke which is extremely damaging to the environment and human health.

Despite the fact that traditional steel production has a substantial environmental impact, no one can manufacture a product without steel. Steel is employed in the production and shipment of things even if it is not used in the product itself. But steel can be produced in far more environmentally friendly ways. A Korean company, for example, has created a steelmaking technology that releases 90% lesser hazardous pollutants than standard methods (Hauge, 2020). Globally around 85% of construction steel is currently recovered from demolition (World Steel Association, 2018). Steel may be recycled multiple times to produce top-quality new metal, with no degradation from prime to lower-quality components. Scrap steel is remelted in an electric arc furnace or utilised as part of the charge in a Basic Oxygen Furnace during recycling. Following the adoption of the EU's 2050 climate neutrality target, the steel sector is under a lot of pressure to increase energy efficiency, reuse and recycle more, and move to low-carbon manufacturing practises. Furthermore, recycling steel provides for CO2 emissions savings of 62% to 90% when compared to primary production and modelling shows that combining hydrogen-based production with a shift to scrap steel recycling allows the industry to continue producing high-quality steel while reducing emissions and maintaining jobs (Branca *et al.*, 2020).

Furthermore, more novel steel-making technologies with considerable reductions in emissions are being developed. In 2016, SSAB, LKAB, and Vattenfall formed Hydrogen Breakthrough Ironmaking

Technology (HYBRIT) with the goal of creating a technology for fossil-free iron and steelmaking, that is, decarbonizing virgin steel manufacturing utilising hydrogen-based processes. The three businesses have presented the world's first hydrogen-reduced sponge iron, which was manufactured at HYBRIT's pilot plant in Luleå (Pei *et al.*, 2020). They are currently working to bring fossil-free steel to market by 2026, and to demonstrate the technique on a large scale. SSAB now has the potential to reduce Sweden's total carbon dioxide emissions by around 10% and Finland's by approximately 7% using HYBRIT technology. Furthermore, SSAB considers the distribution of the produced fossil-free steel to be an important step toward a completely fossil-free supply chain for iron and steelmaking.

Martin Lindqvist, President and CEO of SSAB said, "The first fossil-free steel in the world …..represents proof that it's possible to make the transition and significantly reduce the global carbon footprint of the steel industry…..This is a crucial milestone and an important step towards creating a completely fossil-free value chain from mine to finished steel and it shows that it's possible" (SSAB 2021, para. 3).

The timber factor

Society has been built around the influx of cleared areas and lumber, creating an endless need for these materials; however, these needs should not outweigh the health of the environment. Since 1990, 178 million hectares of forest have been lost around the world. The rate of deforestation has slowed over the last three decades, but experts believe it is not fast enough, given the critical role forests play in reducing global warming (Dangel, 2016). Deforestation can cause a slew of environmental and economic issues in the country, as well as expedite climate change and biodiversity loss. Several reforestation efforts have cropped up in recent years, recognising the potential benefits of green living in the fight against climate change.

The World Economic Forum launched a campaign in 2020 to plant one trillion trees to absorb carbon. While planting trees might help cancel out the last 10 years of CO2 emissions, it cannot solve the climate crisis on its own (Seymour, 2020). Furthermore, some researchers believe (Coleman *et al.*, 2021; Lewis *et al.*, 2019) that large tree-planting initiatives often fail, while others argue that large tree planting initiatives can be done successfully (Brancalion and Holl, 2020; Keane *et al.*, 2016; Morecroft *et al.*, 2019).

Volunteers in Turkey planted 11 million trees in one northern city on November 11, 2019, as part of a government-backed effort dubbed 'Breath for the Future'. The tree-planting campaign set the Guinness World Record for the most saplings planted in one hour in a single location: 303,150.

However, less than three months later, up to 90 percent of the saplings were dead. The trees were planted at the wrong time and there was not enough rainfall to support the saplings (Lewis *et al.*, 2019). In another study carried out by (Coleman *et al.*, 2021) researchers examined long-term restoration efforts in northern India, a country that has spent a lot of money on planting in the last 50 years. The authors found "no evidence" that planting provided significant climatic benefits or supported local residents' lives. According to Coleman et al. (2021), Fleischman et al. (2020), and Lewis et al. (2019), public debate has focused on the potential benefits of tree planting while downplaying the risks and limitations that have been widely documented by social and ecological studies. Fleischman et al. (2020) suggest that in order for natural climate solutions to work while economies decarbonize, governments must identify and avoid the costs, risks, and harm that poorly designed and hurriedly implemented tree plantings impose on ecosystems and people.

On the other hand, some large tree planting schemes have had success. For example, the Dutch 'Meer Bomem Nu' scheme collects young trees and shrubs from areas where they are not wanted and gives them away to civilians and farmers to replant. As of 2021, the scheme had successfully transplanted 250,000 trees into over 800 fields and gardens (World Economic Forum, 2021). In fact, a study led by Professor Tom Crowther Jean to determine the potential for tree planting in slowing down climate change, revealed that forest restoration is not just one of the viable climate change solutions, it is overwhelmingly the top one (Bastin *et al.*, 2019). In fact, what was more startling was the magnitude of its potential influence; the study discovered that forest restoration was far more powerful than any of the other climate change remedies presented. Furthermore, Ethiopia, one of the countries spearheading the battle against climate change launched a vast tree-planting initiative that is helping to reverse decades of deforestation, drought, and land degradation (Bastin *et al.*, 2019). Having pledged to restore 15 million hectares of forests and landscapes by 2030; in 2019, the country highlighted its progress by planting a record 350 million trees in a single day (Forest News, 2020). It was pointed out, however, that the task is more complicated than just planting seeds wherever there is soil: success hinges on selecting the correct tree for the proper location and purpose. In addition, conserving the world's soil, biodiversity, and carbon sinks requires a well-thought-out tree-planting strategy that engages local populations. Fleischman et al. (2020) advocate the creation of a people-centred climate strategy that promotes social, economic, and political conditions that are compatible with the preservation of Earth's terrestrial ecological diversity.

Planting trees in the ground is only the beginning; data on tree growth and how much carbon they store, as well as other types of benefits they bring to people and the environment, must be tracked with globally consistent datasets (Forest News, 2020). Since not all trees grow to maturity, tracking tree growth may help organisations to understand progress on their pledges, encourage people to replicate successful projects and tweak struggling ones and inspire funders to continue investing where they can see past progress.

2.4.1.1 Current remedial efforts

Technology aided reforestation initiatives

Several 'forest tech' initiatives and being developed, each offering different approaches and technological tools to combat climate change. One of these is GoChain, a tech start-up that has developed a Blockchain Tree Registry and Traceability System for Conservation (GoChain, 2019). The novel two-pronged technological and microfinance approach to expedite worldwide forest conservation, restoration, and reforestation operations. The blockchain-based track and trace solution is designed to be a worldwide tree registry, authentication, and traceability system. To ensure transparent supply chains and auditability, time and geostamping of planted trees can be cryptographically recorded on an immutable public ledger. Every transactional change of custody from the forest tract along the value chain can be traced. Also, Samsung announced that it will collaborate with Veritree, a blockchain-based system that will allow it to track the progress of each tree planted on its latest sustainability project, which will see the company plant 2 million mangrove trees in Madagascar by the end of the first quarter of 2022 (Samsung Newsroom, 2021). As a result, instead of depending on auditors to fly over project locations, tree planters may provide planting reports using their phones.

Another example of current innovative approaches includes Peru Rainforest Foundation US, local community organisations, and tech partner Regen Network in Peru are using blockchain technology to track, verify, and reward communities for saving and regenerating forests. The Ticuna community agreed to jointly save 1,000 hectares of Amazon rainforest while also undertaking an ambitious replanting effort on degraded land. The community is reimbursed for achieving net zero deforestation through Regen Network's blockchain-based payment system. Satellite data and community forest monitors offer quarterly reports on the trees planted and their progress. From 2018 to 2020, the community reduced yearly deforestation rates from roughly 10% to zero and is now actively reforesting and sustaining existing forests in one of the most endangered sections of the Peruvian Amazon (Global Forest Resources, 2020).

Ethical certifications

Products, materials, and technology designated for use in any infrastructure or construction project play an important part in attaining the project's sustainability goals. The choice of construction materials is a critical aspect in achieving sustainable design and construction goals (Kubba, 2012). Oguntona et al. (2016) in their study also identified the specification, selection and usage of products and materials having negative environmental impacts as a significant barrier to the construction industry's transition to the global sustainability movement. Products and materials used to construct, operate and maintain infrastructures over their life-cycles contribute to their degrading impacts on the natural environment, thus impeding their sustainability goals. Oguntona and Aigbavboa (2019) affirm that certification, assessment, rating and labelling tools have become the most effective way of authenticating the sustainability attributes of construction products/materials whilst also serving as a means of regulating the green market, specification and use of materials with adverse impacts on the environment. Manufacturers benefit from certification by being able to positively distinguish their products from the competition in a way that purchasers will recognise and accept. Certification also gives performance benchmarks, a better understanding of supply chain impacts, and the ability to detect and solve inefficiencies and hotspots with regard to environmental impact; this led to the evolution of ecolabelling.

EcoLabelling

Eco labels are awarded to products and services meeting high environmental standards throughout their life cycle: from raw material extraction to production, distribution and disposal. There are a variety of assessments, rating, and labelling systems/tools for assessing material and product sustainability. According to the International Organization for Standardization (ISO), the overall goal of these labels and declarations is to encourage the demand for and supply of those products and services that cause less environmental stress, thereby stimulating the potential for market-driven continuous environmental improvement, by communicating verifiable and accurate information on environmental aspects of products and services that is not misleading (ISO, 2000). Building owners increasingly want their constructions to be environmentally friendly and healthy for their residents. Architects and engineers can use sustainability certifications to help them choose materials that address the concerns of their clients. All certifications, however, are not created equal. The focus of the ecolabel requirements for items is usually on the stages where the product has the most environmental impact, which varies each product. Some labels use index scores or units of measurement to quantify pollution or energy consumption, while others claim compliance with a set of practises or minimal requirements for environmental sustainability or damage reduction. Overall, ecolabels aim to reduce the negative environmental impacts of primary production or resource extraction in a certain industry or commodity by enforcing a set of best practises codified in a sustainability standard. Ecolabels can be single-attribute, focusing on a specific product's lifecycle stage or a single environmental issue, like VOC emissions for example. They can also be multi-attribute, focusing on a product's complete lifespan and addressing a variety of environmental challenges ranging from energy use to chemical use to recycling, and more (United States Environmental Protection Agency, 2020). Their rapid spread over the previous three decades has resulted in a wide range of diverse sorts and forms. An often-applied classification is the one provided by the International Organisation of Standardisation (ISO). ISO 14020 standard (2000) classifies Environmental labels according to the three Groups:

1. Type I labels involves a third-party programme that issues a licence for the use of environmental labels on items based on a set of criteria and life cycle factors. These show a product's overall environmental preferability within a specific product category. These labels give rich environmental data. An example is the European Ecolabel whose award criteria are issued on the results of a LCA application under the supervision of the Ecolabel Committee
2. Type II labels are self-declared environmental claims made by manufacturers, importers, distributors, retailers, or anyone else likely to benefit from such a claim without independent third-party certification. For example the recyclability at end of life.
3. Type III labels refer to quantifiable product information that has been independently verified using current indices throughout its life cycle. EPD is a good example.

While ecolabelling schemes are usually voluntary in nature, ecolabels are important tools for checking and comprehending the many factors that influence the sustainability of materials and products. They could also assist in providing users with critical information about the material and product's composition, source, performance, and influence on the human and natural environment. Various environmental performance labels and declarations are currently in use or being considered around the world. Accreditors have different environmental requirements for green product certification, and some are less transparent than others (Gurzawska and Nl, 2019). The Ecolabel Index website, the global directory of ecolabels, lists 455 types of ecolabels being applied today, with 119 of them being listed under 'ecolabels on building products', each covering a different range of environmental criteria to demonstrate environmental excellence. Some are more widely known and used internationally while others were developed for use within specific countries.

Also, a Life Cycle Assessment (LCA) could be carried out on a product to identify the environmental impact of a product or organisation throughout the product's life cycle, accounting for its range of impacts from material extraction through to end-of-life disposal (Blengini and Shields, 2010). It will also consider the product's durability and the ease and cost of replacement. The manufacturer provides details on the factory and the production process. BRE Global examines this data and confirms it with a site audit. After that, it takes about ten weeks to complete the LCA modelling and generate the environmental profile. A client receives a certificate, a Certified Environmental Profile, a Green Guide rating if the product type is covered in the Guide, and a report of the assessment's findings after the profiling is completed. An Environmental Product Declaration (EPD) is sometimes referred to as the condensed version of an LCA report. Where an LCA report often contains private sensitive company details. An EPD contains a proper description of the product and can therefore be shared without worry.

An EPD is a third-party certified document that is formally registered to reveal a product's or service's environmental and human health impact. Despite the fact that EPDs can be created for any product, the construction industry has the most advanced EPD system. The EPD is created based on LCA calculations and it provides a framework for comparing products and services (Liebsch, 2019). It is typically offered by the manufacturer of the product and needs to be verified by an approved system operator before the document is then published. EPDs are usually valid for 5 years.

The tools and systems outlined previously in this section are crucial in allowing buyers to make informed choices in response to the global need for the adoption and implementation of sustainable construction practises and products. They are, however, at risk of being undercut by the growing number of businesses who use "green" claims as a marketing tactic. These assertions are becoming more unclear, if not downright dishonest (de Freitas Netto *et al.*, 2020). Concepts like "eco-friendliness", "green label", "green product", "green consumption", "green packaging", "reuse, reduce, recycle" and the likes are now commonly indiscriminately seen on products (Nguyen and Nguyen, 2020). This misleading, false, meaningless or unclear information can, however, have the opposite effect on the goals of ecolabels resulting in a loss of faith in environmental claims and potentially lead to an outright disregard for ecolabels (Mustow, 2006). This significant proliferation of construction materials and products with false claims on their sustainability attributes is termed 'greenwashing' and it is considered to be a major challenge in the eco-products market today

(BREEAM, 2018; de Freitas Netto *et al.*, 2020; Delmas and Burbano, 2011; Gräuler and Teuteberg, 2014).

Greenwashing

According to Delmas and Burbano (2011), greenwashing is the convergence of shoddy environmental capacity and affirmative disclosure about the environmental performance of a product. Many unethical actors make fraudulent environmental claims and designate things as eco-friendly when they are not. The goal is to flood the green market with bogus eco-friendly materials and products in order to take advantage of the expanding industry and demand for materials with little or no environmental impact (Oguntona and Aigbavboa, 2019).

Several building products and materials have claimed to be green to varying degrees without reference to any standard, thereby contradicting one of the fundamental reasons for the formation of rating systems, standards, and recommendations for products and materials. There have also been instances where counterfeit green labels have been placed on things to confuse eco-conscious shoppers (Chen and Chang, 2013; de Freitas Netto et al., 2020). Greenwashing has also been aided by the lack of specific standards in the field of green marketing, as each country has its own marketing and advertising laws that govern environmental marketing (Delmas and Burbano, 2011). According to a TerraChoice (2010) survey, nearly 40% of building and construction items are guilty of the "Sin of the Hidden Trade-off." While the term 'greenwashing' has been largely used to denote false claims in the area of adherence to environmental ethical standards in production, findings from investigations have revealed that several organisations also falsely claim adherence to social ethical standards in their production and supply network (Gräuler and Teuteberg, 2014; Hamann and Kapelus, 2004; Prentice, 2019; Shapiro *et al.*, 2020).

2.4.2 *Social ethics*

To evaluate the environmental performance of construction materials, a variety of approaches have been developed. However, the social and economic concerns linked with various construction materials and products, which are usually imported from a variety of nations, have not received as much attention as it deserves. Whereas, construction product extraction and manufacturing can have both positive and negative social consequences (Mustow, 2006). Slavery, child labour, forced labour, and human trafficking are all concerns that corporations are becoming concerned about in their supply chains in recent years. All of these acts are referred to as "modern slavery" in this study. Forced labour (involuntary work under threat of punishment); bonded labour (work to repay a debt while losing control over conditions and repayments); trafficking (people moving for exploitation); and child slavery (exploitation of children for the benefit of others) are all examples of modern slavery (Boersma and Nolan, 2020). Stronger Together (2019) reported that in 2016, around 40.3 million people were victims of modern slavery globally and 61.7% of these people were in forced labour in sectors such as construction, manufacturing, mining, utilities, agriculture, forestry, fishing and domestic work. The estimates of modern slavery victims for every region is shown in Figure 2.2.

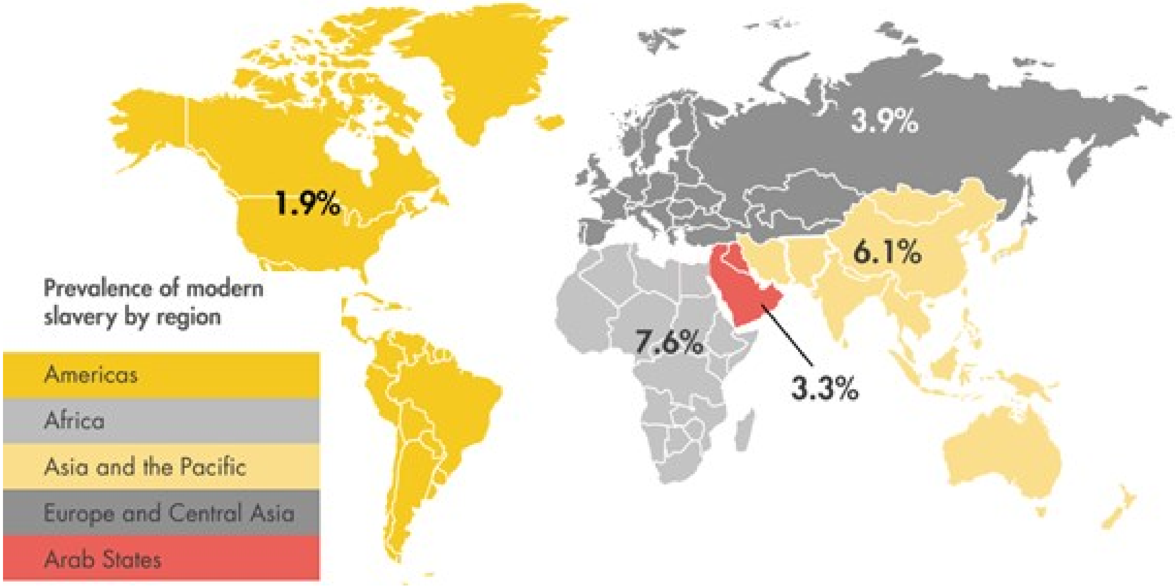

Figure 2.2 Estimates of modern slavery victims for every region. (Source: Alliance (2017))

Furthermore, according to a 2013 investigation by 'Free the Slaves', 866 of the 931 people interviewed in three mining towns were found to be slaves (Boersma and Nolan, 2020). It must also be noted that modern slavery is a threat not just to the labour force of the construction industry, but also to the supply chains for its raw materials and finished goods (CIOB, 2010). According to a 2017 UN Global Compact study on the SDG human rights target, social ethics was the most difficult area for large firms to execute the Ten Principles, with 57 percent seeing this as a challenge (UN Global Compact, 2010). As a result there is still much to be done. With a worker dying every 15 seconds from a work-related accident or disease. It further revealed that 780 million women and men who are working are not earning enough to lift themselves and their families out of poverty and an estimated 200 million children worldwide are engaged in child labour (United Nations Global Compact, 2017).

Although the full extent of modern slavery and human trafficking in the construction business is unknown, a picture is forming that is unsettling to say the least (CIOB, 2018a). Every year, $150 billion is generated by modern slavery around the world, and data suggests that it affects practically every industry. The construction, manufacturing, mining, agriculture, and utility industries, which account for nearly half of the world's forced labour population generate more than 20% of total revenues (US$34 billion) (CIPS, 2013; Werdmüller, 2016). According to a 2018 CIOB report, construction is second only to the sex industry in the EU as the sector most vulnerable to exploitation (CIOB, 2018a). Furthermore, in 2016, an estimated 16 million people were forced to work in the private sector around the world. Construction is second only to domestic employment in terms of the prevalence of this abuse, with 18% and 24%, respectively (CIOB, 2018b). Labour exploitation is a problem that exists in several countries, regardless of their degree of development. Figure 2.3 shows the top countries for labour exploitation in the world.

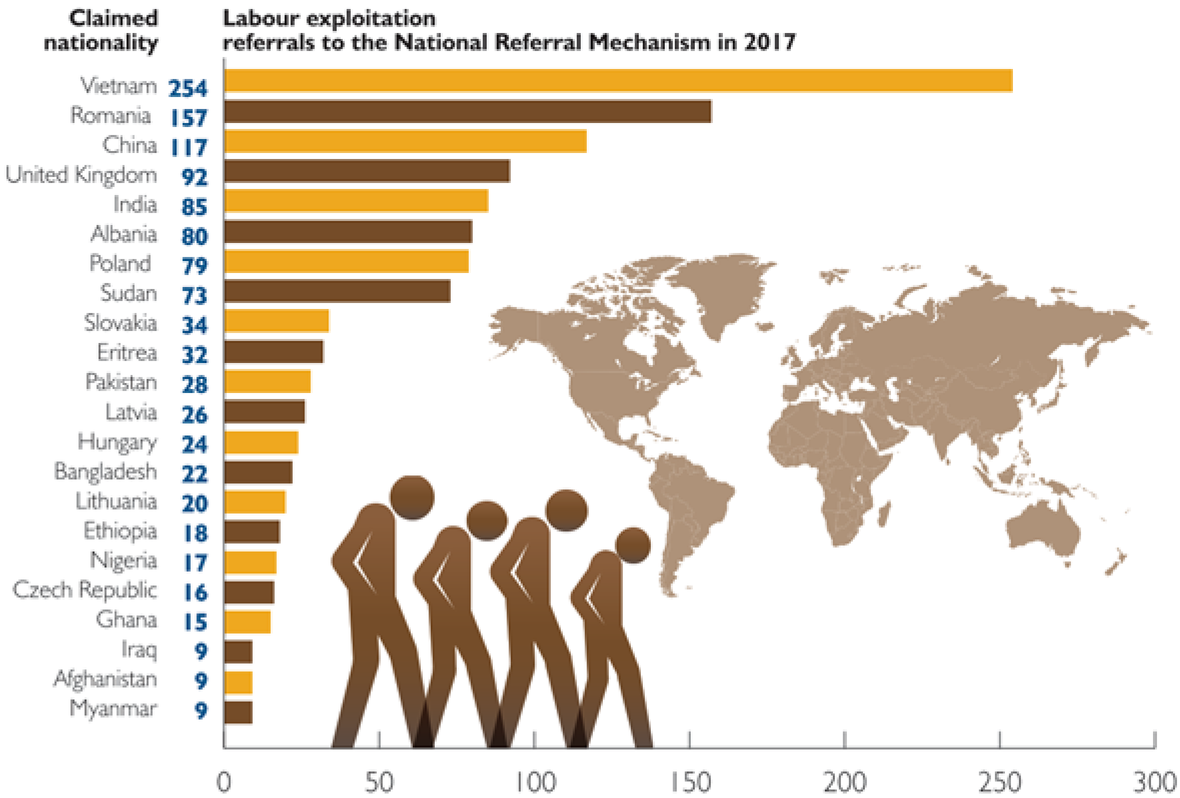

Figure 2.3 The top countries for labour exploitation in the world. (Source: CIOB (2018))

At or below layers four and five of the supply chain, construction projects are regarded to be the most vulnerable to forced labour infiltration. This is challenging because major contractors typically have little visibility below tiers one and two (CIOB, 2018a). To illustrate, the United States Department of Labour's 2014 report on goods believed to be linked to modern slavery contained 136 goods from 74 countries (The Bureau of International Labor Affairs, 2014). Timber from Brazil, Peru, North Korea and

Cambodia were on the list. Again, Verité (2015) classified bricks as one of 43 of the most significant primary commodities worldwide in 2015, and highlighted that 21 nations, including China and India, who are two of the top three exporters of bricks worldwide, use forced labour or child labour in the production of bricks. Other building materials reported to have been linked to modern slavery issues are listed on the map below. Figure 2.4 illustrates some examples of construction materials reported to have been linked to modern slavery issues.

Figure 2.4 A map showing some examples of construction materials reported to have been linked to modern slavery issues. (Source: Verité (2015))

According to a CIPS survey, 58 percent of UK construction procurement managers were "very" or "fairly" convinced that modern slavery was not present in their supply chains. However, given the risks of construction, this is exceedingly unlikely (CIPS, 2013). Even worse, a concerning 37% of procurement managers stated that they had not read the government's modern slavery guidance. Brian Iselin, in his critique of the state of ethics in most supply chains in an interview with Reuters Events, he argues that “everyone is presently buying slave-made products, but they do not know. No one can tell” (Scott, 2019). Shifting the narrative to one of acceptance rather than denial of risks would encourage new ideas and debates. In August 2017, the Chartered Institute of Procurement and Supply (CIPS) released the results of a pan-industry study of procurement managers. In it, 10% of respondents said they had discovered evidence of modern slavery in their companies or suppliers. While some companies are taking aggressive measures, others are denying that the industry has a problem. "In the construction industry, there are a lot of good people. There would be a bigger outcry if they really knew how some people were being treated by ruthless gangmasters," says Peter Jacobs, past president of the CIOB (CIOB, 2018b).

In the mining industry, for example, the Democratic Republic of the Congo accounts for over two-thirds of all cobalt mined worldwide. The central African country's recent history of human rights violations, including slave labour, is well-known (Boersma and Nolan, 2020). In the case of cobalt, the supply chain can be made up of several middlemen who buy and combine cobalt from a variety of sources. This makes it nearly impossible for a cobalt customer, such as a battery manufacturer, to track the metal's origins. Some miners are fairly well compensated and work in relatively safe settings. However, roughly 110,000 to 150,000 people in small "artisanal" mines dig up about a fifth of the cobalt. Those who engage in this unregulated industry frequently earn pitiful wages and operate in hazardous conditions. Working in such conditions defies even the most basic safety procedures. Today, the pull towards green transportation has driven the need for the production of more electric cars at a global scale; however, as sales of electric cars swells demand for cobalt and the conditions of the cobalt miners are worsening. It is not only cobalt; everything from copper to cacao is affected in the same way. It is difficult to tell how or where products are created.

Also, when selecting building materials and goods, health considerations are critical. Unfortunately, this aspect can be overlooked. In the haste to meet energy efficiency goals or cut costs, tenant health can sometimes be jeopardised. This can lead to the use of low-quality, even poisonous materials, putting lives at risk, such as those of tenants of multi-unit housing complexes or individual residences. This scenario, in which material choices have an impact on people's lives, was tragically played out in the 2016 Grenfell Tower fire in London, which killed 72 people (Kassem *et al.*, 2018).

Furthermore, rising costs may lead to clients imposing even more stringent discounts on their supplier chains, weakening due diligence processes for sourcing products. Also, because it is interwoven with criminality and disguised in fragmented supply chains, modern slavery is difficult to combat. Hence, organisations will not be able to end slavery by acting alone; they must band together and begin making difficult decisions (Eastwood Sam *et al.*, 2020). To address these issues, the industry must think and act as a whole (Baldwin, A., and Bordolli, 2014), with a focus on cooperation and the development of working partnerships that benefit all stakeholders (Khalfan *et al.*, 2007). As a result, numerous initiatives are needed to assist industry in sharing intelligence and data more widely, both at a regional and national level.

2.4.2.1 Current Remedial Efforts

Legislation, policies and support for human rights

As Mehra and Dale (2020) state, the issue is not only technical, but also political, in that it includes breaking and reorganising the power relations at the centre of labour exploitation. To put it another way, labour exploitation necessitates not only a technical solution, but also a democratic solution capable of empowering workers' human dignity and agency, as well as enacting workers' human rights and equality. Governments, NGOs and consumers are becoming more aware of these issues and are encouraging, if not requiring, that firms develop ethical sourcing programmes. If it is discovered that a company is procuring from suppliers who use exploitative labour, the company's reputation will suffer. Despite the fact that the construction sector is frequently averse to new regulations, the CIPS study found that 61 percent of construction procurement professionals support tougher laws, with 69 percent feeling that it would help prevent modern slavery (CIPS, 2013). Such influential legislation includes the 2010 California Transparency in Supply Chains Act, which compels large corporations to reveal their risk management strategies for non-financial issues such as the environment, human rights, employee welfare, corruption, and bribery. In fact, France's Duty of Vigilance Law mandates that big corporations publish the efforts they are taking to eliminate human rights and environmental abuses from their supply chains. In addition, in 2016, the Welsh Government released its Code of Practice for Ethical Employment in Supply Chains. This voluntary code encompasses all public entities in the country's supplier chains, accounting for £6 billion in procurement and potentially affecting millions of workers. Aspects of the code are likely to be integrated into tender documents as well as construction and operations contracts (CIOB, 2018b). Authorities are allowed to add appropriate factors in their technical requirements under European procurement laws. They cannot mandate products to carry a specific ethical trade label or certification, but they can indicate the general standards that the products must satisfy as long as these standards are related to the products' qualities, performance, or manufacturing processes. Contracting authorities may specify which ethical trade labels/certifications they believe meet these requirements, but they must always allow for additional verification methods.

The UK Modern Slavery Act 2015 is part of a larger global mosaic of human rights legislation and targets that are coming into effect. Companies having a revenue of £36 million or more are expected to publish an annual statement on the efforts they have taken to address modern slavery in their supply chains under the Modern Slavery Act (MSA) 2015. Compliance, on the other hand, has been sloppy. According to a CIOB 2018 survey, approximately half of businesses missed their annual deadline for issuing modern slavery declarations. Furthermore, many of the submitted reports do not even meet the basic requirements. Even worse, several companies published nearly identical reports that have been watered down. Many organisations, according to anecdotal information, see the preparation of modern slavery statements as a separate activity, apart from company operations, rather than a reflection of relevant activities carried out throughout the year. Also, many large contractors are using the resources developed by the Supply Chain Sustainability School and others have also signed up for the Stronger Together Toolkit. However, according to the CIPS survey, only a quarter of construction companies have introduced procurement policies complying with the Modern Slavery Act (CIPS, 2013). Figure 2.5 shows how companies have responded to the Modern Slavery Act.

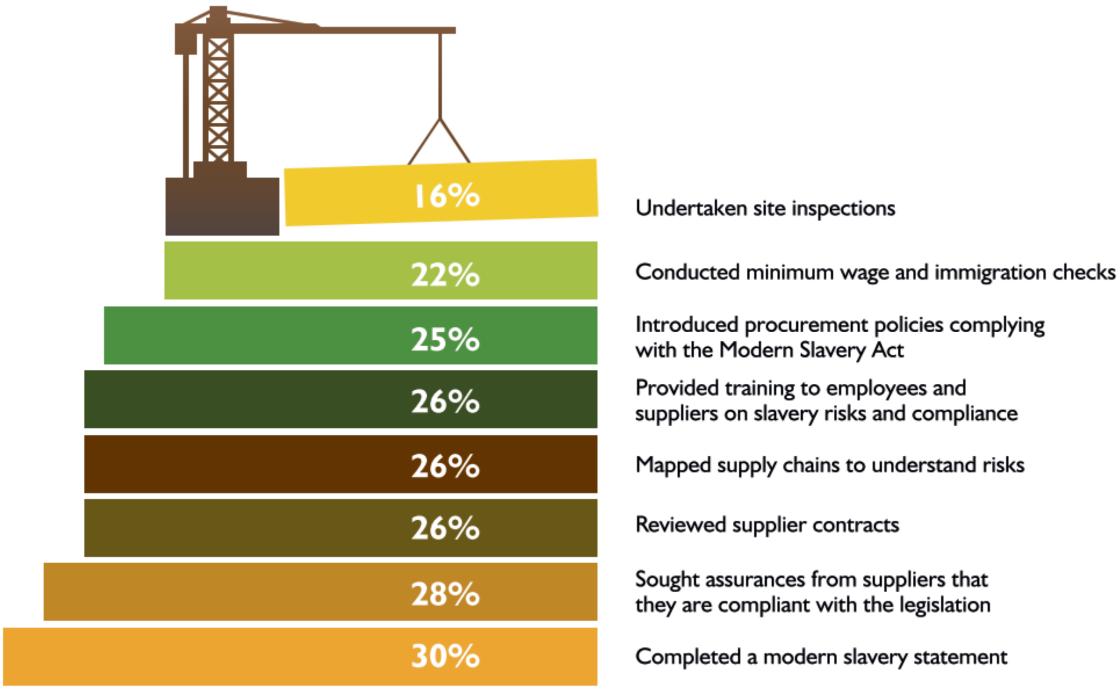

Figure 2.5 How companies have responded to the Modern Slavery Act. (Source: CIPS (2013))

Auditing

While auditing is beneficial for benchmarking and raising standards in general, research in the UK construction and food processing industries has discovered that auditing is poor at discovering modern slavery. In fact, there have been reports of modern slavery being discovered in organisations that have passed audits (CIOB, 2010). Pre-arranged audits provide unethical companies with enough notice to give their employees the day off. In construction, where the workforce is mobile and can swiftly cycle through a project, the challenge of tracking workers is increased. On the same site, auditors are unlikely to meet the same persons repeatedly (CIOB, 2018b).

Ethical trading and sourcing initiatives

The Ethical Trading Initiative (ETI) collaborates with businesses and labour unions to enhance worker rights in supply chains. It cannot guarantee that a company is ethical, but ETI members have pledged to strengthening worker rights in their supply chains and will develop a strategy to do so. The FAIRTRADE mark, for example, is given to products that meet a fair trade criterion. Its goal is to help disadvantaged farmers and workers in developing countries receive a better bargain. The fairtrade standards are determined through a process of research and interaction with important fairtrade actors, including producers, traders, non-governmental organisations, academic institutions, and labelling organisations like the Fairtrade Foundation. However, as previously mentioned, many of these schemes may be subject to greenwashing, as other companies may make their own "fair trade" claims without the independent inspection of the Fairtrade Certification Mark (UNISON, 2013).

Another example is the Supplier Ethical Data Exchange (Sedex), a membership-based, non-profit organisation that works with buyers and suppliers to develop responsible and ethical business practises in global supply chains (Sedex, 2019). A group of retailers created Sedex in 2001 with the goal of bringing social audit standards and monitoring methods closer together. Sedex is a collaborative platform that manages and shares data on responsible sourcing in supply chains. It provides members with access to a secure online database that allows them to keep, exchange, and report data in four major areas: labour standards, health and safety, the environment, and business ethics. Other similar schemes include the ethical procurement for health initiative launched in 2011.

Development of standards

Several ethical standards have been developed to assist organisations in integrating and measuring their performance in areas important to social accountability in the workplace, such as modern slavery (including child labour and forced labour), health and safety, freedom of association and right to collective bargaining, discrimination, disciplinary practises, working hours, remuneration, management system, etc. Some of these standards are discussed in this section.

ISO Standards

ISO standards are developed by groups of experts within technical committees which are made up of representatives from industry, non-governmental organisations, governments and other stakeholders who are put forward by ISO's members (ISO, 2000). Of the more than 21700 International Standards and related documents, ISO has over 1100 related to buildings and construction, with many more in development (ISO, 2017). Being able to count on reliable, quality materials are essential for the construction of safe and robust buildings. ISO has more than 100 standards related to the raw materials used in construction, such as concrete, cement, timber and glass. Three of the most commonly used and well known ISO standards in construction are ISO 9001 (quality in/of business operations), ISO 45001 (occupational health and safety) and ISO 14001 (environmental management). Although ISO does not perform certification or issue certificates. However, ISO's Committee on Conformity Assessment (CASCO) has developed a number of standards related to the certification process that are used by external certification bodies to perform certification. As a result, a company or organisation as a whole cannot be certified by ISO but can be certified by competent accredited certification bodies.

According ISO, the ISO 45001 developed by an ISO committee of occupational health and safety experts has the potential to save almost three million lives each year (ISO, 2017). ISO 45001 builds on the success of previous international standards in this field, including as OHSAS 18001, the ILO-OSH Guidelines, several state standards, and the ILO's international labour standards and conventions. Although certification to ISO 45001 is not required by the standard, it can be a useful tool to demonstrate that organisations respect social ethics when they meet its criteria.

SA8000 Standard

The SA8000 Standard, developed by SAI (Social Accountability International) in 1997 as the first genuine social certification, is the most widely used social certification programme in the world. The SA8000 Standard and Certification System provides a framework for corporations of all types, in any industry, and in any country to conduct business in a fair and decent manner for workers while also demonstrating their commitment to the highest social standards. The concepts of international human rights norms, as articulated in International Labour Organization conventions, the United Nations Convention on the Rights of the Child, and the Universal Declaration of Human Rights, are the foundation of SA8000 (SAI, no date). SA8000 promotes continuous development and takes a management-systems perspective to social performance. It assesses companies' performance in key areas of social accountability in the workplace, including child labour, forced or compulsory labour, health and safety, freedom of association and collective bargaining, discrimination, disciplinary practises, working hours, remuneration, and management system. Adopting SA 8000 certification requires a company to evaluate the social impact of its activities as well as the working conditions of its employees, partners, and suppliers. The certification can be used by any company, of any size, anywhere in the world. Facilities seeking certification must meet more than only the standard's requirements, according to the criteria. Prospective facilities must incorporate the standard into their management practises and demonstrate ongoing compliance.

BES 6001

The construction industry consumes a lot of natural resources, employs a lot of people, and has a significant impact on global sustainability. Recognizing the importance of this issue, BRE Global developed the BES 6001 Framework Standard for the Responsible Sourcing of Construction Products, as well as an associated independent third-party certification scheme, which provides an effective means of objectively assessing and comparing the responsible sourcing characteristics of all construction products and materials (BREEAM, no date). BES 6001 was created to allow construction product producers to ensure and then prove that their goods were produced with sustainably sourced constituent resources. The standard lays up a framework for the organisational governance, supply chain management and environmental and social aspects that must be addressed in order to ensure the responsible sourcing of construction products.

2.4.3 *Business Ethics*

The context of business is understood to include all systems (inter or intra) involved in the exchange of goods and services, which is relevant also to the supplier–customer relationship in many of the transactions that take place to create and maintain the built environment. Sustaining a good reputation and being transparent and honest with the general public, as well as maintaining profit for shareholders, are all important considerations. Businesses are under public and political pressure to achieve climate change targets, and construction in particular is under pressure to “clean up its act” (Fewings, 2008). While there will undoubtedly be debates on what exactly constitutes "ethical" corporate behaviour and corruption, business ethics is regarded in this study as the study of business situations, activities, and decisions where issues of morally right and wrong are addressed (Andrew *et al.*, 2019).

Although it is frequently stated that the term “business ethics” is an oxymoron (Prasad and Agarwal

2015), implying that there are no, or cannot be, ethics in business: that business is intrinsically unethical, or that it is, at best, amoral (i.e. outside of our normal moral considerations). In fact, Andrew *et al (*2019) writes that Carr (1968) suggests that the "game" of business is not subject to the same moral standards as the rest of society, but should be regarded as analogous to a game of poker, where deception and lying are perfectly permissible. Nevertheless, Hamington (2009), Koehn (1997) and Radoilska (2008) argue that it would be incorrect to infer that the subject of business ethics is naive or idealistic in any sense, stating that there are compelling reasons to believe that business ethics can be achieved and as a subject is not an oxymoron.

Also, there is no consistent definition of what corruption means. For instance, Le *et al (*2014) identified twelve forms of corruption in the construction industry: bribery, fraud, collusion, bid rigging, embezzlement, kickback, conflict of interest, dishonesty and unfair conduct, extortion, negligence, front companies, and nepotism; thereby indicating fraud to be a subset of corruption (Sohail and Cavill, 2006; Vian, 2020). The Royal United Services Institute (RUSI) points out that there is no offence of "corruption" in English criminal law; instead, there is a range of criminal offences (RUSI, 2019). Hence, some view "corruption" as synonymous with "fraud" and "bribery" (Aggarwal and Floridi, 2019; Fourie and Malan, 2021; The Royal United Services Institute, 2019), indicating potential overlaps between them, some believe a distinction may be drawn between them (Anthony Bowen *et al.*, 2012; EBRD, 2007; Remo, 2018) while others believe corruption to be the umbrella term for almost all unethical activities (De Jong *et al.*, 2009; Global Infrastructure Anti-Corruption Centre, 2020; Le *et al.*, 2014; Locatelli *et al.*, 2017; Sohail and Cavill, 2006; Vian, 2020).

Further studies identify bribery and fraud as the most common forms of corruption in construction (Bowen *et al.*, 2012; Klitgaard, 1997; Nye, 1967; OECD, 2015; Sohail and Cavill, 2006; Transparency International, 2008). This misconduct primarily takes the forms of misinformation (e.g., alteration of documents and deliberate intention to mislead and withhold information), deceit (e.g., making invoices and payment for materials without being received), and theft (e.g., materials and equipment) (Fourie and Malan, 2021; Yang, 2019). Deceit and misinformation are the most common forms of fraud, according to two questionnaire studies done in Australia and South Africa (Bowen *et al.*, 2007; Vee and Skitmore, 2003).

In this study, corruption is framed as any intentional departure from fundamental ethical standards and values in order to obtain undue advantage, a view also held by (Liang *et al.*, 2016; Moodley *et al.*, 2008; Zarkada-Fraser *et al.*, 2000). While simple and straightforward, this description encompasses the most, if not all, of corrupt behaviour displayed by one party against another. The degree of trustworthiness and integrity with which firms conduct business is frequently used to gauge business ethics. For severe breaches of ethics and compliance on matters ranging from bribery and collusion to modern slavery, several of the world's leading construction contractors have faced multi-million dollar fines (Anthony Bowen *et al.*, 2012; Arnold *et al.*, 2012; Sohail and Cavill, 2006).

2.4.3.1 Corruption within construction materials and products supply chain

Transparency International (2006, 2008, 2011) revealed that the construction industry ranks amidst the most corrupt industries in the world, primarily attributable to the fragmented nature of the construction industry (involving clients, designers, contractors, consultants, and suppliers), which makes it difficult to track payment and information (Kenny 2009), and due to the tremendous expansion of the global construction sector after the turn of the century. The complex structure of the supply chain, with several firms competing for high-value contracts, provides an environment conducive to corruption. As a result, unethical activities in the construction industry takes many forms, including bribery to secure planning approval, budget overstating, counterfeiting of construction materials and products, payment demand abuse, purchasing from unscrupulous players to save costs, etc. Corrupt contractors can swindle on projects to recoup bribe costs and inflate profits by overcharging for products and services, charging for products and services that are never delivered, and replacing less expensive and lower quality materials for those specified in the contract. Furthermore, the bottom tiers of multinational corporations' extensive supply chains are frequently hidden from view. On many construction sites, labour checks are routinely delegated to subcontractors who are under-resourced and less likely to have experience recognising forged paperwork (CIOB, 2018a). Ofori (2019) asserts that corruption is a serious concern that has a considerable impact on fundamental management activities in construction projects, particularly in underdeveloped nations with a weak legal and administrative infrastructure.

Corruption in the construction business is a problem that exists in several countries, regardless of their degree of development. Bribing government officials is a serious corruption risk for projects in China and Turkey (Shan *et al.*, 2017). A four-year investigation into cover pricing in the UK was conducted and it concluded with 103 construction businesses being found guilty of cover pricing and fined a total of £ 129 million (CIOB, 2010) According to the results of a study conducted by the Chartered Institute of Building in 2013, 49% of respondents felt corruption is frequent in the UK construction industry, a 2% decrease from the 2006 survey (CIOB, 2013). Due to the involvement of a considerable number of organisation, the diverse ethical standards, and the numerous points of purchase and transportation of materials and products, the possibility for corruption is heightened, particularly in global operations and supply chain arrangements (SDGs, 2018). Companies are struggling to have a comprehensive picture of their supply networks, both internally and externally, exposing them to a variety of risks, including fraud, code of conduct violations, and other key supply chain challenges. Improved openness and transparency of decision-making processes from procurement to work performance by all parties involved in a project, including clients, consultants, contractors, material and product suppliers and regulators is a major approach to addressing this (De Jong *et al.*, 2009). Other notable forms of corrupt practice in construction industry material and product supply chains further discussed in this study include fraud and counterfeiting (Kjesbu *et al.*, 2017; Remo, 2018; Sohail and Cavill, 2006).

2.4.3.2 Fraud and counterfeiting

This study adapts the definition provided by European Bank for Reconstruction and Development (EBRD) where fraudulent practice is defined as any action or omission, including misrepresentation, that knowingly or recklessly misleads, or attempts to mislead, a party to obtain a financial benefit or to avoid an obligation (EBRD, 2007). Anthony Bowen et al. (2012), Remo (2018) and Vee and Skitmore (2003) argue that using counterfeit substandard materials in a project is a form of fraud, and the most dangerous kind for the construction and transportation industry (Corrugated Metals Inc, 2013; Engebø *et al.*, 2015; Im *et al.*, 2018; Kjesbu *et al.*, 2017; MinchinJr. *et al.*, 2016).

A counterfeit item is a suspect item that is a copy or substitute without legal right or authority to make said copy or one whose materials, performance, or characteristics are knowingly misrepresented by the vendor, supplier, distributor, or manufacturer and with the intent to mislead or defraud by passing as original or genuine (Vielmetti 2016). In construction, counterfeiting can take three forms, according to (Im et al., 2018): counterfeit materials, counterfeit equipment, and counterfeit documentation. In this study, the term 'counterfeit' has been expanded to include fraudulent or substandard products and documents. Counterfeiting is one of the world's fastest-growing economic crimes, accounting for 5–7% of global trade and worth an estimated $600 billion every year (Stevenson and Busby 2015) and the industry continues to grow (Kjesbu *et al.*, 2017).

Certain regions are significantly more prone to produce counterfeit items, with China accounting for the production of between 70 to 87 percent of all counterfeit goods in circulation in the United States and the United Kingdom. Bulk of the materials and products utilised in the construction sector in the United States and Canada are among them, and they range from little items like bolts and fasteners to huge equipment like scaffolds and cranes (Corrugated Metals Inc, 2013). Furthermore, cultural variations compound the counterfeiting phenomenon; for example, counterfeiters in China and other countries frequently assume that their cheap items are "good enough" to accomplish the job (Corrugated Metals Inc, 2013). The Chinese philosophy of "close enough is good enough" has led to a lack of awareness and legal regulations to prevent counterfeiting adequately.

Many earlier studies on counterfeiting concentrated on the fashion or pharmaceutical industries. While there is a lot of research on counterfeiting in general, there is not much on counterfeiting in the construction industry, despite the fact that the use of counterfeit materials in construction can cause catastrophic injuries (Corrugated Metals Inc, 2013; Im et al., 2018). Still, as compared to other counterfeit products such as fashion or pharmaceuticals, one of the most significant differences in manufacturing is that the labels are frequently unnoticeable as the final product may contain multiple counterfeit products and brands, so no single label appears (Minchin *et al.*, 2011).

Buildings are made up of a variety of materials and products, all of which are susceptible to counterfeit production. Due to the nature of building, construction materials and products require additional attention and monitoring. When carrying a counterfeit Gucci bag, no one's life is jeopardised, but the construction sector is a different storey. The scale of the damage is much greater, and because of the potentially fatal consequences of using counterfeit materials in building projects, material quality assurance is critical. The structural integrity of a structure is virtually entirely responsible for the safety of its occupants. There is a substantial risk of catastrophic failure of a structure if any of its structural components are counterfeit or built from poor materials. If the building is occupied at the time of a catastrophic failure, terrible repercussions may follow. Buildings, roads, bridges, and public transportation systems are all vulnerable to counterfeit building materials (Im et al., 2018). For example, the worst-ever industrial event in the clothing sector, the 2013 catastrophic garment factory collapse in Dhaka, Bangladesh, which killed over 1,100 people and injured 2,600 more, was partly blamed on "extremely poor quality" construction materials (Corrugated Metals Inc, 2013).

What materials or products can be counterfeited are nearly limitless (Vielmetti 2016). In 2015, Engebø et al. (2015) discovered that a counterfeit manufacturer created 1500ton Terex boom cranes and sold them on the secondary market. Chinese-made drywall is one of the infamous counterfeit construction materials; it contains excessive amounts of sulphur, which causes corrosion in piping and electrical units in walls. However, the inferior form of drywall is used so widely that it is estimated that counterfeit drywall has infiltrated up to 50,000 homes (Im et al., 2018). Contractors appeared to have specified the appropriate supplies before later swapping counterfeit products to increase profit margins in some circumstances (Shan *et al.*, 2017). Regulatory officials argue that a disregard mentality and the drive to minimise material costs are reasons why counterfeit material is so popular in some developing African countries where building collapses are a recurring problem.

The harm caused by counterfeiting is not confined to monetary values; it frequently results in damages, loss of human lives, and its manufacturing process has serious environmental consequences. Nothing compares to the devastation caused by a catastrophic building failure. Not only is disaster and death a possibility; there have been incidents that demonstrate the terrible proof of how serious the issue of counterfeit construction materials is. Another disaster occurred in North Gyeongsang Province, Korea, in February 2014. More than twice as much snow fell as normal, causing the Mauna Resort Gymnasium to collapse. Due to the faulty building of a gymnasium and substandard materials, ten people died and 204 were injured (Jeong 2015); the police investigation determined that one of the reasons was the use of Chinese counterfeit steel. The Shershah Bridge in Pakistan, which spans the Karachi Northern Bypass, collapsed 25 days after its opening in 2007, killing five people and injuring many more. Steel bars that were counterfeit were considered to be the source of the problem (Moss *et al.*, 2000).

Several researchers agree that concrete and steel are the most commonly counterfeited materials in construction (Corrugated Metals Inc, 2013; Im *et al.*, 2018; Kjesbu *et al.*, 2017; MinchinJr. *et al.*, 2016). An investigation found that fake coal ash was used to create concrete on a several-hundred-kilometre stretch of China's $12 billion high-speed railway. The counterfeit coal ash would cause the concrete to crack, jeopardising the rail's structural integrity and potentially resulting in calamity (Pang 2007). Similarly, in the United States, two distinct construction accidents killed two people in 1987 and 1998. Counterfeit bolts were suspected of failing in both situations. Two workmen were killed in 2007 when an imported counterfeit cement kiln ruptured while in operation in Canada. Two counterfeit stop-check valves were discovered at a nuclear power station in the United States in 2007, according to the Electric Power Research Institute.

Another form of fraud commonly reported is the falsification of specification stamps or documents of origin. In fact, this has been determined as the most prevalent type of counterfeiting in the construction industry (Minchin et al 2010). Due to a lack of transparency in the supply chain and the inability to verify the authenticity of products, well-meaning contractors and procurers may be duped, receiving counterfeit products purported to be genuine, after having paid the price for the original.

2.4.3.3 Current remedial efforts

Anti-corruption initiatives

Several industrial associations, non-governmental organisations, and international organisations have made significant efforts and issued several recommendations to combat corruption. The American Society of Civil Engineers (ASCE) advocated for a "zero tolerance" policy in the construction business in the United States (Crist 2009). The Global Infrastructure Anti-Corruption Centre (GIACC), whose web resources provide free access to information, advice, and tools designed to help stakeholders understand, prevent, and identify corruption in the infrastructure, construction, and engineering sectors, teamed up with Transparency International (TI) to create the Project Anti-Corruption System (PACS). The PACS provides a set of anti-corruption initiatives, including the recruitment of an independent assessor, all participants' commitment, project information sharing, and the adoption of anti-corruption agreements (Global Infrastructure Anti-Corruption Centre, 2020). The World Economic Forum also launched the global Partnering Against Corruption Initiative, which gives businesses a platform to fight corruption (WEF 2013). In addition, the Infrastructure Transparency Initiative (CoST) is one of the leading global initiatives promoting data disclosure, validation, and interpretation from infrastructure projects. CoST collabourates with the government, private sector, and civil society to promote data disclosure, validation, and interpretation from infrastructure projects (CoST International, 2016). Despite significant efforts, the building industry in numerous countries around the world, particularly in emerging countries, appears to be facing an increasingly serious corruption crisis (Locatelli *et al.*, 2017).

Professional codes of conduct

Business ethics is usually policed by a national or international society to ensure that there is a standard of practice threshold below which there is an assumed ethical code. Corruption prevention mechanisms often start with rules that prohibit certain types of conduct. Rules include legal prohibitions against corruption, and criminal and civil penalties directed at both the public and private sectors (Williams-Elegbe, 2012), but also include codes of conduct and ethics for public officials. Many organisations already have Codes of Conduct that establish basic standards and criteria for procurement that go beyond cost. This is due to the business risk of unethical procurement practises.

Professional ethics are frequently cited in the built environment in the form of professional codes of practise. As a result, if a company's suppliers are proved to be implicated in corruption or bribery, legal action may be taken against them. Firms are increasingly facing criminal charges for their roles in fraud, corruption, and bribery, even when they occur offshore. Negative consequences might be costly, such as cleaning up pollution or paying out warranty claims as a result of choosing low-cost, low-quality suppliers. Organisations, understandably, desire to prevent these undesirable consequences.

Legislation

Governments all throughout the world are tightening their anti-corruption legislation. The United Nations Convention against Corruption, the Organization for Economic Cooperation and Development (OECD) Convention on Combating Bribery, Council of Europe Conventions on Corruption and the African Union Convention on Preventing and Combating Corruption are just a few examples. The most significant of these being the United Nations Convention which has been signed by 140 countries. Many countries had to amend their anti-corruption legislation in order to comply with the obligations imposed by these treaties. The OECD Convention mandated all OECD countries to ensure that their laws made it a crime for their corporations and citizens to pay a bribe overseas, which could be prosecuted in their home country. Previously, someone who paid a bribe in another country could be confident that they would never be prosecuted. Historically, it was possible the country where the bribe was paid had an inefficient prosecuting system and that the individual's home country had no jurisdiction over an act that occurred elsewhere, but that limitation has now been overcome. A person can now be prosecuted in both the nation where the bribe was paid and the country where they live. Many governments also operate a prosecution and debarment system, while this approach has its deterrence effects, it is also largely a reactive one. Moreover, a study conducted by The Chartered Institute of Building (2013), indicates, as it did in 2006, that the construction industry and UK Government are not doing enough to tackle corruption (CIOB, 2013).

Role of Technology

As supply chains get more complex, determining whether items are ethically sourced and produced becomes more difficult. Supply chain transparency is currently relatively low in many industries. For example, the largest retailers have visibility into only 0.1 percent to 0.8 percent of their value chain suppliers, and evidence of rogue operations and infiltrations around tiers four and five of the industry’s supply chains is emerging (CIOB, 2018a). As a result, proving that supply chains are free of modern slavery is becoming increasingly challenging. Blockchain technology promises to be capable of offering information on the provenance of products in supply networks. As such, several businesses are currently experimenting with blockchain technology to produce a verifiable and tamper-proof record of supply chains from the source to the end consumer and how they may benefit from the oversight it provides over the origin of items in their supply chains. This is an information that is typically restricted currently, especially when it comes to cross-border sourcing, which puts many organisations at a risk of being linked to modern slavery (Boersma and Nolan, 2020).

2.5 Summary

Although several measures to improve ethics in the construction industry have already been proposed and employed with varying degrees of implementation across various countries, unethical practices within the construction materials and products supply chain (CMPSC) are still prominent (Le *et al.*, 2014). Evidences of unethical environmental practises (Clement *et al.*, 2021; Jonathan Watts, 2019; Kjesbu *et al.*, 2017; SHAZLY *et al.*, 2021), unethical social practises (Boersma and Nolan, 2020; CIOB, 2018b; CIPS, 2013; Stronger Together, 2019; United Nations Global Compact, 2017; Werdmüller, 2016) and unethical business practises (Corrugated Metals Inc, 2013; Im *et al.*, 2018; Shan *et al.*, 2017; Sohail and Cavill, 2006) are still abundant within the construction materials and products supply chain. Thus, there is a need for the development of systems that can further improve the achievement of the industry's ethical goals. Tezel et al., (2019) affirm that digitalization is seen by policy makers as a key strategic solution to the construction industry's well-known problems.

The state of ethics in the CMPSC and the measures set up to both uphold and combat unethical practices within the supply chain have been evaluated in this chapter. The workings of blockchain technology and its feasibility to improve ethics within the CMPSC are discussed in the next chapter.

Chapter 3 Exploring blockchain technology: its workings and impacts in supply chains

3.1 Introduction

This chapter critically examines the workings of blockchain technology and how it has assisted in the supply chain of several industries, considering its benefits, prospects, as well as its limitations. This chapter also critically reflects on the factors that affect the implementation of blockchain within supply chains. The learnings from this chapter are important for evaluating the suitability, feasibility, practicalities and constraints of the technology for improving ethics within the construction supply chain environment.

3.2 Blockchain

Blockchain is a distributed immutable ledger technology that facilitates the process of recording and tracing transactions between two or more parties, using cryptography, hashing and a consensus mechanism to maintain the integrity of the ledger (IBM, 2020; Rath and Kulnigg, 2019). The transactions could range from simple activities like the entry of a record or event on the ledger to more complex ones like the transfer of tangible or intangible assets between multiple parties within the network. The network was initially developed as a decentralised peer-to-peer network to provide a reliable, efficient, cost-effective, and secure system for performing, verifying and documenting financial transactions digitally (IBM, 2020). The technology provides immutability and integrity of data by maintaining a record of transactions made within the network and distributing them across several members (nodes) connected to the network (Viriyasitavat and Hoonsopon, 2019). This immutable and tamper-evident log can be programmed to allow anyone to read data and verify its correctness, or limit that access to make the data privy to a particular category of people (Kassem *et al.*, 2018).

Interestingly, blockchain technology is not totally new; rather, it emerged from a collection of technologies that have been used for some time (Rath and Kulnigg, 2019). It simply combines distributed system technology, cryptography, peer-to-peer networking technology and other well-known technologies (Zhang and Lee, 2019). Its name is derived from its working principle of storing verified transaction data as “blocks” at scheduled intervals that are linked together to form a chain, thereby resulting in an immutable database of blockchain. More generally, the idea of structured record keeping began in the 1900s, dating back to ancient Mesopotamia (Keister, 1963). The idea of a distributed database is one that goes back to at least the 1970s (Wong, 1977). Permissioned blockchains can be modelled using the concept of Byzantine fault-tolerant (BFT) state machine replication, a notion first proposed in 1978 by Lamport (Lamport, 1978), and later concisely formalized by Schneider (Schneider, 1990).

The principle of immutably chaining blocks of data with a cryptographic hash function appears in the 1979 Stanford dissertation of Ralph Merkle (Merkle, 1979). In the same publication, he explains how information can be linked in a tree structure as a more efficient way of chaining information than the well-known linear chain. This is what is today known as a “Merkle hash tree.” David Chaum in a 1982 dissertation, describes the design of a distributed public record-keeping computer system that can be created, maintained, and trusted by mutually suspicious groups whilst the individual privacy of users is provided through cryptography (Chaum, 1982). This is the first known proposal for a blockchain protocol that proposed most of the elements of the blockchain later detailed in the Bitcoin whitepaper. The American computer scientist and cryptographer is widely recognised as the inventor of digital cash and the pioneer in cryptography and Privacy-Preserving Technology (Christine Kim, 2019). Even though there are other technologies that can store data efficiently, blockchain stands out because it can offer a fully decentralised solution with an unknown number of participants (Smith and O’Rourke, 2019).

A user can execute four functions on data in a typical database: Write, read, update, and delete (these are often referred to as the CRUD commands). Users can only read and add data to the blockchain. Its decentralised nature and lack of a central trusted authority further distinguishes it from traditional databases. Also, the entire history of data, including all modifications, as well as the metadata is recorded and protected with a cryptographically strong digital signature (Turk and Klinc, 2017a). While databases have been around since the 1980s and are built on a structure in which the database's information is kept and controlled on a central server system in one area. Regardless of any potential benefits blockchain may have over them, they are likely to stay in widespread usage in the short to medium term (Smith and O’Rourke, 2019). Although the cost of blockchains relative to centralised databases is unclear, many believe Blockchain can lower costs when compared with the support fees charged by database giants such as Oracle (Dabbagh *et al.*, 2019).

New transactions are grouped together and then goes through a verification and validation process. On confirmation of all the grouped transactions, they are then blocked and ‘chained’ to the existing network of blocks within the network; hence the name ‘blockchain’. The new state of the blockchain is updated to all nodes on the network, hence it is distributed (Belle, 2017). This decentralisation therefore makes it resilient to hacks, security compromises and failures of individual systems/nodes. The structure of the blockchain is such that malicious attacks are difficult to achieve as they require significant computational power and simultaneous access to over 50% of the nodes within the network to be successful (Kassem *et al.*, 2018). The immunity of the blockchain is provided by its key characteristics: decentralisation, immutability, transparency, auditability, consensus mechanisms and cryptographic algorithmic functions. According to Aggarwal and Floridi (2019) and the ICE (2018), the Bitcoin network, which uses blockchain technology, was launched in 2009 and has endured the test of time. It has never been hacked and there is currently a 100 billion dollar reward for a hacker to do so. Tong (2017) argues that the integrity of the network is arguably better than bank-level security and virtually anything of value can be tracked and traded on a blockchain network (IBM, 2020). Figure 3.2 provides an illustration of the blockchain transaction process.

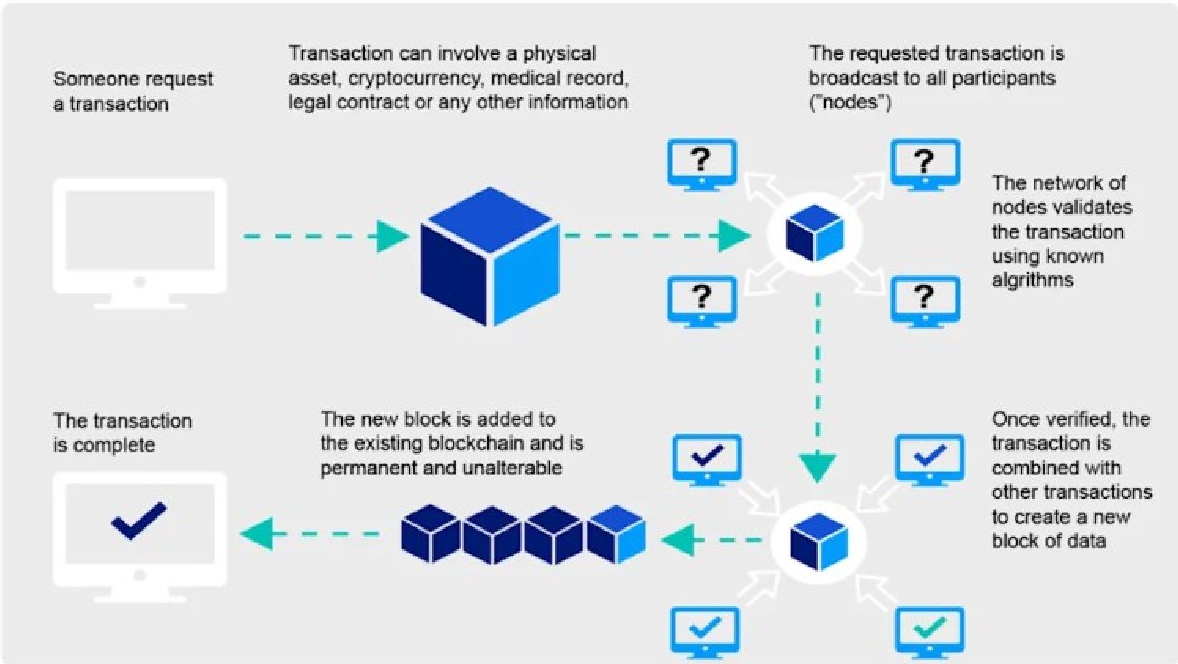

Figure 3.1 An illustration of the blockchain transaction process. (Source: Invesco (2015))

Blockchain technology has been widely discussed as the second wave to change the world after the Internet (San *et al.*, 2019). Yet, blockchain is neither a panacea nor a magic bullet (Aggarwal and Floridi, 2019); rather, it is a technology tool that influences organisational culture. Its code can get no better than the rules of collaboration set and accepted by its user community (Belle, 2017). Most of the value propositions of blockchain rely on the core characteristics of the technology, such as transparency, auditability, decentralisation, immutability, peer-to-peer, distributed database, etc. According to Smith and O'rourke, (2019), these key characteristics make blockchain a more attractive technology than traditional databases.

3.3 The key characteristics of blockchain

Transparency and auditability

Virtually anything of value can be traded and traced on a blockchain network (IBM, 2019). The distributed ledger's timestamped records and persistent information make it simple to verify and trace prior records across nodes in a blockchain network. The level of auditability varies depending on the type of blockchain network and how it is implemented (Viriyasitavat and Hoonsopon, 2019). Private blockchains are the least auditable as nodes are administrated by one entity, permissioned blockchains come second in which some agreements, such as encrypted data, may prevent information to be fully auditable, and public blockchains are the highest as nodes are truly decentralised. All blockchain data is traceable and auditable as new transactions are broadcast to all nodes and participants can verify where it came from and how it has evolved over time.

Decentralisation

Each transaction in traditional centralised transaction systems must be validated by a central trusted agency, resulting in cost and performance bottlenecks at the central servers. In contrast to the centralised option, blockchain does not require the use of a third party. Consensus algorithms are used in blockchain technology to keep data consistent across a distributed network. The technology is built on trust because of its decentralised structure and consensus-based structure, indicating a paradigm shift from trust to a "trustless" system that eliminates the need for third parties. Decentralisation, or decentralised trust within a peer-to-peer network, is an essential characteristic of public distributed ledger systems because it transfers trust from individuals or intermediaries to computational code (Kassem et al., 2018). Blockchain technology is a viable solution to the difficulties of distributed transaction management in a peer-to-peer (P2P) network. Public blockchains operate in a completely decentralised environment, allowing trust in transactions to be created between previously unknown or untrustworthy nodes. To achieve the same stance, private blockchains operate in a controlled and trusted environment and apply access restriction measures (Viriyasitavat and Hoonsopon, 2019).

Peer-to-Peer network

A peer-to-peer network, commonly known as P2P is a decentralised network communications model that consists of a group of devices (nodes) that collectively store and share files where each node acts as an individual peer. In the case of public blockchains, no single entity owns the ledger, but all of the network's participating nodes can add to it and validate transactions. In some permissioned blockchains, such as the consortium blockchain, all members own the blockchain and can change it with a super-majority of votes based on organisational hierarchical considerations or other distributed consensus methods (Baliga, 2016). P2P networks are the bedrock of most cryptocurrencies today, accounting for a large share of the blockchain industry. Blockchain's peer-to-peer architecture enables all cryptocurrencies to be exchanged globally without the use of a middleman, intermediaries, or centralised server. Anyone who wants to participate in the process of verifying and validating blocks can create a node on the distributed peer-to-peer network. The P2P system can be used for a variety of distributed computing applications, including file-sharing networks and energy trading platforms.

Immutability

Immutability refers to a blockchain ledger's ability to remain unmodified; this is achieved through cryptography and hashing. Each transaction that is verified by the blockchain network is timestamped and embedded into a “block” of information, cryptographically secured by a hashing process that links to and incorporates the hash of the previous block, and joins the chain as the next chronological update (Viriyasitavat and Hoonsopon, 2019). A transaction that has been blocked cannot be changed; it remains in the ledger indefinitely. Once transactions are included in the distributed ledger, no entity may erase or revert them (Baliga, 2016). The hashing process of a new block always includes meta-data from the previous block. This link in the hashing process makes the chain “unbreakable”. If attempted, the subsequent blocks in the chain would reject the attempted modification because their hashes would not be valid. The key benefit of hashing is that it cannot be reverse engineered. While not technically immutable, blockchain technology is thought to be so because altering transactions that have already been chained in blocks and published to the blockchain is difficult (Kassem et al., 2018).

3.4 Underlining elements of blockchain technology

Some underlining elements of blockchain technology are discussed in this section.

Transactions

A transaction is an exchange of information between two or more parties. The data that comprises a transaction can be different for every blockchain implementation, however the mechanism for transacting is largely the same. A transaction in a cryptocurrency network, for example, is a cryptocurrency transfer among blockchain network members. A transaction could be a form of recording activity on the state of a digital or physical asset in a business environment. For example, in a blockchain-based supply chain system, a transaction can be used to update a state of the digitised asset, such as the location of a shipment. A continuous supply of new blocks is required for various blockchain implementations to preserve the network's security; maintaining a constant supply of new blocks prevents malevolent users from ever catching up and fabricating a longer, changed blockchain. Transactions are usually digitally signed by the sender's private key, which may be validated at any time using the public key (Yaga *et al.*, 2018).

Blocks

A block is a container data structure. A block in the Bitcoin world often comprises more than 500 transactions and is 1MB in size; however, block size and capacity will vary among platforms depending on their configuration. A block consists of a header, a list of transactions, a cryptographic hash, and the previous block's hash. Furthermore, each blockchain implementation has the ability to define its own data field (Yaga *et al.*, 2018). The block's cryptographic hash is linked to the previous block in the blockchain, and the linked blocks form a chain. This recursive procedure verifies the integrity of each subsequent block, all the way back to the genesis block, which is the first block. A cryptographic hash, or digital signature, is used to identify a block. The block header is hashed twice with the SHA256 method to get this. The “block height” is another technique to identify a certain block. This is the block's position in the blockchain. The timing and sequence of transactions are recorded and confirmed in blocks, which are subsequently posted into the blockchain inside a discrete network defined by rules agreed upon by the network participants (DEV Community, 2017).

Every block starts life as a candidate block, but only the ones that are successfully mined get added to the blockchain. A candidate block is a temporary block that is formed via memory pool operations. The method of mining is then used by each mining node to add a candidate block to the blockchain. Miners compete against one another to validate the next block and add it to the blockchain, but they must first construct a candidate block in order to compete. Figure 3.3 provides an illustration of the basic components of blocks in the blockchain network.

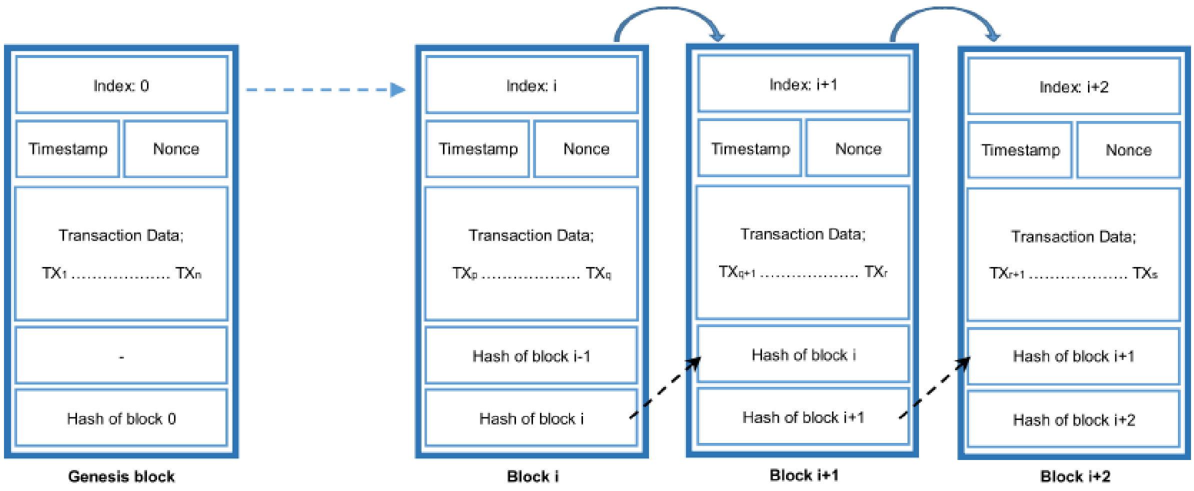

Figure 3.2 An illustration of the basic components of blocks in the blockchain network. (Source: Perera et al. (2020))

Cryptography

Cryptography is the art and science of encoding information so that it is difficult to decode (Blummer and Bohan, 2018). Cryptography ensures that each system participant is uniquely identified and can validate any change to the blockchain using a secure private key in blockchain technology, just as proving one's identity on a digital network usually involves the use of digital signatures and a certificate authority. More complex encryption is required to control privacy and permissions in more advanced systems. Although this encryption method is also used in other technologies, it is a critical component of the blockchain infrastructure because it ensures that data is secure, that ownership is controlled, and that it can only be accessed by those who need it. Only those with the necessary system authorities would have the key to decrypt and access it (Smith and O'rourke, 2019).

Cryptographic hash

Hashing is a method of applying a cryptographic hash function to data, which calculates a relatively unique output for an input of nearly any size (e.g., a file, text, or image). Individuals can separately take input data, hash that data, and return the identical output, proving that the data has not changed. Even the tiniest modification in the input (such as a single bit) results in a completely different output (Sherman *et al.*, 2018).

Nodes

A blockchain is made up of data blocks. These units of data are stored on nodes. Any device that is connected to the blockchain is referred to as a node. Servers, PCs, laptops, online or desktop wallets, and even mobile phones fall into this category. The nodes are then all connected to the blockchain in some fashion and are continually updating each other with new information uploaded to it (Medium, 2018). They store, distribute, and maintain blockchain data, so a blockchain can theoretically exist on nodes. When a miner tries to add a new block of transactions to the blockchain, it broadcasts it to all of the network's nodes. Nodes can accept or reject a block based on its legitimacy (validity of signatures and hashes). Without producing new blocks of transactions, a device can run a full node by receiving, storing, and broadcasting all transaction data. Nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone (Nakamoto, 2008).

A single node can theoretically run a complete blockchain, but because it is kept on a single device, it is particularly vulnerable to things like power outages, hackers, and systemic malfunctions. The more full nodes a blockchain has, the better it is able to withstand such threats. It will be difficult for a corrupt party to wipe out all of the blockchain data at once because the data is dispersed over so many machines. A single node can theoretically keep a full blockchain running even if a significant number of nodes fall offline and become unavailable due to a worldwide crisis (Zouina and Outtai, 2019). Also, nodes may experience fail-stop or crash-failure when they stop processing, emitting, or receiving messages, or when they stop participating in the consensus protocol or byzantine faults, as some compromised nodes may attempt to deliberately undermine the consensus process (Baliga, 2017), and node failure can also result in consensus failure.

A node can be run by anyone, and it is quite easy and does not require a lot of resources. However, some blockchains now contain so much transaction data that running a full node on a device necessitates a lot of memory (Medium, 2018). A node can be a light node, a full node, or a master node, depending on its capacity and functions.

Ledgers

A ledger is a collection of transactions. Throughout history, pen and paper ledgers have been used to keep track of the exchange of goods and services. In modern times, ledgers have been stored digitally, often in large databases owned and operated by a centralised trusted third party on behalf of a community of users. These ledgers with centralised ownership can be implemented in a centralised or distributed fashion (i.e., just one server or a coordinating cluster of servers). There is growing interest in exploring having distributed ownership of the ledger. Blockchain technology enables such an approach using both distributed ownership as well as a distributed physical architecture. The distributed physical architecture of blockchain networks often involve a much larger set of computers than is typical for centrally managed distributed physical architecture.

Furthermore, blockchain is a type of distributed ledger technology. A distributed ledger is a database that is replicated around multiple locations as a ledger, a record of a transaction, each synchronised across the system network (Smith and O'rourke, 2019). This makes malicious activity more difficult because any modifications made to the ledger by a hacked node would be opposed by the authentic record kept by other benign nodes on the network. Any two network participants can exchange asset ownership, and the transaction is recorded in the shared ledger (IBM, 2020).

Time stamp

Blockchain's distributed data structure allows for the chronological recording and secure storage of transactional data (Baliga, 2016). All transactions on the blockchain are validated and timestamped after the transaction is verified and included in the distributed ledger. This creates a global truth that any node in the network may verify in the future, and no node in the network can alter the data in this distributed ledger. The blockchain technology's time mapping feature improves the accountability and transparency of the data stored on the blockchain.

3.4.1 *Consensus in blockchain*

Consensus is described as the agreement among a group of nodes on the truth about their data (Viriyasitavat and Hoonsopon, 2019). In addition to cryptography and peer-to-peer technology, consensus mechanisms are also a vital element of the blockchain infrastructure as it relies on consensus mechanisms to determine the overall performance and scalability of the system.

The blockchain technology is consensus-based and transactional, that is, all relevant network participants must agree that a transaction is valid, and this is achieved using consensus algorithms (IBM, 2020). As a result, a modification to the ledger can only be performed once the transaction has been verified by a sufficient number of nodes in the system. The nodes perform this validation automatically using pre-set rules to obtain a consensus on whether the new data entry is valid (Smith and O'rourke, 2019). As a result, a robust consensus protocol helps ensure that blockchain systems are fault-tolerant and secure (Zhang and Lee, 2019).

As blockchain independently emerged as a powerful technology, decoupled from the cryptocurrency, its consensus mechanisms also evolved independently dictated by the blockchain platform and application requirements (Baliga, 2017). As a result, blockchain technology is adaptable enough to let any network define the terms under which a transaction or asset exchange can take place. Since the consensus model protects the integrity of data stored on the blockchain, it is critical to make sure it works properly in both normal and adverse situations. According to Viriyasitavat (2019), this system consists of three major roles: proposers who propose a value, acceptors who validate and decide which value to be taken, and learners who accept the chosen value.

Each type of blockchain has different application scenarios. As a result, the consensus protocol adopted must meet the requirements of the specific application situation. Thus, organisations that want to use blockchain to improve procurement integrity face the challenge of choosing the correct consensus protocol and network architecture while also understanding the benefits and drawbacks of each approach (Andoni et al., 2019). In a permissionless platform, the number of nodes is expected to be large, and these nodes are anonymous and untrusted since any node is allowed to join the network. Consensus mechanisms for such a setup have to account for maliciousness; particularly Sybil attacks (Baliga, 2017). Validators in consortium chains, on the other hand, are known in advance according to the governance system and can be trusted to some extent. Validators are defined at the inception of the blockchain in the majority of consortium protocols. Although certain systems allow for the dynamic addition and removal of validators, the current validators always have control over these operations. As a result, by utilising less demanding consensus techniques, the security and necessary computational power can be reduced. This reduction of complexity in the consensus protocol leads directly to an increased scalability in terms of transaction throughput (Litke *et al.*, 2019). There are several approaches to reaching a consensus in blockchain today, some of the most widely used consensus protocols are identified below. Examples of commonly used protocols include: proof of work, proof of stake, practical byzantine fault tolerance, proof of authority/identity, etc.

3.4.2 *Smart contracts*

In 1994, Szabo coined the term “smart contract” (Szabo Nick, 1994) but the underlining principle of systematically applying set rules to execute the terms of a contract has been used in trading systems dating back to the late 1940s (Automated Trading, 2014). Smart contracts based on the blockchain use coding to automatically carry out an agreement's terms once predefined conditions are satisfied, partially or fully removing the need for an intermediary. It is considered as one of the most important, intriguing, and potentially revolutionary components of blockchain (O'Grady, 2019). A blockchain can store any type of data, including code, in its records, but storing and executing data are not synonymous. Smart contracts can be created by combining executable code with blockchain technology. However, a smart contract is simply an executable code that contains arbitrary programming logic; not necessarily a 'contract' between parties (Di Francesco Maesa and Mori, 2020). It permits trusted transactions and agreements to be carried out among disparate, anonymous parties and they render transactions traceable, transparent, and irreversible (Nanayakkara *et al.*, 2019). Figure 3.6 illustrates how smart contracts work.

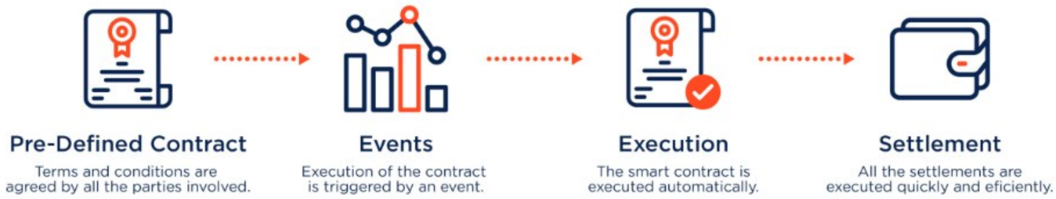

Figure 3.3 How smart contracts work. (Source: CoinDCX (2019))

However, while smart contracts offer a lot of benefits, RICS (2020) warns that they also come with a lot of risk, and their implementation has been difficult and expensive so far. Also, whilst blockchain itself is protected by military grade cryptography, smart contracts and other information added may however open a backdoor for malware (Belle, 2017). Esmaeilian et al. (2020) also argue that it will be difficult to write all conceivable possibilities in complicated business scenarios as computer codes in smart contracts, and smart contracts will still have to rely on courts and traditional legislators in the event of ambiguity. Smart contracts' inability to adapt to changing preferences of parties and unique unpredictable events, as well as their inadequacy in connecting to the physical world and verifying information recorded on the ledger, are still challenges to be addressed. Furthermore, the management of information that is drawn from an external source referred to as an "oracle" is of high importance, as a lack of this poses a risk of corrupting the blockchain (Dewey *et al.*, 2020).

3.4.3 *Asset digitization on blockchain*

Although blockchain has mostly been used to reinvent financial services transactions, a rising number of examples show that it is also being used to track the ownership and provenance of tangible assets. Everledger is a blockchain-based technology for tracking the provenance of diamonds, wine and spirits, and high-end goods (Everledger 2020). Asset digitization is the process of creating a digital version of an asset, whether it is a tangible or financial asset. The properties of the underlying assets are carried by these digital replicas. In these solutions, unique digital representations of tangible assets are created, hosted and tracked on a blockchain, thereby establishing a shared, unaltered, and verified history of the asset.

When tangible products are digitized, the rights of ownership associated with the physical asset can be determined or transferred on the digital platform. These assets may be represented by digital tokens that can be transferred between individuals. By creating digital versions of tangible assets, the digitized assets can help strengthen rights of ownership, allow everyone to track their assets and create a tamperproof record of transactions. However, a challenge in using blockchain to track the status of tangible assets is ensuring the physical and digital worlds remain in sync (McKinsey, 2021) as accounting complications such as inaccurate inventory valuations and conflicts in ownership claims could result from any discrepancies.

3.4.4 *Blockchain oracles*

Al-Breiki et al. (2020) suggests that there is a widespread misconception about blockchain and trust, with individuals believing that blockchain networks are "trustless" environments. Blockchain, on the other hand, does not abolish trust; rather, it alters the nature of trust. Traditional trusted intermediaries and centralised governing bodies, for example, are being replaced by oracles and sophisticated algorithms, while interpersonal trust between transacting parties is evolving through smart contracts. The blockchain distributes trust among system members and provides a variety of economic models to incentivize actors to follow the rules of participation. Also, while information stored in blockchains can be used to verify the origin of goods, it is vital to highlight that blockchain does not track goods. As a result, combining blockchain technology with monitoring and tracking technologies would allow users to get information on transportation mechanisms and conditions of products at any point along the supply chain, making supply chain operations more transparent (Kawabara and Acharya, 2020). Also, blockchains and smart contracts are only able to access data outside of the network (which is needed for many contractual agreements) through oracles (Beniiche, 2020).

Oracles can collect data from a variety of sources, based on their data source, they can be classified into: software oracles, hardware oracles, and humans oracles (Al-Breiki *et al.*, 2020). Software oracles work with data originating from online sources on the Internet, searching through it for the information it requires, extracting it, and returning it to the smart contract. Hardware oracles gather data directly from the physical world through scanners, asset tagging solutions like Bar codes, QR codes, NFC tags, GPS trackers, RFID tags, etc., and IoT sensors. Human oracles rely on people's actions to provide external data to blockchain systems, for example, people can vote on whether or not an event is true. Blockchain oracles can also be classified based on their trust model, design pattern and interaction (Al-Breiki *et al.*, 2020).

Honest data sources have been advocated as a means of improving the transparency of supply chains and of addressing problems such as product counterfeiting (Baranwal, 2020) as the ability of ERP to provide a network solution is restricted because implementation is typically limited to the boundaries of the firm (Cole *et al.*, 2019). In evaluating hardware data sources and asset tagging solutions, Sheldon (2020) identifies some risks specific to using these devices to collect data from the physical world, including: whether they remain attached to the relevant asset, whether they are designed to capture the intended occurrence, whether the devices store data securely, and whether the data is sent to the necessary processor in a complete and accurate manner. However, if properly managed, it allows the digital item on the blockchain to stay in sync with its physical counterpart, effectively positioning blockchain as a ledger for tangible goods (Helo and Shamsuzzoha, 2020; Lanko *et al.*, 2018a). Some of the most commonly used asset tagging solutions include QR codes, RFID, IoT, etc.

3.5 Types of blockchain networks

Network configurations can vary in terms of the degree of centralization and openness necessary. Permissioned blockchains are more centralised, with varying degrees of access to information, whereas permissionless blockchains are more open. The primary distinctions between these two types of blockchains are usually the technique of ledger sharing and the structure of system participation (Viriyasitavat and Hoonsopon, 2019). Despite the fact that blockchain structures vary, all varieties of blockchain are founded on the same core structure and leverage its functionalities.

Although, some researchers posit that there are three main types of blockchain that have emerged since Bitcoin was first introduced: private, public and consortium (Nanayakkara *et al.*, 2019; Smith and O'Rourke, 2019). Others argue that blockchain type indicates the type of blockchain platform and as such, it can either be permissioned or permissionless, indicating that the consortium blockchain is only a form of permissioned blockchain (Baliga, 2017; Hijazi *et al.*, 2019; Yaga *et al.*, 2019). Other researchers also suggest that blockchain can either be private, public or permissioned (Kassem *et al.*, 2018; Viriyasitavat and Hoonsopon, 2019; Zhang and Lee, 2019). Stating that private and permissioned blockchains tend to be more centralized than public blockchains. They further state that private blockchains are the least auditable as nodes are administrated by one entity, followed by permissioned blockchains in which some agreements, such as encrypted data, may prevent information from being fully auditable, and public blockchains are the highest as nodes are truly decentralised (Viriyasitavat and Hoonsopon, 2019). Although private blockchain and consortium blockchain are not as decentralised as public blockchains, due to the strong consistency and high efficiency of consensus, they are more suitable for some commercial and medical scenarios (Zhang and Lee, 2019) thereby suggesting a similarity in node adoption but a difference in accessibility to network content, thereby making one more suitable than the other, depending on the use case scenario. Some researchers also use the terms 'private blockchain' and 'permissioned blockchain' interchangeably thereby inferring that there is either a high level of similarity or that both are the same. Figure 3.7 shows some differences between permissioned and permissionless blockchain network.

Permissioned Blockchain vs Permissionless Blockchain		
Category	**Permissioned**	**Permissionless**
Speed	Faster	Slower
Privacy	Private membership	Transparent and open - anyone can become a member
Legitimacy	Legal	Allegal
Ownership	Managed by a group of nodes pre-defined	Public ownership - no one owns the network
Decentralization	Partially decentralized	Truly decentralized
Cost	Cost-effective	Not so cost-effective
Security	Less secure	More secure

Figure 3.4 Permissioned vs permissionless blockchain network. (Source: 101 Blockchains (2019)))

Regarding blockchain network naming conventions, this research takes the same position as Androulaki et al. (2018), Baliga (2017), Falazi et al. (2019), Helliar et al. (2020), It (2018), Luo et al. (2019), Miller (2019), Verhoeven et al. (2018) and Yaga et al. (2018); positing that blockchain platforms can either be permissioned or permissionless. However, permissioned blockchains could further be categorised into either private blockchains or consortium blockchains. This is due to the fact that fundamentally, both platforms require permission before new nodes can be added. In private blockchains, sole authority and finality is given to a predefined singular deciding node or group of nodes whilst in consortium blockchains, authority is shared in varying degrees among participants and finality is usually constituted.

3.5.1 ***Permissionless blockchains***

A permissionless blockchain also referred to as a public blockchain network, is one that is open, transparent and distributed; allowing anyone to join or leave the network whilst allowing every member to participate in viewing, modifying or auditing the blockchain, without one single person being in charge (Smith and O'Rourke, 2019). As such, the network operates under unknown and untrusted nodes (Viriyasitavat and Hoonsopon, 2019). Since no one is in charge, decisions are made by decentralised consensus mechanisms. The full decentralisation of permissionless networks means that no single node has sole authority over the database, network shutdown, or protocol changes (It, 2018). Many private blockchains store an extensive amount of data relating to the transactions, and operations carried out by identified users but with a public blockchain, the level of transaction detail, particularly the identity of the actors may be limited, to provide confidentiality and anonymity. Some permissionless networks do not require users to provide personal information in order to join. Personal information is, nonetheless, essential for legal purposes in some circumstances. Bitcoin, for example, does not provide complete anonymity because the address of a user's private key is indirectly linked to their identity (It, 2018).

Participants in the network would need to be incentivised to run a protocol for checking and validating transactions because the network is decentralised and there is no central trusted entity to verify and validate transactions. Some full nodes on the network function as miners, competing to validate new transactions and add them to the blockchain, as it is with the bitcoin network (Smith and O'Rourke, 2019). As a result, a permissionless blockchain cannot exist without a digital token or crypto asset, because miners must be compensated fairly, and users must trade digital tokens to make use of the network. The value of these tokens may rise or decline depending on the relevance and state of the blockchain to which it belongs, with many using either monetary or utility tokens, depending on the purpose (It, 2018).The majority of digital currencies on the market today are hosted on permissionless networks and managed by their users. As a result, any user will be able to create a personal account and receive a personal address with which they may begin interacting with the network by making transactions and so adding entries to the ledger.

Although, permissionless blockchains may be unsuitable for corporate organisations due to privacy concerns, whereas permissioned blockchains meet enterprise needs such as rapid transactions, higher resilience, and privacy, but may suffer from certain computational risks due to lower network involvement (Kassem *et al.*, 2018).

3.5.2 *Permissioned blockchains*

A permissioned blockchain network is one in which potential members must obtain some form of authorization before joining (Androulaki et al., 2018). In contrast to permissionless blockchains, where any interested party can join the network and automatically gain access to all records of transactions made since the network's inception due to its open nature, permissioned blockchains typically reserve transaction data and participants may have varying hierarchical clearances to access data. In permissioned blockchains, transactions are performed and processed by a set of known and delegated nodes. These properties make permissioned networks very attractive in cases, where transaction-processing nodes need to be known to comply with regulations, especially in financial institutions and in other business applications (Baliga, 2017). Cryptographic certificates with IDs and permissions can be used to indicate which transaction details other participants are allowed to see, and permissions can be enhanced for special users like auditors who may require access to additional transaction details. A permissioned blockchain network also allows for improved auditability due to the use of a shared ledger among known participants that serves as a single source of truth, this improves the ability to monitor and audit transactions (IBM, 2020).

Furthermore, while permissionless blockchain data is public, it is not necessary that permissioned blockchain data must be private. Whilst permissioned blockchain are not required to be transparent, they can choose to do so freely, depending on the inner organisation of the businesses. Since transparency and auditability are two of the key benefits of blockchain technology, data from a permissioned blockchain can be made public if, for example, a business institution's data needs to be made available to auditors to verify for compliance (Baliga, 2016). In such a blockchain, such as Ripple, an intrinsic configuration defines the participants' roles in which certain members can access, write information on the blockchain, or approve admission of new members (Ripple, 2020). That is, some participants may be authorized to view only certain transactions, while others, such as auditors, may be given access to a broader range of transactions by cryptographic digital certificates.

Now, since transacting parties and transaction processors are known entities, the necessary need for a native token is absent and similarly, the need for mining. Although tokens and other real-world incentives may be used to facilitate the processing of transactions and ensuring data integrity. The permissioned membership structure of this network helps to ensure that members are who they say they are, and that assets traded are exactly as represented thereby protecting against tampering, fraud, and cybercrime. Cryptography and data partitioning techniques are used to provide selective access into the ledger to participants; both transactions and the identities of transacting parties can be veiled (IBM, 2020).

Furthermore, hashes of block headers can be intermittently uploaded to permissionless chains to improve the security of the permissioned chain. This improves the permissioned blockchain's security against attacks in which numerous entities work together to generate forks in the permissioned blockchain (Baliga, 2016). Usually, permissioned networks run faster than permissionless networks because they usually involve fewer nodes and their control and consensus strategies depend on quicker fault-tolerant protocols (Lamport *et al.*, 1982).

Although, some authors (Baliga, 2016; Rath and Kulnigg, 2019; Sherman *et al.*, 2018) argue that permissioned blockchain may have by their structure defeated the purpose of the blockchain technology which was introduced to function as a decentralised system without restrictions or the need for permissions for participation or data access (Nakamoto, 2008), and thereby susceptible to attack. On the other hand, Sherman et al. (2018) refutes this, stating that such assertions are made when people naively think of Bitcoin as a fully distributed system free of any centralized control, but in fact, Bitcoin's core developers, similarly to other distributed systems, carry out vital roles similar to changing the underlying software that implements policy. This is further substantiated by the finding from an investigation on the level of decentralisation in two most popular cryptocurrencies (Bitcoin and Ethereum) by Gencer et al (2018), results show that decentralised blockchain networks (such as Bitcoin and Ethereum) are much more centralized than many assume. For example, in the case of Bitcoin, 20 major mining pools, 81% of which are estimated to be located in China and 10% in Czech Republic control over 90% of the network hash rate (Jordan Tuwiner, 2019). In another study of the Bitcoin network, Miller et al., (2015) discovered that a small fraction of the network, containing about 2% of the nodes, represents more than 75% of the mining power and as a result, these nodes have disproportionate influence on the Bitcoin network. However, despite these significant powers, the control structure is still more distributed than for a permissioned system entirely controlled by a pre-specified entity (Miller, 2019). Permissioned blockchains can further be either private or consortium networks depending on the ownership, membership and hierarchical structure of the network.

3.5.2.1 Private blockchain network

The private blockchain network is a type of permissioned network as it requires a protocol of validation and authorization before members can be added to the network. All private blockchains are permissioned but not all permissioned blockchains are private. Private blockchains usually rely on a single entity or owner who controls how nodes are selected and the degree of data openness based on policies and only participating nodes within the network can access the network data (Smith and O'Rourke, 2019). Usually, in a private blockchain network, the owner who is usually a predefined node has highest authority to control access of authorized nodes to ledgers. They function as closed ecosystems, where nodes are not allowed to join the network simply at will, access recorded history, or initiate transactions of their own. Hence, a private blockchain is suitable for closed systems, where all nodes are fully trusted (Viriyasitavat and Hoonsopon, 2019) and thereby suitable for internal business operations by centralized organisations, as it allows the central governing entity to decide how the network is created, its protocols and what users can do, thereby leveraging the power of the network for their own, internal business operations (It, 2018).

Baliga (2016) notes that while private blockchains may serve as the perfect tools for large entities to collabourate with each other on a project, the reality is that blockchain was intended to be an open-source decentralised system. Zhang and Lee (2019) admits that although private blockchain and consortium blockchain are not as decentralised as public blockchain, due to the strong consistency and high efficiency of consensus, they are more suitable for use within a private organisation and in some commercial and medical scenarios.

3.5.2.2 Consortium blockchains

Consortium blockchains are a hybrid between private and public blockchains that aims to achieve the best of both worlds by being a partly private blockchain solution without a single owner (Nanayakkara *et al.*, 2019). Thereby suitable for a federated enterprise-level application with a shared interest. It functions in a trusted environment, similar to private blockchain networks, but with a suitable degree of decentralisation, similar to permissionless blockchains. A consortium blockchain aims to eliminate the exclusive autonomy available in private blockchains by putting numerous members in charge, each with known and recognised identities, who are responsible for making decisions for the common interest of the entire members of the blockchain network. For example, the consortium could consist of some companies with a network protocol which states that a transaction can only be added to the blockchain if it has been verified by at least 70 percent of the member companies of the consortium network (Smith and O'Rourke, 2019). In this federated system, only authorised members have the ability to run nodes on the network, validating transaction blocks, issuing transactions, executing smart contracts, or reading the transaction records.

Even though the network is not fully open as in permissionless blockchains as members are approved based on consortium policies, the benefits of decentralisation can be partially gained as all nodes maintain blockchain information, where no single entity has full control of the system thereby eliminating the possibility of a single point of failure or data compromise (Viriyasitavat and Hoonsopon, 2019). The level of data openness varying across different participants is controlled by the policies of the consortium, which can regulate the information to be fully open, partially open, or closed thereby making it suitable for semi-closed systems consisting of enterprises, cross-organisational business processes involving several enterprises usually structured in the form of a consortium, hence the name consortium blockchain. The consortium blockchain implementation benefits including persistency, validity, and auditability can be gained to some degree by members of the network. Blummer and Bohan (2018), considers that this makes it a suitable use case when a database is to be shared, but one does not have a lot of trust in the other network members to use the information on the database as agreed without degrading someone else's performance to gain a competitive advantage or interfere with each other's private information.

3.6 Applications of blockchain technology across industries

Although cryptocurrencies have tended to dominate blockchain conversations, blockchain has far wider potential applications. Blockchain is to only Bitcoin what the internet is to email; a wide electronic system on top of which you can build applications, currency is just one (Smith and O'rourke, 2019). According to Bheemaiah (2017), blockchain, which has been lauded as having the potential to have a greater impact than the internet, has the ability to increase productivity, enhance efficiencies, and lower costs, as it has already demonstrated in a variety of industries. There are numerous other applications for blockchain technology that are being explored for a variety of industries, leading to a number of platforms, applications, start-ups, projects, and research around this new invention, including but not limited to health care, information sharing, supply chain, information management, insurance, automated dispute resolution, real estate, crowdfunding, big data analytics, and education, to name a few that could transform the way the world does business, much like the internet did over 20 years ago (ICE, 2018; Rath and Kulnigg, 2019).

The impact of blockchain technology is currently revolutionizing several industries; the following section describes three of the industries who have been the biggest implementers and beneficiaries of blockchain and some of their use cases, namely: Financial Industry, trade and supply chain industry (Brown, 2018; Consensys, 2018; Deloitte, 2017; Erol *et al.*, 2021; IBM, 2020; TradeLens, 2020; Verhoeven *et al.*, 2018).

3.6.1 *The financial industry*

Blockchain technology was popularized with the Bitcoin cryptocurrency. As such, it is not surprising that the majority of applications of blockchain technology have been in the financial sector. In 2008, Satoshi Nakamoto published his study on "Bitcoin: A Peer-to-Peer Electronic Cash System", in which a peer-to-peer (P2P) electronic cash system was proposed (Nakamoto, 2008). This technology allowed payments to be initiated and executed directly from one party to the other without the use of a third-party financial institution. As a result of blockchain's success in supporting cryptocurrencies, it was only logical for the financial industry to further explore the applications of the technology in financial domains.

However, in contrast to the revolutionary permissionless bitcoin network's initial essential attribute of anonymity, further research and applications of cryptocurrency technology in finance suggest that being able to identify a counterparty is crucial for many reasons in a transaction (Banerjee and Kashyap, 2018; CH Alliance, 2019; Sprenger and Balsiger, 2019; UK Finance, 2019) thereby proposing a permissioned network with the inclusion of know-your-customer (KYC) and anti-money laundering (AML) regulations and privacy considerations, to blockchain and cryptocurrency (Fenergo, 2019). Due to these factors, permissioned networks with known members provide the best environment for mainstream financial implementations (Houben and Snyers, 2018).

Several financial institutions have also been experimenting, for example by using stable coins as new digital instruments to transform international payments and transactions by lowering remittance fees and enabling near instantaneous transactions. As cryptocurrencies and stablecoins have become more popular, the world's central banks are looking into how blockchain may help their countries' payment systems. As a result, several countries are now issuing virtual money backed and by the central bank, referred to as "Central Bank Digital Currency (CBDC)". In fact, 9 countries have now fully launched a digital currency, 14 countries, including China and South Korea, are now in the pilot stage with their CBDCs and preparing a possible full launch and 87 countries (representing over 90 percent of global GDP) are exploring a CBDC (Atlantic Council n.d.). Wholesale CBDCs can help central banks and their member banks run more efficient clearing operations, whereas retail CBDCs would be the digital counterpart of a bank note for public usage (PWC, 2020).

Many leading technology companies are also developing financial applications on the blockchain infrastructure. For example, IBM's blockchain World Wire enables near real-time settlement of transactions through the use and exchange of digital assets. Holding real-world intrinsic value, a digital asset is used as the means for settling cross-border payments in seconds, thereby eliminating the long-standing challenges that have impeded the cross-border payments industry for a long time (IBM, 2020). Similarly, Ripple Labs Incorporation, a US-based technology company created Ripple; a real-time gross settlement system, currency exchange and remittance network with a growing network of millions of users with over 300 financial institutions across over 40 countries and 6 continents to facilitate real time payments (Ripple, 2020). Blockchain is considered by many as a game changer in the financial world, but another area where it holds great promise is supply chain management.

3.6.2 *Trade and supply chain industry*

The decentralised ledger, similar to a stock ledger, works as a single unified source of data, providing a clear audit trail and consistency across all vendors involved in production, assembly, supply, and maintenance activities, for example. Manufacturing companies may be able to enhance how quickly they track problems with a single product, component, or material producer by using blockchain (Angrish et al., 2018). In real time, blockchains can provide data to the network on the origins of materials, purchase orders, inventory levels, goods received, shipping manifests and invoices. Smart contracts match and verify this data against the agreement and trigger payment. It can autonomously trigger other transactions when key milestones are met. The transparent, decentralised, and immutable nature of blockchain has piqued the interest of private actors and governments to investigate the technology's potential to improve the efficiency of trade processes, and a myriad of proof-of-concept and pilot projects have been developed in virtually every area of international trade (World Trade Organisation, 2018). A generalized outline of what a supply chain supported by blockchain may look like is presented in Figure 3.8.

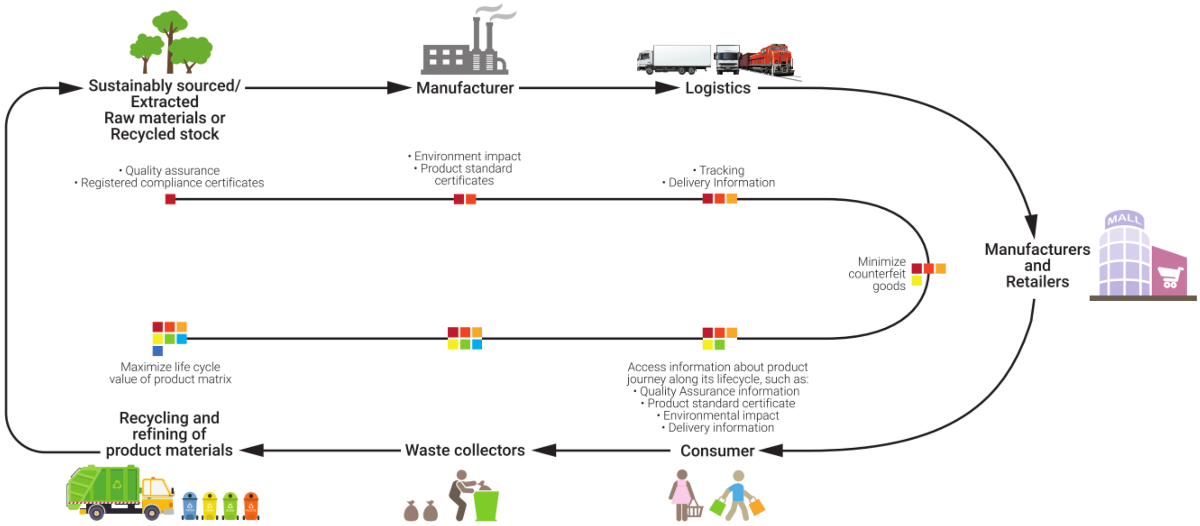

Figure 3.5 A generalized outline of a blockchain supported supply chain. (Source: Kawabara and Acharya (2020))

It is estimated that global trade is now worth more than $18 trillion USD per year. The majority of traded goods are transported, at some point, by ocean shipping industry. However, many supply chain actors rely on disparate traditional systems to perform transactions. This often slows or totally stops the transfer of commodities. The digitization of the process can remove supply chain bottlenecks and expand global trade enormously. Blockchain delivers significant value to complex supply chains around the world, eliminating traditional friction points and providing entirely new degrees of transparency and trust (IBM, 2020).

Supply chain and logistics companies are integrating blockchain with their logistics management systems to assist in the coordination of the distribution of raw materials, finished goods, and services between producers/sellers and consumer destinations. This could also comprise a number of synchronised sub-activities carried out by other companies, such as manufacturers, storage companies, transportation companies, and regulatory agencies (Al-Jaroodi and Mohamed, 2019). According to Saberi et al. (2019), blockchain technology can highlight and detail at least five key product dimensions: the nature, the quality, the quantity, the location and the ownership at any moment. Thereby allowing customers to inspect the uninterrupted chain of custody and transactions from the raw materials to the end sale of a product. The technology is currently used in supply chains to prove the provenance of goods ranging from fresh produce to raw materials, or even diamonds. As these goods change hands, records can be added, inspections and deliveries can be logged, and payments can be released automatically, all in a secure, verifiable and trusted manner (PWC, 2020). Figure 3.9 shows a blockchain network for a food traceability use case.

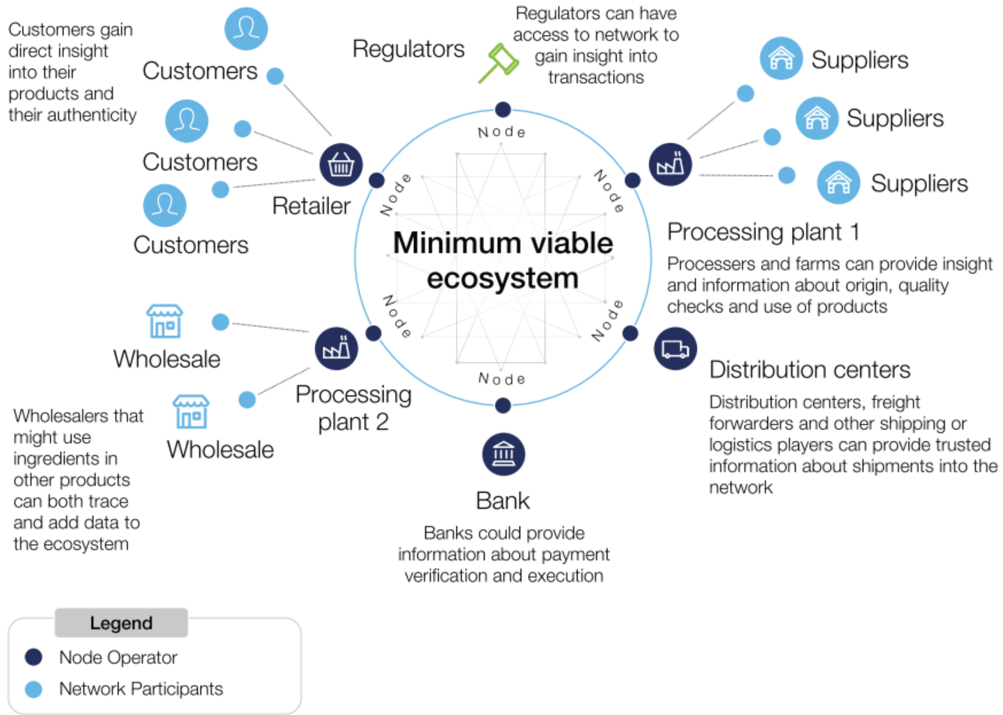

Figure 3.6 Illustrative example of a network of participants for a supply chain traceability use case. (Source: WEF (2020))

A myriad of start-ups in this field are developing blockchain-based solutions to track and identify products such as food items, pharmaceuticals, electronics, and luxury and fashion items, and to ensure that consumers or producers receive an authentic product. Some of them include: Tradelens, IBM food trust, Everledger, VeChain, etc.

3.6.3 *Current use cases in the construction industry*

The construction industry is notoriously characterised by fragmentation in information flows, processes, services and firms with different pursuits of interest. Lack of trust has been an ongoing issue for decades in the construction industry, hindering the improvement of construction quality. A collaborative and trusted environment is needed to improve the quality performance of construction and blockchain technology due to its key characteristics and underlining elements as earlier discussed, has some potential in setting up such an environment (M N N Rodrigo *et al.*, 2018; Qian and Papadonikolaki, 2020; Smith and O'Rourke, 2019). Furthermore, San et al. (2019) presented a conceptual framework that reveals the potential and implication of blockchain application in construction, as shown in Figure 3.10.

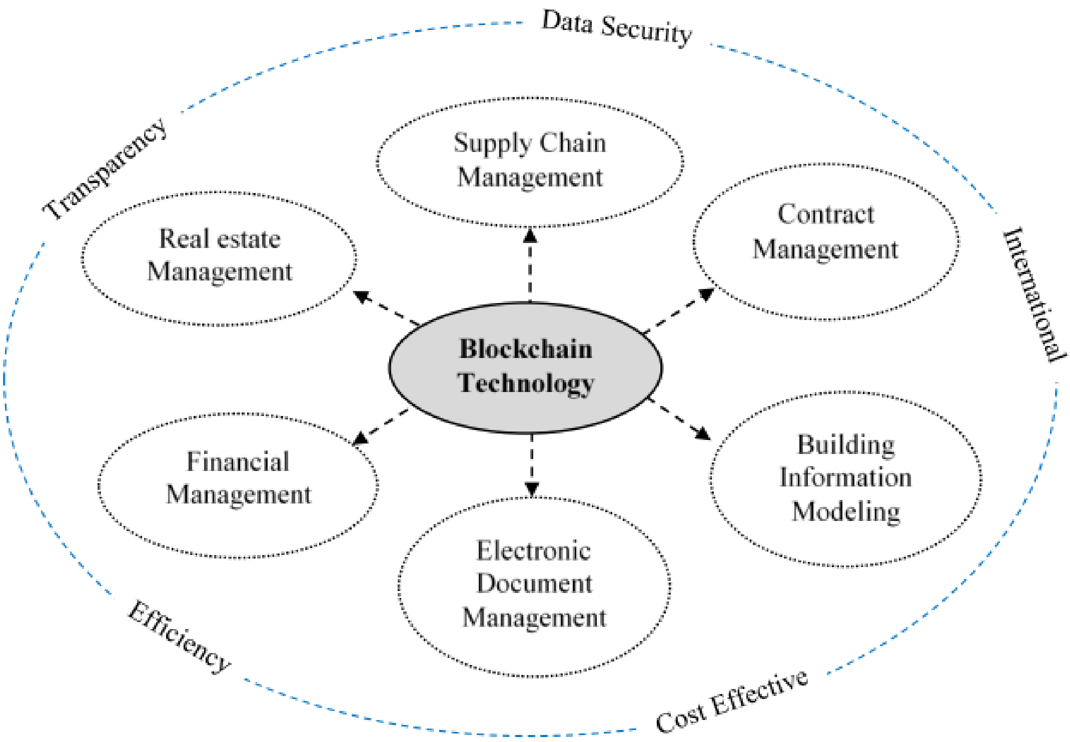

Figure 3.7 A conceptual framework revealing the potential and implication of blockchain application in construction. (Source: San et al. (2019))

However, unlike the industries discussed in the prior sections, only a limited number of use cases of blockchain in construction exist today. This may be due to the construction industry's typical slow response to the adoption of new technology (Dave *et al.*, 2018; Gad and Shane, 2014) or due to the limited understanding of the workings of blockchain technology within the construction sector (Kifokeris and Koch, 2019). Examples of current implementations in the industry are discussed below.

Briq

Briq, a blockchain company focusing on construction solutions based in California, is demonstrating the ability to collect and secure all of a construction project's paperwork in a blockchain ledger that parties can explore and pass over to the owner as a deliverable at handover (Williams *et al.*, 2019). Briq created a "digital twin" of a new office structure for Minneapolis-based Gardner Builders, which includes a room-by-room inventory of every installed asset. The construction assets' blockchain-encoded specifications are detailed, down to paint colours, ceiling fittings, LED bulbs, and door hardware, as well as manuals, warranty information. Any renovations or modifications to the structure can be recorded on the ledger. For the current and future owners, this essentially creates a "living ledger" of the building.

BIMCHAIN

The digital platform powered by blockchain brings trust in the data shared among AEC stakeholders, and transforms the current disposable 3D model into a contractual, auditable, qualified-and thus valuable - digital asset (Crunchbase, no date). BIMCHAIN integrates the BIM software and processes to create a binding traceability of data exchanges, allowing stakeholders to engage their responsibility on the BIM Model itself while scoping their liability and protecting their intellectual property. BIMCHAIN can also be used to make payments faster and more frequent based on the BIM deliveries. Moreover, through the development of a Smart Contract, it is possible to validate the exchange process, the roles, the skills of the stakeholders involved in the processes and all the information that contributes to demonstrating ownership of the corporate know-how.

Propy

Propy leverages blockchain for transparent, secure, and traceable property transactions. It uses the Ethereum blockchain to bring agents and clients together in an unified, safe environment to make property acquisition transactions easier. From offer to deed recording, the Propy Transaction Platform allows for a safe online closing process. Propy completed the world's first blockchain real estate transaction in 2017 and also completed the world's first homeownership transfer using Non-fungible Token technology. The company also implemented the world's first blockchain-based government-approved title register. In June, 2021, Propy, was selected as one of the World Economic Forum’s ‘Technology Pioneers of 2021’(WEF, 2020). Innovations in the use of blockchain will undoubtedly change the way the real estate profession operates over the coming years (RICS, 2020).

3.7 Blockchain and BIM

The construction industry is ranked as the second-lowest sector in adopting information technology (Agarwal et al., 2016). However, due to the increasing demand for quality scopes, predictable schedules, and reliable budgets, there is a rising demand for digitalisation to support the transfer of information, including design decisions, to make the industry more effective and efficient (Construction Blockchain Consortium, 2020). Building Information Modelling (BIM) was expected to be such a disruptor but despite its potential, its adoption has lagged as project teams grapple with the trust and liability issues that come with sharing project information. New technologies, such as BIM, that promise to improve collaboration in the construction sector appear to be hampered once again by issues of trust and liability that affects the industry (Hunhevicz and Hall, 2020).

According to Dave et al. (2018) technologies such as BIM were expected to provide the step change for the construction industry in the last decade but its penetration is yet to be seen on global scale. Esmaeilian et al. (2020) and Helo and Shamsuzzoha, (2020) recommend that data produced by IoT can be kept in a blockchain enabled environment for enhanced transparency, security; while BIM functions as the baseline tool to digitize the construction project data. Qian and Papadonikolaki (2020), Turk and Klinc (2017b) and Xiaoning and Papadonikolaki (2019) suggest that the combination of blockchain, BIM and IoT can increase inter-firm trust in construction and supply chain. In addition, Paras Taneja of Autodesk University affirms:

> *"Blockchain can address issues surrounding secure access to the model and allow for a reliable audit of who made changes, when they were made, and what those changes were. Contractual processes that typically require human intervention and oversight can be partially or fully automated with smart contracts, originating from blockchain technology." (Autodesk, 2020, para. 2).*

Several researchers believe that blockchain is a technology that has enormous potential to change the construction procurement process (M N N Rodrigo *et al.*, 2018; Qian and Papadonikolaki, 2020; Tezel *et al.*, 2019, 2020; Yang, 2019). In addition, the integration of BIM with blockchain can help to generate a more reliable asset register of the entire building as well as provide a repository of information that can be used to plan maintenance schedules. As Aziz *et al.* (2017) observed, data from the design and construction phases of projects can be used to inform asset registers from an earlier stage. This data may be combined with data produced from various other sensors to support key decision-making. The potential of blockchain in the construction industry supply chain are further explored in the next chapter.

3.8 Blockchain for ethics

In this section, the potential and current implementations of blockchain to foster environmental, social and business ethics are discussed.

3.8.1 *Blockchain for environmental ethics*

Although, carbon neutrality is not the first thing that springs to mind when thinking about blockchain. In order to confirm transactions and maintain the network, Bitcoin, blockchain's first application, is commonly seen as an environmental polluter, requiring large quantities of energy and releasing vast amounts of CO_2. Concerns of this type, on the other hand, only apply to certain uses of the underlying technology. Blockchain can be deployed in more energy-efficient ways depending on network architecture and protocol selection. When correctly set up, private blockchains using algorithms such as proof-of-authority (PoA) cost no more energy than standard database solutions.

Over the past few years, scholars have increasingly proposed blockchain as a potential solution for sustainable development, including the environmental dimension focused on sustainability (Kawabara and Acharya, 2020; OECD, 2020; PWC, 2020). Environmental blockchain applications usually necessitate the adoption of a supplementary technology, such as environmental sensors, satellite remote sensing, Internet of Things devices, artificial intelligence, biometrics, smart metres, QR codes, or radio-frequency identification chips (Kawabara and Acharya, 2020). Supply chain monitoring, energy transmissions, emissions tracking, carbon trading, and other environmental management operations might all benefit from blockchain, as could achieving Agenda 2030 and other global environmental agreement commitments. In fact, Saberi et al. (2019) suggest that a worldwide blockchain network could improve the efficiency of emissions certificate trading systems by offering reliable data that aids the effective control of quota restrictions, certificate circulation, market integrity, and rigorous carbon accounting, as well as the automation of transactions and overall efficiency.

The transition to a low-carbon future necessitates a radical reappraisal of infrastructure systems and services from consumer engagement through planning, procurement, financing, building, and operations. A successful transition will require the adoption of new technologies that allow for significant reductions in greenhouse gas emissions. Emerging technologies such as blockchain, have the potential to improve current processes and systems by acting as digital enablers across the infrastructure value chain (Yang, 2019). According to Kawabara and Acharya (2020), blockchains equipped with enhanced record-keeping, transparency, value transferring, tokenized ecosystem show the technology's potential to tackle global environmental challenges and help with addressing issues like climate change, energy, biodiversity conservation, water security, ocean sustainability, and air pollution. Some well-known energy businesses, such as Acciona Energy, Irene Energy, and Iberdrola, are currently promoting environmental ethics through blockchain implementations for green energy. Iberdrola has launched a blockchain-based network to ensure that electricity supplied and consumed is totally renewable (Saberi *et al.*, 2019b).

3.8.2 *Blockchain for social ethics*

The use of blockchain to improve supply chains for humanitarian projects has picked up steam over the last five years, thanks in large part to the technology's promise of openness and security (Mehra and Dale, 2020). Projects that involve the design of blockchain for applications that address humanitarian crises and human rights abuses been dubbed “Humanitarian blockchain”. Governments, corporations, and human rights organisations are increasingly promoting blockchain technology as a cutting-edge tool for addressing humanitarian and human rights concerns, including those that directly affect refugees, such as food shortages. For example, the UN World Food Programme used blockchain to distribute relief to refugees in Jordanian camps, saving 98% on bank transfer fees whilst increasing refugee anonymity (Zambrano *et al.*, 2018).

Also, investors are increasingly demanding that corporations be evaluated using stronger environmental, social, and governance standards. Greater transparency in reporting programmes such as ShareAction's Workforce Disclosure Initiative, are raising the pressure on major corporations to demonstrate the effectiveness of their supply chain policies (CIOB, 2018a). According to Saberi *et al.* (2019b), blockchain technology has the potential to enhance the sustainability of social supply chains since its traceability promotes sustainability through improved assurance of human rights and fair, safe work practises. For example, a clear product history helps buyers trust that the things purchased are ethical. Furthermore, Boersma and Nolan (2020) posit that blockchain can track commodities' origins in supply chains. This can benefit firms and their stakeholders, as corporations' management of items' origin in supply chains is often limited, especially when sourcing cross-border. As a result, businesses risk being linked to modern slavery. For example, the demand for cobalt has been met by people trapped in modern slavery. In response to this, Ford and IBM are part of a group that is looking to utilise blockchain to track cobalt supplies from mine to battery. It plans to do so by logging ethically mined cobalt on the blockchain and tracking it as it passes through the supply chain (IBM, 2020).

Boersma and Nolan (2020) however caution that blockchain is not a panacea for addressing modern slavery. Rather they advise that instead of relying on a technology as a remedy for a complicated social problem, successful approaches would require businesses to understand the plethora of elements that contribute to modern slavery and seek to mitigate it in every way possible. Mehra and Dale (2020) also argue that the concentration on tracing the commodity itself rather than addressing the labour circumstances of commodity production is a fundamental shortcoming of blockchain solutions for labour exploitation and simply incorporating digital technology into the process does not offer workers with legally binding methods to demand that their rights be respected without fear of retaliation. They further add that simply recording the path of the commodity does not exclude bad actors from entering false data; data can be corrupted at the point of entry. As such, although well-intentioned, humanitarian blockchain may inadvertently facilitate the illusion of a global supply chain "free" of exploited labour. According to Boersma and Nolan (2020), transactions at all supply chain tiers, especially in lower-tiers must be validated to effectively manage the risk of modern slavery. However, determining whether all transactions and the labour circumstances that surround them are appropriate is difficult.

3.8.3 *Blockchain for business ethics*

Blockchain is considered as one of the most promising disruptive technologies in the fight against unethical activities in business relations corruption. It possesses important features that can help provide transparency and prevent fraud between transacting business parties, foster integrity in bureaucracies, track flow of funds and assets, removal of payment bottlenecks, registering assets and securing registries, notarization and enforcing contract terms, etc. (Aggarwal and Floridi, 2019; Mohite and Acharya, 2018; Yang, 2019). As such, several blockchain projects are being developed mostly in the financial and supply chain sectors to improve business ethics within their organisations and supply chain.

For example, blockchain is being implemented in the finance industry for automated decentralised accounting, real-time reporting, audit and analysis, thereby helping to significantly reduce fraud while also offering a robust fraud detection system. An example of one of these implementations is Auditchain. Auditchain proposes an ecosystem that includes a blockchain protocol and an open source library of accounting smart contracts capable of capturing, processing, auditing, and reporting enterprise data and performance data in real time while also exceeding current accounting, auditing, and control standards (Auditchain, 2018).

Given that blockchain data cannot be amended without the approval of authorised actors, blockchain has the potential to transform transactional datasets into more reliable datasets. Thereby helping to prevent corrupt players from acting unethically. According to (Saberi *et al.*, 2019b), blockchain can mitigate potential opportunistic behaviours in business environments through its transparency features.

While the most common form of counterfeiting in the construction industry is the falsification of specification stamps or papers of origin (Minchin *et al.*, 2011), Helo and Shamsuzzoha (2020) posit that blockchain when combined with tagging/tracking systems and IoT devices has a lot of potential in this field; for example, RFID tags are nearly impossible to falsify and they can take the place of accompanying documents which can be easily falsified. As such, all stakeholders can rely on the traceability and quality of materials being transported to the project site. If contrasted with the augmented design model, it can be verified if the product is appropriately stored and installed (CBC, 2020).

Furthermore, the construction sector is rife with partial and non-payments. For example, in 2015, the unpaid payment for work done in Hong Kong construction projects was reported to be above HK$20 billion due to the conflicting interests of various parties and the complexity of the construction environment (Luo *et al.*, 2019). Due to these concerns, significant construction firms including Carillion, Strongbuild, Interserve, and Dawnus have gone bankrupt (Perera *et al.*, 2020). With this prevalence of payment challenges in most construction contracts, many have hailed blockchain for its ability to resolve payment disputes through smart contracts (San *et al.*, 2019). These smart contracts can also be interlined to generate a web of payments to all parties involved when certain conditions are met; for example, reaching a project milestone (Wang *et al.*, 2017). In fact, construction firms such as Arup have expressed strong interest in implementing blockchain to improve the industry's performance across a range of services, including automating the payment process, supply chain, and smart cities (Abrishami and Elghaish, 2019).

Dewey et al. (2020) however cautions that even though smart contracts are one of the most exciting and possibly disruptive parts of blockchain, there are still barriers to overcome before they become ubiquitous. Smart contracts require significant investment in both technical infrastructure and legal framework to govern their implementation and this is often disregarded in the promotion of smart contract implementations (RICS, 2020). While this is true, numerous initiatives aimed at fostering smart contract usability and implementation are developing domain-specific programming languages that are accessible to managers and lawyers. Such initiatives attempt to make smart legal contracts mainstream and accessible to anybody (CBC, 2020). Also, Yang (2019) believes that while the implementation of blockchain in the business environment may mitigate the risk of corruption caused by dishonest middlemen, it is contingent on the integrity of the principal’s agent to adhere to an ethical code of conduct. Further adding that when "rats" exist within a system, a carefully handled auditing and public scrutiny would be needed to expose malfeasance.

3.9 Factors affecting implementation of blockchain in supply chain

The identification of challenges and barriers to be managed is the first step in successfully implementing blockchain technology to trace ethical practises and manage supply chain operations and products (Saberi *et al.*, 2019b). In this section, various factors that must be considered for an effective blockchain solution and its adoption for ethical supply chains in construction are discussed**.** These factors are summarised and grouped into three main categories:

1. Factors related to the blockchain system
2. Factors related to the construction industry
3. Factors related to external barriers

3.9.1 *Factors related to the blockchain system*

Linking physical products to a digital ledger

Supply chains, unlike cryptocurrencies, which operate in a self-contained environment, are made up of tangible products, equipment, and materials that are separate or separable from their ledgers. Few assets are entirely digital, relying on both real and virtual world actors and mechanisms to keep the physical and digital worlds in sync. When used to track tangible assets, the blockchain ecosystem is no longer self-contained, requiring external inputs to keep the physical and digital worlds aligned (Sheldon, 2022). As a result, a digital version of a tangible object must be produced and recorded on the blockchain if blockchain is to be utilised for processing and tracing things to their sources. This tracking allows businesses to keep real-time views of their tangible asset holdings as well as view records of each item's provenance, which can affect its value.

Several asset identification mechanisms currently exist. Jabbari and Kaminsky (2018) posit that most of the available technologies such as barcodes, RFID-tags, 3D-stamps, and sensors, have some significant limitations, they are: duplicable, removable and replaceable. Mechanisms used must prove that they can effectively seal the object and authenticate them uniquely over time (Deloitte, 2017).

To achieve reliable provenance, a digital asset on the blockchain must remain in sync with its tangible counterpart in the physical world. This requires the digital asset to be promptly updated for any changes in ownership or custody of the tangible asset. While a single company might use a blockchain to track tangible assets, participants in a horizontal or vertical ecosystem can join a consortium to do so.

Establishing credible links between offline events and their online record

The World Trade Organisation argues that while the use of blockchain can enhance transparency and help trace products along the supply chain, it can only guarantee that information on the blockchain has not been tampered with (WTO, 2018). Off-chain processes may still require third-party verification to ensure that they meet the claimed assertions. For example, ethical and social claims made on a blockchain are only as good as the offline verification methods that ensure essential ethical and social requirements have been fulfilled off-chain. It is consequently critical to establish a meaningful relationship between offline events and their online records. While it can be relatively easy and cheap to verify transactions of goods whose offline attributes are easy to capture and expensive to alter, Catalini and Gans (2017) note that maintaining a robust link between offline events and online ledgers is still expensive in many cases and may often require multiple trusted parties within the same ecosystem to agree on validity of the entry. Connecting tangible products and events to a blockchain usually involves the use of enabling technologies such as the Internet of Things. This link can also be a security risk, as physical objects and IoT sensors can be tampered with (Helo and Shamsuzzoha, 2020).

Dependence on oracles

According to Kifokeris and Koch (2019), some researchers believe that blockchain is vague in its claim of value creation and that it is impossible to deploy without the concurrent implementation and support of other types of infrastructure, such as BIM and IoT. For digital data networking, blockchain relies on complementary assets, particularly the Internet. New IT tools are required to integrate blockchain technology and gather data for supply chain management, which can be a challenge for some supply chain actors (Saberi *et al.*, 2019b). The IT system to be used must also demonstrate that the whole infrastructure as a whole is effective, efficient, secure, and robust. Also, because it is a mix of technologies, standards must be created and agreed in order for them to work together (Deloitte, 2017).

Immutability

Immutability is one of the benefits of blockchain. This prevents data falsification and alteration. The inability to edit a blockchain ledger, on the other hand, could be an issue in and of itself. If an error is made in whilst entering data on the blockchain, the transaction may be inalterable. Although it may be rectified by a correction transaction, this may necessitate the beneficiary of the erroneous transaction's cooperation (RICS, 2020). Again, if a fraudulent transaction is performed, for example, by an employee who manages a company's blockchain ledger, it will be easy to track down the user who made the transaction but impossible to reverse it. Furthermore, because humans are still engaged in the application of this technology, it is possible to capture incorrect data. Palombini Maria (2017) argues that even though the key owners may be able to add new correct information, the blockchain will always have the scar of an incorrect record.

Scalability 'trilemma'

Following various investigations on the unique characteristics of blockchain, some researchers have proposed the concept of the blockchain trilemma. The trilemma is developing a blockchain technology that offers security, decentralisation, and scalability without compromising any one of them. It emphasises that these three key characteristics of a blockchain system cannot coexist flawlessly. That is, any improvement in scalability, security or decentralisation will adversely affect at least one of the other two. As a result, adequate considerations for balancing or even accomplishing these three elements of the blockchain system are critical for the creation of a network that can handle complicated implementations (Zhou *et al.*, 2020).

However, in the study "Scaling blockchains without giving up decentralisation and security" by Monte et al. (2020), findings disprove the trilemma considering the scalability of all architectural elements of a blockchain and not only the consensus protocol. It is believed that the theoretical result may stimulate significant practical contributions. The paper demonstrates that the blockchain scalability trilemma can be solved under reasonable assumptions, and it presents a structure that can be used as inspiration for practical implementations in both permissioned and permissionless scenarios. In addition, an innovative protocol called Algorand has been proposed to overcome these limitations (Conti *et al.*, 2019; Gilad *et al.*, 2017).

Data storage

According to Zheng et al. (2017), blockchain is not considered suitable for storing big data, due to the large volumes of data and low velocity of data taken for processing. The quantity of data that can be saved on a blockchain in a public blockchain is limited. Since construction projects comprise of a massive amount of data, Perera et al. (2020) proffers the storage of only the most important data required to be processed on the blockchain on-chain, and the storage of all other data off-chain as a solution to this.

The cryptocurrencies-scam stigma

Blockchain is still misunderstood, with some associating it with the dark web. Due to the "Silk Road" and other high-profile examples of people exploiting cryptocurrencies for illicit purposes, many people associate cryptocurrencies with crime (Rath and Kulnigg, 2019). It is a fact of life in law enforcement that criminals are always among the first adopters of any novel technology that works (Yar, 2005) and law enforcement has a long history of adapting in order to pursue criminals who use new technology to commit old crimes. Rath and Kulnigg (2019) and Weinstein and Cohn (2019) argue that contrary to popular belief, blockchain technology is friendlier to law-enforcers than it is to law-breakers and as it becomes more established, a wider audience will come to understand what blockchain offers beyond cryptocurrency (O'Grady, 2019).

Cost

The development and deployment of blockchains can be labour and resource intensive. Expert programmers are needed to write the code for a blockchain-based application, and in some circumstances, specialised infrastructure, such as dedicated server farms, are required to manage the blockchain protocol (RICS, 2020). The advantages of blockchain ledgering over conventional ledger systems such as low transaction costs and fast execution speeds must be weighed up against the infrastructure costs, both for setting up the blockchain ledger and for maintaining it. In some cases, the overall costs may be as expensive as a traditional ledger system if these costs are aggregated throughout the life cycle.

Cyber security threat

According to Aggarwal and Floridi (2019), although cryptographic technologies and algorithmic consensus processes provide security benefits, blockchain is not immune to malevolent actor attacks. This might happen either within the blockchain or via software clients, third-party applications and smart contracts. The threat of cyber security is one of the most significant challenges that blockchain faces. Since the beginning of 2017, hackers have stolen roughly $2 billion in cryptocurrencies (RICS, 2020). Yang (2019) posits that all blockchain implementations, from fully open to completely private, are vulnerable to both internal and external threats, and security breaches and malfunctions are very likely before the technology fully develops. Smaller blockchain implementations are more vulnerable because rewriting the chain requires less computing power. Consortium (2020) argues that the notion that blockchain technology is inherently secure is incorrect because security flaws have been discovered, and more could be discovered in the future, hence the need for security issues to be identified and addressed rapidly on an ongoing basis.

3.9.2 *Factors related to construction industry*

The slow response to new technology

The construction industry is known for its lateness in adopting new technologies and its history of resistance to change (Kassem et al., 2018). According to Tezel et al. (2020), there are currently no substantial exemplary use cases in blockchain based asset digitization, supply chain management, procurement, etc. in the industry. This is exacerbated by the limited understanding of the workings of blockchain within the construction sector, making knowledgeable practitioners relatively rare (Kifokeris and Koch, 2019). Due to this constraint, a genuine investment in blockchain for construction logistics may require the development process to be outsourced to blockchain technologists which may be unfamiliar with the construction supply chains environment. Even companies who want to adopt BIM find it difficult to find qualified personnel (Abrishami *et al.*, 2014). Also, Kassem et al (2018) argue that the construction industry is not current sufficiently digitised to take full advantage of blockchain technology. In addition, the perceived risks and hesitancy associated with the technology's immaturity has prompted construction members to take a "wait-and-see" approach to blockchain technology.

Intra-organisational barriers

Another challenge would be to persuade the relevant players and stakeholders to adopt a new digital business model based on this technology. Apart from the financial cost effects that comes with the implementation of new technology, the use of blockchain technology has the potential to alter or modify present organisational cultures and replace legacy systems (Mougayar 2016). In addition, incorporating blockchain technology into supply chain processes necessitates the creation of new roles and skills to support various aspects of technology adoption. Adoption of this new technology into the supply chain is hampered by a lack of technical competence and knowledge of blockchain technology. Whereas companies have made heavy investment on building their Enterprise Resource Planning (ERP) systems in the last few decades (Wang et al., 2017) and have gotten accustomed to maintaining their business activities on their own ledger in the last many centuries. Conversion to new systems may alter organisational culture or hierarchy, causing individuals and organisations to hesitate its implementation (Saberi *et al.*, 2019b).

Inter-organisational barriers

Blockchain requires a team. It works best when companies collaborate, even if they are competitors, to set up processes, share data, and automate processes via smart contracts. To develop a global end-to-end supply chain solution using blockchain, all stakeholders must agree to invest in and use these new technologies. This is required to make it viable and provide traceability throughout the chain (Deloitte, 2017).

However, integrating information technology and sustainability practises may be difficult between partners. Although information transparency and verifiability are required to assess a supply chain's sustainability, some organisations may view information as a competitive advantage, making it difficult to share vital information (Viriyasitavat and Hoonsopon, 2019). Difficulties in data sharing between partners due to differing privacy policies could arise. This reluctance from some partners to reveal information may limit the full benefits of adopting blockchain technology and impede implementation (Saberi *et al.*, 2019a). However, PWC (2020) points out that once stakeholders understand the value that comes out of it, blockchain will become an integral part of business technology. Also, finding the right balance of confidentiality and transparency will be critical in convincing all stakeholders to use a distributed ledger to record and share supply chain data. A company's business activities and strategy could be easily accessed if all information is put on a ledger without enough confidentiality barriers (Deloitte, 2017).

3.9.3 *Factors related to external barriers*

External barriers

External pressures and support for implementing ethical and technological practises can encourage businesses to incorporate them into their operations. A barrier to achieving sustainability and advanced technological supporting mechanisms is a lack of appropriate governmental and industry policy and willingness to direct and support sustainable practises (Saberi *et al.*, 2019b).

Digitized ecosystem

Another important aspect of expanding use cases is ensuring that the blockchain has access to sufficient amount of data and transactions. Blockchain technology is aimed at managing information, data, and value, it does not solve the problem of data collection per se (Schmidt and Sandner 2017). As a result, it is critical to ensure that sufficient qualified data is available for blockchain use, and this may currently be a challenge in the Global South. The majority of countries in the Global South face a digital divide, which may hamper innovation in the development of their digital economies (United Nations Global Compact, 2017). Indeed, the efficiency of a blockchain-based platform is determined by a country's social and digital infrastructure, as well as the population's technological literacy (Aggarwal and Floridi, 2019).

Regulations and policies

In many countries, there are still gaps in legal regulations regarding blockchain-based supply chains and procurement mechanisms. Without addressing regulatory concerns about privacy, money/value transmission, anti-money laundering, and information reporting, blockchain use cases cannot be scaled up to commercial levels. This has led to the unavailability of sufficient evidence on business gains for the industry (Tezel *et al.*, 2019). Also, there remains considerable legal and regulatory uncertainty over blockchain-based transactions. The difficulty of altering the blockchain, makes it unclear how regulations such as the EU's General Data Protection and Regulation (GDPR) data privacy 'right to erasure' law will be enforced. Furthermore, because the blockchain is distributed, it raises issues of conflict of laws because the nodes are spread across multiple jurisdictions. It is also unclear who will be held responsible if the network malfunctions (Aggarwal and Floridi, 2019).

3.10 Summary

In this chapter, the workings of blockchain technology and its implementations for ethics within the TBL construct is studied. An evaluation of the core characteristics, underlining elements of the technology and the outcomes of its implementation in other supply chain does position it as a technology that holds strong potential within the construction industry supply chain environment. This is in tandem with the propositions of ICE (2018), Kassem et al. (2018), Li et al. (2019), M Rodrigo et al. (2018), Qian and Papadonikolaki (2020), Smith and O'rourke (2019), Tezel et al.(2019) and Turk and Klinc (2017) and several other researchers.

The findings in this chapter reveal that new technologies in construction, such as BIM, that promise to improve collaboration in the construction sector appear to be stifled usually by issues of trust among actors (Dave *et al.*, 2018; Hunhevicz and Hall, 2020). In respect of this and other obstacles identified in the chapter, findings show that due to blockchain's core characteristics, it does indeed have potential of tackling the identified ethical challenges within the CPMSM. However, it also points out that blockchain is neither a panacea nor a magic bullet (Aggarwal and Floridi, 2019; Boersma and Nolan, 2020); rather, it is a socio-technical tool, in that it functions as a technology tool that could (should) influence individual and organisational culture. Furthermore, its code can get no better than the rules of collaboration set and the members of the network and the willingness of the network members to act collectively (Belle, 2017). Hence, beyond technological solutions, human collaboration is key to the achievement of best practice and the afore stated ethical goals within the CMPSC.

In the next chapter, the conceptual model developed to achieve the overarching aim of the research is proposed and discussed. In addition, the theoretical framework underpinning the proposed conceptual model is also discussed in the next chapter.

Chapter 4 Theoretical framework and conceptual model

4.1 Introduction

According to Kuada (2012), theory provides the concepts, the structure, and assumptions that help researchers to make sense of the phenomenon that they seek to investigate and enables them to connect it to the existing body of knowledge in the field. Researchers can use a theory to make predictions about the phenomena being studied. They can to figure out which variables to look at and how to gather, analyse and evaluate data to present and support findings (Rocco and Plakhotnik, 2009). Theoretical frameworks provide a particular perspective, or lens, through which to frame, inform or examine a topic. Such lenses include group theories, psychological theories, social theories, organisational theories and economic theories, which may be used to define concepts and explain phenomena (Elangovan and Rajendran, 2015). The selected theory (or theories) underlies the thinking of the researcher with regard to how the concepts and definitions from that theory are relevant to the fundamental goal of the research (Grant, 2014). A conceptual model, on the other hand, is a system representation. It is often an abstraction of real-world systems, whether physical or social, and it comprises of concepts intended to assist people analyse, understand, or simulate a subject the model depicts (Tang and Omega, 2021).

4.2 Rationale for the theoretical framework and conceptual model

Chapter 2 describes the nature of the construction industry with a focus on its supply chain. It reveals that the supply chain for construction materials and products is a huge network typically comprising a variety of resources, processes and players involved in the production of materials and products; and provides evidence of how the activities of these networks hugely impact the environment, people and the economy. Hence, the need to maintain a supply network whose members respect and strive to integrate fundamental environmental, social, and business standards within its supply-demand network. Therefore, a holistic triple bottom line approach is utilised to evaluate the current ethical state of its materials and product supply chain to help understand how it can be improved and the roles blockchain can play in its improvement.

Based on a critical review of substantial literature, it was found that although several strategies to uphold ethics in the construction industry have already been proposed and employed with varying degrees of implementation across various countries; evidence of unethical environmental, social and business practices are still abundant within the construction materials and products supply chain. In addition to transparency and digitization, more collaboration between supply chain participants on ethical initiatives was also identified as a key contributor to the improvement of ethics in the supply chain. Hence, the need for the further development of systems that synergise these factors to improve the achievement of the industry's ethical goals.

In Chapter 3, following the propositions of the ICE (2018), Kassem et al. (2018), Li et al. (2019), M Rodrigo et al. (2018), Qian and Papadonikolaki (2020), Smith and O'rourke (2019), Tezel et al.(2019) and Turk and Klinc (2017) and several other researchers, that blockchain technology due to its key characteristics and underlining elements has some potential to provide solution to some of the construction industry's well-known problems. The workings of blockchain technology and how it has assisted in the supply chain of several industries are examined, considering its benefits, prospects, as well as its limitations. This section also critically considers the factors that affect the implementation of blockchain within supply chains. The learnings from the chapter help to evaluate the suitability and feasibility of the technology in improving ethics within the construction supply chain environment.

The findings in this chapter reveal that new technologies in construction, such as BIM, that promise to improve collaboration in the construction sector appear to be hampered once again by issues of trust among actors (Dave *et al.*, 2018; Hunhevicz and Hall, 2020). In respect of this and other obstacles identified in the chapter, findings show that blockchain due to its core characteristics does indeed have potential to tackle the identified ethical challenges in construction materials and products supply chain (CMPSC). However, it also points out that blockchain is neither a panacea nor a magic bullet (Aggarwal and Floridi, 2019); rather, it is a socio-technical tool, in that it functions as a technology tool that could (should) influence individual and organisational culture. Furthermore, its code can get no better than the rules of collaboration set by the members of the network and the willingness of the network members to act collectively (Belle, 2017).

Given the complexity of the construction materials and products supply chain (CMPSC) and the multiplicity of ways through which unethical practices can be perpetuated, the findings from Chapters 2 and 3 stress the inability of individual companies to tackle the systemic challenges alone and suggest collaboration as a pivotal component for developing tools and best practice (CIOB, 2018a). Hence, in order to understand, set up and propose a feasible collaborative solution, the collective action theory is utilised as the theoretical bedrock for the proposed solution. The collective action theory lends itself to an understanding of the intricacies of collaborative systems. Hence, a critical evaluation of the theory helps to recognise the countervailing reasons for individuals not to cooperate (Olson, 1965), even though we should cooperate because it is socially optimal to do so and it is in our individual "enlightened" self-interest to do so (Bentley, 1967; Jordan, 1999). These findings help to shape the development of collective action agendas that take due account of the "rationality" of humans and hence, help to develop a more robust and feasible solution. This is in tandem with the overall aim of this study.

Furthermore, blockchain is often hailed as a collaborative and trusted ecosystem which works best when individuals or groups collaborate, even if they are competitors, to set up processes, share data, and automate processes via smart contracts (Baliga, 2016; Belle, 2017; M N N Rodrigo *et al.*, 2018; Marquardt and Pohlmann, 2021; Tan and Ngan, 2020). This presents it as a potential technology upon which a system to achieve collective action as well as mitigate its challenges as identified by theorists can be built. Hence, this study utilises the theory of collective action as the theoretical framework that underpins the conceptual model developed to improve ethics within the CMPSC through blockchain. The model is developed to incorporate the principles of collective action to improve ethics in the CMPSC whilst leveraging the core features of blockchain. The theoretical framework underpinning the proposed model is discussed in the subsequent sections of this chapter.

4.3 The theoretical framework

4.3.1 *Collective action theory*

Collective action is a group theory that investigates the "actions undertaken by individuals or groups for a collective purpose"(Postmes and Brunsting, 2002, p. 290). According to group theorists (Jordan, 1999; LaVaque-Manty, 2006; Verba *et al.*, 2000), when individuals have a shared goal and will profit from collaboration, they will establish a group to work together for the greater good (Gillinson, 2004). Collective action theory, as formulated in the social sciences, posits rational social actors who regularly assess the actions of others to inform their own decisions to cooperate (DeMarrais and Earle, 2017). Cooperation is socially optimum, according to theorists ranging from Bentley to Schlozman and it is clearly in everyone's best interests to collaborate, therefore they do; the story ends here for Bentley and the group theorists.

Mancur Olson's major paper, "The Logic of Collective Action," however, turned this on its head (Olson, 1965). There are countervailing motives for the individual not to collaborate, according to Olson. The 'problem' of collective action arises as a result of these factors. As Olson points out, if society is made up of many rational people, it will not be just one, but every single one of them who tries to free-ride.

We will free-ride and leave cooperation to others, according to Olson, where we believe we can get the benefits of cooperation without contributing to the expense. Olson's conditions for collaboration stated that we cooperate when one or more of the following three conditions are met: when free-riding would be detected because the group is small; when we are compelled to do so and/or when “selective incentives” are being used to persuade us to collaborate. However, his model of the “rational” individual is criticised by group theorists because it sees collaboration as merely a by-product of narrowly conceived, individually rational activities (Gillinson, 2004). As a result, theorists like Schlozman (1995) have created a more comprehensive approach. They argue that our emotions or passion for a cause often lead us to act collectively, and that Olson's notion of rationality is too thin (Verba *et al.*, 2000).

Enriching Olson’s critique

Although Olson’s logic of collective action led him to the conclusion that we will not cooperate as rational individuals, except under very limited circumstances. Despite this, we observe numerous examples of cooperation today that do not meet his criteria for "when" we should cooperate. For instance, in the social context, one example was the massive “Black Lives Matter” demonstrations that peaked in 2020, taking centre stage all around the world. Black Lives Matter (BLM) is a decentralised political and social movement that seeks to highlight racism, discrimination, and inequality experienced by black people. When its supporters come together, they do so primarily to protest incidents of police brutality and racially motivated violence against black people. The BLM movement was nominated for a Nobel Peace Prize in January 2022. Another of this kind was the “End Sars” protest, which was another decentralised social movement, and a series of mass protests against police brutality in Nigeria that led to the deaths of several protesters. In both of these cases, the groups involved were not small, neither were participants coerced into taking these actions nor incentivised to induce their cooperation.

Also, in the technology space, the emergence of Internet-based technologies such as open-source software developments and crowdfunding platforms for example has made collective action become even more “theoretically and empirically intriguing” (Bimber et al., 2005, p. 365). Open-source software projects are growing in importance as an economic and social phenomenon that contradicts Olson's model and private investment paradigms. Thousands of free and open-source software projects exist today with millions of software users. Linux is a well-known example of open-source software, and it runs the servers for many of the services with which we share personal information on a daily basis, including Google, Facebook, and other major websites. Linux is not owned by a company, it is free to use, and it was developed through a collaborative effort. Since its inception in 2005, more than 20,000 developers from over 1,700 firms have contributed to its code (Linux, 2018). Also, much of the software code that serves as the base for blockchain and cryptocurrency has been developed using open-source software (Nakamoto, 2008). Hyperledger is another multi-project open-source collaborative effort hosted by The Linux Foundation, created to advance cross-industry blockchain technologies (IBM, 2020). Clearly, the collective action to build open-source software is not hindered by prevailing opinion that implies that appropriate incentives must be given to encourage participation and punish defection in order for participants to contribute software code. Despite the fact that they are prone to it (free-riding), as potential software beneficiary has the option.

In addition, crowdfunding, a method for soliciting financial support from (potentially) large numbers of people typically through the internet is another vivid example of this. Online portals or third-party platforms are used to advertise a particular funding need and a request for donation is made. Crowdfunding has proven to be efficient in raising money for a broad range of applications.

At an institutional level, the Royal National Lifeboat Institution (RNLI), the largest charity that saves lives at sea around the coasts of the United Kingdom, the Republic of Ireland, the Channel Islands, and the Isle of Man, as well as on some inland waterways does not coerce people into joining and does not provide selective benefits for its members. Yet, over 32,280 people had registered as volunteers as of 2019. In 2015, crews rescued on average 22 people a day (RNLI, 2015).

According to Cohen (1985), we know that the post-industrial society is new because it triggers new forms of collective action. As a result, Olson's -thin- model of the “rational” individual has been widely criticised. Critics argue that it ignores the elements that they believe make us human - emotion, passion, and a limited ability to analyse the actual advantages and disadvantages of a scenario. Various models have since been presented to flesh out Olson's rational individual in order to provide a more realistic paradigm of human decision-making (Gillinson, 2004). Many of which propose the addition of three further factors to enrich Olson’s list and not to replace it. We cooperate when we are impassioned about a subject, especially when we are mobilising against a common evil; we cooperate when we would profit from the company of like-minded people or when we are professionally representing ourselves or a firm; and we also cooperate for the good of the community if it is in peril and we believe no-one else will (Oliver, 1984).

The concept of collaborative action is multi-dimensional when put into practise. Its application may vary depending on the unique needs recognised or the circumstances faced by parties who want to work together (OECD, 2020). Collective action can take many different forms, each with its own set of binding commitments. A statement or declaration condemning corruption, an integrity agreement, a project to promote uniform norms and values, or a certification process are some examples. In this study, collective action lies at the core of the proposed model developed to improve ethics in the CMPSC. In practise, participants must act collectively to fulfil their individual functions on the proposed network. Only then can the potential of the proposed model to achieve its aim, which is to improve ethics within the CMPSC, be fully realised.

Achieving collective action

Ostrom and Walker (2003) make further additions to Olson's list by pointing out that the core relationships of reputation, trust and reciprocity affect cooperation to a great extent. They argue that this relationship is so important that the links between one participant's trust in other participants in a collective action situation are at the heart of a theoretical explanation of a successful or failed collective action. Also, Tang and Omega (2021) particularly emphasise the relevance of social ties and trust, arguing that large-scale collaborative decision-making technologies require an underlying trust and reputation architecture in order to trigger meaningful cooperation.

Marquardt and Pohlmann (2021) affirm that aside from the well-known applications of blockchain, its key properties, which ensure higher transparency and integrity, strengthen trust and reputation in distributed decision-making processes, can potentially make it an engine for large-scale collective decision-making. The technical features and properties of blockchain have the potential to accelerate collective action; sets of rules and conditions could be coded into smart contracts to help mitigate free riding. Hence, blockchain not only provides a distributed and transparent mechanism to establish consensus, but can also leverage trust due to a commonly agreed consensus process within the entire network and thus have a great potential to trigger collective action (Marquardt and Pohlmann, 2021). Furthermore, as Rozas *et al.* (2021) point out, that blockchain gives commons-based peer production communities the opportunity to socially create software that makes specific actions and operations more easily trackable, auditable, and communally validated by the members. Nevertheless, Khan (2017) warns that collective action blockchain based models should be cognizant of the limitations of the technology.

Hence, the model developed to improve ethics within the CMPSC with the triple bottom line approach in this study relies on a robust construct of the human rationality and robust intrinsic and extrinsic factors that spur individuals into cooperation.

Rationale for collective action

Given the scope and complexity of unethical practises in the supply chain, a single company's actions, while noteworthy, may have only a minimal impact. Collective actions by several corporations in a given industry have proven to be far more effective in supporting standards that companies will actively follow (OECD, 2020). However, collective action requires time, expertise and close collaboration to succeed. Also, there is growing support for collective action. The United Nations Global Compact's new 2021–2023 Strategy, an ambitious corporate sustainability project that aids firms throughout the world in achieving sustainable and responsible business operations throughout their supply chains, is developed with a strong emphasis on collective action. The UN Global Compact's support for collective action is part of a broader trend among standard-setters, international organisations and governments to promote this approach (OECD, 2020; SDGs, 2018; UN Global Compact, 2010).

4.4 The conceptual model

Conceptual modelling, in its broadest sense, is the process of creating a graphical representation (or model) of the real world. It gives an easily understood depiction of the system for the various stakeholders participating in collaborative problem-solving. The process of conceptual modelling necessitates establishing assumptions about the situation under consideration. The conceptual modeller must decide which characteristics of the real world to include in the model and which to leave out, as well as at what level of detail to model each one. According to Chan *et al.* (2015), modelling is the task-driven, purposeful simplification and abstraction of a view of reality moulded by physical and cognitive restrictions that leads to a conception of the relevant subset of the problem domain. Robinson (2008) posits that assumptions and simplifications exist in conceptual models. When there are unknowns or views about the real world to be modelled, assumptions are made. Simplifications are incorporated into the model to enable more rapid model development and use and to improve the transparency of the model. Model abstraction is linked to simplifications since they are purposeful choices to model the world more simply.

4.4.1 *Rationale for blockchain as the technology underlying the model*

As discussed in Chapter 3 of this study, blockchain, due to its core features allow for distributed, immutable, automated, transparent, and trustworthy databases which are elements necessary to improve trust and foster collaboration among individuals who may have varying interests (Marquardt and Pohlmann, 2021; Tan and Ngan, 2020), thereby making it suitable for use in the construction industry supply chain environment (Lanko *et al.*, 2018a).

Current IT applications to manage the complex supply chain of the construction industry utilise a centralised platform to record, manage, trace and analyse the data (San *et al.*, 2019). However, many of its limitations stem from the lack of information reliability as information stored in centralised servers is inherently more vulnerable to tampering and attacks (Yang, 2019). They are also susceptible to external single point of attack and Single Point of Failure (SPoF) where just one malfunction or fault compromises and topples the whole system. OECD (2020) asserts that distributed ledger technologies like blockchain, have the potential to improve current processes and systems by acting as a digital enabler across the infrastructure value chain.

Also, a transition to decentralised services and implementing smart contract and blockchain technologies will ensure a proper level of transparency and credibility within supply chains and that of the construction industry in particular (Lanko *et al.*, 2018a). According to (Wang *et al.*, 2017), provenance-related applications to improve transparency and traceability of the construction supply chain, transaction-related applications to facilitate automated procurement and payment, and notarization-related applications to eliminate the time spent verifying the validity of documents are major potential applications of blockchain in the construction supply chain. Similarly, (Perera *et al.*, 2020) point out that blockchain-based supply chain management improves payment security, helps to verify product compliance and authenticity, streamlines payment processing, lowers finance costs, builds confidence between suppliers and clients, and provides transparency for auditing operations. World Trade Organisation (2018) recognises traceability of products along the supply chain to assert origin, authenticity, and ethical and social claims as undeniably some of the most promising uses of blockchain technology.

Also, according to OECD (2020), the core features of blockchain technology can be used to drive the systemic changes needed to deliver sustainable infrastructure. Due to the stronger drive for sustainability across several sectors in recent times, clients and stakeholders are now requiring access to relevant standardised information, not just on business performance, but also social and environmental-related disclosures on their infrastructure (OECD, 2020). Given that existing data is fragmented and may be unaligned with climate objectives, a blockchain-enabled platform would provide the digital backbone required to support data transparency for sustainable infrastructure development. In fact, Global Enviromental Facility, (2019) affirms(that it is an enabling technology that can help with the secure monitoring and tracking of environmental data and natural resources, thereby facilitating their effective management and enabling sustainable outcomes.

Hence, the core features of blockchain technology favourably position it as a potential technology upon which a system to improve ethics in CMPSC following the TBL construct can be built. The approach blockchain takes to addressing ethics within each dimension of the TBL construct is discussed in subsequent sections of this chapter.

4.4.2 *The proposed model*

The model proposes a socio-technical solution to improve ethics in the CMPSC via a collective action approach that seeks to bring together the multiple parties involved in the construction materials and products supply chain (including organisations involved in mineral extraction, forest harvesting, production, manufacturing, retailing, logistics, waste management, etc.); organisations that help to drive ethics in production and supply chains (either by creating standards, helping to implement them or monitoring their implementation); customers who procure construction materials and products (either as a singular individual or integrated as part of a construction organisation/team); and stakeholders involved in the delivery of a construction project (including clients or client representative, consultants, contractors, sub-contractors, etc.) to work collaboratively to improve ethics within the TBL construct in the CMPSC. A conceptual illustration of the model's evolution is presented in Figure 4.1.

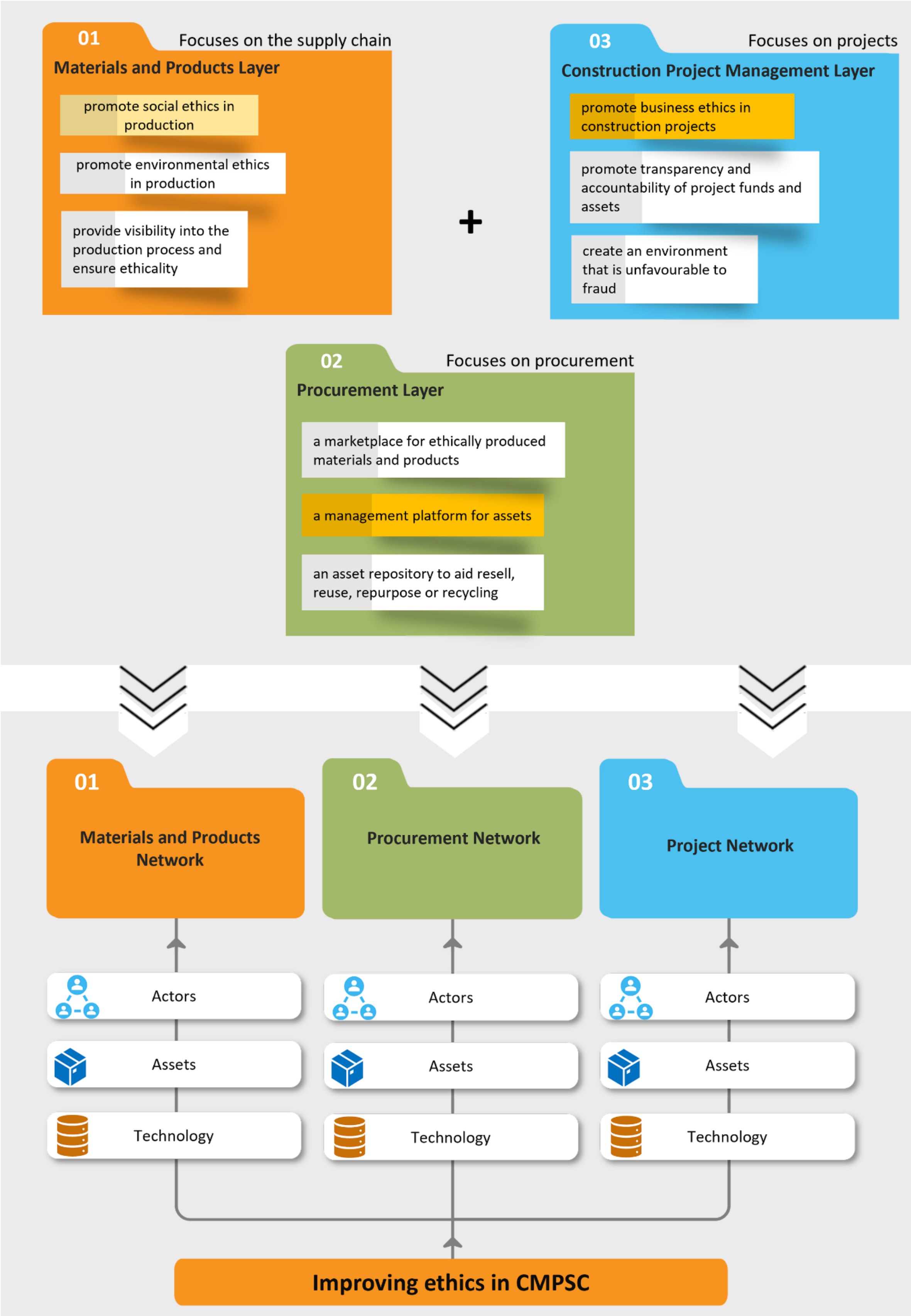

Figure 4.1 A conceptual illustration of the model's evolution

In order to achieve the afore stated goals, the conceptual model based on blockchain is made up of three sub-models as illustrated in Figure 4.1. These sub-models function as distinct yet integrated networks of the overall model, namely: the material and product network (MP-Network), the project network and the procurement network.

Firstly, the MP-Network comprises of supply chain actors who respect social and environmental ethical standards in their production; ethically sourced and produced construction materials and products; and the underlying technological infrastructure. Secondly, the project network is a project-by-project consortium based blockchain platform where multiple organisations/stakeholders involved in the project can decide, verify, execute, and record transactions collaboratively. Thirdly, the procurement network functions as an e-commerce online marketplace that brings actors onto a single shared platform, with enough degree of transparency to verify product ethicality and authenticity. The workings of the elements and components of the model and how its sub-models (networks) integrate to achieve the model's overall objective are identified and discussed in the subsequent sections of this chapter. The developed conceptual model is presented in Figure 4.2.

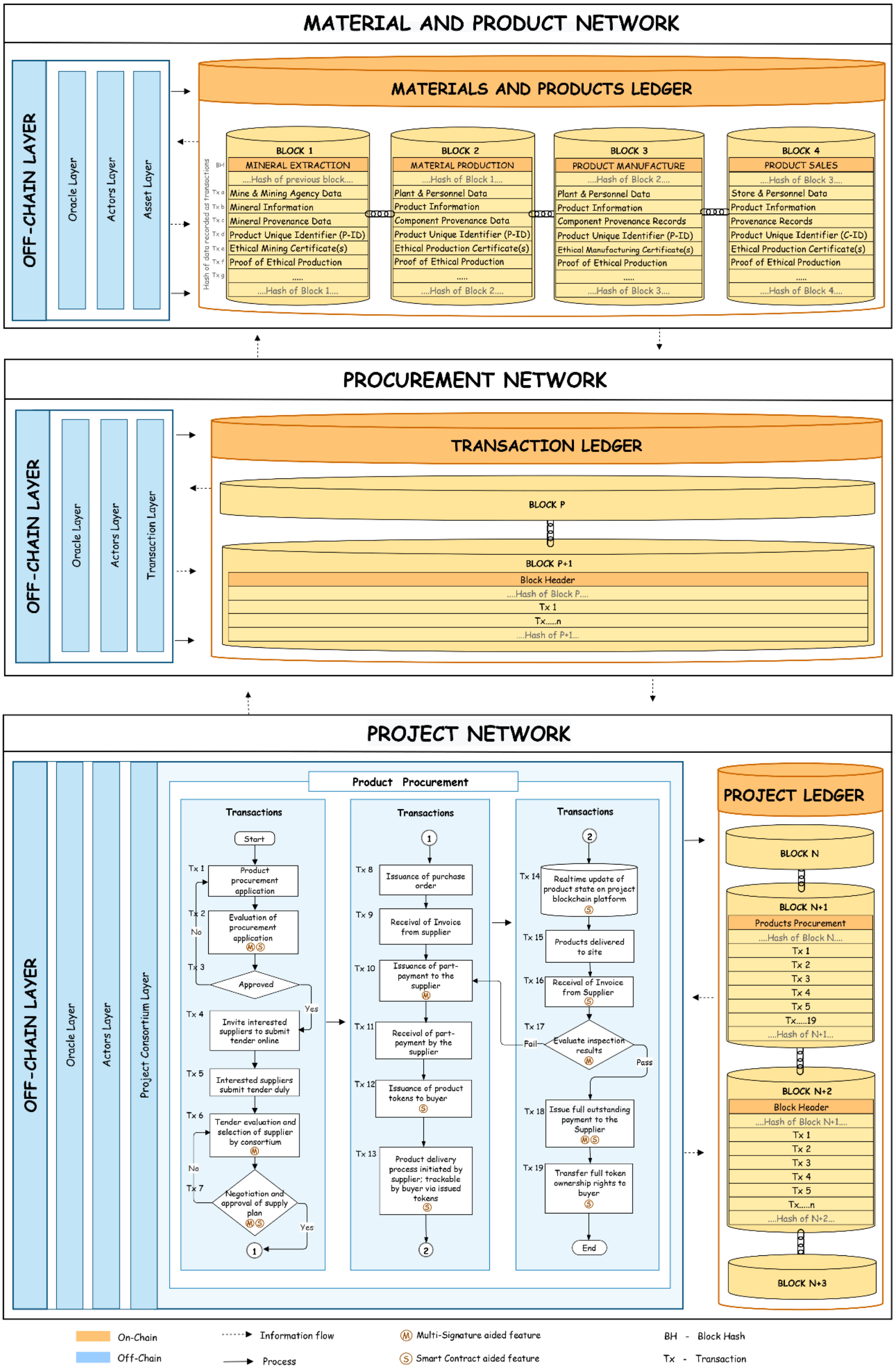

Figure 4.2 The conceptual model developed to improve ethics within the CMPSC

4.4.3 *Material and Product Network (MP-Network)*

This is a proposed digital network of ethically sourced and produced construction materials and products. It proposes a collaboration between several actors, which includes organisations involved in the construction materials and products supply chains, organisations that help to drive ethics in production and supply chain, and customers who procure construction materials and products. The several actors that collaborate on this consortium network control their own data, and the network provides a secure way to share it publicly. The ethical claims made by organisations are validated before the organisations and their products get listed on the network. The registered assets are digitized, thereby, enabling the tangible assets to be tracked through their digital counterparts on the network. Individual actors are responsible for the accuracy of their data and the network utilises smart contracts and other blockchain features and elements to confirm the validity and authenticity of the data provided by actors through a Proof of Authority (PoA) consensus algorithm.

The model also utilises data protection and data access clearance mechanisms to enable actors to grant permission to certain types of data on a need-to-know basis. Thereby providing an appropriate degree of data transparency that strikes a balance between ensuring transparency on the one hand, and on the other hand, protecting trade secrets and respecting data confidentiality. This network allows for the ethically produced materials and products (assets) registered therein to be queried by those with the appropriate permissions to verify proof of ethical production across the supply chain tiers (individual actors/materials involved in the production of the asset). The actors collaboratively play different roles on the network to achieve the overarching aim of the model. The means by which this is accomplished is explicated in subsequent parts of this section. The Material and Product Network sub-model is presented in Figure 4.3.

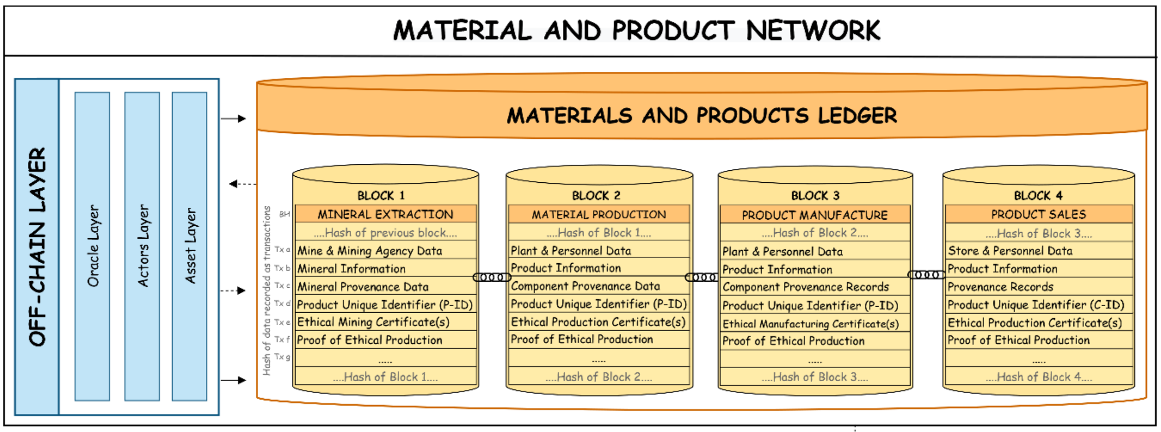

Figure 4.3 Sub-model 1: Material and Product Network

The fundamental goal of a blockchain is to store information, which makes it a database. However, blockchains differ from other database types in the way they store data. On traditional databases, data can be created, read, updated or deleted; however, on blockchain, data can only be read or added. Due to the immutability of the data on the blockchain, if all the data involved in a transaction is stored on the blockchain, the data will build up and the network will eventually become overloaded. Also, because the data saved on-chain must be stored by every full node on the network, this would increase the overall size of the blockchain ledger, resulting in an increase in the system requirements for full nodes. In addition, most personal or confidential information may need to be erased at some point under GDPR policy, but data deletion from the chain is not possible by design.

Moreover, blockchains are designed to be fast, streamlined, and lightweight, and as such, they are not ideal for storing large amounts of data. Hence, transactional data can be stored on the blockchain (on-chain), while other forms of data associated with the transaction may be stored elsewhere (off-chain). While storing large volumes of data on-chain might cause severe performance issues, placing too little information on the blockchain also implies that counterparties may not have access to enough information to trust one another. Hence, this model proposes a dual-layer data solution for the material and product network that combines an off-chain layer and an on-chain layer to meet the functional requirements of the model. The off-chain layer contains non-transactional data that is too large to be stored in the blockchain efficiently, or that requires the ability to be changed or deleted, whilst the on-chain layer (materials and products ledger) contains transactional data and hashes that are directly linked to the non-transactional data or other large data that is associated with the transaction, stored off-chain.

4.4.3.1 Materials and Products Ledger (MP-Ledger)

This model proposes the storage of only hashed representations of large sets of the data on-chain. This involves generating a unique digest/fingerprint of a given data item; the resulting hash value is then stored on-chain. As the hash value is substantially less than the data, this results in a significant decrease in the amount of data stored on-chain. When a user is presented with raw data for future validation (for example, during auditing), the user can generate the hash using the raw data and then compare it with the hash stored on the blockchain. As a result, the integrity of data may be ensured by keeping the hash of the data on-chain (Blockchain Patterns, 2020). Therefore, the MP-Ledger is fed by the off-chain layer which garners and stores other contract-related data too large to be stored on the MP-Ledger and also helps to verify and update the MP-Ledger on real world transactions, occurrences and identities. An illustration of the MP-Ledger is presented in Figure 4.4.

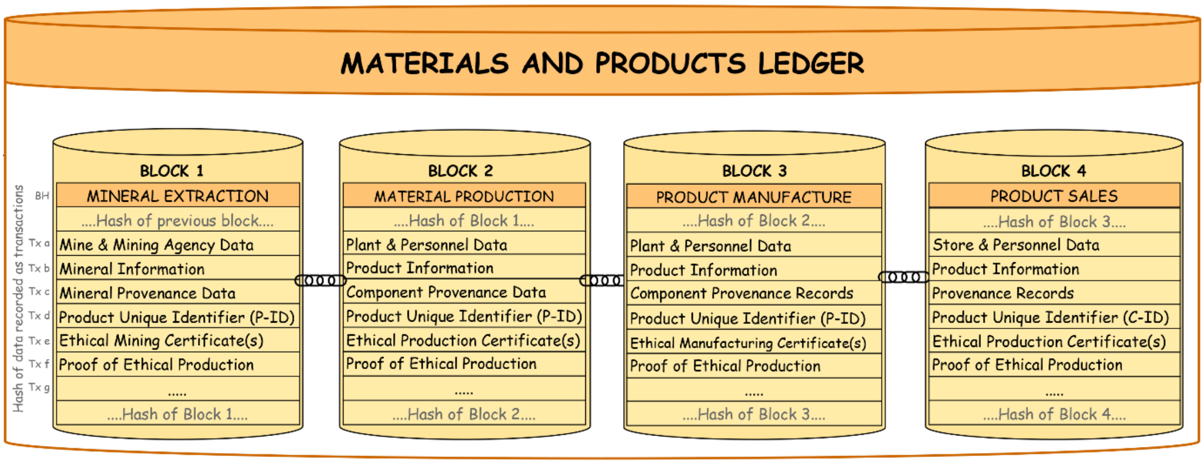

Figure 4.4 An illustration of the MP-Ledger

The MP-Ledger contains "blocks" that store data (including hashes) about assets (ethically produced materials and products); hence, referred to as "asset blocks". This ledger of ethically produced materials and products (assets) can be queried by those with the appropriate permissions to verify proof of ethical production across the supply chain tiers (individual actors and materials involved in the production of the asset).

Asset block

The asset block is a block of data about an asset (construction material or product) that has been validated and authenticated through the network's consensus protocol and hence added to the existing chain of asset blocks in the MP-Ledger. While the asset profile stores and manages different types and sizes of data associated with the asset, the asset block however only records and stores hashes of data needed for on-chain processes such as the asset's transactional data, chain of custody data, proof of ethical production, etc. These transactional on-chain data can be captured through oracles (that read bar codes, digital tags assigned to tangible products that allow for those products to be tracked along the supply chain) and relay the captured data to the blockchain. For example, associated snapshots of the product's state may be intermittently taken as the product move through the supply chain can be stored off-chain and the hash value can be recorded on-chain as a transaction. Also, the "proof of ethical production", which is a digital certificate issued to assets on the network that serves as evidence that the asset has been produced with respect for fundamental environmental and social ethical standards, is also stored on the MP-Ledger (on-chain), whilst the associated proofs (e.g., certificates, documentation, assessment records, ecolabel data, etc.) are stored in the asset profile on the off-chain layer. An illustration of the asset blocks are presented in Figure 4.5.

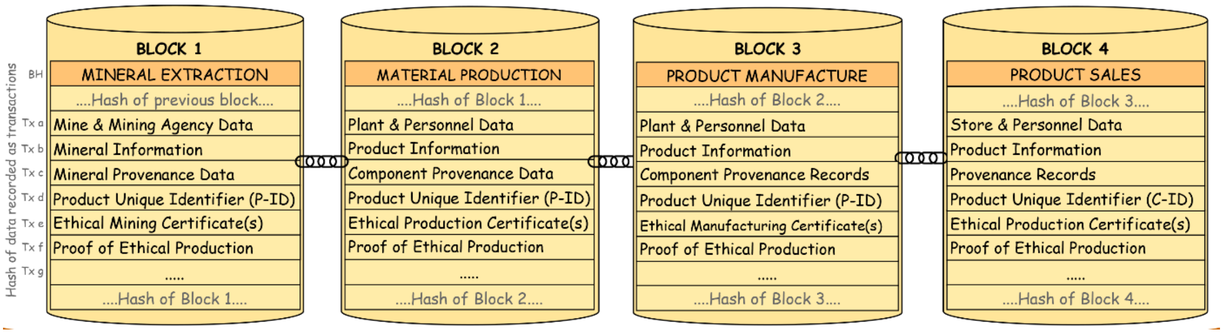

Figure 4.5 An illustration of asset blocks

Each block contains a hash of the data on the actor's asset profile which fundamentally includes organisation-related data, (e.g., producer or manufacturer's data, the location of the facility, proof of adherence to social ethics within the organisation, etc.); hash values of provenance related data which could include origin and ownership data, block header of assets (materials/products) that make up the finished product. It also contains hash values of asset related data such as material/product details and properties, product LCA, ethical production certificate(s), etc. The data supplied in each asset block aids the indication and verification of ethical production across the individual players involved in the production of that asset (including its raw materials) when actors with the required permissions run a query on the system. As earlier alluded, the "proof of ethical production" certificate contained in each block can be publicly seen on the block and shared with upper/lower tiers of the supply chain. This serves as substantial proof to customers and procurers of the ethicality of the product and its production process without necessarily having to look through other contents of the block. This digital proof of ethical production is immediately presented to the buyer when the tag on the tangible product is scanned on delivery.

4.4.3.2 Off-chain layer

The off-chain layer of the MP-Network consists of an oracle layer, actors layer and asset layer and their workings are discussed below. An illustration showing the Off-chain layer and its components is presented in Figure 4.6.

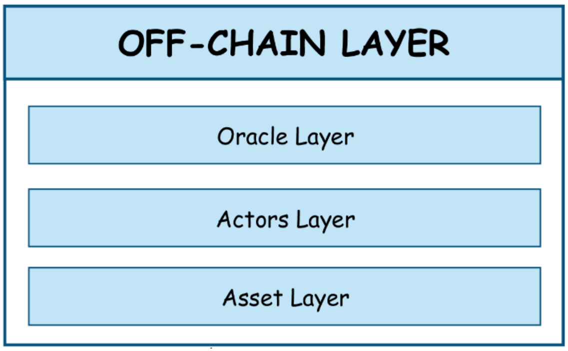

Figure 4.6 An illustration showing the Off-chain layer and its components

Oracle layer

Many blockchains cannot function without oracle networks that link them to underlying database storage. Hence oracles operate as a decentralised third-party technology that connects blockchain ledgers and smart contracts to the real world and off-chain data storage (Carey Wodehouse, 2020). These oracles also have the ability to not only relay information to smart contracts but also send it back to external sources (Beniiche, 2020)**.** This model utilises a distributed NoSQL (Non-Structured Query Language) database solution as it allows for the storage of large amounts of structured information and to search for content by request. It also possesses high fault tolerance, high speed, simple horizontal scalability (Eugene Tarasenko, 2020).

Oracles are notable in computer science for their capacity to deliver accurate external information from outside a system that is not immediately accessible from inside it. However, in the context of blockchain, an oracle is an external data agent that monitors real-world events and reports them to the blockchain so that smart contracts may utilise them (Al-Breiki *et al.*, 2020). This model utilises oracles to provide reliable external information from outside the system that is not directly accessible from inside the system. Also, the oracles in the proposed model help to query, verify, and authenticate external data sources before relaying that information to the blockchain. The MP-Network of the proposed model utilises human, hardware and software oracles for its functionality.

Human oracles, for example rely on people's actions to provide external data to blockchain systems. In the proposed model, individuals with specialised knowledge in particular fields would also serve as oracles. For example, compliance monitors could carry out a visit to a mine site to evaluate the on-going adherence of a particular mining organisation to social and environmental ethics and then report the findings to the blockchain through smart contracts. Similarly, hardware oracles are designed to get information from the physical world and make it available to smart contracts. Such information could be relayed from information reading devices such as electronic sensors, barcode scanners, etc. An example of this could be a sensor that helps to provide products geolocation and checks if the truck transporting the products has arrived at the designated construction site. When it confirms its arrival, it automatically relays the information to a smart contract that can then execute certain processes based on the fulfilment of the fulfilled condition; an example of such a process could be the issuance of an invoice or release of payments to the contracted parties. Software oracles interact with online sources of information and transmit the information to the blockchain. This information can come from online databases, servers, websites, etc., providing provenance related data, asset related data or even personnel related data (which may have been extracted from the organisation's website). The fact that they are linked to the internet enables real-time data transmission. Different oracles' data may also be utilised to verify or confirm each other's findings.

Actors layer

The actors layer fundamentally comprises of the actor's profile and the onboarding mechanisms. The actors' profile is a digital profile on the network, which is created upon registration. It contains documents and information that are subjected to a verification protocol at the onboarding phase. It utilises the notarization and security features of blockchain, which enables individuals to be able to access and share their professional qualifications with the receivers being able to rest assured on the genuineness of those presented qualifications (PWC, 2020). The actors' profiles contain personnel and organisational-related data such as their description, location, certifications and association with products and their profiles. However, data encryption algorithms help to ensure that actors are able to prevent sensitive data from being displayed publicly. The onboarding protocol involves a consensus algorithm that runs to verify the validity and authenticity of the submitted data; this consensus algorithm is extensively discussed in later sections of this chapter. A successful onboarding provides the actors with the required permissions to fully participate in the network. Asset profiles and asset blocks published by the actor would also be linked to the actor's profile.

The MP-Network of the proposed model adapts the multi-actor approach utilised by Abeyratne (2016) and Provenence (2019) to design blockchain solutions for supply chain. They include: registrars, who provide unique identities to actors in the network; standard organisations, who define standards schemes or blockchain policies and technological requirements; certifiers and auditors, who inspect actors to verify certain standards and also provide certifications to actors for supply chain network participation; actors, including service providers, manufacturers, retailers, who must be certified by a registered auditor or certifier to maintain the system trust; and customers, who purchase materials and products (Tezel *et al.*, 2020). The proposed model consists of six types of actors: Registrars, standards organisations, certifying organisations, compliance monitors, product-players and customers. The role of each actor and their onboarding protocols are discussed below in this section.

Registrars

Individuals or organisations that have special permissions and authority to define, manage, register and assign unique identities to actors on the network whilst also possessing special permissions to oversee the transactions happening within the network. Registrars would work closely with programmers to set up networks, applications and smart contracts that enable the blockchain users to conduct transactions on the blockchain network. They may include professionals from relevant fields, such as the field of blockchain and information technology, ethics and sustainability, academics, and construction supply chain (e.g., contractors, consultants, producers, miners, suppliers, etc.). They operate master nodes and they function on the network as Registrar Nodes (RN). The registrars implement the process for the registration and validation through the consensus algorithm and aims to link actor's real-world identities with their blockchain-based digital identities, thus allowing them to interact with the blockchain using their real-world identities, since the MP-Network is a permissioned blockchain network of known and verifiable participants.

Standards organisations

They are organisations that develop standards and rules for a certain scheme (such as ISO, SAI, BSI). Most standards organisations simply develop the standards but they are neither directly involved in their certification nor the issuance of certificates; instead, third-party accredited certification bodies carry out audits and issue certificates of compliance to the standard. Whereas others develop the standards and also carry out certification. For example, BSI (British Standards Institution) develops standards and carries out certification.

Members of standards organisations operate full nodes and function on the network as Standards Organisation Nodes (SON). The onboarding protocol involves core members of standards organisations setting up individual accounts with known and verifiable identities on the network's actors layer through a web server. Documentation to prove identity and genuineness would be submitted on the account profile and verification protocols would be deployed to verify the account. The verification protocols could involve certain actions by the registrars and the deployment of smart contracts. On successful onboarding, SONs seek to oversee certifying organisations registered on the network, to ensure that standards related to the certification processes are appropriately upheld by the certifying organisations, particularly when the certifications are carried out by a third-party organisation (as it is in the case of ISO and SAI). In cases where the standards organisation also doubles as a certifying organisation, some nodes from members of the organisation are set up to operate on the network as SONs whilst others operate as Certifying Organisations Node (CON). Additionally, they also serve as arbitrators on the network to resolve issues that may arise from unsatisfactory feedback from the validation and authentication process of candidate blocks, particularly when issues stem from matters related to compliance with standards.

Certifying organisations

These are third party accredited certification bodies that provide written assurance (a certificate) that the product, service, system or organisation in question meets specific standards or requirements. They also include organisations that issue ecolabels. Some certifiers, for example, grant the right to use certain ecolabels on products that have demonstrated compliance with standards to reduce the negative ecological impacts of primary production or resource extraction in a given sector or commodity through a set of good practises captured in a sustainability standard after a verification process. Hence, earn the right to sell its products as certified through the supply chain.

Similar to standards organisations, the onboarding protocol of certifying organisations involves core members of the organisations' accreditation team setting up individual accounts with known and verifiable identities on the network's actors layer through a web server as full nodes. Documentation to prove identity and genuineness would be submitted on the account profile and verification protocols would be deployed to verify the account. The verification protocols of certifying organisations usually involve registrars, standards organisations and the deployment of smart contracts. On successful onboarding, certifying organisations operate on the network as Certifying Organisations Nodes (CON) and they would have the permission to issue their digital certificates on the network (a digital blockchain version of the hardcopy certificate usually issued to those who have earned it) and sign them with their private keys. The certificates would contain the public key of the recipient, expiration dates and the digital signature of the CON. It utilises asymmetric encryption mechanisms to prevent forgery and tampering. They also function as validators during the validation and consensus process.

Compliance monitors

They monitor product-players to ensure compliance with production standards (either through manual or automated monitoring) and serve as arbitrators on the network. They include professional organisations that currently provide a wide range of monitoring and reporting services to support compliance with social and environmental values and standards. They collect, manage and interpret monitoring data through human agents, software or hardware devices. They could be established as NGO's, national or local organisations set up by the government in several jurisdictions to monitor ESG compliance. Furthermore, knowledgeable and skilled individuals in the field of ethics can also independently sign-up as compliance monitors by providing demonstrable evidence at the onboarding phase.

The onboarding protocol of compliance monitors involves core members of the compliance monitoring organisation's accreditation team setting up individual accounts with known and verifiable identities as full nodes on the network's actors layer through a web server. Documentation to prove identity and genuineness would be submitted on the account profile and verification protocols would be deployed to verify the account. Once verified, they are then added to the network as Compliance Monitoring Nodes (CMN). CMNs utilise a flagging and reporting mechanism within the proposed network to identify defaulters. It could be initiated by a consensus protocol on the network by CMNs, CONs or CNs. The flagging mechanism could be used to identify and scrutinise members of the network found to be defaulting on upholding purported social and environmental ethical standards in their current activities.

Product-players

These comprises of actors involved in the materials and product production process from mine to market; usually including organisations involved in mineral extracting, forest harvesting, production, manufacturing, retailing, logistics, waste management, etc. Product-players run full nodes on the network to be able to cater for their activities on the network. Prior to setting up asset profiles and publishing asset blocks, product-player organisations must first be admitted into the network as Product-Player Nodes (PPN). The proposed model aims to only comprise product-players who are in compliance with social ethical standards within their organisations and who have proof of the same.

Hence, the onboarding protocol of product-players focuses on a demonstration of fundamental social ethical standards and therefore requires intending PPNs to provide proof of adherence to fundamental social ethical standards within their organisation's production process. This helps to prove first that workers responsible for the production of the product are not doing so under any form of modern slavery before demonstrating the reduction of the impact of the organisation's products and its production activities on the environment. The onboarding protocol requires some submissions to prove a commitment to fundamental social ethical standards within each organisation on the actors layer. Such proofs could include assessment reports, licences or certifications based on fundamentally recognised standards of decent work, anti-slavery, occupational health and safety standards. The onboarding process for product-players is illustrated in Figure 4.7.

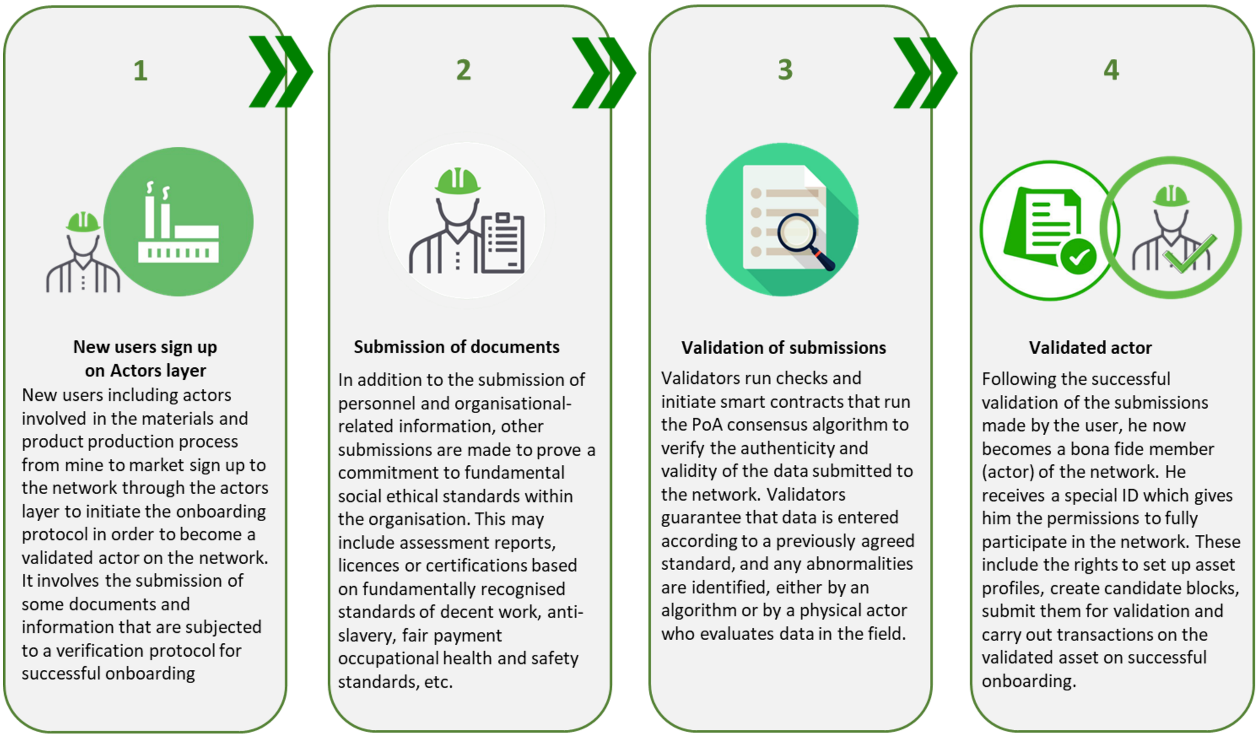

Figure 4.7 Onboarding process for product-players

For example, a mining organisation may provide the Initiative for Responsible Mining Assurance (IRMA) certificate as proof of their adherence to social ethical standards. IRMA offers a third-party certification of mine sites mines all over the world, to certify social and environmental performance at mine sites globally using a comprehensive standard that has been developed in consultation with a wide range of stakeholders (IRMA, 2018). Similarly, an organisation that produces precast concrete products for example could provide a certification from Concrete Sustainability Council (CSC) as proof of their adherence to social ethical standards. CSC manages a product certification system for concrete, which typically applies to all products manufactured and supplied by a concrete plant, including ready-mix and precast concrete plants. The certification system pursues the concept of continuous improvement in the responsible sourcing of concrete, offering four levels of certificates, to stimulate the strive for a next higher level of compliance (Concrete Sustainability Council, 2020). In the same vein, organisations involved in the production of steel could present ResponsibleSteel certifications. ResponsibleSteel is a global multi-stakeholder standard and certification initiative in the steel industry that supports organisations in taking a broad approach to not only address climate change, but also to address other issues including biodiversity and workers' rights in steel production. Its standard sets forth requirements for responsible processing and production, helping the industry respond to increasing demand for more sustainable practices in steel production.

Following the submission of such proofs in addition to other required information, the consensus algorithm runs to validate the data submitted to the network. Product-players who successfully onboard operate on the network as Product-Player Nodes (PPN). They are primarily responsible for entering key asset specific data into the network and they possess permissions to conduct transactions with other participants in the network. The onboarding protocol of product-players is utilised to ensure that organisations that join the network as product-players do not only address GHG emissions in their production processes but also consider a wide range of social issues in addition to environmental issues. PPNs receive the rights to set up asset profiles, create candidate blocks, submit them for validation and carry out transactions on the validated asset on successful onboarding.

Having completed the onboarding process, the product-player's next goal is to publish its assets (materials or products) on the MP-Ledger, as that helps to prove that the products have been produced ethically. The Product-Player Node (PPN) then sets up a profile for the asset with the asset related data as earlier itemised, entered and stored on the off-chain layer. Following this, a candidate block which contains relevant required asset related data extracted from the asset profile is set up. The candidate block is then submitted for validation and authentication through a consensus algorithm. If the outcome of the validation and authentication process is successful, then the data within the asset profile is "blocked" and then added to the existing chain of ethically produced construction materials and products on the MP-Ledger. The asset is represented on the MP-Ledger as an "asset block". The validation protocol of the model is discussed further in subsequent sections of this chapter.

Customers

This refers to individuals or organisations that purchase products. Customers can either join the network as full nodes or light nodes. Those who wish to join the network as a full node must join the network through the actors layer whilst those who wish to join as light nodes simply need to access the procurement layer through a web server. The customer creates an account and follows the Know Your Customer (KYC) protocol utilised by the network to provide information that can help other members of the network identify them and link them to their actual offline identities. This is done to facilitate benign trade and help protect businesses from fraud and other forms of corruption and crime.

Following this, the customer is assigned a personal profile and then able to access the network as a Customer Node (CN) to carry out optioneering and make purchases through the procurement network which is the procurement layer of the model. When the customer completes a purchase, the digital counterpart of the tangible item is also completely transferred to the customer and the system updates the permissions to allow only the customer who is the new owner of the product to create new entries and updates on the product via the CNs private key, completely shifting ownership and the responsibility for updating the asset's digital data to the customer. The data could be added either manually or automatically during the product's use by the customer, depending on the nature of the product and its use. The updated information supplied on the asset provides a life-cycle repository that can aid reuse, repurpose or recycling procedures. Furthermore, such information could not only aid resale of the product but also increase its market value.

Asset layer

The asset (material/product) layer aims at organizing, storing, and managing asset related data. It may include documents (structured, semi-structured and unstructured) and multimedia files (such as images, videos, animations, graphics, logos, presentations, etc.) of assets (materials and products) registered on the network. Due to the enormous size of data that could be associated with each asset, this model proposes the utilisation of a dual-asset data system: asset profiles (off-chain) and asset blocks (on-chain).

Asset profile

The asset profile sits on the off-chain distributed data layer while the asset block is stored on the MP-Ledger, on-chain. The asset profile contains asset-related data stored off-chain and it feeds the hash values to the asset block on the blockchain ledger. Thereby allowing for a wide range of data, relevant to the asset to be collected and stored on the system without clogging up the blockchain ledger. The data could vary depending on the status of the asset, the asset type, and the standards that are to be implemented for the asset. However, each asset profile fundamentally contains organisation related data, which could include the producer or manufacturer's data, the location of the facility, proof of adherence to social ethics within the organisation, etc.; provenance related data which could include origin and ownership data, block header data of assets (materials/products) that are components of the finished product and asset related data, which could include material/product details and properties, product LCA, proof of environmentally responsible production, etc. Data recorded on the asset profile could also include properties of the product, transfer locations, actors involved in supply chain transactions, asset raw-material sourcing data, product life cycle analysis, certificates to prove adherence to ethical values, etc. The asset profile is configured to be able to store several types of data; for example, for mineral extractors, the following properties of minerals could be recorded onto the asset profile: Quantity, weight, grade, timestamped chain of custody, 3D images of the material, mineral tokens, certificates of responsible production, etc. Product-players have total control over their own data and the platform provides a secure way to share it with certain players with a legitimate need-to-know. The network utilises APIs to help actors create, query and interact with the asset profiles on the off-chain layer.

As earlier discussed in this section, the asset block is a block of data about an asset that has been validated and authenticated through the network's consensus protocol and hence added to the existing chain of asset blocks in the MP-Ledger. Basically, it is the validated and "chained" version of the candidate block setup from the asset profile, which contains data needed for the asset's on-chain transactions and hash values of other data related to the asset, contained in the asset profile.

4.4.4 *Other underlying algorithms and protocols of the model*

Validation protocol

Product-player's aim to publish their products on the MP-Ledger as that helps to prove that the products have been produced with respect for social and environmental ethical standards since the protocols and requirements have been met. It then becomes an objective satisfactory proof of adherence to social and environmental ethics on the blockchain. However, a series of protocols and algorithms must be engaged for this to be achieved. Validators run checks and initiate smart contracts that run the consensus algorithm to verify the authenticity and validity of the data submitted to the network. Validators guarantee that data is entered according to a previously agreed standard, and any abnormalities are identified, either by an algorithm or by a physical actor who evaluates data in the field. The proposed model utilises a Proof of Authority (PoA) consensus algorithm to validate blocks and transactions on the network.

Proof of Authority (PoA)

As earlier discussed in Chapter 3 of this study, the Proof of Authenticity (PoA) consensus algorithm is an identity/reputation-based algorithm that provides a practical and efficient solution for achieving consensus particularly within permissioned blockchain networks. Individuals whose reputations are at stake for securing the network are incentivized to preserve the network as they do not wish to have their identities attached to a negative reputation.

Within the proposed model, only standards organisation nodes (SON), certifying organisation nodes (CON) and compliance monitors nodes (CMN) are eligible to be validators within the network. As such, a validator must be registered on the network as a SON or CON or CMN running a full node; however, not all SONs, CONs or CMNs are validators. Nodes interested in functioning as validators must indicate their interest to the registrars and satisfy certain conditions. Such nodes must have established their true identity through the robust notarization features of the model during the onboarding process. They must also demonstrate that they have earned the right to be validators through their knowledge of ethics in the supply chain coupled with good moral standing and a commitment to securing the integrity of the network by acting honestly on the network. Although validators get financial rewards each time they validate a block; however, a stronger incentive for them to act fairly is due to the fact that their real-world identities are linked to their digital nodes on the network, hence, they stake their reputation. As such, any nefarious activity linked to them on the network will hurt their reputation and also cause them to lose their validation rights, therefore, they have more reasons to act ethically than otherwise.

Approved validators basically run checks and algorithms to verify the authenticity and validity of the data submitted to the network. For example, during the validation process, once the PPN submits a candidate block for validation, having coupled and provided the data required from the asset profile (organisation-personnel related data, provenance related data and asset related data). A reference number is associated with the submission and referenced in the network's memory pool. Afterwards, a smart contract is triggered to notify validators of the new submission; a validator responds to validate the asset and the validation begins. The validator seeks to verify the authenticity and validity of the submitted "proofs." He/she triggers a smart contract to invite the certifying organisation to confirm the authenticity and validity of the submitted certificate. If the certificate was issued as a digital certificate by a certifying organisation registered on the blockchain as a CON, then the smart contract runs to verify that the certificate had been indeed digitally signed with the private key of that particular certifying organisation's node.

This is achieved through asymmetric encryption where a public key and a private key are used. The public key and private key in digital signatures are mathematically related but cannot be generated from each other. In this case, the SON or CON uses the private key specially assigned to its node to digitally sign the certificate issued to the PPN, and a smart contract runs to verify that the public key of that SON or CON matches its private pair with which the document was signed. A match signifies that the certificate is authentic. Hence, it is believed that the organisation is one that acts with respect for ethics (environmental and or social), having met the required standards for the obtained certification. Also, the smart contract is also programmed to check the validity of the certificate, to ensure that it has not expired.

However, if the certifying organisation believed to have issued the submitted certificate is unregistered on the blockchain network as a CON, then the certifying organisation is contacted online to verify the authenticity and validity of the submitted certificate by a consent signature function embedded within the authenticity and validity mail sent to the certifying organisation, triggered by the smart contract. The certifying organisation then approves or rejects the authenticity and/or validity of the submitted certificate by replying to the mail.

Also, while that is ongoing on one end, the validator on the other end evaluates the submitted data (contained within the candidate block) to verify its validity and correctness. The validation and authentication proof that returns from the SON or CON in addition to the validation of the data in the candidate block by the validator culminates in a consensus that validates the candidate block and adds it as an asset block to the existing chain of blocks (ethically produced materials and products) on the MP-Ledger. Validated blocks are issued a digital "proof of ethical production" certificate that can be publicly seen on the block and can serve as proof enough for customers and procurers of the ethicality of the product and its production process without necessarily having to look through the entire data that is visible on the block. This digital proof of ethical production certificate is immediately presented to the buyer when the tag on the tangible product is scanned on delivery.

The consensus algorithm runs to verify the authenticity and validity of the submitted data. A major component of the submitted data required in the onboarding stage is proof to demonstrate adherence to social ethics within the particular organisation. Whereas, in the block validation phase, a major component of the submitted data required is proof of adherence to environmental ethics during the production of the product. This is achieved through the submission of relevant documents and/or certificates. Issues arising from unresolved or unsatisfactory feedback from the validation process are directed to the arbitrators on the network.

New users comprising of actors involved in the materials and product production process from mine to market sign up to the network through the actors layer to initiate the onboarding protocol to become a validated actor on the network. It contains documents and information that are subjected to a verification protocol at the onboarding phase

Asset digitization protocol

When a product is manufactured, a (parent) unique identifier (P-ID) is generated for that product which is registered on the asset block. This P-ID typifies that asset on the MP-Network. From that P-ID, other (child) unique identifiers (C-ID) are then generated for every replica of that typical asset owned by the product-player. While the C-ID differs per asset, and from the overall P-ID represented on the MP Layer, the C-IDs are linkable to the P-ID. This ID represents a unique digital cryptographic identifier that links a tangible product to its “digital twin” on the network.

The C-ID of each asset is encoded in a secured information tag, attached to the asset. This information tag could be in the form of a barcode, RFID, QR code, etc. Through the integration of oracles and smart contracts, the status of the digital twin of the product gets updated on the blockchain as the tangible counterpart moves through the supply chain. However, real-time traceability would be a function of the tagging system deployed which would also be a function of the value of the asset and the existence of a digital ecosystem to shoulder it. The data contained in the asset’s profile is linked to the P-ID of the asset that sits on the MP-Ledger within its asset block and actors with the appropriate permissions may be granted access to it on a need-to-know basis by the producer of the asset. The C-ID references and displays specific data from the MP-Ledger when queried. The C-ID can be used to: track and trace products as it makes its way from the supplier/producer to the customer; view provenance of asset; view asset description, properties, measurements, etc.; link asset to manufacturer to proof authenticity; identify it with reference to the asset block on the MP-Ledger and help to proof ethical production of the asset across the supply chain players involved in its production. These data are accessible by scanning the information tag on the tangible product.

However, there are instances where tagging a material or product may be impractical. In such a case where a tier 1 producer for example procures an untagged material from a tier 2 manufacturer, it then becomes the responsibility of the tier 1 producer to verify that the material has been produced ethically by the tier 2 manufacturer before integrating the material into the final tagged product.

Data management protocol

Actors within the network have varying degree of access to the asset profile and asset block depending on the role of the node within the network. Actors have control over their own data and the platform provides a secure way to share it. Data sharing access within the proposed network is limited to entities with a legitimate need-to-know. For example, CNs would have access to data enough to verify the ethicality of the asset, whereas certain kinds of actors (nodes) such as certifying organisations or compliance monitors could be granted permissioned access to more information during validation or monitoring phases.

The content of the asset block offers a reasonable degree of transparency on provenance related data, asset related data and personnel related data, enough to prove ethical production without giving away sensitive business information. For example, actors involved in the supply chain might securely display their proof of ethical production certificate downstream while maintaining some privacy. Also, customers can check important qualities of acquired assets without having to observe the entire supply chain that developed them as the workings of the model seeks to ensure that confirmed data is reliable. The MP-Network would be easily assessable by any interested party through software APIs and underlying algorithms. On query of an asset block on the network, the algorithm runs through the hashes on the block, links them with their primary data stored in the asset profile (off-chain) and presents the data whose hash digest matches the hash presented on the asset block. That way, only the intended and requested data is supplied.

4.4.5 *Project Network*

The project network is a project-by-project consortium based blockchain platform where multiple organisations/stakeholders involved in the project can decide, verify, execute, and record transactions collaboratively. Stakeholders participate in the development of standards and monitoring of project flows. It fosters an accountability system that obligates stakeholders to make understandable benign decisions and take responsibility for their actions. Establishing collaborative practices is particularly important for construction projects, as it typically involves bringing together people from a wide range of disciplines, many of whom will not have worked together before. However, as earlier indicated, new technologies, such as BIM, that promise to improve collaboration in the construction sector appear to be hampered by issues of trust and liability that affect the industry (Hunhevicz and Hall, 2020). Hence, this layer combines blockchain, BIM and oracles to improve business ethics within construction players on a project. It seeks to foster inter-firm trust through transparent collaboration and helps to create a binding traceability of data exchanges, thereby transforming the current disposable BIM model into a contractual, auditable, and valuable digital asset.

Considering the fact that the construction industry has a significant amount of sensitive data, control mechanisms to allow or reject participants joining certain transactions are required. A permissioned design would allow only authorised users to submit transactions, verify transactions, participate in the consensus to add transactions to the ledger, and maintain a copy of the blockchain ledger. This makes a permissioned design ideal for the transactional business environment of the construction industry. As such, this model utilises a consortium blockchain configuration with a Proof of Authority consensus mechanism for the project network. The project network sub-model is shown in Figure 4.8.

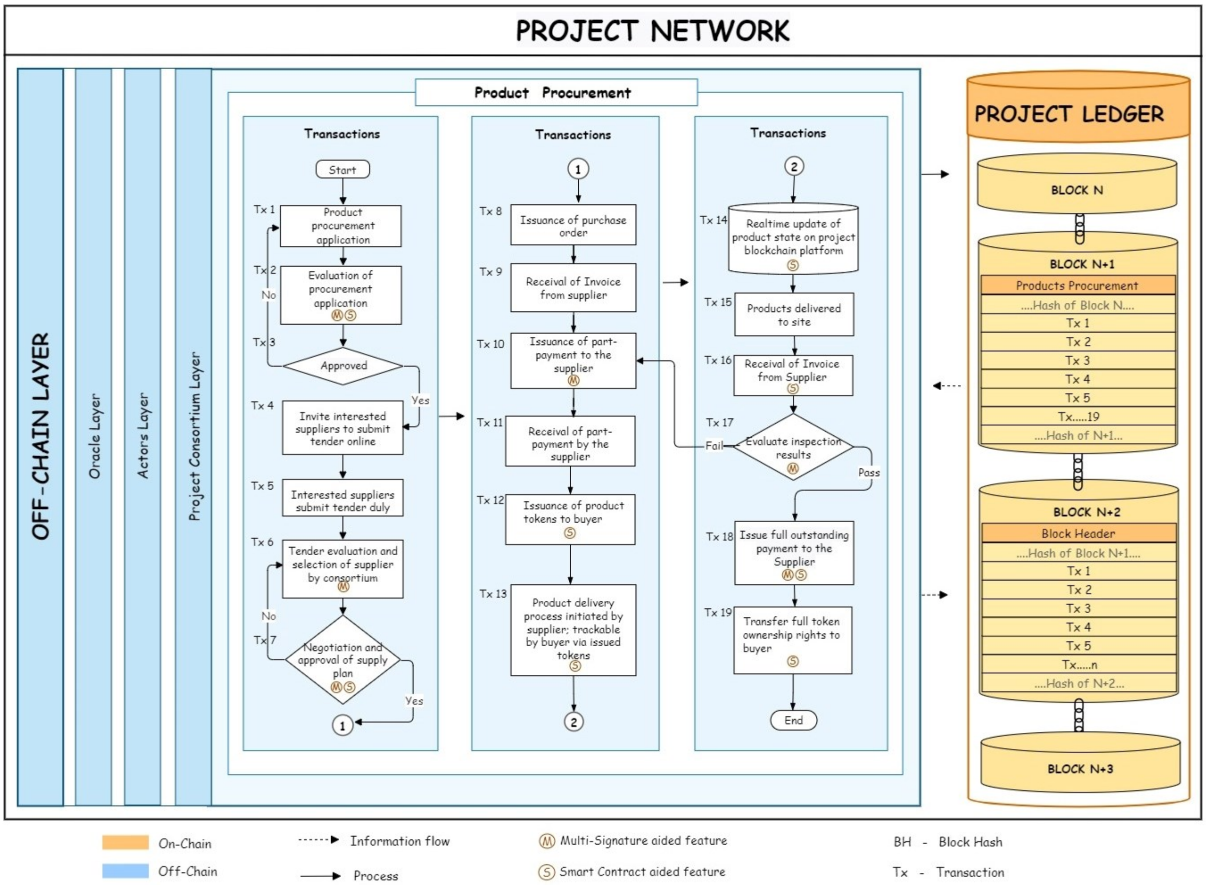

Figure 4.8 Sub-Model 2: The Project Network

Due to the limitations of blockchain as a database earlier identified in this chapter, such as the data immutability cum GDPR concerns and the inefficiency that comes with storing large amounts of data on-chain, this model proposes a dual-layer data solution for the project layer similar to the MP-Network by proposing an off-chain and on-chain data solution for the project network. It includes a project ledger that records the transactions (which denotes decisions made and changes to the BIM model) by the project stakeholders and an off-chain layer that garners and stores other contract related data too large to be stored on-chain and also helps to update the digital project ledger with real world transactions, occurrences and identities.

4.4.5.1 Off-chain layer

This layer houses the BIM model and other contract related documents. It also verifies and records data related to construction projects which could include asset data, tasks and payments data, etc., that are too large to be stored on-chain. The off-chain layer consists of the oracle layer, actors layer and project consortium layer.

Oracle layer

The protocol of the oracle layer within the project layer works similarly to that of the MP-Network. The oracle layer consists of oracles (human, hardware and software) that help to connect the project ledger (on-chain) and the smart contracts to the real world and the off-chain layer. For example, as the truck transporting products makes its way from the retailer's warehouse to the site, sensors attached to the product and the delivery truck can report live updates on the dashboard of the Project Consortium Layer (PCL). When it finally arrives at the designated construction site and is unloaded in the offloading facility, it relays the information to the system and automatically triggers a smart contract to notify the appropriate department to carry out an inspection. Following the results of the inspection, the smart contract executes settlements as programmed into it. For example, this could be to issue an invoice or release payment to a network of parties involved in the sales and supply (e.g., the distributor and the logistics company) if the delivered assets meet the expected agreements. Essentially, the smart contract is configured to listen to event updates from an oracle and execute the agreed processes once it receives the appropriate mix of events from one or more oracles confirming that the terms of the contract have been met. Further workings of the oracle layer have been earlier discussed in this chapter.

Actors Layer

The administrators have the authority to grant permissions to project stakeholders and assign the required degrees of permissions to each project stakeholder needed to fulfil their duties on the project and on the network. The lead consultant on the project could be best suited for the administrator's role. The model proposes the use of an interactive presentation layer and APIs so that users (administrators and project stakeholders) do not need any coding knowledge to carry out their activities and responsibilities on the network. The project stakeholders refer to stakeholders within a particular construction project who have been chosen to participate in the collaborative decision-making process of the project. It could include the client or client representative, consultants, contractors, sub-contractors, etc. The actors (administrators and project stakeholders) create an account on the actors layer by providing some personal information that can help other members of the consortium identify them, the organisation they represent and their roles and responsibilities within the project. Following this, the stakeholder is assigned a personal profile and granted permission to access the PCL and participate in the collaboration based on his roles, responsibilities and the configuration of the consortium network. Actors within a particular PCL may have equal or unequal rights and access to data on the network based on the procurement route being utilised in the project or due to hierarchical business/organisational structures.

Project Consortium Layer (PCL)

This layer integrates BIM into the blockchain ecosystem and helps to address current issues surrounding secure access to the BIM model and allows for a reliable audit of who made changes, when they were made, and what those changes were. The data produced and garnered by actors and oracles is kept on the off-chain layer for enhanced transparency and security, while BIM functions as the baseline tool to digitise the construction project data. The PCL of the project network sub-model is presented in Figure 4.9.

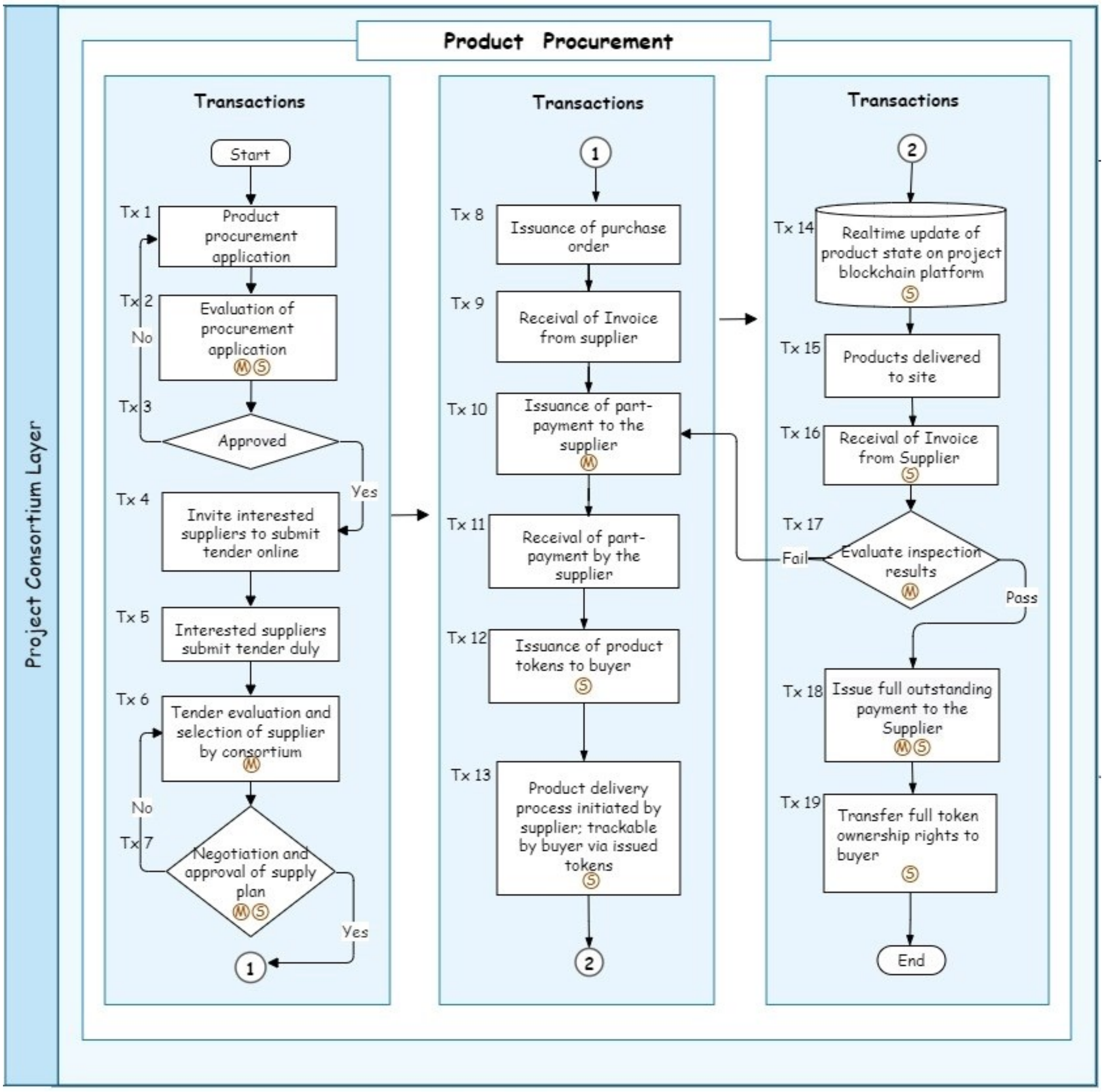

Figure 4.9 The Project Consortium Layer of the project network sub-model

This layer facilitates collaboration among different stakeholders (organisations) by helping them to communicate and share digital assets with each other seamlessly. Thereby, making it possible to build more partnerships among different organisations involved in the project and drive greater business value. Actors (project stakeholders) on the project layer can access the MP-Network through the procurement layer for optioneering and procurement of assets (materials and product). This layer also utilises smart contracts, oracles and other features of blockchain to partially or fully automate contractual processes that traditionally require human intervention and oversight. This layer, through a combination of these technologies helps all project stakeholders on the platform to have a higher probability to rely and trust the traceability and quality of conditions of assets that are being transferred to the project site as their movement can be tracked on the project dashboard on the PCL. Feedback from oracles can help to verify that the materials/products are stored properly on site. Stakeholders can also evaluate and verify the accuracy of its installation by reviewing it against the augmented design model. Stakeholders are able to collaboratively decide, verify and execute transactions on the project dashboard; these actions/decisions are then recorded as transactions on the immutable project ledger.

4.4.5.2 Project ledger

The project ledger is an auditable ledger that immutably records transactions (actions and decisions of authorised project stakeholders) made on the project via the PCL. The consolidation of data in the project network (data from the off-chain layer and data from the project ledger) provides a probative end-to-end chronicle of records, contracts, payments and transactions made within the construction project that can be trusted. Access to this immutable record of data, stored and maintained throughout the construction phase could then be transferred to the client at the handover stage. Future updates made to the BIM model during the building's use-phase would also be reflected on the blockchain database. This would provide a repository of data about the building that could enhance facility management and help to inform decisions in the building's end-of-use phase.

4.4.6 *Procurement Network*

This network proposes a new procurement model for the construction industry that brings actors onto a single shared platform, with enough degree of transparency to verify product ethicality and authenticity. The procurement network functions as an e-commerce online marketplace that facilitates the procurement of ethically produced construction materials and products through a website that is connected to the MP-Network. Assets (materials and products) contained in the MP-Ledger are presented on this platform with the help of APIs for actors to purchase. Whether or not actors have accounts on the material and product layer or project layer, they are still able to access assets and procure them by setting up accounts on the procurement layer as light nodes. The procurement layer possesses an off-chain layer which includes an oracle layer, actors layer and a transaction layer; it also contains the transaction ledger which is built on-chain. The procurement network sub-model is shown in Figure 4.10.

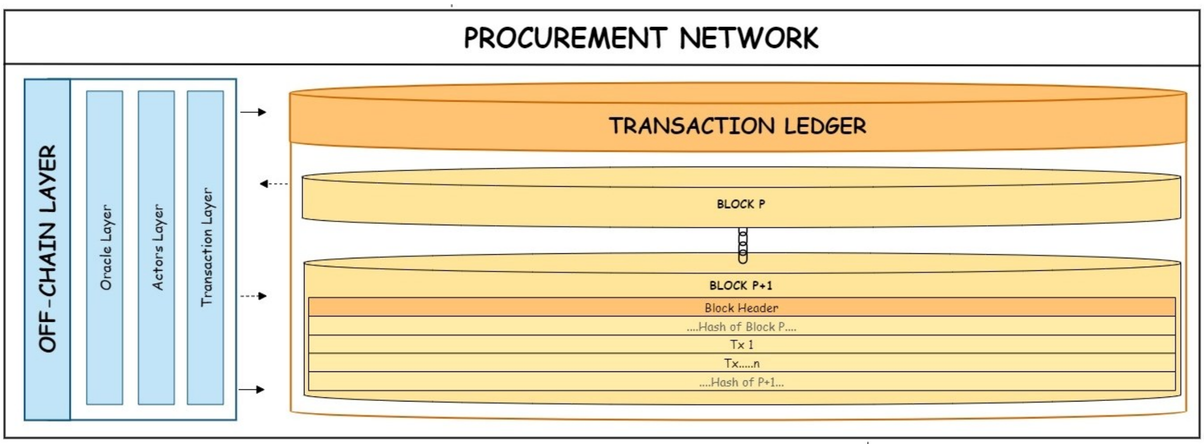

Figure 4.10 Sub-Model 3: The Procurement Network

The proposed network allows actors (customers and sellers) to operate as nodes on the same network, and automatically keep track of changes in asset ownership. It enables corporate processes to be moved from ERP systems unique to different organisations to a shared blockchain-based solution. The network is accessible to actors through an internet platform that utilises an intuitive UI and API.

4.4.6.1 Off-chain layer

The off-chain layer consists of the oracle layer, actors layer and transaction layer and they are discussed below.

Oracle layer

The protocol of the oracle layer within the procurement network is similar to that of the MP-Network and the procurement network. Human oracles, hardware oracles and software oracles help to connect real world events and transactions to the transaction ledger (on-chain) and the smart contracts. Thereby improving the automation and transparency of the entire purchasing cycle from purchase order to settlement. For example, a sensor attached to a product can help to track products as they are conveyed from the manufacturer to another producer and provide real-time geolocation of product on the dashboard of the buyer. The workings of the oracle layer have been earlier discussed in this chapter.

Actors layer

The actors create an account on the actors layer by providing some personal information that can help other members of the network identify them and link them to their actual offline identities. A potential customer joins the procurement network through a website and sets up an account. The Know Your Customer (KYC) protocol utilised in the proposed model helps to facilitate benign trade and helps to protect businesses from fraud and other forms of corruption and crime. Following this, the actor is assigned a personal profile and granted permission to interact with the network and purchase assets on the platform through the public and private cryptographic key pair generated for the actor. This allows each asset to be digitally signed by the actors when being procured on the network and ownership of data is transferred on the transaction layer. Once the transfer is complete, the new owner receives the digital identifier of the product which is connected to its tangible counterpart. The actors layer also contains a dashboard that contains the asset owned by the actor and can be used to trace and update the asset data of owned assets. The asset dashboard through the workings of smart contract, oracles and the digital twin can be used to track and trace the location of the tangible asset as it makes its way from the seller to the new owner.

Transaction layer

This layer facilitates the transfer (sale) of assets between actors. When a producer manufactures a product, the producer generates the P-ID by which that specific product is typically identified on the MP-Ledger. Furthermore, C-IDs (which are linked to the P-ID) are then generated by the producer for every subsequent unit of that product that the producer produces. The model assumes that a producer manufactures only a fixed number/units of a certain product. As such, the producer has only a specific number of C-IDs that matches the total number of units produced. The C-IDs are embedded in a secured information tag that is attached to each of the tangible products. When the producer transfers or sells the product to another actor (such as distributors, wholesalers, retailers, etc.), the ownership of the tangible products (which have already been appropriately tagged) and their digital counterparts (C-IDs) are equally transferred to the new owner as a product can only be owned by a particular actor at any given time. Hence, the actor (distributors, wholesalers, retailers, etc.) has a limited number of C-IDs (stored on the actor's profile and visible only to the actor on the asset dashboard of his profile) which is consistent with the total number of tangible products in the wholesaler's possession (stored in the wholesaler's warehouse). At the instance of the transfer or sale to another actor, a smart contract is triggered that requires the signature of both parties to authenticate the exchange. Once both have signed the contract, the details of the transaction will be added to the transaction ledger on the blockchain.

Following the completion of the exchange, the system updates the permissions such that the new owner can now set up a profile for that asset on the asset dashboard found on the owner's profile and begin to make entries on that profile during the product's use-phase (depending on the kind of product it is). Certain "smart" products could even be programmed to automatically transmit their performance data to their online profiles during their working life span. This data may then be consummated later in the future to aid resale, reuse, repurpose or recycling activities. Furthermore, the proposed model is crypto-currency agnostic, as such, all digital currencies would be supported, and there is no preference built into the platform for any currency over another. The transaction layer within its interface also contains a function that allows for actors (buyers) to provide feedback on the procured asset and rate the service performance of the seller. Ratings would help to build trust and provide social proof as customers are often swayed by the opinions of others; favourable ratings will help drive more sales.

4.4.6.2 Transaction ledger

The transaction ledger records the asset's transactional information. It functions at the core of the procurement layer to keep a chronological immutable record of transaction of assets in the network. The transparency and auditability of this ledger allows the network to maintain an indisputable record of ownership for each asset and also helps to prevent the problem of "double spending". Each time the product is exchanged between two actors, a new entry is made on the ledger to record the details of the transaction. The oracles help to enrich and enhance the integrity of the ledger as they inform the smart contracts that then update the ledger about real world events and transactions on the off-chain layer.

4.5 A model to improve ethics in construction materials and products supply chain

Although a synergistic implementation of the three networks that make up the model is needed to achieve the model's goal and value propositions. In practice however, actors can implement each network independent of the other. For example, private procurers do not have to be actors on the MP-Network or project network to procure from the procurement network; similarly, a project stakeholder registered as an actor on the project network, seeking to procure products for a construction project through the procurement layer does not have to be registered on the MP-Network.

Material and Product Network

The proposed model contains actors (PPN) who have demonstrated adherence to fundamental standards against human rights abuse (social ethics) within their organisation as outlined by standards organisations (SON), and ensure that their materials, products and production processes foster the achievement of global green environmental goals (environmental ethics) and have hence been certified by certifying organisations (CON). Thereby allowing consumers (CN) to be able to procure authentic materials and products that have been ethically produced and to rationally prove or confirm their ethicality. The network is set up by registrars (RN) who would also ensure the smooth running of the blockchain network while ongoing compliance to ethical standards would be monitored by the compliance monitoring organisations (CMN) to ensure that product-players do not camouflage or lower their standards after the issuance of certificates.

Furthermore, in practice, for standards organisations, certifying organisations and organisations that monitor ethical compliance in supply chains, this model serves as a sociotechnical tool which these actors can utilise to improve their business activities as well as their sustainability evaluation and monitoring strategies through the workings of the model and its elements. They can utilise the model to make their activities and processes more efficient and more globalised.

Project Network

The workings of the project network help to promote transparency and accountability in the appropriate use of project funds and assets, and the performance of contractors whilst also creating an environment that is unfavourable to fraud. Stakeholders would be held accountable for the use of funds and could be held responsible for decisions made. More specifically, this network can contribute to improving business ethics within construction projects through its deterrence and detection mechanisms. This network could also be further utilised to audit the project under the triple constraint (quality, cost and time). For example, when construction activities take longer than expected or fail to achieve the planned results or projected costs are exceeded in project milestones, a red signal could be triggered which would prompt stakeholders within the network to further examine the situation.

Procurement Network

The procurement network allows for customers to procure with an assurance of the ethicality and authenticity of the products listed on the network. It also offers a means for customers to decide whether the product they are looking to purchase is a more sustainable choice or not during optioneering. Furthermore, customers are able to provide updates on the products during their use. This helps to build a repository that can aid reuse, repurpose or recycling procedures. Additionally, such information could not only aid resale of the product but also increase its market value.

4.6 How the proposed model seeks to improve environmental ethics in CMPSC

As earlier discussed in Chapter 2, construction is unquestionably one of the most resource-intensive and environmentally harmful businesses on the planet (Earth Watch Institute, no date) and its activities from production of materials and products to construction have contributed greatly to global warming (Lai *et al.*, 2019). The construction industry is responsible for 23% of air pollution, 40% of drinking water contamination, and 50% of landfill waste and the fabrication of building supplies contribute to this high percentage (Morledge and Jackson, 2001). Furthermore, the sector consumes 40% of the world's raw stones, gravel, and sand; 25% of virgin timber per year, with half of those resources being non-renewable (Karolina, 2021); 51% of world steel which is made from 98% of all iron ore mined (World Steel Association, 2018); and the processing of this materials exude an immense volume of greenhouse gases (GHG). However, according to Concrete Sustainability Council (2020), Hauge (2020), Monteiro *et al.* (2017) and SSAB (2021), steel and concrete can be produced in far more environmentally friendly ways and the use of sustainable timber can help to meet social, economic and environmental demand for timber for construction (Abere and Opara, 2012; Vajpeyi, 2001)**.**

The proposed model seeks to improve environmental ethics in CMPSC by acting as a digital enabler to grow a network of ethical players whose products and services meet fundamental environmental ethical standards throughout their life cycle: from raw material extraction to production, distribution, use and recycle. Thereby fostering ethical environmental production across CMPSC. It seeks to achieve this majorly through the workings of the MP-Network and how it proposes to achieve this is discussed in this section.

Fostering environmental ethics across the various stages and actors in the CMPSC

The collaborative multi-stakeholder approach utilised in the proposed model fosters environmental ethics as product-players (organisations involved in product production) are required to provide proof of adherence to environmental ethics for their products and within their production processes before their products can be published (chained) on the network. Hence, ethical producers can utilise this model to objectively prove and substantiate their ethical claims. As the proposed model allows for upper-tier actors to make trusted verifiable claims as to the provenance and ethicality of the production activities of their lower-tier actors who supply the materials for their end products. That is, different players in the supply chain are able to procure the materials and products needed for their own phase of the production process from organisations that have implemented responsible environmental standards in the prior phases of production.

The interconnected network structure offers a new collaborative approach between product-players that helps to nurture a supply network of ethical players and products. This encourages and allows product-players to procure materials and products needed for their own production process from co-ethical players who are also registered within the network, having proven their organisation's and production processes' respect for fundamental ethical standards. Therefore, the adherence of different individual organisations that play different roles in the supply chain to ethical environmental standards culminates in an environmentally responsible supply chain network. As such, other actors involved in the materials and products production who are yet to be registered on the network are urged to do so in other not to lose out on the market but more importantly, to also be able to prove their value for human and environmental well-being, over and above their interest in immediate economic gains. Thereby, fostering environmental ethics across the various stages and actors in the supply chain and consequently fostering the achievement of global green environmental goals.

Demonstrate respect for environmental ethics in production

As earlier discussed, certifications, assessments, ratings and eco-labelling tools have become the most effective way of demonstrating and authenticating the sustainability attributes of construction materials and products. While these numerous tools that help to demonstrate ethical production have certain differences, most of them hugely focus on improving environmental practices and reducing GHG emissions from products during production and usage. The proposed model requires product-players to substantiate ethical claims using one or more of the above-mentioned tools to help to signify and demonstrate their respect for environmental ethics in the production of their products before they can be published on the MP-Network.

Sustaining continuity of commitment to environmental ethical standards

A flagging and reporting mechanism exists within the proposed network to identify defaulters. A consensus can be initiated on the network by compliance monitoring nodes, certifying nodes or consumer nodes to validate queries raised on the network and follow through on the consequent protocols. It could also be used to identify and scrutinise members of the network suspected of performing below purported standards. Thereby serving as a system that helps to ensure continual improvement or at least, a sustained practise of ethical production rather than a checklist-style system. Since blockchain cannot solve environmental-ethical problems on its own, this model utilises the workings of oracles and monitoring nodes in addition to the validation protocol and consensus algorithm of the model to ensure that organisations really keep up with their purported environmental ethical standards and that they are not just green washing.

Helping to curb greenwashing

The monitoring nodes' activities, in addition to the validation process and consensus algorithm used in the model, helps to guarantee that organisations follow through on their pledges to be more ethical. In both the onboarding and block validation stages, once the required data is submitted, the validation protocol and the consensus algorithm are initiated to verify the authenticity and validity of the submitted data. This helps to solve problems relating to green washing by helping to prevent companies from greenwashing whilst also preventing end users from buying greenwashed products.

In the block verification stage for example, once the required data is submitted by the PPN, the PoA consensus algorithm runs to verify that if the submitted proof certifications/assessments/ratings/ ecolabels) to demonstrate that the submitted data are genuine. The certification body reported to have issued the proof is contacted via a smart contract protocol to verify the authenticity and validity of the proof submitted by the PPN. Once verified, the block is then added to the chained and published on the network (added to existing network of ethically produced materials and products). Conversely, if the verification process falls through due to the commission of any of the “Sins of Greenwashing” as identified by TerraChoice Environmental Marketing organisation, then the candidate block returns to the PPN unverified and therefore not chained or published on the network. Hence, an asset (materials/product) block is only added to the chain when it is sufficiently proven that the product meets the environmental standards to the degree declared by the proof contained in the product block. Product-players can demonstrate compliance with a standard and earn the ability to market their products as certified across the supply chain through the verification procedure. This helps to prevent product-players from making fraudulent environmental claims with the aim to flood the green market with bogus eco-friendly materials and products in order to take advantage of the demand for materials with little or no environmental impact. Also, the transparency of the proposed model provides a means to help end users or intending buyers confirm claims product-players make about their product’s impact, from raw materials to the customer. In addition, it is decentralised, in that the information is stored in a way that it is not owned by one company; hence, it is more resilient to internal compromise as compared to traditional centralised systems.

Fostering environmental ethics through transparency

The proposed model allows all members of the supply chain on the network to have fair visibility of how environmentally responsible their products and services are. Actors can track the provenance of products, enabling them to build customer loyalty and trust through transparency and helping to prove that product-players live up to their purported ethical standards. Hence, product-players can sufficiently demonstrate that a product truly owns up to the environmentally friendly claims through the validation and consensus protocol of the network. This may also help to enhance corporate performance reporting and sustainability monitoring capabilities.

Unlike conventional centralised supply chain management systems that cannot present data in real-time, this model proposes an asset digitization mechanism to track the ownership and provenance of tangible assets. Oracles can collect data from a variety of sources, including software, hardware, and humans to ensure that tangible products in the real world are in sync with their "digital twin" on the blockchain network. This ability to track the journey of the product along the supply chain not only helps to provide accurate provenance data, but it can also help to further enrich the identification of greenhouse gas emissions during transportation of materials and products. Fortunately, the collaboration between the different participants could be leveraged to optimize transport activities and reduce greenhouse gas emissions.

Fostering circular construction through trust

If emerging nations build their infrastructure to present global average levels; urbanisation, population expansion, and economic development will further drive global timber, concrete and steel usage and the construction sector will produce 470 gigatonnes of carbon dioxide by 2050 (WEF, 2020). Hence, the need for the implementation of circular construction strategies and practices, if the terms of the Paris Climate Agreement will ever be met as it requires every nation to reduce yearly carbon emissions from the cement industry by at least 16% by 2030 if the world is to stay within 1.5°C to 2°C of warming. Circular economy initiatives promote sustainable resource management, waste reduction and the repurposing and recycling of resources. However, to implement these initiatives, trust is key, and a key element to gaining trust is the availability of information on products and waste.

The proposed model seeks to foster implementation of circular construction concepts through its potential to provide information throughout a product's lifecycle, which is required to drive trust needed for circular construction to thrive. The visibility into the supply chain that the model provides offers an immutable record of transactions that can help to verify the origin of products, thereby providing trusted transparent provenance and usage related information on the product. For example, currently most concrete goes to landfill sites or is crushed and reused as aggregate. As an alternative to this, the model proposes the use of identification tags attached/embedded in building products such as a precast concrete slab to gather and transmit data about them to the product profile online, thereby making the maintenance and reuse process more efficient and rational.

Furthermore, since more than 450 million tonnes of construction and demolition waste is generated yearly in the EU alone, making it one of the largest waste stream in quantitative terms (El-Haggar, 2007). The proposed model could provide information to facilitate reuse and recycling whilst also providing construction waste recyclers with data which may be utilised to determine the quality of the construction materials and products entering and exiting their recycling facilities. This also enables consumers to trust the materials and products coming from the recycling facilities. Also, the proposed model may help to enrich current blockchain solutions for environmental ethics by serving as an oracle (a source of information) to already existing blockchain networks built to aid waste reduction and recycling value chain such as Project Trackcycle, Provenance, Eiravato, Cirplus, etc., set up with the aim of providing a fully traceable and accurately labelled record of recycled materials, from waste sourcing up to its use in production streams.

4.7 How the proposed model seeks to improve social ethics in CMPSC

As earlier discussed in chapter 2 of this study, the construction, manufacturing, mining, agriculture, and utility industries, which account for nearly half of the world's forced labour population generate more than 20% of total revenues (CIPS, 2013; Werdmüller, 2016). At or below tiers four and five of the supply chain, construction projects are regarded to be the most vulnerable to modern slavery infiltration and construction is second only to the sex industry in the EU as the sector most vulnerable to exploitation (CIOB, 2018a). This exploitation could occur during the construction of buildings, within the materials and products production stage, or at other stages within the supply chain. This is challenging because major contractors typically have little visibility below tiers one and two (CIOB, 2018a); as such, it is difficult to prove that supply chain players have no traces of modern slavery within their organisations and other organisations they conduct business with. As WTO (2018) posits, beyond issues of product quality, blockchain technology can also be used by organisations to track ethical claims and fair-trading practices. Hence, the proposed model seeks to improve social ethics in CMPSC majorly through the workings of the MP-Network. The approach this model takes to ensure that the network consists of only supply chain members who adhere to anti-modern slavery standards within their organisation is discussed in this section.

By helping to ensure member organisation's adherence to social ethical standards

As discussed in the earlier sections of this chapter, the proposed model consists of six categories of actors: registrars, standards organisations, certifying organisations, compliance monitors, product-players and customers. Product-players, which are organisations that extract minerals, produce or source raw materials, product manufacturers, product distributors, etc., seeking to join the network must first be admitted into the network as product-player nodes (PPN) to be able to then set up and publish product blocks.

A major component of the onboarding protocol for product-players utilised by this model focuses on providing proof of commitment to adherence to social ethical standards within the organisation. Such proofs could include assessment reports or certifications based on fundamentally recognised standards of decent work, anti-slavery, occupational health and safety standards. They usually draw elements from the Universal Declaration of Human Rights, International Labour Organisation (ILO) conventions, and national laws. Examples of such certifications are ISO 45001 certification (occupational health and safety), SA8000 certification, Human Rights Supply Chain (HRSC) Certification, etc. That is, it signifies that the organisation is first free from child labour, forced labour and other forms of modern slavery before then demonstrating the reduction of the impact of its products and their production on the environment. Thereby helping to ensure that organisations that join the ethical supply chain network as product-players do not only address GHG emissions alone but also consider a wide range of social issues which are important to people, within and outside of the supply chain. On successful onboarding, PPNs receive the rights to set up asset profiles, create candidate blocks, submit them for validation and carry out transactions on the validated assets.

Furthermore, once the organisation has successfully joined the network as a PPN, every time the PPN creates a candidate block, and submits it for validation, the blockchain via a smart contract protocol runs to ascertain that the afore presented certificates for adherence to social ethical values are still valid. Hence, it is not a one-off process, the mechanism helps to ensure that companies do not lower their standards after the issuance of certificates by certifying organisations or after being admitted to the network as a PPN.

Fostering due diligence within the supply chain through a "trustable data and network"

The proposed model helps to solve issues that exude from betrayed trust where an organisation simply hopes that the other organisation whom it is contracting with must have done its due diligence in maintaining a modern-slavery free supply chain, perhaps due to the "old boys" factor, or the immense complexity of the supply chains and their low transparency at the lower-tiers, or better still, due to the sheer laziness of the contracting party. While every organisation does have a responsibility to ensure that its activities are slavery free, a degree of vulnerability is also opened up through its dealings with other supply chain members who may betray their trust if forms of modern slavery exist within their organisations.

The proposed model therefore acts as a tool to help organisations to be more rational and thorough in their approach to ensuring a slavery-free supply chain where compliance with social ethics of all members can be proven based on genuine certifications from trustable third-party certifiers on the "trustable network". The proof of ethical production certificate issued to supply chain actors on the network could be securely shared across the supply chain tiers, while maintaining some privacy and actors can check important information on acquired assets without having to personally observe the entire supply chain that developed them since the validation mechanism of the network already helps to ensure that the presented data is reliable. This drastically reduces the need to set-up social ethical compliance teams to conduct private checks through the fragmented supply chain, investigating breaches in ethical standards. Moreover, in cases were setting up a social ethical compliance team to investigate the ethical compliance of supply chain members becomes necessary, access to data from this network will richly enhance their efforts.

Sustaining continuity of adherence to social ethical standards

Also, similar to the protocol the model utilises to ensure sustenance of environmental ethics across the supply chain, a flagging and reporting mechanism exists within the proposed network to identify defaulters. A consensus can be initiated on the network by compliance monitoring nodes, certifying nodes or consumer nodes to validate queries and follow through on the consequent protocols. It could be used to identify and scrutinise members of the network suspected of performing below purported standards. Since blockchain cannot solely solve social ethical problems, this model utilises oracles and the notarization mechanism of blockchain to ascertain that those organisations within the network have indeed been certified by a recognized third-party to have upheld standards against the violation of human rights within their organisation; while the validation protocol and the duties of CMNs on the network help to ensure that members sustain their ethicality to remain on the network.

It assures customers of adherence to social ethical standards and urges a demand of the same from other supply chain actors outside the network

As already indicated in Chapter 2 of this study, implementation of ethical schemes and standards within the supply chain thrives the most when it is driven by a consumer-demand. The proposed model helps to build a network of producers who have been certified to be practitioners of social fairness in their production activities and are worthy of attracting the interest of customers who are ethically driven. The ripple effect from this can foster the reduction of human rights abuses across the entire construction supply chain. The proposed model utilises notarization to indicate that everyone involved in the production process was paid and treated fairly. The level of assurance provided therefore helps end users feel comfortable using the product because they can trace ethical compliance across the supply chain and more easily identify products certified to not contain human rights abuses within the world-wide market. The assurance provided by the entire process could also enhance the social reputation of all supply chain members on the network whilst also putting pressure on actors outside the network who do not provide this information or do so inaccurately to get on board, either due to motivation from customer's demand for social ethical production proof or even the sheer fear of being excluded from market competition and missing out on potential market gains.

4.8 How the proposed model seeks to improve business ethics in CMPSC

As pointed out in chapter 2 of this study, Transparency International (2006, 2008, 2011) revealed that the construction industry was the most corrupt industry, primarily attributable to the fragmented nature of the construction industry, which makes it difficult to track payment and information (Kenny 2009). As a result, unethical activities in the construction industry take many forms, including bribery to secure planning approval, budget overstating, counterfeiting of construction materials and products, payment demand abuse, and purchasing from unethical players to save costs, etc. Other notable forms of corrupt practice in the CMPSC also discussed in this study include fraud and counterfeiting (Kjesbu *et al.*, 2017; Remo, 2018; Sohail and Cavill, 2006).

Das *et al.* (2020), De Jong *et al.* (2009), Locatelli *et al.* (2017), Smith and O'rourke (2019) and Tezel *et al.* (2019) affirm that improved openness within the supply chain and transparency of decision-making processes from procurement to work performance for all parties involved in a project, including clients, consultants, contractors and material and product suppliers is a major approach to addressing unethical business practices in the construction industry. Hence, within the CMPSC, the proposed model seeks to improve business ethics by helping to curb counterfeiting through the traceability and asset digitization mechanism that the model provides. While it acts as a digital enabler to improve openness within the supply chain and transparency of decision-making processes from procurement to work performance within construction projects for all stakeholders involved in the project.

Asset digitization and supply chain transparency to curb purchase of counterfeits

The transparency achieved through the MP-Network of the proposed model helps to prove product authenticity as it combines benign oracles with the core features of blockchain to link product to its producer. Hence, counterfeits and fakes can more easily be contrasted and detected; as such, procurers can rest assured of the authenticity of the products listed on the network during optioneering and procurement. Also, as earlier discussed in the asset digitization section, each asset on the MP-Ledger and its associated P-ID and C-IDs are generated by the producers through an algorithm on the network, allowing a product's unique ID to be directly linked to the producers. Hence, procurers can easily trace products to the actual producers to verify authenticity by running a query on the asset's C-ID or by scanning the information tag on the asset. It is assumed that producers care about the quality of their products and their reputation; therefore, they will not generate a unique ID for a counterfeit product or generate a unique ID and pass it on to adversaries.

Also, the digitization of products enables physical products to be tracked by their digital twin on the network from market to site. Once a part-payment for a supply is made to the retailer, a smart contract could be programmed to trigger the release of the asset's C-ID. These digital identifiers work with the system oracles to collect data from a variety of sources to provide traceability of products from market to construction site. This model possesses the potential to help procurers verify the sources of their goods and track their movement from purchase to delivery, thereby strengthening transparency in the CMPSC. Thereby helping procurers to keep track of transactions, manage supply chains and prevent substitution of authentic assets with fake ones. Following the delivery of materials or products to the site, the personnel carrying out the evaluation and inspection of supplies only needs to scan the asset tag to verify ethicality and to verify that the delivered products match what is presented on the Network. Supplies can be rejected if the delivered materials or products are suspicious, or if they are suspected to be fake. Furthermore, the business and market reputation of producers are protected against the counterfeit organisations that take advantage of high-quality brands through the proliferation of online marketplaces; hence, more consumer-producer trust is gained.

Although traces of improvements in business ethics within the CMPSC can be seen across the three networks of the proposed model; however, the perceived improvement in business ethics is predominantly achieved mainly through the workings of the proposed model's project network which mainly seeks to improve business ethics within construction projects. The proposed model aims to improve business ethics within a construction project supply chain through its deterrence and detection of unethical business activities which is achieved by its immutable history of commitments.

Deterrence and detection of unethical business activities through the immutable history of commitments

Currently many unethical actors take advantage of the lack of transparency and reporting mechanisms within some traditional systems to propagate and conceal their acts. The transactions (actions and decisions of authorised project stakeholders) recorded on the immutable project ledger within the proposed model serves as an auditable chronicle of records, contracts, payments and transactions made within the construction project. Since the project consortium layer consists of stakeholders within the construction project with known identities, the existence of this immutable digital record of decisions could dissuade players from acting unethically. Also, the model proposes a self-auditing protocol which can be programmed to run in tandem with project milestones or the Gregorian calendar. The model utilises blockchain protocols, artificial intelligence (AI) and smart contracts sufficient to capture, process, audit and report data on a real time continuous basis. A copy of the results of these audits could then be automatically sent to trained auditors to inform and enhance their auditing. As such, it becomes clear to players that if an unethical move is attempted by any of the party, at any point during the project, there is a greater chance of being exposed even if such an act is not noticed in the interim. It is highly probable that it would eventually be discovered when the project ledger is audited at any point in the future; and if discovered, the reputation of such personnel or organisation will suffer. Therefore, the project ledger not only serves as a deterrent to unethical actions or decisions by project stakeholders but also as a useful resource to investigate them.

Also, in public sector projects, the reliable reporting mechanism of the proposed model could contribute to the prevention and detection of unethical business practices and curb principal-agent related corrupt activities. Furthermore, the disclosure of wrongdoing through the publication of audit reports can strengthen the deterrent effect and discourage project stakeholders or public officials from engaging in fraudulent or unethical behaviour; thereby, helping to improve ethics in public sector construction projects.

Enforced four-eyes principle to provide the needed oversight to curb unethical business activities

The 4-eyes principle (4EP) is a well-known access control and authorization principle and it is used in many scenarios to minimize the likelihood of unethical activities. It states that at least two separate entities must approve a transaction before it is considered authentic. Hence, an adversarial player aiming to make an unethical move is forced to convince other parties to collude in the attack. It is however assumed that the network contains other benign players that would refuse to collude and can help prevent the suspected malevolent activity from occurring.

The proposed model's project network utilises a multi signature function to achieve consensus needed to enforce the 4EP needed to guard against unethical business practices within a construction project. Business activities such as approvals, transactions, payments, etc., must be approved by at least two stakeholders before the system considers them valid and then executes them. In practise, the number of stakeholders necessary to validate the transaction could be more than two, depending on the protocols programmed into the consortium set up. Designated stakeholders within the project network can collaboratively monitor work units and track quality of work done, issue payments, verify claims, approve transactions, etc., within the project consortium layer. This mechanism helps increase transparency as decisions and approvals of all stakeholders can be seen by other stakeholders on the network with the required clearance. This function aims to provide greater transparency and oversight, thereby making shady activities like fraud or corruption harder to execute without detection.

Fair payment system through smart contracts

Late and missed payments are top issues within the construction sector, resulting in cash flow problems, business failures and major disputes. Smart contracts utilised to automate payments from a project escrow account could effectively be used to resolve these issues. The model proposes the utilisation of smart contracts to automate/semi-automate payments to increase payment integrity and avoid late payment issues, funds misappropriation and other forms of unethical business activities that commonly emerge within a project. It also utilises smart contracts to satisfy common contractual conditions such as payment terms, liens, confidentiality, prevent fraudulent inflation of labour costs, etc. This application helps to provide more trust in the transaction as automation allows greater enforceability of the contract. For example, hardware oracles (sensors on site) can be used to log in the number of hours spent on site by a worker and a smart contract can be programmed to pay the worker duly. Also, smart contracts could help to schedule and automatically trigger payment for the delivery of supplies on site following due inspection. In smart contracts where the terms are payable upon receipt, a proof of delivery from the logistics personnel will immediately trigger automatic digital invoicing and payments. They can also be programmed to trigger penalties on deflections from contract terms. Smart contracts can help to eliminate uncertainty and make payments within a construction project completely transparent and fair.

BIM modification provenance

The proposed model allows for the integration of the Building Information Model within the PCL and records the modifications made to it. This helps to address issues surrounding secure access to the model and allows for a reliable audit of who made changes, when they were made, and what those changes were, thus providing a basis for any legal arguments that may occur. These functions are aided by the core features of the blockchain technology. As a result, the present disposable BIM model is transformed into a contractual, auditable, digital asset that assures security and traceability of player actions and information shared during the project. It also adds a probative element to the BIM model to help project stakeholders scope their liabilities.

4.9 Summary

In this chapter, the theoretical framework underpinning the model and the conceptual model developed are discussed. It reveals the study's utilisation of the theory of collective action as the theoretical framework that underpins the conceptual model built on blockchain to improve ethics in the CMPSC. The model is developed to incorporate the principles of collective action to improve ethics in the CMPSC following the TBL construct whilst leveraging the core features of blockchain. It proposes a sociotechnical solution to improve ethics in the CMPSC via a collective action approach that seeks to bring together the multiple enterprises involved in the construction materials and products supply chain, organisations that help to drive ethics in production and supply chain, customers who procure construction materials and products and stakeholders involved in the delivery of a construction project to work collaboratively to improve ethics (within the triple bottom line construct) in the CMPSC.

According to Will (2018), conceptual models provide a useful starting point for participatory and collaborative modelling efforts. Hence, the developed model helps provide a common language that allows for more inventive evaluation and collaborative development by different stakeholders at the interview and focus group stages of the study.

Chapter 5 Research methodology

5.1 Introduction

The research approach adopted for this research is discussed in this chapter, it also reveals the technique utilised for the gathering and analysis of data in order to achieve the research objectives. In addition, it presents the research paradigm regarding what can be known and how it can be known from the perspective of the researcher. The range of research philosophies, research approaches, research strategies, research choices, data collection techniques and procedures to gather the appropriate primary data required for the achievement of the objectives of the research are also discussed in this chapter.

5.2 Research methodology

The Oxford dictionary defines the term "research" as "the systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions." According to Gao and Low (2014), research consists of a careful search and a systematic investigation that adds to the sum of knowledge. According to Hede and Bullen (1982), the logic and approach to the principles and procedures of scientific research are referred to as the research methodology. Also, Fellows and Liu (2013), posit that a research methodology refers to the principles and procedures of a logical thought process that is applied to a scientific investigation. There is also a substantial body of knowledge concerning research principles, which describes the philosophical prospects, methods, designs and strategies. Creswell, (2009), Fellows and Liu (2013), Gao and Low (2014), Hede and Bullen (1982) and Saunders (2012) suggest various forms of frameworks for conducting social research, and the research methodology was developed using writings by these scholars.

The "research onion" developed by Saunders (2012) was mainly used in this research. It presents the research methodology in the form of an onion with different overlapping layers. Saunders (2012) categorised research into six phases and presented the model as a research onion as can be seen in Figure 5.1. The research is separated into categories incorporating approaches, strategies, philosophies, time horizons, choices, techniques and procedures, and each layer of the onion explains a more comprehensive phase of the research. This approach provides an important progression from which the methodology of the study can be established and also gives a theoretical justification for the assumed issues used in the research design.

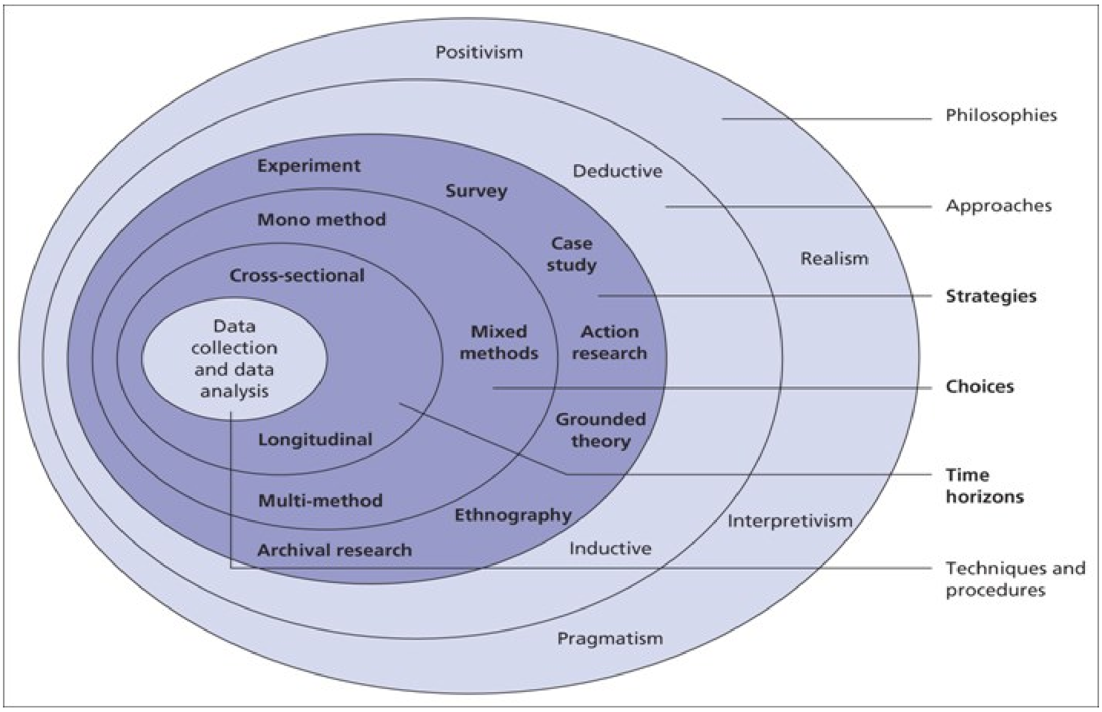

Figure 5.1 Research onion methodology approach. (Source: Saunders (2011))

As shown in Figure 5.1, the main layers, from outer to inner, include research philosophy, research approach, research strategies, time horizon, and data collection methods. The outer ring represents the unifying research philosophy, which guides the research approaches and methodological choices, while the research strategy, time horizon, and research techniques form the corresponding layers. This section also discusses the different areas of the research onion based on the goal of this research, showing how it influenced the methodology adopted for this research.

5.3 Research philosophy and approaches

According to Saunders (2012), the research philosophy is the all-embracing term used to communicate the development of knowledge and the nature of that knowledge in relation to research. He further adds that when conducting research, an underlying theoretical perspective should be implemented by the researcher, which is referred to as the “philosophical paradigm.” A research philosophy gives the underlying definition of the nature of knowledge; it refers to the set of beliefs concerning the nature of reality and how reality can be investigated (Ansari *et al.*, 2016). It is through the use of assumed matters in a research philosophy that the study's reasoning and validation is conducted (Flick, 2013). Saunders et al. (2011), report that the research philosophy explains the essential assumptions regarding the style in which a researcher sees the world. The assumptions needed will support the selection of research strategies and methods used to achieve the goals. The impact of the specific views of the relationship between knowledge and the process employed in creating it cannot be underestimated. Giving due consideration to the philosophies at an early stage helps to identify the type of evidence required, how to gather the evidence and how to interpret the evidence to find a solution to the research question.

Research philosophy consists of a theoretical perspective that is informed by the ontological and epistemological standpoint of the researcher (Levers, 2013). Grit (2010) also posits that there are two traditional philosophies in relation to research, and these are ontology and epistemology which are the foundations upon which the research is built. Furthermore, researchers like Saunders (2011), Lu and Sexton (2004), Flick (2013), Gao and Low (2014) argue that philosophical positions can be considered under three main categories that guide the design of any research, namely: epistemology, ontology and axiology. However, philosophical choice is often a debate between epistemology and ontology. Nevertheless, Ansari and Panhwar (2016) advocate that the philosophy adopted in any research should be seen as a continuum, rather than opposing positions. Therefore, pragmatism maintains that the research topic is the most critical determinant of the research paradigm embraced and that both philosophies can be worked with (Feilzer, 2010). The preference of the research philosophy therefore prescribes the premises for how the researcher observes the world at large (Flick, 2013) and these assumptions will underpin the research strategy (Creswell, 2009a). Therefore, understanding the researcher's philosophy may be useful in the explanation of the matters assumed in the research procedures and the way in which they fit into the methodologies used in the research. Figure 5.2 shows the inter-relationship between the basic elements of research.

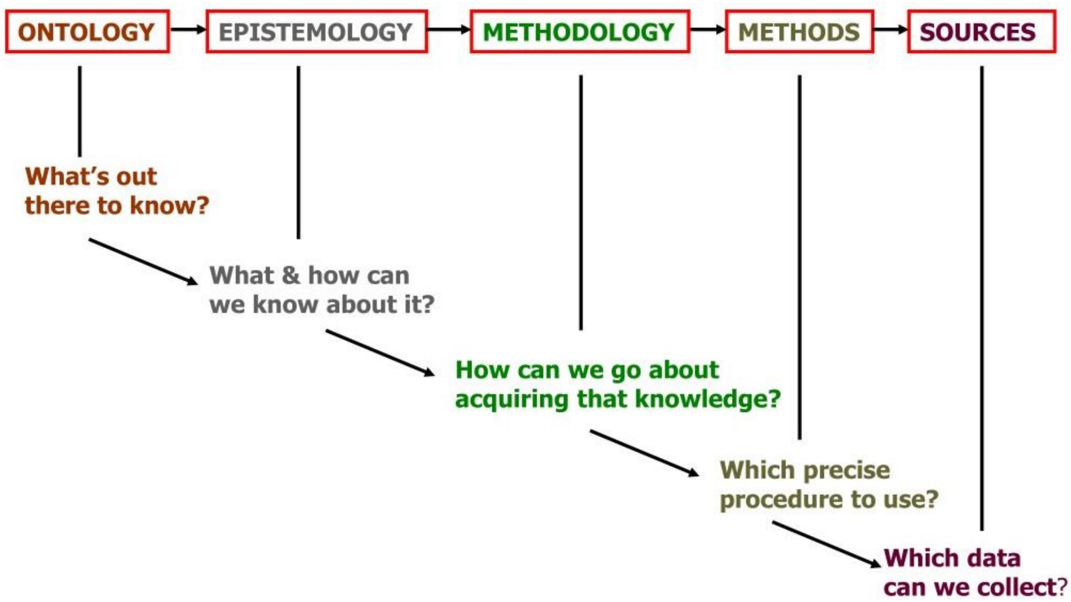

Figure 5.2 Inter-relationship between the basic elements of research. (Source: Hay (2002))

The rigorous consideration of the available theoretical philosophies strengthened the understanding of scientific knowledge of the researcher and consequently enhanced the quality of this research. Since research philosophy is the underlining perspective of the researcher and it can therefore be argued that the researcher's ontological and epistemological assumptions inform the choice of methodology and methods of research.

5.3.1 *Ontology*

Ontological philosophy is concerned with the nature of reality. It requires researchers to ask themselves how they think the world operates, how society is constructed and how this influences everything around us. Creswell (2009) states that ontological assumptions hold a diverse range of viewpoints on social realities, but they have to be placed within political, cultural, historical and economic value systems to establish the differences. Saunders et al. (2012) identify two aspects of ontology, the first being objectivism and the second, subjectivism. Ontology basically addresses matters relating to the nature of reality and most researchers adopt a varied degree of commitment to objectivism and/or subjectivism depending on the specific research aims.

Objectivism

It signifies the position where social objects exist on the exterior to social actors concerned with their existence (Crotty, 1998). It purports that "reality" is definite and out there and can be discovered by specific measures; that is, reality exists independent of the issue being investigated. As such, it lends itself to the scientific method of enquiry in that the elements that can be subjected to a quantitative analysis are investigated.

Subjectivism

It takes the standpoint that social phenomena forms the views and resulting actions of social actors are concerned with their existence (Saunders et al., 2011). That is, 'reality' is framed through the perception of the observer thereby inferring that reality is of a subjective texture, thereby leading to multiple realities. In the subjectivism approach, it is considered that it is the perceptions and actions of the social actors that create the social entity itself and that the continuous interaction of the social actors results in the constant state of change in the social phenomena (Bryman *et al.*, 2008).

5.3.2 *Epistemology*

Epistemology is concerned with the theory of knowledge with regard to its methods, validity, scope and the distinction between justified belief and mere opinion. Bryman (2012) argues that epistemology is influenced by what creates satisfactory knowledge in a specific field of study. It addresses what the researcher considers to be valid, consistent knowledge and its impacts on the research approaches. Saunders (2012) asserts that there are four viewpoints on epistemology, which are positivism, interpretivism, realism and pragmatism.

Positivism

Positivism asserts that only "factual" knowledge gained through observation, including measurement, is reliable, thereby proposing the practice of quantitative experimental methods to test hypothetical-deductive generalisations. The positivist researcher is limited to the collection and interpretation of data by an objective method, and the outcomes of the study are typically measurable and quantifiable. It adopts the stance of the natural scientist and collects data about an observable reality, searching for regularities and casual relationships in the data to create lawlike generalisations.

Interpretivism

Interpretivism on the other hand proposes the practice of qualitative and naturalistic approaches to inductively understand and explain a certain phenomenon. Interpretivism stems from the phenomenological perspective that requires researchers to take a different approach to humans than when studying objects like phones or cars. Creswell (2009) claims that the goal of interpretivism is to improve the general perception of the subject in which scientific advances are generated by the processing of rich data. Therefore, the approach to gaining knowledge requires the subjective views of the participants within the phenomenon being researched.

Table 5.1 Properties of two main research paradigms. (Source: adapted from: Yin (2013) and Creswell (2012))

Component	**Paradigm**	
	Positivism	**Interpretivism**
Ontology	Veracity (truthfulness) is exceptional Reality exists before any investigation	Multiple truths may be constructed, based on the outlook of study. Reality emerges during the investigation.
Epistemology	Signifies decision Events are divided into subunits The distance between the investigator and investigated is maintained	Signifies interpretation Events are studied as a whole Keeps interactivity between the investigator and the investigated
Methodology	Quantitative methods often employed	Qualitative methods often employed

Realism

This research philosophy also relates to scientific enquiry and is dependent on the idea of the objectivity of the reality of the human mind. The essence of realism is that what human's sense is reality and that objects have an existence independent of the human mind. Realism can be divided into two groups: critical realism and direct realism. Critical realism is a branch of philosophy that distinguishes between the "real" world and the "observable" world. According to critical realist Easton (2010) the "real" cannot be observed and it exists independent from human perceptions, theories, and constructions. Therefore, while perceptions and pictures of the observable world are used to depict the real world at best, they can be deceptive and usually do not portray the real world. On the other hand, Saunders (2011) describes direct realism as "what you see is what you get", that is, it portrays the world through personal human senses.

5.3.3 *Pragmatism*

Pragmatism offers a middle ground, it shares strong links with subjectivism and also enables the researcher to use empirical methods (Cameron, 2009). It carries an everyday meaning of being practical, paying attention to the particular context in which you find yourself and not being constrained by traditional fixated ideologies. As such, this philosophy suggests that there are singular and multiple realities that are open to empirical inquiry, positioning itself toward solving practical problems in the "real world." The approach of the Pragmatist is to start with a problem and argue that the research philosophy for the study should be determined by the research question and that the best method is the one which solves the problem. Pragmatism acknowledges that because there are multiple realities (constantly evolving and being interpreted) and no one point of view can paint the full picture, there are different approaches to solving a problem (Saunders et al., 2012). Pragmatist research therefore has components of objectivism and subjectivism, as well as positivism and interpretivism.

5.3.4 *Philosophical stance adopted by this research*

After the review of research philosophies and approaches, this section presents the philosophy adopted for this research and provides a justification for how it can help to ensure this research generates reliable results and meets its goals. The research question to be addressed in this study involves the evaluation and improvement of ethics within the construction materials and products supply chain. Due to the socially constructed nature of the object of inquiry, it was important to understand the realities in this context through the perspectives of different professionals. Such inquiry best lends itself to the interpretivist tradition which involves an interpretivist epistemological position and subjectivist ontological concepts as outlined by Lincoln and Guba (2003) and Ritchie and Lewis (2011) because it considers reality to be socially constructed and value-laden as against positivism concepts which view reality as context-free and value-free (Lincoln and Guba, 2003).

This Interpretivist approach allows the researcher to understand motives, meanings, reasons and other subjective experiences which are time and context bound (Djamba and Neuman, 2002). This in fact agrees with the position of Seymour *et al.* (1997) that construction management research should adopt an interpretivist approach and focus on making more sense of the world rather than concentrating on generalisations (positivism). They claim that it will "recognise the prospective viewpoints of practitioners in the process.… and it better reflects the realities of construction management" (Seymour *et al.*, 1997, p118). Having identified the philosophical stance, the next section looks into the research approach of the study.

5.4 Research approach

According to Saunders' research onion, after determining the philosophical approach to a study, the researcher must determine the research approach, providing detailed guidelines for the research design, and method of enquiry, for the collection and analysis of data. He further describes the research approach as how theory is established and suggests that this can be categorised as mainly deductive or inductive, each with its own specific links to theory, empirical phenomena and methods. Some researchers are of the view that the traditional approaches that lead to either qualitative or quantitative research methods may not always be appropriate for a given research (Ansari *et al.*, 2016; Bryman *et al.*, 2008; Creswell, 2009a; Feilzer, 2010). They posit that there are instances in which the researcher may need to combine aspects of the two traditional approaches in order to ensure that the research objectives are achieved, thereby yielding the concept of mixed methods.

5.4.1 *Deductive approach*

The deductive approach is one in which the hypothesis or hypotheses are developed based on a pre-existing theory and an empirical research approach is then formulated to test it (Silverman, 2013). That is, the development from general to particular in which the base theory is first established, and then the specific knowledge gained from the research process is tested against it. The deductive approach can be considered especially suited to the positivist approach, which allows hypotheses to be formulated based on a theory and predicted outcomes to be statistically evaluated to an agreed degree of likelihood (Russell, 2010). The deductive approach is focused on hypothesis tests which may be appropriate to clarify "what" problems, being the main reasoning applied within natural science. Also, a deductive study is characterised by the testing of a theoretical proposition through empirical research (Saunders et al., 2012) and often involves the testing of prior hypotheses or theories using quantitative data that incorporates standardised measures and statistical techniques. Although, a deductive approach may also be used with qualitative research techniques, but in such cases the expectations formed by pre-existing research would be formulated differently than through hypothesis testing (Saunders et al., 2012). Usually, a deductive approach uses a questionnaire to create an understanding of the observation which allows you to compare different understandings of the people through empirical data. The data gathered helps confirm or reject the hypothesis and the process can be repeated.

5.4.2 *Inductive approach*

In comparison, inductive reasoning is often referred to as a "bottom up" approach and is used to explore a phenomenon while identifying themes and patterns to formulate a theory to create for example, a conceptual framework (Saunders et al. 2012). The inductive approach allows the researcher to create a theory rather than adopt a pre-existing one, as in the case of deductive approach; this clearly outlines the difference between the two approaches. The inductive approach is characterised as a move from the specific to the general (Bryman *et al.*, 2008). The inductive approach is often referred to as a "base-up" approach in that it goes from the particular to the general and it is frequently used in subjectivist ontology. An inductive approach involves perceptions that promote the development of a hypothesis. In this approach, there is no framework that initially informs the data collection and the research focus can thus be formed after the data has been collected (Flick, 2013). Although this may be seen as the point at which new theories are generated, it is also true that as the data is analysed, it may be found to fit into an existing theory (Bryman *et al.*, 2008).

This technique is commonly used for qualitative research. Interviews are performed on particular phenomena and then trends between respondents can be analysed for data (Flick, 2013). However, this approach may also be used effectively within positivist methodologies, in which data is analysed at first and significant patterns are used to inform the generation of results. The approach starts with basic observations and findings, from which the researcher begins to note trends and regularities, formulates some cautious hypotheses that can be explored, and eventually emerges with certain general conclusions or theories (Bryman *et al.*, 2008). The aim of the inductive research strategy is to establish limited generalisations about the distribution and patterns of association amongst observed or measured characteristics of individuals and social phenomena (Blaikie 2009). Participants are therefore carefully selected using purposive or theoretical sampling approaches based on their appropriateness in terms of the inquiry (Philip, 1998). Therefore, inductive reasoning, particularly during the early stages, is more open-ended and exploratory, whereas deductive reasoning is narrower and is usually used to evaluate or confirm theories (Dakhil, 2017). The contrast drawn by Saunders (2011) between deductive and inductive approaches to help to easily comprehend their differences can be seen in Table 5.2.

Table 5.2 The contrasts between deductive and inductive approaches. (Source: Saunders (2011))

Deduction emphasis on...	Induction emphasis on...
• Scientific principles • Moving theory to data • The need to clarify causal connections between variables • The gathering of quantitative data • The use of controls to make sure the validity of data • The operationalisation of concepts to make sure transparency of definition • A highly structured approach • Researcher independence of what is being researched • The need to choose samples of satisfactory size in order to generalise conclusions	• Gaining an understanding of the meanings • humans attach to events • A deep understanding of the research context • The gathering of qualitative data • A more flexible structure to permit changes of research emphasis as the research progress • A realisation that the research is part of the research process • Less worry about the need to generalise

5.4.3 ***Pragmatic approach***

This approach is based on a pragmatic perspective, which suggests that positivism and interpretivism are not opposing views, but rather represent the two ends of a continuum (Creswell, 2009a; Feilzer, 2010). The central principle of this approach is that such unification allows data to be used more fully and synergistically than the independent compilation and analysis of quantitative and qualitative data. This method seeks to utilise the strengths of both qualitative and quantitative research. As the complexity of some research problems makes it such that the sole use of either quantitative or qualitative approaches is inadequate to address them, as such, there is more insight to be gained from mixing both qualitative and quantitative approaches than from either form by itself. The use of such methods is reasonable for developing quantifiable and comprehensible outcomes (Bell, 2009). Whereas the positivism and interpretivism stances align with quantitative and qualitative research respectively, the pragmatic stance aligns with a mixed methodology where both quantitative and qualitative methods can be adopted for a single study to investigate different aspects of the phenomenon. (Cameron, 2009; Creswell, 2009b). The advantages of the mixed method are the ability to answer questions that singular methodologies cannot and the opportunity to present a greater variety of opinions (Feilzer, 2010).

5.4.4 *Research approach adopted for this research*

The research adopts an inductive approach to answer the research questions and achieve the objectives of this study. This is also in tune with the interpretivist philosophical stance of the study, and it is an approach best suited for new research topics with little literature in its actual context such as this. An inductive reasoning through its explorative approach is used to gain a deeper understanding of ethics within the CMPSC and how blockchain technology can impact it, based on learnings of its impact within the supply chain of other industries. The inductive approach starts with the observations from the literature review on ethics in the construction industry and the impact of blockchain generally and on sustainability and ethics in supply chains. The consistent pattern of impact the technology has had on the different industries where it has been implemented and its value propositions as revealed by literature helped to theorise on its potential to impact ethics within the construction supply chain and to develop a conceptual model that exemplifies it. The findings from the interview and the respondents' feedback on the model further substantiates the development of the theory that initially emerged from the observation of patterns across the reviewed literature.

5.5 Research method

The fourth layer of the research onion addresses choices; it includes the mono method, the mixed method, and the multi-method (Saunders et al., 2011). In this layer, considerations are given to the use of quantitative and qualitative methods for research purposes.

5.5.1 *Quantitative research method*

According to Jonker and Pennink (1937), quantitative research is often regarded as being purely scientific, justifiable, precise and based on facts often reflected in exact figures. Quantitative methods emphasise objective measurements and the statistical, mathematical, or numerical analysis of data collected through polls, questionnaires, and surveys, or by manipulating pre-existing statistical data using computational techniques. Quantitative research focuses on gathering numerical data and generalising it across groups of people or to explain a particular phenomenon. Quantitative methods look to quantify data and generalise results from a sample of the population of interest (Castiglione *et al.*, 2018). The quantitative approach which is mainly connected with experiments, survey research strategies, archival research, and case studies follows the positivist school of thought. As such, it forms a critical part of the investigation in physical sciences, such as physics, chemistry and mathematics.

The common research approaches adopted within quantitative research are normally experimental and survey approaches, adopting questionnaires or structured interviews to quantify the collected data (Saunders et al. 2012). Unlike qualitative research, in quantitative research, numerical data is collected and analysed, and it is concerned with frequencies rather than words and meanings. The strengths and weaknesses of quantitative research are presented in Table 5.3.

Table 5.3 Strengths and weaknesses of quantitative research

Strengths	**Weaknesses**
• Stating the research problem in very specific and set terms. • Clearly and precisely specifying both the independent and the dependent variables under investigation. • Following firmly the original set of research goals, arriving at more objective conclusions, testing hypothesis, determining the issues of causality. • Achieving high levels of reliability of gathered data due to controlled observations, laboratory experiments, mass surveys, or other form of research manipulations. • Eliminating or minimising subjectivity of judgment (Kealey and Protheroe, 1996). Allowing for longitudinal measures of subsequent performance of research subjects.	• Failure to provide the researcher with information on the context of the situation where the studied phenomenon occurs. • Inability to control the environment where the respondents provide the answers to the questions in the survey. • Limited outcomes to only those outlined in the original research proposal due to closed type questions and the structured format. • Not encouraging the evolving and continuous investigation of a research phenomenon (Matveev, 2002).

5.5.2 *Qualitative research method*

According to Fellows and Liu (2013) qualitative research can be defined as an exploration of a subject, undertaken without prior formulations in a bid to gain understanding and collect information and data, such that theories will emerge. It is concerned with the richness of information as this method attempts to gain an understanding of the underlying reasons and motivations for actions and how people interpret their experiences and the world around them. A qualitative study is linked with a variety of strategies, and whilst these share epistemological roots and normal characteristics, each strategy has a particular stress and scope as well as a specific arrangement of procedures. Some of the strategies utilised in qualitative research include action research, case study research, ethnography, grounded theory and narrative research. Usually, qualitative methods provide insights into the setting of a problem, generating ideas and/or hypotheses. Creswell (2013) suggests that mixing qualitative and quantitative methods leads to a process of "triangulation" in order to search for convergence amongst the results. In addition, Denzin and Lincoln (2006) describe the concept of "methodological triangulation" as the grouping of multiple methods to study a phenomenon. Table 5.4 presents the strengths and weaknesses of qualitative research.

Table 5.4 Strengths and weaknesses of qualitative research

Strengths	**Weaknesses**
• Obtaining a more realistic feel of the world that cannot be experienced in the numerical data and statistical analysis used in quantitative research. • Flexible ways to perform data collection, subsequent analysis, and interpretation of collected information. • Provide a holistic view of the phenomena under investigation (Bogdan and Taylor, 1975; Patton, 1980). • Ability to interact with the research subjects in their own language and on their own terms (Kirk and Miller, 1986). • Descriptive capability based on primary and unstructured data is useful for describing complex phenomena. • It is useful for studying a limited number of cases in depth (Johnson and Onwuegbuzie, 2004).	• Departing from the original objectives of the research in response to the changing nature of the context (Cassell and Symon, 1994). • Arriving to different conclusions based on the same information depending on the personal characteristics of the researcher. • Inability to investigate causality between different research phenomena. • Difficulty in explaining the difference in the quality and quantity of information obtained from different respondents and arriving at different, non-consistent conclusions. • Requiring a high level of experience from the researcher to obtain the targeted information from the respondent. • Lacking consistency and reliability because the researcher can employ different probing techniques and the respondent can choose to tell some particular stories and ignore others (Matveev, 2002).

5.5.3 *Multiple methods research*

Multiple methods are thus separated into multi-method and mixed methods research. Whether a researcher decides to combine quantitative with qualitative approaches or combines different qualitative approaches in one research project, the objective is to emphasise the value of the different approaches. In this way, a combination can contribute to a better understanding of a research problem compared to research that is based on only one methodological approach (Creswell, 2015).

While Morse (2010) points out that there is no actual consensus regarding the actual definitions of multi-method and mixed method research; however, the perspective shared by most researchers is that in multi-method research uses multiple methods within the same philosophical paradigm while mixed methods uses methods across different philosophical paradigms (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

Multi-method Research

Multi-method research is research that uses multiple methods within the same philosophical paradigm. That is, it could use multiple forms of qualitative data (e.g., interviews and observations) or multiple forms of quantitative data (e.g., survey data and experimental data) (Creswell 2015). For example, in multi-method qualitative designs, the researcher adopts a subjectivist philosophical paradigm to establish their proposed ideas, which will be validated by implementing different types of qualitative methods (for example, in-depth interviews and diary accounts) with associated analysis procedures (Tashakkori *et al.*, 2010). Although the literature presents a wide range of arguments for why a multi-method qualitative design is preferable to a single methodological approach. According to (Mik-meyer, 2021) there seems to be two overall considerations among scholars when arguing for the advantages of a multimethod approach: To discover what is truly at stake in the "real world" they are investigating (a world that is ostensibly separate from themselves and their bias); and to gather as many voices and features from the participants' social worlds as possible, in order for the analysis to be as multifaceted as possible, and thus in compliance with the complex and multi-layered social world. The former is more suited to a more positivistic or realistic research strategy, whilst the latter is better suited to a more constructivist research approach.

Mixed Method Research

Traditional approaches that lead to either qualitative or quantitative research methods, according to some academics, may not always be appropriate for a given research (Ansari *et al.*, 2016; Onwuegbuzie *et al.*, 2009). In other cases, the researcher will need to blend elements from both traditional approaches to guarantee that the research objectives are met. As a result, the concept of mixed methods emerged. This method is based on a pragmatic viewpoint, which indicates that positivism and interpretivism are not diametrically opposed viewpoints, but rather two endpoints of a continuum. This means that two philosophical positions can lead to mixed methods research designs where the researcher could start with an objectivist philosophy and follow this with subjectivist philosophy, or vice versa (Amaratunga *et al.*, 2002; Ansari *et al.*, 2016; Creswell, 2009b). As a result, a mixed methods research design can take either a deductive or an inductive approach, or a combination of the two; for example, quantitative or qualitative research can be used to test a theoretical proposition, followed by more quantitative or qualitative research to develop a more comprehensive theoretical perspective (Saunders, 2012). The strengths of mixed methods research offset the weaknesses of quantitative and qualitative research, it provides a more complete and comprehensive understanding of the research problem than either quantitative or qualitative approaches alone, and it aids in explaining findings or causal processes (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

However, despite the advantages of the mixed method approach, several researchers have also expressed scepticism towards the mixed method approach. Scholars argue, for instance, that project designs end up being "unnecessarily complicated" with a "myriad of designs" or conversely "too simplistic"(Mik-meyer, 2021). Mixed method research does not "represent [a] consistent system" (Onwuegbuzie *et al.*, 2009, p. 267), as mixed method designs do not fully grasp the difference between paradigms (Sale et al., 2002, p. 49), that is, the fundamental difference between a positivist-inspired quantitative approach and an interpretive-inspired qualitative approach (Järvinen and Mik-Meyer, 2020). Silverman (2013) suggests that it is usually far better to celebrate the partiality of your data and delight in the particular phenomenon that it allows you to inspect (hopefully in detail).

Nevertheless, regardless of these deficiencies, there are still good reasons for implementing a mixed method approach, it all depends on what you are trying to find out. He adds that "there are no right or wrong methods. There are only methods that are appropriate to your research topic and the model with which you are working" (p. 195). Dakhil (2017) identifies the contrasts between multi-method and mixed method research, as presented in Table 5.5.

Table 5.5 The main differences between multi-method and mixed method

Multi-method	**Mixed Method**
Multiple methods used within the same paradigmatic influence (e.g., two qualitative or quantitative methods). Each method could answer different sub questions. The goals of multiple methods are usually: • Outcome triangulation — seeing social phenomena in its multiple dimensions.	Mixed methods usually employ research strategies or methods from different paradigms (i.e., using both qualitative and quantitative methods), whereby the goals are just not convergence or comparison of data, but: • Corroboration through convergence of findings, • Elaboration, by providing richness and detail, and

• Data triangulation—use of two or more methods which are exhaustive and rigorous in themselves, leading to several forms of data in studying the same phenomenon	• Initiation, by prompting new interpretations and suggesting areas of further exploration through recasting the entire research question.

5.5.4 *Research method approach adopted for this research*

Having understood the characteristics, strengths and weaknesses of the different approaches, the approach adopted for this research is a (qualitative) multi-method design. This research follows the (QUAL-qual) design as illustrated by Lambert and Loiselle (2008), Mik-meyer (2021) and Morse (2010). The qualitative (QUAL-qual) multi-method design was conducted using two data sets with two groups of participants. Based on the research question, this research's inductive theoretical drive utilises a qualitative core component (QUAL) with a sequential qualitative supplementary component (qual). According to Morse (2010), a QUAL-qual design can include "a complete technique (i.e., the core component) and one (or more) incomplete method(s) (i.e., the supplementary component[s]) that cannot be published alone, within a single study" (p. 485). As a result, the supplementary component gives information within the context of the core component, but it cannot be interpreted or used alone. Perhaps because the supplementary component has an insufficient sample, lacks saturation, or is simply too narrow to be of interest on its own, but it is sufficient to answer a particular question to the researcher's satisfaction and allow the research programme to continue (Morse, 2010).

In this research, the data from the expert interviews which is the core component is grouped for all participants and analysed thematically. The data from the focus group which is the supplementary component is also pooled for all participants. These participants were selected from the pool of participants who participated in the core component. The data from both components are analysed separately, and the results of each analysis meet in the results point of interface.

5.5.5 *Rationale for employing qualitative multi-method design*

While different approaches possess differing characteristics, strengths and weaknesses, choosing an approach for this study surpasses simply looking at the advantages and disadvantages of each method but an evaluation of different approaches to identify which approach provides the best data for the purpose of the study. Having understood this, the approach adopted for this research is a (qualitative) multi-method design as the qualitative approach is considered best suited to answer the research questions and to fulfil the research objectives, thereby achieving the overall aim of the study.

According to Tierney et al. (2019), using different qualitative methods, all based on the same epistemological perspective may strengthen the quality of the research, as different methods allow for different angles and nuances to be visible. The utilisation of a multi-method research design may develop comprehensiveness and rich knowledge (Mills et al., 2010) and can help to mitigate the flaws that individual approaches have (Wood et al., 1999). Hence, expert interviews and focus group were deemed to be the most appropriate for the study and hence selected as the qualitative data collection techniques for this study. Their combination is advantageous to the study as it allows for the generation of complementary or even opposing views on the subject being studied. They may also be combined for the purposes of data completeness and/or confirmation (Adami 2005). While this study takes an interpretive approach, which is generally associated with qualitative research (Williamson and Bow, 2002), there are in fact more reasons for which a qualitative multi-method design was considered best suited for this study.

Firstly, the research questions presented in Chapter 1 of this study require rich in-depth information from experts in the fields of ethics, blockchain and the construction industry in order to understand the dynamics of ethics within the construction industry and the potential of blockchain as a socio-technical approach for the improvement of ethics within the construction materials and products supply chain. Denzin *et al.* (2006) affirm that the researcher cannot obtain such depth of information through quantitative analysis. They explain that the word “qualitative” implies an emphasis on the qualities of entities and on processes and meanings that are not experimentally examined or measured (if measured at all) in terms of quantity, amount, intensity, or frequency. Babbie (2004) stresses that this type of research can produce a richer understanding of many social phenomena. Therefore, a qualitative research approach has been chosen for this study, because following the substantial review of relevant literature, it became clearer that “ethics” is socially constructed phenomena. As such, it was important to understand how various industry practitioners interpret ethics within the context of their industry and the larger world around them. With interpretivism, reality is socially constructed and thus an inquiry has a value-laden nature, as opposed to positivism which views reality as context-free and value-free. Hence, the study lends itself to interpretivist ontological and epistemological based concepts with qualitative methods as outlined by Lincoln and Guba (2003).

Secondly, the reason for employing two qualitative data collection techniques—the expert interviews and the focus group—was to thoroughly evaluate and validate the conceptual model developed for the improvement of ethics in the construction materials and products supply chain. According to Abraham et al. (2006), expert interviews are a way of validating research models and frameworks. The validation process for the developed model involved a dual phase approach.

In the first phase, semi-structured interviews were conducted with 30 industry professionals to validate the model elements and components, providing feedback on each layer of the model and the workability of its components. The layout of interview questions was broken into three sections and the semi-structuredness of the interview allowed the researcher to adapt the interview to gain detailed feedback on the model from the participants. In the third section of the interview, the researcher conducts a presentation of the conceptual model and allows for immediate reactions from the participant before the researcher then begins to ask questions. This served as the first phase of the dual-phase validation strategy for the conceptual model. The interview strategy adopted for this research is further discussed in section 5.6.2.1 of this study.

Following the feedback of participants in the first phase, the model was then revised and then presented for validation in the second phase. The revised model was then presented in the focus group and the table was opened for participant interactions, comments and feedback on the model to consummate the validation of the model. The focus group discussion involving 5 industry professionals was conducted to validate the workability of the model within the industry and its feasibility to improve ethics within the CMPSC. The focus group strategy adopted for this research is further discussed in section 5.6.3.1 of this study. The interview and focus group approaches utilised for the dual phase validation of the model allowed for a dynamic flow of rich thoughts that could not have been otherwise gotten through a quantitative approach due to its rigid structure.

Lastly, a qualitative approach was chosen for this study because blockchain, the technology upon which the proposed model is developed in this research is built is still relatively new, even more so within the construction industry context and there is also spareness of studies on sociotechnical approaches to ethics in construction. Drisko (1997) and Onwuegbuzie *et al.* (2009) affirm that a qualitative approach is better when not so much is known about the subject being studied. As such, qualitative data was considered best suited to extract in-depth information relevant to this study from the limited number of experts in the fields of ethics and construction who also understand the workings of blockchain technology.

5.6 Research technique adopted by this research

Saunders (2011) distinguishes data collection and analysis as the most vital parts of the conduct of research. In connection with data gathering, some key issues identified by Saunders (2011) consist of sampling, secondary data and primary data. Three key linked research techniques have been adopted for this study, which are: the literature review, in-depth semi-structured interviews and focus group. In this section, these techniques are further expounded and discussed in the context of the current research. Table 5.6 illustrates the mode of investigation that will be adopted to achieve each research objective.

Table 5.6 Research objectives in relation to the mode of investigation

S/N	Objectives	Methods of Investigation			Outcomes
		Literature review	***Interviews***	***Focus group***	
1	To evaluate the current state of ethics in the CMPSC following the TBL construct and how effective the current ethical measures have been	✓	✓		The current state of ethics in the CMPSC is weak across the three dimensions examined and the effectiveness of the current ethical measures in the CMPSC has been limited due to corruption.
2	To explore blockchain technology and its implementations for ethics following the TBL construct, in view of applying the learning to evaluate its feasibility to improve ethics in the CMPSC	✓			Blockchain possesses potential to tackle environmental, social and business ethical concerns in the CMPSC based on its core features and current implementations. However, it is not a panacea for addressing the ethical concerns.
3	To establish how blockchain technology can help improve ethics in the CMPSC within the TBL construct	✓	✓	✓	
4	To determine the factors that may affect the acceptance and implementation of blockchain technology in the CMPSC	✓	✓	✓	Blockchain holds promising potential for improving ethics in the CMPSC. However, factors related to the blockchain system, the construction industry and factors related to external barriers may affect its acceptance and implementation.
5	To develop and validate a model for improving ethics across the CMPSC following the TBL construct using blockchain technology	✓	✓	✓	An industry validated model for improving ethics in the CMPSC using blockchain.

5.6.1 *The literature review*

The literature review was required in order to comprehend the current state of knowledge in this field of study and to identify knowledge gaps. According to Bryman (2012), the purpose of a literature review in any research endeavour is to ensure that the researcher is aware of what is already known about the topic area so that old ground is not being covered. The literature review was crucial in achieving the research objectives and providing the necessary insights to meet the aim of the research. At the initial stage of the research, a substantial review of literature was conducted to gain knowledge in the fields of blockchain, ethics and construction supply chain. With the aim of exploring how blockchain technology can impact ethics within the construction industry supply chain, based on an evaluation of its documented impact within the supply chains of other industries and subsequently to identify the research gaps, form the research aim and objectives as well as the research methodology required to achieve them. Following the identification of the study's aim and objectives, a more detailed literature review was conducted to further develop knowledge on the subject matter, with the goal of developing the theoretical framework and conceptual model required to achieve the study's overarching aim. The literature review helped to explain, justify, validate and situate findings within the body of knowledge.

5.6.2 *Interviews*

The interview is a well-established tool in qualitative research and can be modified to fulfil various research aims. They can be employed at any stage during the data gathering process, and they can be combined with other approaches in the same study (Lambert and Loiselle, 2008). Bogdan and Biklen (1992) described an interview as a "purposeful conversation" (pp.135). This view is also supported by Kale and Brinkmann (2008), as they identified an interview as a professional conversation between the interviewer and the interviewee through which knowledge is created in the interaction. Interviews offer an opportunity for the researcher to discover new meanings, and reveal new extents of a problem (Yin, 2009).

According to Easterby-Smith *et al.* (2012), interviews are either structured, semi-structured or unstructured. They also emphasise that in-depth, semi-structured interviews are essential for qualitative methods. Furthermore, interviews are usually conducted with individual participants or with a group of participants. Individual interviews are one of the most widely adopted methods of collecting data in built environment research (Amaratunga *et al.*, 2002). Individual interviews are commonly used by researchers to get thorough accounts of participants' opinions, attitudes, beliefs, and knowledge about a certain phenomenon with the assumption that if questions are formulated correctly, participants' expressions of their experiences will reflect their reality (Lambert and Loiselle, 2008). Individual interviews allow the researcher to delve into the subject matter in a manner that allows for the development of aspects in the conversation in contrast to group interviews which are focused on multiple participants speaking on the same issue. Additionally, there may be greater motivation of participants wanting to give more socially acceptable answers when interviewed as part of a group.

It is normal for qualitative studies to conduct face-to-face interviews with the participants but it is not mandatory (Creswell, 2009b). Advances in ICT offer new opportunities for interviewing research participants (Archibald *et al.*, 2019). They further add that online methods are more convenient, flexible and cost-effective than in-person interviews or focus groups, especially when doing research with participants spread across a large geographical area both for the researcher and the participants. Furthermore, they added that online methods can complement and possibly improve traditional methods like in-person interviews and focus groups. Given the necessity to engage numerous stakeholder groups and communicate with geographically dispersed people, these factors are especially important in many research contexts.

Furthermore, the unprecedented change and disruption caused by COVID-19 presented qualitative researchers with unique opportunities and challenges. Most researchers had to switch from face-to-face qualitative data gathering to a "socially distant" strategy using videoconferencing services (Lobe *et al.*, 2020). Platforms such as Skype, Zoom, Microsoft Teams, Webex, Streamyard, Googlemeet offer (online) face-to-face communication, and interviews and focus groups conducted online are simply versions of traditional methods, using internet venues instead of face-to-face interaction (Nobrega *et al.*, 2021). People have become accustomed to using numerous platforms and software's to transmit at least some of their daily interactions and communication online, due to our ever-growing digital society and the COVID-19 epidemic. In addition, findings from a study by Archibald *et al.* (2019) and Howlett (2021) suggest the viability of Zoom as a highly suitable platform for collecting qualitative data because of its ability to facilitate personal connections between users due to its relative ease of use, cost-effectiveness, data management features, security, interactivity, and its screen sharing and video recording features .

Nonetheless, Seitz (2016) argues that online video interviews present potential disadvantages such as loss of signal, leading to dropped calls and segments where audio is missing. Further adding that interviews are an intimate setting where the researcher both listens for the verbal responses and reads nonverbal cues, such as body language, to interpret and rephrase questions and while video platforms allow the researcher to see the respondent, they might not provide sufficient ability to read nonverbal cues and body language as respondents often sit close to their devices, allowing the researcher to see only the face in most cases.

5.6.2.1 Interview strategy adopted for this research

In-depth individual semi-structured interviews were conducted with experts in the fields of ethics, blockchain and construction. The interviews were designed based on best practice guidelines as suggested by Bryman *et al.* (2008). They point out that the use of semi-structured interview methods enables the investigator to check the level of understanding that a participant has around a specific issue – generally in more detail than a questionnaire – and can be utilised as an effective tool for conducting an exploratory evaluation of a phenomenon. According to C. Robson (2002), semi-structured interviews have pre-programmed questions, but the order of the questions can be changed depending on the interviewer's perceptions of what seems to be most suitable.

In this research, the layout of interview questions could be broken into three sections. The main goal of the questions from the first section was to ease the participant into the interview whilst also getting the participant's understanding of blockchain technology. In the second section, the main goal was to obtain in-depth information on ethics within the construction industry and the potential of blockchain as a socio-technical approach for its improvement within the construction materials and products supply chain context. In the third section, the researcher conducts a presentation of the conceptual model and allows for immediate reactions from the participant following the presentation before the researcher then begins to ask questions with the aim to validate the conceptual model. The main goal in this section is to validate the model elements and components and its feasibility to improve ethics within construction materials and products supply chain. This serves as the first phase of the dual-phase validation strategy for the conceptual model, as expert interview is a way of validating research models and frameworks (Abraham, 2007).

The semi-structuredness of the interview allowed the researcher to adapt the interview to gain detailed feedback on each layer of the model from the participants since different participants had different degrees of knowledge of blockchain, and at the same time dive deep into the factors shaping them. For example, if one study participant mentioned that they would add a specific feature to the model for their implementation, it was asked if they could talk more about this feature. This flexibility favoured the use of semi-structured interviews for this research over its structured and unstructured counterparts.

Furthermore, on one hand, the rigidity of structured interviews and the inability to alter questions without compromising the quality of data stifles the opportunity to generate a flow of thoughts from the participants. This limited room for nuances therefore limits both the researcher and the participants from going into much detail in the conversation. On the other hand, while the flexibility of unstructured interviews can allow for the flow of new ideas, it can also be challenging to keep such interviews on track, with the risk that tangents and side questions can unnecessarily extend interview time and derail the interview objectives, thereby decreasing the internal validity of the research.

The interviews were recorded, transcribed, and coded for analysis. The analysis of the findings from the interview informed the refinement of the conceptual model and the design of the focus group. The revised model was then validated via focus group (the last phase of the validation strategy). This approach is also in line with the interpretive epistemological point of view that underlies this research (Saunders et al., 2009).

All participants received emails containing relevant documents for the research interview including: a debriefing sheet, a participant information sheet, a consent form, a copy of the final model and some notes to help understand the workings of its elements and components. A copy of the model was usually sent ahead two days before the interview to give the interviewee ample time to critically evaluate the model, so as to be able to give rich feedback during the interview. However, individual questions from the interview were not sent to the interviewees to prevent scripted inorganic interview answers and experiences. Each individual interview lasted at least an hour; allowing ample time for participants to share their insights on the subject matter and the conceptual model developed.

The interviews were conducted until theoretical saturation was reached, meaning that new interviews were carried out until no substantially new information was generated. Thus, the validity of the results based on the interviews can be considered high. The interviews once completed were then transcribed, cleaned and thematically analysed using NVIVO 12. This “is a method for identifying, analysing and reporting patterns (themes) within data" (Braun and Clarke, 2006, p. 79). An interactive inductive and deductive procedure was adopted to compile a set of themes and subthemes, aimed at representing the datasets through a thorough analysis of the transcripts. Rich results were drawn from the collected data, indicating the suitability and quality of online audio-visual interviews for this research.

Given the significant potential of online communication technologies to support qualitative data collection despite the face-to-face restrictions due to social distancing government regulations as earlier discussed in section 5.6.1 of this chapter, this research utilises the use of online videoconferencing applications to interview participants. As such, potential participants needed to meet certain technological and logistical requirements to be able to participate. However, this was not really a challenge as digital skills and competence have also grown since the wake of the pandemic, consequently making their participation in this online interview easier. The online videoconferencing applications utilised for interviews in this research were Microsoft Teams and Zoom as they both offer the ability to communicate in real time with geographically dispersed individuals via computer or mobile devices. A key reason being their ability to securely record and store sessions without recourse to third-party software. This feature is particularly important in research where the protection of data is required. They also both possess other important security features including user-specific authentication, real-time encryption of meetings, and the ability to backup recordings to the cloud or on local drives, which can then be shared securely for the purpose of collaboration.

Lastly, while the basis for the semi-structured interview approach used in this research has been sufficiently justified. It is however acknowledged that the use of only qualitative methods results in methodological limitations that might impact the generalisability of the research findings. As findings from qualitative approaches may not be extended to wider populations with the same degree of certainty that quantitative methods provide.

5.6.2.2 Criteria for interview participants selection

A purposive sampling strategy was utilised for this research to ensure that participants meet the selection criteria and the required characteristics for this study, as decided by the researcher. The sample had to include participants from the following fields: ethics/sustainability in construction, IT/ blockchain technology and construction supply chain. As such, this study targeted participants with a minimum of 5 years' experience in any of the underlisted sectors. Most of the interviewed participants belonged to at least two of the underlisted fields.

- Construction Industry – consultants, contractors, procurement managers
- Ethics / Sustainability in Construction
- Blockchain / Information Technology - blockchain developers/researchers

The personal and professional networks of the researcher were considered, and appropriate professionals were contacted mostly through LinkedIn. A few others were also contacted through online messaging applications to seek their interest in participating in the interview. Amongst the 85 potential participants that were contacted for this study, 33 eventually agreed to be interviewed. The demographics of interview participants are shown in Table 5.7.

However, only a total of 30 participants were interviewed in this study, comprising of 16 construction industry supply chain professionals, 10 professionals in the ethics/sustainability in construction and 4 blockchain technology experts. The interviews started in August 2021 and continued until data saturation was reached in December 2021. Although actual theoretical saturation in the study occurred before the twenty-sixth interview, the interviews were brought to a stop only after interviewing the thirtieth participant to ensure greater dependability and transferability (Creswell, 2014), as it had become evident that no substantially new information would be generated from conducting further interviews. Thus, these were considered to fulfil the adequacy of the sample for theoretical saturation; hence, the validity of the results based on the interviews can be considered high.

Table 5.7 Demographics of interview participants

Participant Identifier	Years of Experience	Field	Description
PC1	45+	Construction	A leading expert in the built environment digitalisation space through the Digital Twin Consortium, Building 4.0 CRC, AEC Hackathon, etc.
PC2	40+		An experienced fraud investigator with over 40 years of experience in construction
PC3	40+		Former President of the Institute of Structural Engineers (ISE) with high involvements in anti-corruption programmes and forums
PC4	36+		Principal partner of an Architectural firm and adjunct professor
PC5	24+		Director of procurement and supply chain at one of the world's largest development and construction companies

PC6	15+		A construction manager with a private sector property management company with a trade background, currently a fellow with the institute of carpenters
PC7	10+		Quantity Surveyor with multinational contractor experience with a master's degree in a blockchain cum construction field
PC8	10+		Business and technology analysis for design, construction, engineering, and blockchain.
PC9	8+		Architect and Project Manager with strong interest in green buildings
PC10	7+		Quantity Surveyor with experience in consultancy and contracting and a blockchain cum construction researcher
PC11	7+		Architect and construction manager
PC12	7+		Architect, CAD expert and web designer
PC13	7+		Project Architect and CAD expert
PC14	7+		Architect and CAD expert with strong interest in sustainability
PC15	6+		A Civil Engineer, construction Project Manager and a Web3 Blockchain developer
PC16	5+		Architect with strong interest in circular economy schemes in construction
PES17	43+	Ethics / Sustainability in Construction	International anti-corruption expert running projects in countries with very high corruption risk including 18 countries in Africa and some European countries
PES18	40+		A construction lawyer and director of anti-corruption programmes, providing training resources and on a website which gets visited by thousands of organisations monthly from 190 countries involved. He is also involved in the publication of ISO 37001 and the Commonwealth anti-corruption benchmarks
PES19	20+		Lead construction supply chain sustainability professional with keen interest in sustainable procurement. Also involved in the creation of ISO 2400 (International standard for sustainable procurement)
PES20	15+		Social value in supply chains expert; optimising, measuring and reporting social, environmental and economic performance of businesses, programmes and supply chains
PES21	10+		Regional manager for Africa in one of the world's leading anti-corruption and transparency in public sector construction organisations
PES22	10+		Open data specialist and software developer in one of the world's leading anti-corruption and transparency in public sector construction organisations
PES23	10+		Policy lead on public contracting in one of the world's leading anti-corruption and transparency organisations
PES24	10+		Head of open data and country manager in one of the world's leading anti-corruption and transparency in public sector construction organisations
PES25	7+		Director of social value and sustainability at a construction and infrastructure company
PES26	7+		A sustainability and climate change lecturer and practitioner
PB27	30+	Block chain /	Possess over 30 years in IT industry and over 9 years of experience in blockchain and has developed a currently running blockchain enterprise solution

PB28	20+		Possesses over 20 years of experience in IT with over 10 years of experience in blockchain and has helped develop blockchain enterprise sustainability solutions for consumer products such as cocoa and palm oil
PB29	8+		Managing director of a blockchain solutions organisation and developer of blockchain solutions with a background in real estate
PB30	5+		Researcher focused on blockchain applications to reform the construction industry

5.6.3 *Focus group*

The primary goal of this method is to use interaction data resulting from discussion among participants (for example, questioning one another and commenting on each other's experiences) to increase the depth of the inquiry and uncover aspects of the phenomenon assumed to be otherwise less accessible (Gill *et al.*, 2008). Group interactions may accentuate members' similarities and differences and give rich information about the range of perspectives and experiences (Lambert and Loiselle, 2008). Powell and Single (1996) define a focus group as a group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research. According to Morgan (2012), they can be used as a stand-alone approach or as a supplement to other methods, particularly for triangulation and validity checking. They can also be adopted as a single source method, supplementary source or multi-method study. Although focus groups are a form of group interviewing but there are differences between the two. A key characteristic that distinguishes focus groups from group interviews is the insight and data produced by the interaction between participants. Merton and Kendall (1946) posit that focus group participants must have a specific experience of or opinion about the topic under investigation; that an explicit interview guide is used; and that the subjective experiences of participants are explored in relation to predetermined research questions. Powell and Single (1996) affirm that a focus group is especially useful when the subject under investigation is complex, and the concurrent use of additional data collection methods is required to ensure validity.

Although focus group research has numerous advantages, it does have limitations, just like any other research approach. In comparison to quantitative studies or individual interviews, the researcher or moderator has less control over the data collected (Morgan 1988). The moderator must let participants converse with one another, ask questions, and express doubts and viewpoints while exerting little control over the conversation other than ensuring that participants remain focused on the issue. Focus group research is inherently open-ended and cannot be completely predetermined.

Also, Gill *et al.* (2008) argue that focus group research is limited in terms of its ability to generalise findings to a whole population, mainly because of the small numbers of people participating and the likelihood that the participants will not be a representative sample. Although, face-to-face focus groups usually work well with anywhere between four and ten participants, and even though videoconferencing platforms usually allow for a large number of people to be included in a single session, online focus groups call for even lower numbers, ideally from three to five, because the platforms work best with a relatively small number of participants (Lobe *et al.*, 2020; Morgan, 2012).

In addition, finding the right people to participate in a focus group is not always straightforward (Powell and Single, 1996). The disparities between members might have a significant impact on their contributions if a group is excessively varied, whether in terms of gender or class, or in terms of professional and lay perspectives. Diverse perspectives and experiences may not be conveyed if a group is homogeneous in terms of specific qualities.

Furthermore, on a practical note, focus groups can be difficult to assemble (Gibbs, 1997). It may not be easy to get a representative sample and focus groups may discourage certain people from participating. For example, those who are not very articulate or confident, and those who have communication problems or special needs. Also, with group interviews, there is the problem of bringing together professionals within the target fields for an interview at the same time. This may be difficult to achieve as each person belongs to different organisations with unique work environments. Even more, the nature of the open group discussion may also discourage some people from trusting others with sensitive or personal information.

5.6.3.1 Focus group strategy adopted for this research

It has previously been stated that similar characteristics among participants and mutual knowledge of the subject area are essential to facilitate an open and transparent discussion in a focus group. To ensure the appropriate people were invited to participate in the focus group for this research, the researcher invited all the participants who had participated in the first phase of the primary data collection process. Although all interviewees had earlier signified their interest in participating in the subsequent focus group discussion; however, when they were later contacted for the focus group discussion, only five participants were able to follow through due to other personal and official engagements and possibly due to some factors that were earlier identified in section 5.6.3.

Morgan and Kreuger (1993) posit that focus groups are particularly useful when one wants to explore the degree of consensus on a given topic; hence, a focus group discussion was utilised to evaluate the degree of consensus on the validity of the conceptual model. However, Gill *et al.* (2008) argue that they are limited in terms of their ability to generalise findings to a whole population, mainly because of the small numbers of people participating and the likelihood that the participants will not be a representative sample. Therefore, it is utilised in this study as a supplementary component of the data collection to give information within the context of the core component, and hence, it cannot be interpreted or used alone. The recommended number of people per group is usually six to ten (MacIntosh, 1993), but some researchers have used up to fifteen people (Goss and Leinbach 1996) or as few as four (Kitzinger, 1995). The feedback from the experts interviewed helped the researcher learn more about the knowledge domains from the perspective of experts and to also incorporate the requirements of the end users better. This led to a revision of the model in order to foster its acceptance and implementation. The focus group was then conducted as a final validation exercise for the revised model. The focus group for the research comprised five professionals, all being participants who took part in the first phase of the data collection. As such, they were already acquainted with the research focus and the model objectives.

As discussed in section 5.6.3, the COVID-19 pandemic and the subsequent lock-down and rules for social distancing imposed severe restrictions on in-person research. Although, focus group interviews have been conducted in online settings well before now; however, only a few papers have been identified (Nobrega *et al.*, 2021). Meanwhile, a well-planned virtual focus group protocol is a valuable tool to engage intervention stakeholders for research and evaluation from a distance. The focus group discussion for this study was held online on the Microsoft Teams video conferencing platform. Careful planning of privacy measures for a secure online environment and procedures for facilitation of group dialogue were put in place to ensure the success of the focus group.

Similar to the protocol adopted for the interviews, the intending participants were sent details of the research by email. The mail contained relevant documents for the research interview including: a debriefing sheet, a participant information sheet, a consent form, a copy of the revised model and some notes to help understand it. A copy of the revised model was sent ahead before the discussion day to give the participants ample time to critically evaluate the model, so as to be able to give richer feedback during the discussion.

The focus group discussion lasted for two hours, giving participants ample time to share their thoughts on the study and validate the model. The discussion opened up with (participants) introductions before moving to more salient discussions aimed at answering the research questions and fulfilling the objectives of the study. The researcher presented the revised model and allowed for participant interactions, comments and feedback on the model for its validation.

5.7 Data sampling

The method by which individuals from a group of people are selected to take part in the collection of data during the research is known as sampling (Saunders, 2012). The sample to be studied should represent the full set of cases in a way that is meaningful and that can be justified (Becker, 1998). It is usually done because it is impossible to test every single case in the population. There are two methods of sampling for the purposes of research: probability and non-probability sampling.

Probability sampling infers that the units from the population were selected with some level of randomness (Trochim and Donnelly, 2001). This sampling technique is primarily used in quantitative research and the outcomes may be considered representative of the general population (Saunders, 2012). It involves ‘‘selecting a relatively large number of units from a population, or from specific subgroups (strata) of a population, in a random manner where the probability of inclusion for every member of the population is determinable’’ (Tashakkori and Teddlie, 2010, p. 713). It guarantees that the selection process is completely randomised and without bias.

Non-probability sampling techniques are also referred to as purposive or purposeful sampling, expert sampling or qualitative sampling (Tashakkori and Teddlie, 2010). Maxwell (1997, p. 87) defined purposive sampling as a type of sampling in which, ‘‘particular settings, people, or events are deliberately selected for the important information they can provide that cannot be gotten as well from other choices.’’ According to Sbaraini *et al.* (2011), purposive sampling should be adopted in selecting those particular samples who are the best few people to explain the basic concerns of the study. As the name suggests, “qualitative” sampling techniques are primarily used in qualitative research and they are usually ‘‘based on a specific purpose rather than randomly’’ (Tashakkori *et al.*, 2010, p. 713).

Following the recommendation of Saunders et al. (2009) to use this technique when the intention of the data gathering is to establish an in-depth understanding of a phenomenon and based on its suitability for qualitative approaches (Denzin *et al.*, 2006). This research utilises purposive sampling techniques for both the interview and focus group participants as experts in the fields of ethics/sustainability in construction, blockchain technology and construction supply chain were purposely selected in order to help establish in-depth understanding regarding the dynamics of ethics within the construction industry; the potential impact blockchain may have on the improvement of ethics within the construction industry; and to validate the developed conceptual model. Findings and feedback from participants informed the refinement of the conceptual model and the validation of the revised model. Hence, participants had to be chosen based on their knowledge of the research focus and their willingness to participate in the study.

5.8 Data analysis

The method of analysis chosen for the primary data gathered in this study is thematic analysis. Generally, thematic analysis is the most widely used qualitative approach for analysing interviews. The protocol of the thematic analysis of the data is mainly built upon the theoretical positions of Braun and Clarke (2006). According to them, thematic analysis is a method used for “identifying, analysing, and reporting patterns (themes) within the data” (2006, p.79). This method was chosen as “a rigorous thematic approach can produce an insightful analysis that answers particular research questions” (Braun and Clarke, 2006, p.97). This approach was utilised to investigate the data from two perspectives: first, from a data-driven perspective (a perspective based on coding in an inductive way); and second from the research question perspective (to check if the data is consistent with the research questions and if it provides sufficient information). Blismas *et al.* (2010) recommend the use of computer-aided qualitative data analysis in the field of construction management. They posit that it can enhance qualitative research by improving the ability to code and retrieve all of the data. NVivo 12 was selected as the most appropriate programme to support this research and the thematic analysis used to analyse both the interviews and the focus group data. This study adopted the guide proposed by Braun and Clarke (2006) to analyse the data from the interviews and focus group as discussed below.

1. Familiarity with the data

In order to fully analyse the collected data, it becomes necessary to have a good understanding of the interviewees’ responses. Therefore, familiarisation with data has been internalised through transcription and cleaning of the interviews. The video recordings of the interviews of 30 respondents were listened to for accurate understanding and transcription. The researcher read through the entire data set over and over to search for meanings, patterns and ideas that relate to the research questions and objectives. Relevant matters and possible relationships between these matters were also identified and noted for coding purposes.

2. Generating the initial codes

At this stage, the transcripts were read over and over to identify the relevant issues and patterns arising across the interviews and to also find possible links between the issues identified. The transcripts were cleaned and then imported to a computer aided analysis application for coding. Initial codes were generated to organise the data into meaningful categories on NVivo. This was done by using labels for the extracted words and phrases above which relate to the research question and objectives. Therefore, codes were used to bring meaning out of the data corpus and establish links and patterns across the entire interview transcripts.

While Braun and Clarke (2006) suggest that data can be coded either in an inductive "bottom-up" way or in a theoretical, deductive "top-down" way. However, following the approach presented by Jugder (2019), this research acknowledges that top-down and bottom-up approaches are interactive in some way because although the researcher looks into the data to generate the themes, he also approaches the data with some specific questions in mind, which also influences the identification of the themes. Therefore, the transcripts were coded from both a data-driven perspective and a research question perspective, to check if the data was responding to the questions and if it was providing sufficient information in response to research questions and associated principles. Having satisfied that the codes generated from the transcripts were aligning with research questions and were adequate for the purpose, the data-driven coding was continued with to look for the patterns of meaning.

3. Searching for themes

The next step after coding the data was to group the codes under various themes. This stage involved sorting the different codes into potential themes and collating all the relevant coded data extracts within the identified themes. Themes capture the key idea about the data in relation to the research question and represent some level of patterned response or meaning within the data set (Braun and Clarke, 2006). The extracts were also used to define titles for the different themes.

4. Reviewing themes

The categorised extracts with similar codes were further re-organised and re-examined with respect to the whole transcript to ensure that it was in line with the context where it was originally mentioned in the interview (Anderson 2007). In some cases, the categories were merged or broken down where it was found more appropriate to ensure that the themes were coherent but also distinct from each other. Hence, some themes were renamed to more suitable titles.

5. Interpretation and discussion

Having fully worked out the themes, the final themes and categorised extracts were then used to compile and discuss the findings from the thematic analysis. It provides a concise, coherent, logical, non- repetitive and interesting report of the data, as seen within and across themes. The discussion was further enriched with quotations from the interview transcripts to give the reader a better understanding of the findings. In addition, findings from the interview were further compared and discussed with respect to findings from the literature review.

5.9 Reliability and validity

According to Neuman (2006), reliability and validity are key issues for quality research. It is critical to assess the quality of the data once it has been collected (Miles and Huberman, 1994), as an invalidated framework or model could impair the research's evaluation (Amaratunga *et al.*, 2002). The term "reliability" refers to a consistency metric whose goal is to reduce inconsistency and instability in results. Lincoln and Guba (1985) discussed validation in relation to the trustworthiness of the research and used terms like credibility, transferability, dependability and conformability. Also, Creswell (2013) presents validation in qualitative research as an endeavour to evaluate the results in relation to their accuracy. Data triangulation is the widely recommended method to ensure the validity of findings (Djamba and Neuman, 2002). It is regarded as a means of verifying the meaning and repeatability of interpretations or observations using more than one source of information (Denzin *et al.*, 2006). Instead of depending on only one measure and perceiving a phenomenon from a single perspective, data triangulation allows you to perceive a phenomenon from various perspectives using multiple measures. Furthermore, Bryman *et al.* (2008) posit that triangulation using multiple methods can help facilitate deeper understanding and increase the accuracy of the data collected. The goal is to ensure that if another investigator followed the same processes, they would come up with identical results and conclusions (Amaratunga *et al.*, 2002). Saini and Shlonsky (2012) argue that there is no consensus among researchers regarding this issue, nevertheless, they recommend three things to ensure reliability in qualitative research:

- Use of quotes and examples to support themes
- Consistency of themes and quotes
- Transparency of the research process

The validation strategy adopted for this research is triangulation, in order to confirm the findings through the use of numerous autonomous sources and different systems or investigators, and to demonstrate the self-consistency of the findings (Miles and Huberman, 1994). This study conducted first, the literature review, followed by expert semi-structured interviews and then a focus group. Adopting semi structured interviews and focus group, served as a means to triangulate the data. The intention being that the outcome of the triangulation will provide a more accurate measurement of a phenomenon and help to enhance the validity and credibility of the findings (Denscombe, 2008). In some instances, the two methods confirmed the literature and each other, whilst there were some identifications that highlighted areas for further research. The literature through an exploratory approach set the coordinates for the interview, the interviews further explored the subject matter and helped to validate (first phase) the conceptual model which led to a revised version of the model that was subsequently validated (final phase) in the focus group.

5.10 Ethics

As these methods involve human participants, it is essential that ethics be given consideration within this chapter as “ethics are critical aspects for the success of any research project” (Saunders et al. 2012, p208). Whether the researcher collects secondary data or primary data, via interviews or questionnaires, it is important that prior to commencing the research, the research is scrutinised and approved as adhering to ethical guidelines. Having met the required standards, this research gained ethical approval from the Research Committee of the School of Built Environment and Architecture of London South Bank University. The ethical activities that have been implemented by each of the adopted research methods are illustrated in Table 5.8.

Table 5.8 The ethical activities undertaken in this research

Ethical activity	**Interviews**	**Focus Group**
Written consent obtained from the research participants	✓	✓

Research participants were provided with an information sheet detailing the purpose, benefits and risks appertaining to the research	✓	✓
The contact details of the researcher were provided to the research participants	✓	✓
The research participants were guaranteed anonymity	✓	✓

5.11 Research design

The research design refers to the overall strategy that is chosen to integrate the different components of the study in a coherent and logical way, thereby ensuring that the overarching research aim is achieved. It serves as the blueprint for the research's data collection, measurement, and analysis (Claybaugh, 2006). Furthermore, it provides an underlying structure or model to support and guide the collective research steps and efforts. It is normally used as a guide for researchers so that they are more focused on the scope of their studies (Akanbi *et al.*, 2014). This study is divided into five phases, and the output of each phase feeds into the next phase. The overall research design adopted in this research, along with the corresponding phases involved, is shown in Figure 5.3. The phases are discussed in this section.

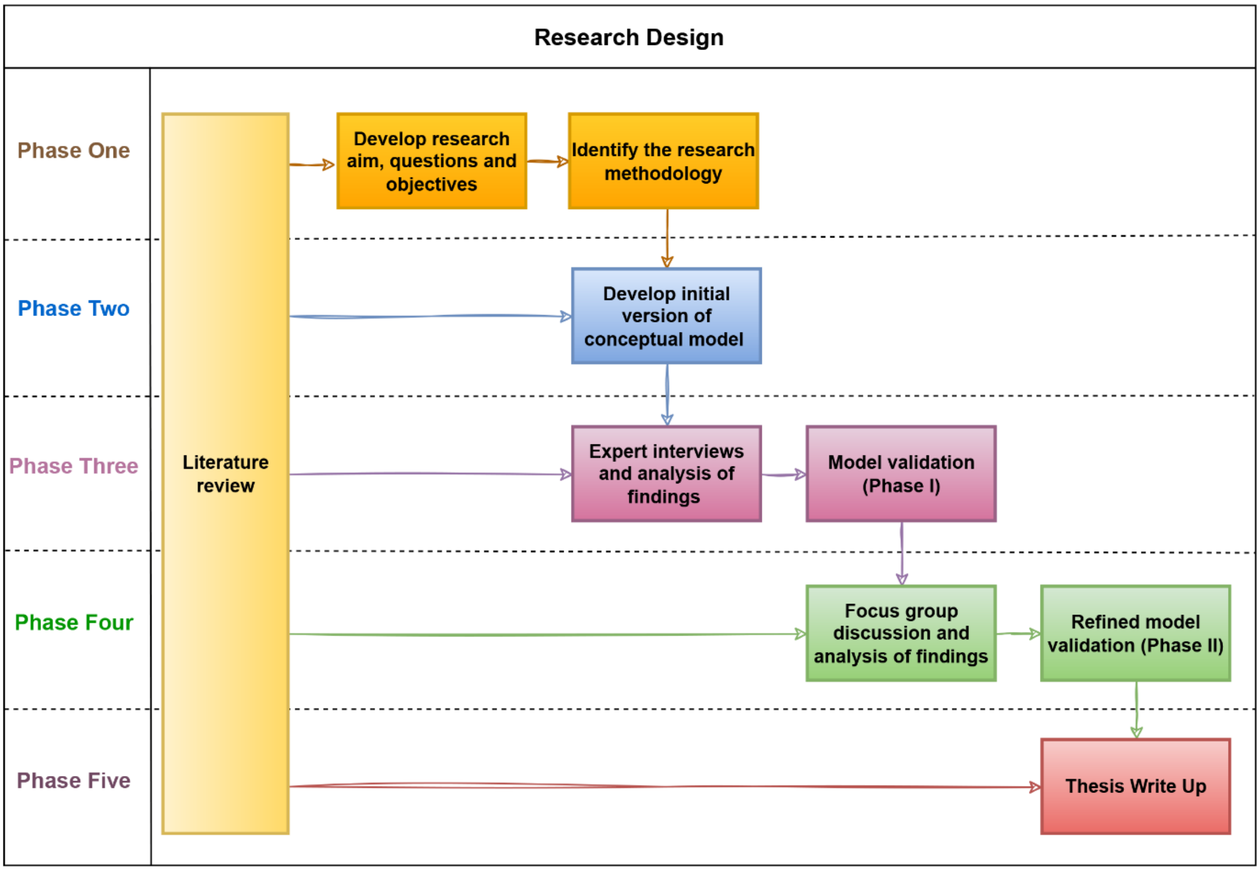

Figure 5.3 Schematic representation of research design

Phase one: At this initial stage of the research, a substantial review of literature was conducted to gain knowledge in the fields of blockchain, ethics and the construction supply chain. With the aim of exploring how blockchain technology can impact ethics within the construction industry supply chain, based on learnings of its impact within the supply chain of other industries; and subsequently to identify the research gaps, form the research aim and objectives as well as the research methodology required to achieve them.

Phase two: Following the identification of the study's aim and objectives, a more detailed literature review was conducted to further develop knowledge on the subject matter, with the goal of developing the theoretical framework and conceptual model required to achieve the study's overarching goal. Following this, the initial version of the conceptual model was developed.

Phase three: This phase involves interviewing experts in the fields of ethics/sustainability, blockchain technology and construction supply chain which were purposely selected in order to help establish in-depth understanding regarding the state of ethics within the construction industry and the potential impact blockchain may have for the improvement of ethics within the construction industry supply chain. Also, in this phase, the model's elements and components and its potential to improve ethics within the construction materials and products supply chain were evaluated. This was the first phase of the dual-phase validation protocol for the conceptual model, as expert interviews are a way of validating research models and frameworks (Abraham et al., 2007). The analysis of the interview data in this phase led to the revision of the conceptual model and a richer understanding of the subject matter.

Phase four: In this phase of this study, having revised the model based on feedback from the interview participants in phase three, a focus group was conducted as the final validation exercise for the revised model.

Phase five: In the final phase of this study, the researcher consummated the research work by writing up the thesis whilst staying up to date on new literature in the field.

5.12 Summary

This chapter has introduced and established the research methodology chosen for this research, justifying the philosophy and method adopted with substantial literature. This has led to the selection of an interpretive philosophical stance and qualitative multi-methods approach as being appropriate for the research. It has provided a justification in relation to the aims and objectives of the research for the methodological tools adopted. It further demonstrates why the methodological decisions are appropriate and how they are used within this study.

As discussed in the Research Design section of this chapter, the next chapter entails phase three of the study, which deals with the interview of experts in the fields of ethics/sustainability, blockchain technology and construction supply chain in order to help establish in-depth understanding regarding the state of ethics within the construction industry and the potential impact blockchain may have on its improvement, and to validate the developed conceptual model presented and discussed in Chapter 4 of this study.

Chapter 6 Results and analysis

6.1 Introduction

Having justified the underlying approach of the research and having presented the data collection and analysis procedures of the study in the previous chapter, this chapter then presents the results and analysis of the interview and focus group data. The findings will support the achievement of objectives 2, 3 and 4 of this research (see Section 1.3). The qualitative multi-method design employed in this study will aid the achievement of the fourth objective of this research as the discussion and feedback of participants from the interview and focus group will help to thoroughly evaluate and validate the conceptual model developed for the improvement of ethics in the CMPSC. The results and its analysis are presented in the subsequent sections of this chapter.

6.2 In-depth Interviews: results and analysis

The analysis is structured into four sections covering each of the high-level themes and associated mid-level and low-level themes. The interviews present views regarding the state of ethics within the construction industry supply chain, an evaluation of current improvement efforts, the potential impact blockchain may have for the improvement of ethics within CMPSC and the factors affecting its acceptance and implementation. Also, the interviews present views regarding the validity of model's elements and components and its feasibility to improve ethics within the CMPSC. This served as the first phase of the dual-phase validation protocol for the conceptual model, as expert interviews are a way of validating research models and frameworks (Abraham et al., 2007). A total of 30 participants were interviewed, comprising of 16 construction industry professionals, 10 professionals in the ethics/sustainability in construction and 4 blockchain experts. These participants were chosen based on their knowledge of the research focus and their willingness to participate in the study. The demography of the participants has been earlier presented in Table 5.7. The bar chart in Figure 6.1 indicates participants demography and knowledge of blockchain technology.

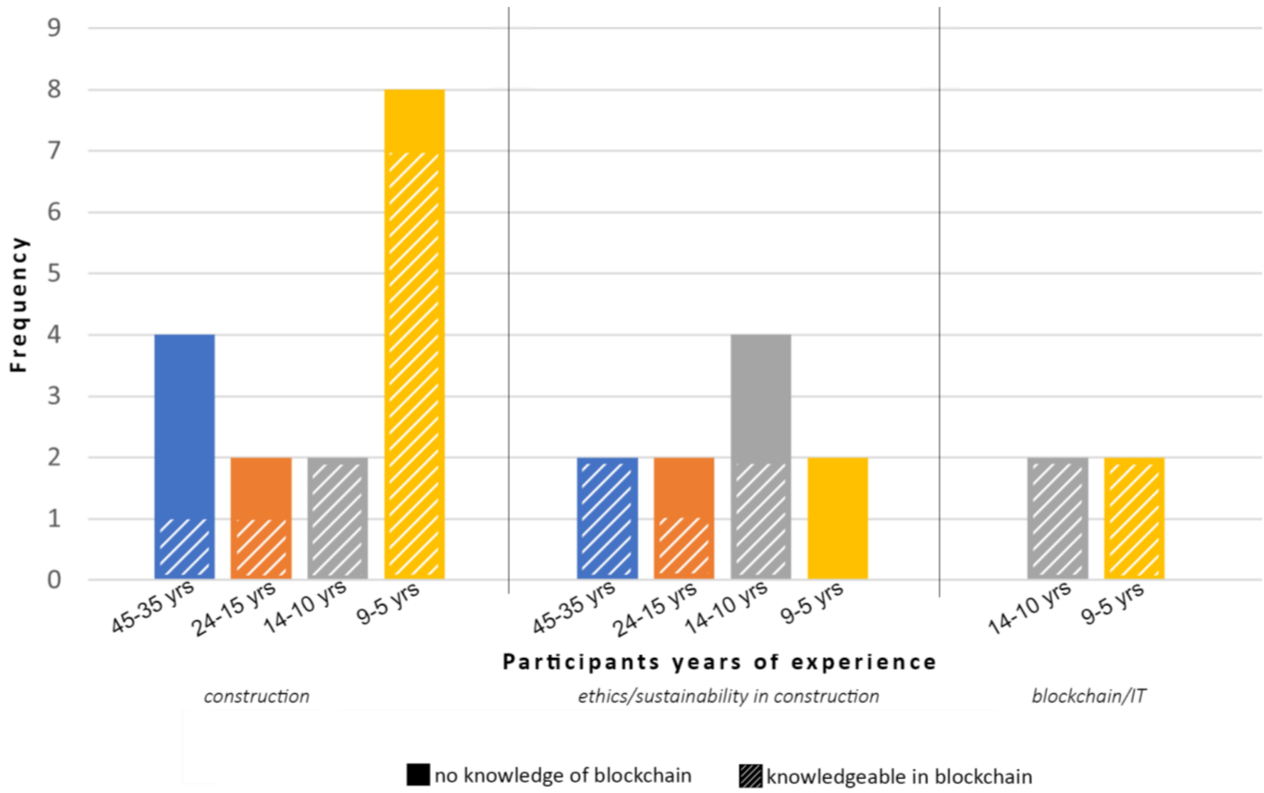

Figure 6.1 Bar chart indicating participants demography and knowledge of blockchain technology

As earlier discussed in Section 5.8 of this study, the data from the expert interviews are grouped for all participants and thematically analysed using NVIVO 12. Following the approach presented by Jugder (2019), this research acknowledges that both inductive and deductive approaches in data analysis are interactive in some way because although the researcher looks into the data to generate the themes (inductive), he also approaches the data with some specific questions in mind (deductive), which also influences the identification of the themes. Therefore, the transcripts were coded from both a data-driven perspective and a research question perspective. After coding the data, the codes were then sorted into potential themes and all the relevant coded data extracts within the identified themes were collated. The themes were then reviewed to ensure that the themes were coherent but also distinct from each other. This resulted in the development of a thematic framework with high, medium and low-level themes. The framework is illustrated in Table 6.1.

Table 6.1 Thematic framework: High, medium and low-level themes from interviews

High, medium and low-level themes	Codes	Contributors
1. Current state of ethics in the CMPSC	**148**	28
1.1 Business ethics	90	25
1.1.1 Issue of corruption	40	18
1.1.2 Issues at the procurement phase	32	12
1.1.3 Exploitation of loopholes in documentation	18	9
1.2 Environmental ethics	32	18
1.2.1 Issue of neglect	18	14
1.2.2 Cost implications	14	9
1.3. Social Ethics	26	14
1.3.1 Need to improve due diligence	15	11
1.3.2 Lack of concern	11	8
2. Current improvement measures	**80**	28
2.1 Effectiveness	32	27
2.2 Factors affecting effectiveness	48	23
2.2.1 Low implementation and compliance	22	18
2.2.2 Role of government	14	11
2.2.3 Denial	12	9
3. Improving ethics in the CMPSC	**122**	28
3.1 Need for education	18	14
3.2 Improving ethics in the CMPSC through blockchain	26	25
3.3 Factors affecting acceptance and implementation of blockchain	60	21
3.3.1 Scepticism surrounding the technology	10	9
3.3.2 Knowledge of blockchain technology	12	10
3.3.3 Digitised ecosystem	13	9
3.3.4 Resistance to change	14	12
3.3.5 Client's awareness and demand for it	11	8
3.4 Personal ethical values	18	12
4. Model validation and feedback	**377**	30
4.1 Evaluation of the model's potential to improve ethics	84	30
4.1.1 It urges ethicality	30	24
4.1.2 Provision of information	28	21
4.1.2 Transparency and visibility	26	23
4.2 Validation of the elements and components	127	30
4.2.1 Material and Product Network	48	30
4.2.2 Procurement Network	38	30
4.2.3 Project Network	41	30
4.3 Acceptance and implementation	84	30
4.3.1 Cost of implementing the model	20	18
4.3.2 Differing standards across boundaries	12	9
4.3.3 Corruption	23	17
4.3.4 Simplicity in use	11	8
4.3.5 Digitised ecosystem	18	11
4.4 Limitations of the model	40	24
4.4.1 Ethicality of its oracles	21	17
4.4.2 Not robust enough	4	1
4.4.3 Limited access to technology in lower tiers	15	10
4.5 Feedback on the overall model	30	30
4.6 Suggested adjustments to model	6	4
Overall	**721**	**30**

The 30 interviews resulted in 4 high-level themes, 15 mid-level themes and 28 low-level themes. The total number of codes within all the themes is **721**. The high-level theme ***Model Validation and Feedback*** recorded the highest number of relevant codes with a total of 377 codes. It is then followed by the high-level theme ***Ethics in Construction Supply Chain*** with 148 codes. Following this are the high-level themes ***Improving Ethics in CMPSC*** with 122 codes and ***Current Improvement Efforts*** which recorded 80 codes. The distribution of the codes across the high-level themes is illustrated in Figure 6.2.

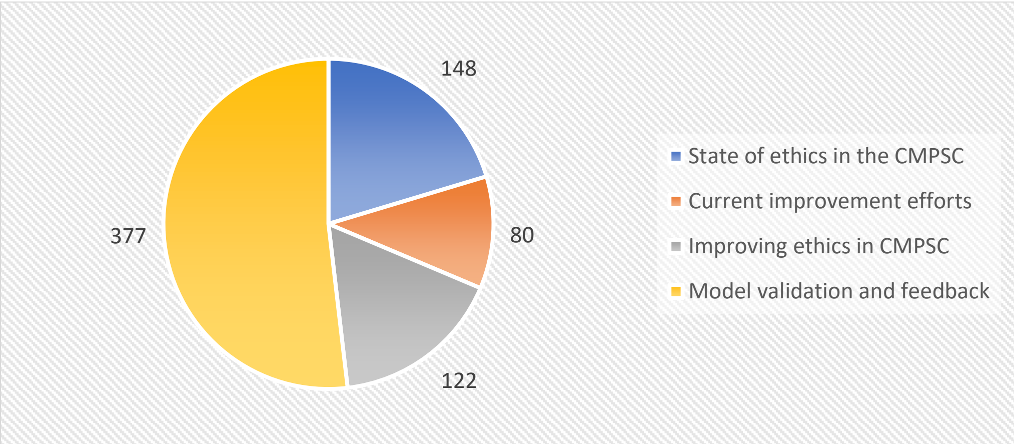

Figure 6.2 Distribution of the codes across the high-level themes from interview data

In the subsequent sections of this chapter, the contents of the high, medium and low-level themes will be elaborated on in detail.

6.2.1 *Theme 1: Current state of ethics in CMPSC*

Participants expressed concerns about the state of ethics within the construction supply chain today. The discussion within the theme ***state of ethics in CMPSC*** concentrated on the perceptions on the current state of ethics within the supply chain of the construction industry in reference to the triple bottom line: environmental ethics, social ethics, and business ethics. This produced a total of 162 relevant codes from 28 participants. This theme is then further broken down into 3 mid-level themes: ***business ethics***, ***environmental ethics*** and ***social ethics***; recording 90 codes, 32 codes and 26 codes respectively, all possessing individual low-level themes as illustrated in the thematic model shown in Figure 6.3.

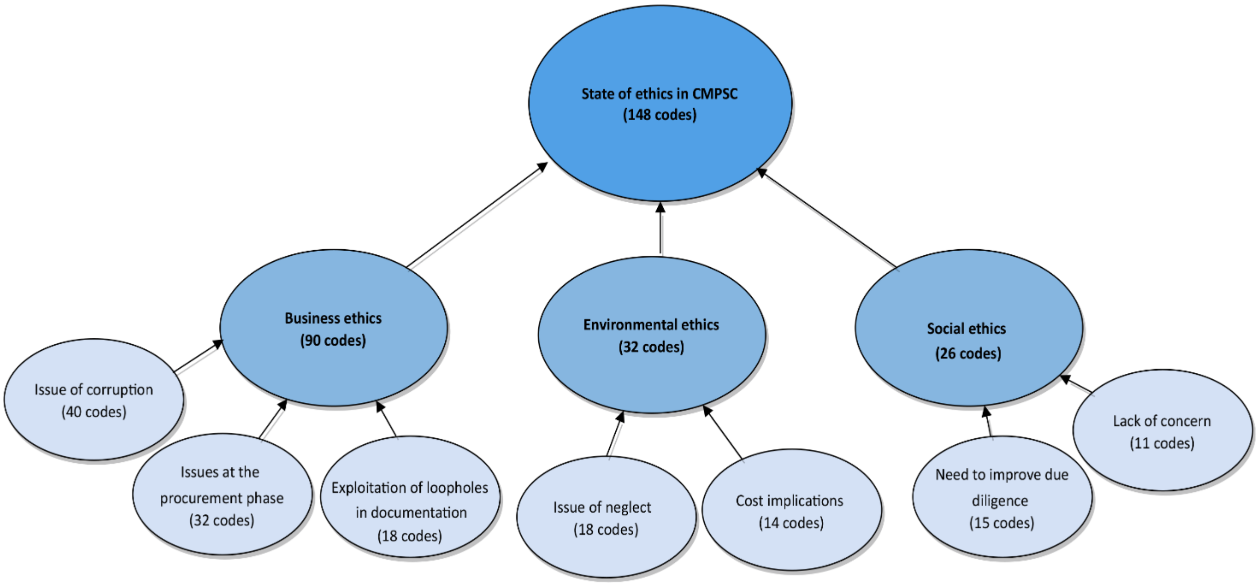

Figure 6.3 State of ethics in the CMPSC

6.2.1.1 Business ethics

In discussing the state of ethics within the construction supply chain, several concerns surfaced, 60% of which were in relation to business ethics; as such, they were categorised under the mid-level theme of ***business ethics*** which produced 90 relevant codes. A categorisation of the concerns expressed further resulted into the emergence of associated low-level themes of the ***issue of corruption*** in the industry, issues that arise at the ***procurement phase*** of the project and the issue of ***exploitation of loopholes in documentation***. This is illustrated in the thematic model shown in Figure 6.4

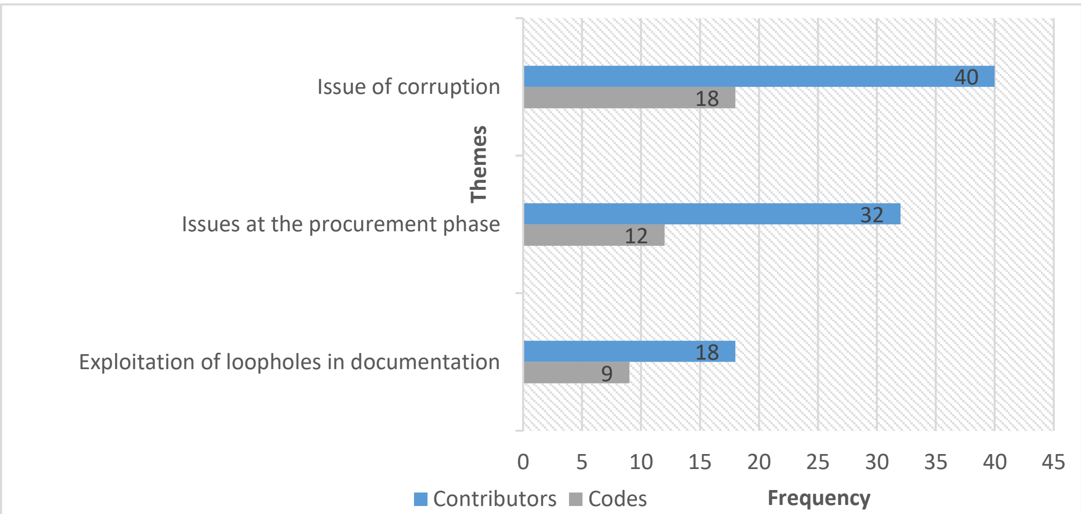

Figure 6.4 Thematic model 2: Business ethics

6.2.1.1.1 The Issue of corruption in construction industry

In discussing the state of business ethics within the construction supply chain, concerns regarding the issue of corruption in construction were more widespread. A common view expressed by 18 participants was that the ***issue of corruption*** in construction continues to be a major challenge in this industry with 40 codes in total being recorded. PC10 stated, "*the construction industry today is one of the most corrupt industries globally*" and "*I think it is more serious in the construction industry than other industries simply because of the uncontrolled supply chain (….) because you have a huge number of suppliers with little control over them, the entire system becomes prone to corruption*" PC2 adds. According to PC3, "*the system is corrupt because there are many other corrupting influences that go on, for example, the system encourages the cheapest budget. So effectively, what I see is 'cheaper is better,' and that itself has a corrupting influence*."

Talking about the issue of corruption in the industry, PES17 said, "*I always assume that everybody is compromised, even if they have not been directly involved in a corrupt activity, they have turned a blind eye to it or something (….) So, I am not as hopeful as some people are*." PC3 pointed out that "*corruption can happen at very early stages which could then carry on through the other phases of the project*" and "*it is much better hidden now (….) it is changing, and we must not underestimate it*" claims PC17. PC17 further explained that some corruption is opportunistic, while some are highly sophisticated and that before the tender stage, bribes may have already been agreed on with the anti-corruption agency which would investigate it if there was ever a complaint.

Moreover, some participants also argue that the corruption in construction is a result of a wider ethical imbalance in the countries of the world. As PC12 puts it, "*the corruption in construction practices is a superstructure of the foundation of corruption that has been laid in most countries, and not just because the construction industry itself gives room for corrupt activities to thrive."* Similarly, PC14 believes that *"people naturally would not want to be corrupted, but corruption happens as a ripple effect of some fundamental issues within the country."* Talking about this issue, PES18 said *"corruption happens everywhere in the world. Some countries have more corruption than others, but every country has corruption."*

Also, some participants opined that the issue of corruption in construction is exacerbated in public sector projects. For example, PB29 said, "*public sector projects ought to help advance public good, but it is being monopolised by several entities and officials who bypass several basic procedures in public sector procurement,*" further adding that "*sometimes, you may have to give out huge sums of money* *to different officials to get the job, which is part of the capital needed to execute the project. How then can you build to standard that way?"*

However, the experience shared by PC6 also indicates that sometimes, these monies are willingly offered as bribes by the party looking to secure undue favour and it is therefore not always a case of compulsive extorsion as it is usually made to seem. PC6 reported: "O*bviously, I have come across it in past places I have worked in, and I have even had offers of bribery and stuff,*" he further added that "*it is mainly when people are trying to gain more work (….) So sometimes, people offer me cash to make sure that they get the project*."

Participants also pointed out that sometimes, materials and products are also involved. According to PC6, "*in some instances where it is materials, they want to take extra materials and sometimes they are asking if I can order more than what is required*". PC13 also commented saying, *"I have witnessed quite a few, especially in procurement of material. I know of an architect who claimed to have ordered some building materials from China and for two years, the client got nothing."* However*, "it has not happened many times, but there have been cases where we arrive at that*" PC6 adds. PES18 in his concluding words on corruption within the industry said, "*my summary would be that we know exactly how to stop corruption, but we cannot get there because the gatekeepers are corrupt. That is our challenge*."

6.2.1.1.2 Issues at the procurement phase of a project

Another reported problem among participants were related to the issues that arise at the procurement phase of the project. This resulted in the ***issues at the procurement phase*** theme with 32 codes by 12 participants. Some participants argued that the very structure of the procurement process in construction is one that aids unethical activities. According to PC8, "*construction as a whole is a wasteful industry; it is the nature of how things are built, but it is also a nature of how things are procured*." A view also supported by PC9, who claimed that "*many processes in procurement are not vetted and there are so many loopholes for manipulations and fraudulent practices*."

While discussing this, several participants pointed out middlemen as the chief culprits of unethical activities in procurement. PC13 elaborated: "*Especially when you are not fortunate to have direct plugs with which to procure materials when you need them, you can easily be cheated by self-proclaimed suppliers who are at best middlemen,*" according to him, "*there are several unnecessary middlemen who profit from the transaction individually before it gets to the customer, usually at an amount way higher than the fair price.*" Even worse, while commenting on his experiences with unethical actors and actions during procurement, PC6 said: "*Certainly not with the manufacturers. I do not think I have ever come across it when I have dealt with the manufacturer, only when dealing with the resellers*." Hence, PC10 suggests the removal of middlemen, he opines that "*if that link is made clear from production straight to site and the middlemen are removed, it would help mitigate fraud in material and product procurement*."

Another issue that surfaced in relation to issues at the procurement phase was concerning the purchase and/or delivery of counterfeit products and materials. According to PC7, "*sometimes, there is no clear means to verify whether we are getting the genuine product or fake, and that makes it very difficult to ascertain genuineness*." PC10 also comments that "*the nature of most construction works does not allow for the verification of the appropriateness of whatever material has been used (….) So, it is important to ensure that products used are as specified.*" Participants also reported that "*sometimes, to work things out on a skewed budget, some contractors may purchase low class materials whilst also trying to make gains off it*"(PC9), "*so, some contractors go to China to get a manufacturer to manufacture certain products at a cheaper and lower quality and then brand it in the name of the organisation*" (PC13), eventually you end up "*seeing cracks and damages in the bathtubs, wash basins and all of those products few years after completion*" (PC13) and "*a really bad building that is not going to stand the test of time*" (PC9). When commenting on how he ensures avoidance of procurement of counterfeit materials and products, PC5 responded: "N*ormally we would have a specification that is accreditation based. So, you would have to hit a certain standard or have a certain accreditation to be able to get on there, depending on which trade it is."*

In relation to procurement phase issues, concerns were also expressed about delivery of materials and products in lesser quantity and at later date than the contract specifies. Talking about this issue, PC14 said: "*Sometimes the ordered product does not arrive on time, or you get something different from what was ordered. Other times, the products are not received in good condition; quality is jeopardised, and timing is disturbed."* PC13 commented that *"especially when it comes to iron rods, sometimes you are supplied with rods of varying diameters to what was ordered (….) usually, this inconsistencies in the supplies are noticed when construction is on-going,*" he believes that the reason for this is that "*those who usually receive the supplies on site do not have enough technical knowledge to conduct a thorough assessment of the supplies*." PC10 suggests that another reason for this is "*the inability to monitor materials from procurement to delivery"* this he believes have *"given room for some actors to cheat the system, sometimes by supplying a lower quantity than was ordered*." PES 17 adds that "*just the supply of materials from the quarries directly to construction sites is often a major source of fraud*." Even worse, PC14 reports: "*I have heard stories of workers who pretend to be acting in the interest of the organisation, but behind, they connive with the material sellers to make their own cuts.*"

When commenting on how due diligence is done to ensure procurement within her organisation, PC4 comments: "*We generally repeat contractors with the understanding that they already know how the system works and therefore they know what the consequences of not following the rules are and it seems to be working for most cases*." As the discussion progressed, she however noted that "*every now and then we hear that a particular product such as wood or steel, was purchased outside of the market that they are supposed to purchase from*." A word of caution however was raised by PES19, stating that the industry needs to be careful about "*using third parties to take responsibility for our due diligence without looking at the data it is providing.*"

6.2.1.1.3 Exploitation of loopholes in documentation

Another reported problem among participants was based on the exploitation of contract loopholes by unethical construction players. This resulted in the ***exploitation of loopholes in documentation*** theme with 18 codes from 9 participants. PC1 stated that "*often what we see is that in a regular go-to-market bid strategy, the contractor will be basing his bid on the loopholes in contract documents that he feels he can exploit*." As an example, PC1 added that "*I know a general contractor who submitted a bid for the construction of a stadium with a 1% profit margin because he saw how chaotic and ill-defined the construction documents were, hoping to make money from frequent change orders*" and this "*to me is unethical.*"

PC12 also adds that "*sometimes, there is a measure of trust clients lay on contractors, consultants and sometimes, they take advantage of that to cheat the client.*" He further elucidates, "*because of the lack of records, retailers or actors take advantage of that, and unfortunately clients who have put blind trusts in these professionals or retailers unfortunately fall victim*." In his view, "*in cases where a client employs a contractor based on familiarity of social ties, the familiarity allows for blind trust. As such, proper contractual agreements are not usually put in place, and this exacerbates the issue.*"

PC12 suggests the need for "*proper contracting and proper documentation*," a view also shared by PC14 who asserts that in the construction industry, "*everything can get a bit messy if not neatly documented, in some places, the documentation strategy is not digital yet so there is that potential loophole of not having some of things documented with current paper-based approaches*." In an experience that reflects this challenge, PES17 shared that "*they had some paper records which were* *incomplete and inconsistent, nobody assembled it. Much of the data was not properly documented, rather, it was in the head of engineers and the workers*."

6.2.1.2 Environmental ethics

In discussing the state of ethics within the construction supply chain, several concerns surfaced, 22% of which were in relation to environmental ethics; as such, they were categorised under the mid-level theme of ***environmental ethics*** which produced ***32*** codes from 18 participants. A categorisation of the concerns expressed further resulted into the emergence of associated low-level themes of the ***issue of neglect*** of matters of environmental ethics in the industry and its ***cost implications***. This is illustrated in the thematic model shown in Figure 6.5.

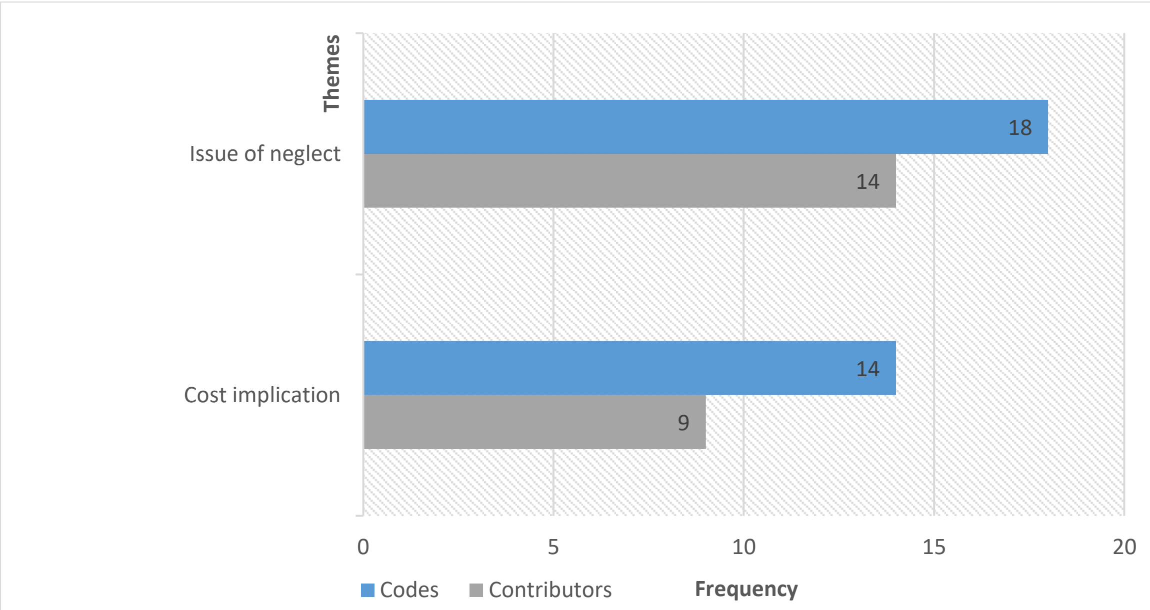

Figure 6.5 Thematic model 3: Environmental ethics

6.2.1.2.1 The issue of neglect of matters of environmental ethics in the industry

In discussing the state of environmental ethics within the construction supply chain, a common view expressed by the participants was that the ***issue of neglect*** of environmental ethical matters in the industry constitutes a barrier to the improvement of environmental ethics in the industry with 18 codes in total being recorded by 14 participants. It was revealed that matters of environmental ethics had been hitherto neglected, however, it is now "*slowly coming up*" (PC10), a view also supported by PC3, who commented: "*I see one of the important things at the moment is reducing carbon*." According to PC10, "*at present, the industry is not focused on the environmental part of sustainability (….) however, based on the climate change campaigns in recent years, people have started thinking about it*."

For example, PC10 states: "*I use to work in the Middle East, where the use of concrete is high compared to other countries and we had no plans for recycle, reuse or disposal*." According to PC9, "*the 'cradle to grave' concept is pivotal to achieving environmental ethics, but people do not care about the embodied energy and the potential impact of most of the materials used in construction on the environment on the long term*", he adds that rather, "*most people are only concerned with where they can get the material and how much it will cost*." PES19 argues that the construction professionals share a major portion of the neglect-pie, claiming that "*simple things like getting some of our architects to not just design something, but to also think about the carbon impact associated with it for example is still considered a tall order in the industry today*." However, PES26 argues that the government also need to be more serious with their approach to environmental ethics in construction, claiming that "*if you say to developers, 'will you please build a passive house?' They will say not until it is required by the regulations and so I find it frustrating that if the regulations were more stringent, we would be building better today.*" PC5 draws an interesting contrast between the private sector and the public sector practices and priorities and approach to environmental ethics, claiming that "*government funded projects consider sustainability, but the private sector on the other hand is less interested in the sustainability. They just want a building for a price within a time frame and not bothered about how you do that*."

6.2.1.2.2 Cost implications

Concerns regarding cost implications were widespread in discussing the state of environmental ethics within the construction supply chain, a common view expressed by the participants was that the ***cost implications*** of imbibing good environmental ethical standards hamper the improvement of environmental ethics in the industry with 14 codes in total being recorded by 9 participants. As PC6 reports, "*everyone talks about ethics, but I have found that when it comes down to money and cost, sometimes that is one of the things that goes out the window*." This view was echoed by PES26 who said: *"It frustrates me because I know that the industry knows how to build better for performance and lower impact (….) yet they are not being applied because it is about the financials, returns on investment and margins."* PES19 stresses that "*some projects do not have enough front-end loading of sustainability from a client perspective. If it does not have it, it will not get delivered*." Reponses from participants show that the added cost could be the reason for this. For example, PES26 submits that "*greener is costlier*", however, she adds that "*I think that the premium will come down as the number of homes that are built or retrofitted increases*." According to her, it is more expensive because "*when people build green, they are making an effort to build something better, designed better and built with better materials (…..) if we built all our houses like that, it would just cost the same as it does now.*"

6.2.1.3 Social ethics

In discussing the state of ethics within the construction supply chain, a number of issues were identified, 18% of which were in relation to social ethics. These issues were categorised under the mid-level theme of ***social ethics*** which produced ***26*** relevant codes by 14 participants. A categorisation of the concerns expressed further resulted into the emergence of associated low-level themes of the ***lack of concern*** in matters relating to social ethics within the supply chain and the ***need to improve due diligence*** in the supply chain. This is illustrated in the thematic model shown in Figure 6.6.

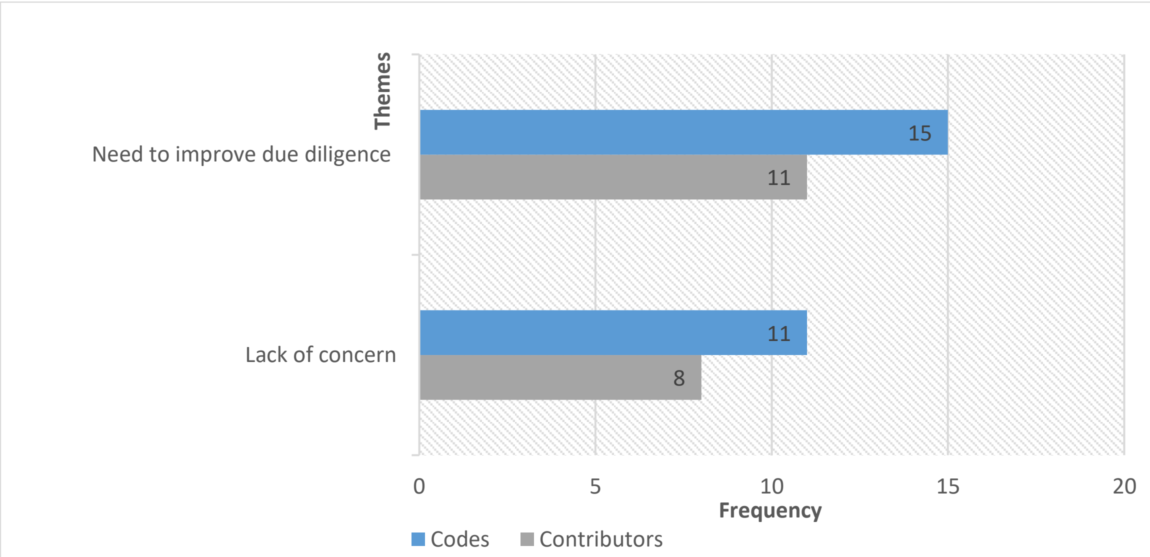

Figure 6.6 Thematic model 4: Social ethics

6.2.1.3.2 The lack of concern in matters relating to social ethics within the supply chain

In discussing the state of social ethics within the construction supply chain, another concern expressed by participants was that people are interested in the product and not bothered about how it was produced or the people that produced it. This generated the low-level theme ***lack of concern*** in matters relating to social ethics within the supply chain with 11 codes in total being recorded under the theme by 8 participants.

PC9 admits that "*most times as architects, we are considering if the product works aesthetically or with the design intent; but we are not really thinking about whether or not the product was manufactured with respect for social ethics*." PES26 alluded to this, saying: "*People say to me, 'well, should I put photovoltaic system on my roof because of the issues of mining these resources?' In terms of the social and ethical aspects of that, it is not really something I know about very much*." Further adding that, "*it is not something I know very much about, to be honest. It does concern me as someone within the industry, but more like an observer*."

According to PC9, "*the main thing I think most people really care about is that the materials are available on site and that they are able to do the things they want to do with them*." As an illustration, in commenting on how much information he has about a product being procured, PC6 stated that "*it would just be the technical information about that product and what it complies with and how suitable it is. So, it is more about what it is used for rather than where it has come from*." He further added, "*obviously I have not really thought about how it is made, where it comes from exactly; I probably concentrate more on the quality of it and what it can do and that has always been my priority*." On the contrary, PES19 argues that "*it is important to think not just about the product itself, but also the way the product is manufactured*."

PES19 also believes that many construction players due to their sheer a lack of interest in social ethical matters are unaware of social ethical risks, she believes this is so because "*it is not easy to monetise, so people would rather not do it*." According to her, "*the biggest challenge to achieving sustainability in the industry is that everybody says that 'if my client would not ask for it and pay for it, then I am not doing it.'*" To illustrate the lack of interest displayed by construction players on social ethical matters, she said: "*I do a lot of trainings on human rights and in most of the trainings, I hardly speak to architects, and yet architects specify the products that goes into the project*." This is also evidenced by PES26's comments while discussing this: "*To be honest it is not something I have thought about. I do not hear about this for construction. I only hear about environmental analysis, I do not hear about, wages and payments.*"

6.2.1.3.1 The need to improve due diligence within the supply chain

As participants shared their thoughts on the state of social ethics within the construction supply chain, participants pointed out the need to improve due diligence within the supply chain. This ***need to***

improve due diligence theme came up in the discourses with 15 codes in total being recorded from 12 participants. As PC5 states, "*if you look at how we do our due diligence on the supply chain now compared to what we did 10 years ago, it is light years away from that; howbeit, we are not quite where we need to be.*" PES19 added that "*the reality is that most of the products that have the biggest human rights breaches are usually quarry, electrical and steel products but they are also then held in a supply chain that is deliberately designed to be untransparent*" and "*tracking value [beyond monetary terms] of items and their supply is very fundamental because how can you show that the items you get on the construction project are not blood products*" comments PES18. Hence, PC5 suggests that "*it would be great if we could get some surety on where something is in the process, where it came from, the certifications as well as the circumstances in which those people involved in the production process are working*."

While commenting on how their organisations carry out their due diligence within their supply chains, some participants acknowledge the use of third parties as one of their major approaches. For instance, PC5 stated: "*Traditionally, we would contact a well-established provider who would give us surety that they had audited where they buy from, and that they understood that the people working in those environments were being paid and treated fairly,*" as such, "*we would not necessarily go and see it for ourselves because we have that.*" Although, he makes an exception for products from China by saying *"if we were buying from China we would probably go and see it manufactured and look around the premises and understand where that is coming from."* Notwithstanding, PES19 warns that organisations must be careful of a blind use of third parties to take responsibility for due diligence in their supply chain. Instead, she suggests that "*organisations embed sustainable procurement policies in their procurement and then work with their supply chain to get the supply chain to respond to those issues*." According to PES19, such policies "*help organisations to think about their whole supply chain and what the sustainability impacts and opportunities are within their supply chain*."

6.2.2 *Theme 2: Current improvement measures*

Participants expressed concerns about the degree to which the measures currently in place to improve ethics within the construction supply chain is successful in producing the desired results. Some of these measures include anti-corruption initiatives, sustainability initiatives, professional codes of conduct, legislation, ethical supply chain models, etc. These concerns were expressed by 28 participants, producing a total of 80 relevant codes captured within the ***current improvement measures*** theme.

This theme is then further broken down into 2 mid-level themes: ***effectiveness*** and ***factors affecting effectiveness***; recording 32 codes and 48 codes respectively. ***Factors affecting effectiveness*** theme possess 3 low-level themes: ***low implementation, role of government*** and ***denial*** as illustrated in the thematic model shown in Figure 6.7.

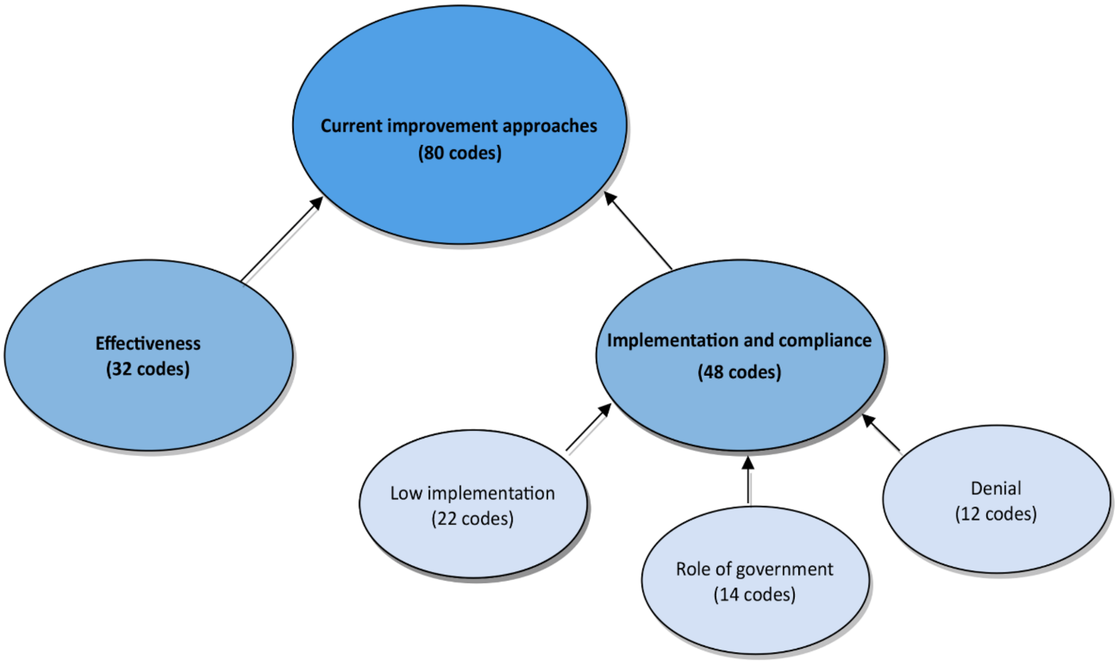

Figure 6.7 Thematic model 5: Current improvement measures

6.2.2.1 Effectiveness

In discussing the degree to which the measures currently in place to improve ethics within the construction supply chain is successful in producing the desired results, a variety of perspectives were expressed regarding the effectiveness of the measures. These perspectives were coded under the mid-level theme ***effectiveness*** with **32** relevant codes by 27 participants.

Without any doubt, several measures and tools to improve the state of ethics within the construction supply chain exists and the number continues to grow. As PES18 puts it: "*There are very well tracked methods of preventing corruption and they are the simple solutions of division of responsibility, multi-signatories and transparent objectivity in the process with justifiable reasons for the decisions made and the publication of those decisions.*" Another participant, PES19 also reports: "We *helped create ISO 2400, which is the international standard for sustainable procurement and the goal is getting* *organisations to think about their whole supply chain and what the sustainability impacts and opportunities are within their supply chain*."

The participants generally agreed that these measures have been effective to a certain degree, but much work remains to be done; that is, "*there is no doubt that the climate has changed but there are still risks*" (PES17). PC3 also thinks that "*they have made an impact (…..) and there have been improvements*." A view supported by PES20 who said that "th*ere are companies who have improved their ethical performance and their sustainability performance significantly compared to their peers*," however adding that "*unfortunately, there are still companies in construction that behave unethically, who have not adequately managed or mitigated risk of modern slavery in their supply chains*." Similarly, PES17 also argued that "*at the global level, these measures have been effective in tackling unethical practices, because I see a complete change in attitudes and a complete change in the legal environment and in policies and so on*", but cautioned that in terms of practice, "*many markets are still characterised by inefficiency expressed through either mismanagement or corruption or a combination of the two*."

Another participant who is involved in the publication of ISO 37001, the Commonwealth anti-corruption benchmarks, provision of training resources and anti-corruption programmes on a website which gets visited by thousands of organisations monthly from 190 countries said: "*How successful it is, we cannot tell because only very few people actually return to give feedback; so you have to hope that it is having some impact….*" (PES18).

6.2.2.2 Implementation and compliance

A major consensus among participants is that the reason for the limited effectiveness of these measures is due to low implementation and sloppy compliance. These perspectives generated the mid-level theme ***factors affecting effectiveness*** with **48** relevant codes by 23 participants with low level theme ***low implementation*** with 22 codes, ***role of government*** with 14 codes and the ***denial*** of the presence of unethical practices within organisations and their supply chain with 12 codes as illustrated in the thematic model shown in Figure 6.8.

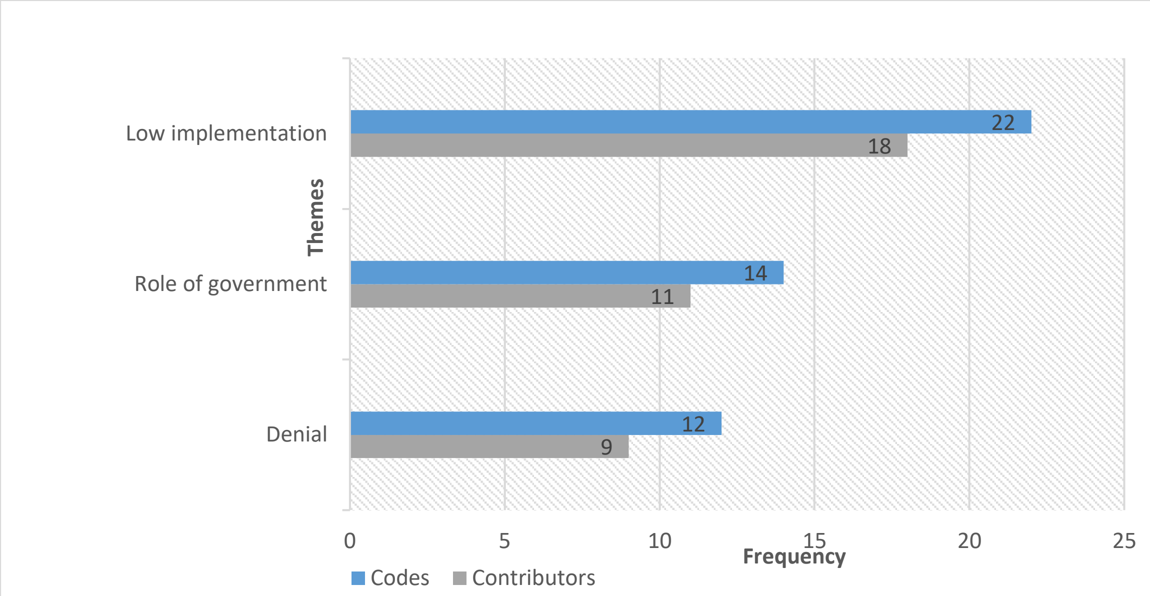

Figure 6.8 Thematic model 6: Factors affecting effectiveness

6.2.2.2.1 Low Implementation

Several participants also agreed that implementation and compliance with these measures have been rather low, pointing out possible reasons for this. This generated the low-level theme ***low implementation*** of current ethical measures with 22 codes in total being recorded under this theme by 18 participants.

According to PC10, although the industry has several standards and processes being outlined, "*but then, there is no proper check and balance system to ensure that these ethical standards are being followed in the daily activities of the industry; as such, these ethical standards are not yielding maximum expected benefits*." A view also echoed by PC13 who commented that "*the policies are there but the enforcement is always the issue; most enforcers do not take their duties seriously and they do not understand the gravity of their duties.*" As PES17 also said, "*there is evidence that it works, but its application was very limited. You know, it might be 5% of the market," and "policies and regulations are only as efficient as their implementation*," says PC12.

Some participants argue that reason for the low implementation is due to conflict of interest. According to PES18, "*we have brilliant systems, laws and fantastic procurement regulations; but unfortunately, these solutions are not being implemented, and the reason for that primarily is that the people who could implement the solutions are the people profiting from the corruption*," so the "*great challenge*" he says is "*how can we bring in change when the change has to be brought in by the* *crooks?"* PES17 adds that "*what tends to happen usually is that you get a very good procurement law and then the government just passes a law to exempt certain projects from that procurement route*." He shared examples from Ukraine and Mongolia to buttress this point. Illustrating, he said Mongolia has a great public procurement standard in terms of transparency and accountability, but the Parliament passed a law saying it does not apply to projects that follow a specific procurement route; so, they put most infrastructure projects through that route, thereby exempting them.

PES18, a construction lawyer for about 40 years who heads an anti-corruption in construction agency and was heavily involved in the publication of ISO 37001 submits that "*the great tragic conundrum of corruption prevention is that we know the solutions, we know what has to be done, but the people who can implement it are benefiting from the corruption*…." A view also shared by PB28 who commented that it is not something individual organisations do on their own, and some of the challenges have been around getting people from the different organisations that have to uphold those policies, especially for organisations that are used to acting unethically. Whilst speaking about corruption prevention in relation to public sector procurement, PES18 further explains:

> *Sadly, a lot of the ministers and civil servants responsible for placing contracts are benefiting corruptly from the contracts everywhere in the world, but they are also the people who could bring about change (…..) What we find a lot is that our systems get applauded and welcomed. We get invited to the country to provide training on our systems, and often we get met by the minister of infrastructure, who shakes us warmly by the hand, and sometimes the TV cameras suddenly appear. Then the Minister gives a brave speech and then vanishes, and we are left with the implementers who tell us that they have no power and no authority to implement anything. (PES18)*

While the occurrence of the above presented scenario may be more prevalent in developing countries, where implementation and compliance with ethical supply chain measures are weak, similar occurrences are also seen in many developed countries claims PES17, PES18 and PES20.

6.2.2.2.2 Role of government

Most participants also agreed that the government has a huge role to play for these measures to be well implemented. This generated the low-level theme ***role of government*** in fostering implementation of ethical measures, with 14 codes in total being recorded under this theme by 11 participants.

Regarding participants views on the effect of legislation on the effectiveness and implementation of measures provided to improve ethics in the supply chain, PC12 comments that "*it is working but it is not efficient enough, perhaps due to jurisdictional barriers. Every country is sovereign, so although several organisations may propose policies, the government still decides whether it is implemented or not*." PC4 also adds that they are very effective mechanisms, "*but I think the way they have been implemented seems to be on a project-by-project basis, whereas the governments should be the major drivers of these policies*." According to PES 26, the reason why the industry is not doing better ethically is simply due to "*the fact the regulations do not call for it," because as PC5 puts it, "legislation is the only thing that really makes things stick*."

On the contrary, PC2 believes that there "*are tons of legislation already and those legislation fall through in the means of compliance*." According to him, you can have all the policies but "*the difficulty with compliance is that it has to come from the individuals in the company, they need to recognise that detecting fraud is not a speciality, anyone can do it*." PC2 even criticises that "*many governments are only doing it because of financial incentives, perhaps from multilateral development banks or so. So unfortunately, it all seems to be money led, as opposed to wanting to do it.*"

Furthermore, in discussing the impact legislation has had on the improvement of ethics within the supply chain of their countries, two divergent views emerged among participants. On one hand, some participants reported that "*they have a relatively strong legislative and regulatory context in their countries*" (PES20), that "*works quite well*" (PES18) and it has "*certainly helped a lot*" (PES3). While some others on the other hand reported that the legislative and regulatory context within their country is "*weak*" (PC11), "*corrupt*" (PC14) and with a lot of loopholes (PC13) that unethical players take advantage of (PB29).

6.2.2.2.3 Denial

Another reported reason for the limited effectiveness of these measures is the outright denial of the presence of unethical practices within construction and/or supply chain organisations. This gave rise to the low-level theme ***denial*** with 12 codes in total being recorded under this theme by 9 participants. Commenting on this, PC3, a former President of the Institute of Structural Engineers (ISE), said that when the anti-Corruption forum started, "*people did not want to accept that corruption existed*" and people did not want their names or their companies to be mentioned, "*they were totally in denial*."

As PC2, experienced fraud investigator with over 40 years of experience in construction affirms:

> *The biggest challenge is denial. People do not want to accept that it happens within their organisations. They say, 'yes, I agree, fraud is not a good thing and we are all committed to eradicating it. We have got compliance in our company and fortunately it does not happen in our company, and that unfortunately is not true because the average in all companies of unexplained losses throughout the world is 6%. And of course, it is higher in our industry so that maybe about 10-12%. So, getting people to accept it is happening remains a challenge and that needs to come from the top. (PC2)*

PC5 suggests that as an industry, we ought to raise the profile of the consequences of doing something that is not right. "*There must be loads of these around and we do not seem to hear about them, so people think that there is no problem*." These comments suggest that the effectiveness current measures to improve ethics in the CMPSC has been limited due to weak implementation and sloppy compliance. Together, these results provide important insights into the current state of ethics in the CMPSC.

6.2.3 *Theme 3: Improving ethics in CMPSC*

A variety of perspectives were expressed by the participants regarding how ethics in the CMPSC can be improved. These views were expressed by 28 participants, which produced a total of 109 relevant codes that led to the emergence of the high-level theme ***improving ethics in CMPSC***. This theme further contains 4 mid-level themes: ***Need for education*** *(18* codes*),* ***improving ethics in CMPSC through blockchain*** *(26* codes*),* ***factors affecting acceptance and implementation of blockchain*** *(60* codes*),* and ***personal ethical values*** *(18* codes*)***.** This is further illustrated in the thematic model shown in Figure 6.8.

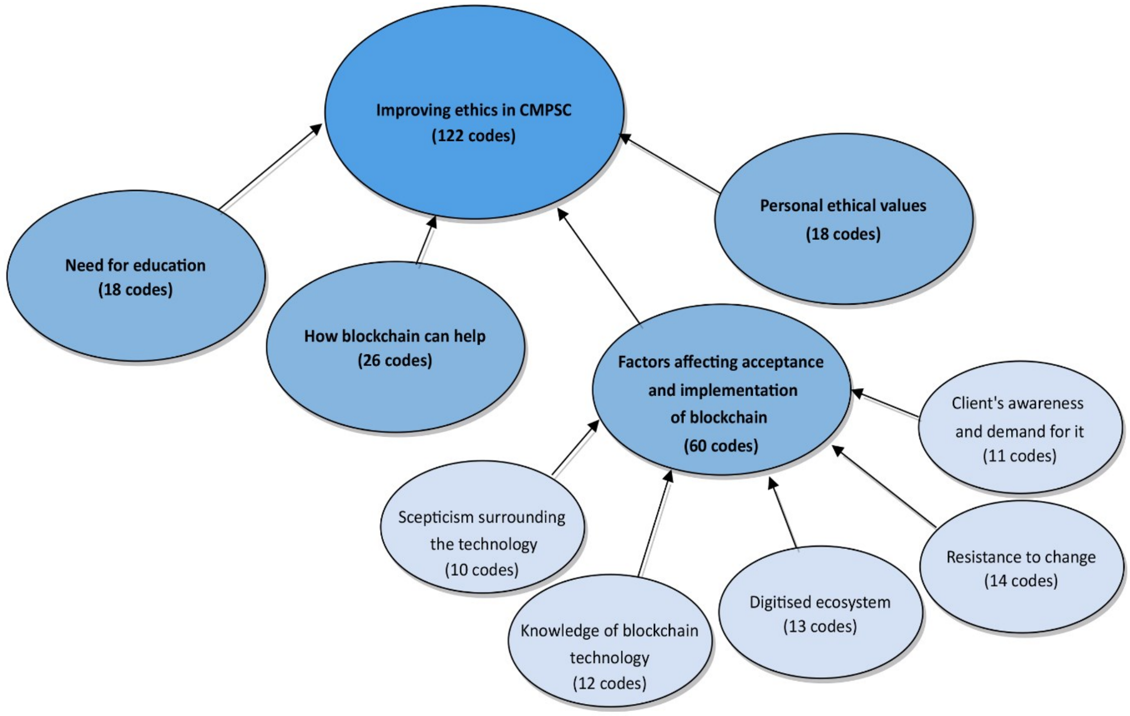

Figure 6.8 Thematic model 7: Improving ethics in CMPSC

6.2.3.1 Need for education

In discussing how ethics in construction materials and products supply chain (CMPSC) can be improved, several views surfaced, one of which viewed the need for education as a pivotal ingredient to the improvement of ethics in the CMPSC. As such, they were categorised under the mid-level theme ***need for education*** which produced ***18*** relevant codes by 14 participants. As PC12 states: "*A culture of ethics should be engrained into citizens right from their early learning stages*" and "*it is the citizens of the country that can really drive the change, it is not going to be the World Bank or the IMF*," PES18 added.

According to PC2, in construction, during our academic degrees or professional training, a lot of things are ingrained in us, such as: health and safety, sustainability, equality, diversity and inclusion, etc., and we all know what our responsibilities are to ensure good practice, "*but fighting fraud is not one of them and I feel that is something we need to ingrain too.*" A view also echoed by PES19 who believes that there is a real need to begin "*getting people to understand that ethics is their responsibility, and it should not be consequent upon the demand of clients*." In a bid to achieve this, PC5 reports: "*I run ethics days where we just talk about various elements of ethics, including modern slavery and try to* *raise awareness about them*," with the top 250 players of the supply chain of his organisation. Although, he also believes that you are always going to have someone who "*decides to take a little bit of a risk and do something that is dodgy.*"

The need for education in improving ethics in CMPSC is further strengthened by the responses of some participants when asked to comment on the effectiveness of some current measures and initiatives to improve ethics in the CMPSC. In their responses, PC6 said "*I am not really aware of some of these anyway. I have not really come across too many of them to be honest, I am not quite sure if I have ever come across some of those names*," and PC5 admits, "*well I guess the fact that I do not really know what those are says its own thing in terms of that*."

Thankfully, there are organisations who seek to bridge this knowledge gap by "*providing information, training resources and anti-corruption preventive programmes*" (PES18) on their website and it gets visited by thousands of organisations every month from 190 countries. Also, PC5 added that, there is the supply chain sustainability school which helps to "*educate the supply chain so that they know the right thing to do.*" Commenting on the supply chain sustainability school, PES19 said that the school is free, and it has about "*50,000 members now and about 3,000 or 4,000 companies, so they are all getting our knowledge and experience*."

Some participants also particularly stressed the need for education among clients and owners. For example, PC1 asserts that "*one of our biggest challenges to really shift the industry and minimise corruption is in its owner's education*." PES19 also agrees with this, saying, "*there is no sophistication of understanding on what sustainability is, so clients do not ask for it*." PES26 further explained this from a consumer marketing perspective, saying that companies show what their products do to the consumers and consumers only buy what is available to them, "*but if we can educate the consumer that actually, there is a better way of producing the products, then people would demand better standards and we might be able to create consumer pull.*"

6.2.3.2 Improving ethics in CMPSC through blockchain

The discussion within the mid-level theme ***improving ethics in CMPSC through blockchain*** concentrated on the role blockchain technology could play in the improvement of ethics in CMPSC. Participants were asked whether or not they think blockchain can help to improve ethics in the CMPSC and if so, how they think it can. This theme contains all the relevant responses which produced 26 codes from 25 participants.

The majority of the participants agreed that blockchain technology could indeed help to improve ethics in the CMPSC particularly because of its "*transparency*" (PC1, PC5, PC10, PC11, PC13, PC14, PC8, PB29) and "*immutability*" (PB27, PB28, PC10, PC12) features. As PC10 asserts: "*Yes, blockchain can help to improve ethics in CMPSC, due to its immutability and transparency characteristics, it is very likely to be able to drive people to do what is expected of them*." Similarly, as PC12 affirms: "*I think blockchain has a role to play because you have got that immutability and transparency factor*." PC10 believes that since the industry deals with a lot of data and information, the ability to "*ensure that the information is secured, such that it is not editable without the permission of every participant connected to that particular network makes it a promising one for the industry*." According to PC14, lack of oversight is one of the factors that fuels corruption, but "*a system that puts on the spotlight can help to checkmate such moves, and this is where blockchain comes in*." This view was also echoed by PC8 who opines that there are many opportunities to syphon away value in the supply chain as it is today, but blockchain could change that because there would be "*a record of every transaction*." The distributed nature of the blockchain ledger introduces transparency, which can help achieve "*real-time auditing, so people can see all that is going on….*"

Two participants highlighted how the transparency and immutability features of blockchain help to position it advantageously as a tool for certification validity and authenticity. PB28 comments that being able to prove that the certification you have hosted on the blockchain network is genuine helps to gain the trust of potential employers. Also, PB27, a participant with over 30 years in the IT industry and over 10 years' experience in blockchain, who has also developed a currently running blockchain enterprise solution comments that:

> *My interest in blockchain started a little while ago, really monitoring how it was being used in the pharmaceutical industry. And I quickly came to see opportunities in construction to apply distributed ledger technology in the area of quality. The problem that I have observed over 30 years is specifically in welding quality and all of the documentation, certifications, qualifications, and records that are required in order to demonstrate that a weld was made according to the appropriate codes and qualified personnel and that is a huge paperwork burden on the industry. It looks to me like, from a cross-organisational standpoint, having immutable records focusing on certifications would be a great application for blockchain and construction and looking at what Web 3.0 enables in terms of different business models" (PB27).*

Also, PC1 claims that the transparency and immutability features of blockchain also qualify it to "be the platform that houses the digital thread of the digital twin consortium." Further explaining, he said, "*I call blockchain potentially the DNA. It becomes the DNA of any facility because it will always have that full history of who did what if it is implemented correctly,*" however, he also warns that "*it does not mean there are not going to be a lot of challenges.*"

Furthermore, contrary to the views of most participants on the immutability of blockchain, PC2, PC13 and PES18 raised concerns about how the very same immutability feature of blockchain may make it unsuitable for the variations and reworks that come up during construction. "*You know we are constantly saying, 'Oh no! that it is the wrong material, we want to change the strength of concrete' or something like that"* said PC2.

Also, some participants raised some words of caution, emphasising that the involvement of humans in the process may open the door for unethical players to undermine the technology. As PC14 puts it, "*except it is a fully digitised system, but as long as someone is still sitting behind the computer to impute data, humans will always be humans, and there is still a possibility of someone doing the wrong thing intentionally."* PES17 further explains that blockchain is "*data hungry*" and the process of getting good data in the first place requires capacity, and in an environment where you have capacity constraints, "*I would be sceptical about the quality and the scope of the data, if its good enough in the first place.*" This view is also shared by PC10 who believes that blockchain can play "*a major role in improving ethics in the CMPSC. However, the human aspect would always come in because you still need a human being to feed data or information into the system,*" he suggests that "*check and balance systems be used to scrutinise the human inputs into the system. Site monitoring drone imagery reports can be used to crossmatch the milestone claims of a project for example*," claiming that such implementations help "*to prove or disprove the legitimacy*" of whatever is being fed into the system by humans.

Due to the "*human aspect*" (PC10), some participants reported: "*I am not as hopeful as some people are*" (PES17), because "*I am sure there is always someone that is going to find a way round the back to pay someone off*" (PC6) and "*it could also be abused, of course; any system can be distorted to promote bad practice as well if not managed carefully and that is another risk*" (PES17).

PC3 sums it up by saying, "*yes! it [blockchain] certainly should help improve ethics in the CMPSC, but there has to be a desire for people to get better and I think the way the world is going at the moment, there is a great desire to do things better*."

6.2.3.3 Factors affecting acceptance and implementation of blockchain

The discussion of the role blockchain technology could play in the improvement of ethics in CMPSC gave rise to the mid-level theme ***factors affecting acceptance and implementation of blockchain*** with 60 codes in total being recorded under this theme by 21 participants. In discussing this, a variety of factors were identified from participants feedback as factors that may affect its acceptance and implementation. This led to the further emergence of 5 low-level themes as illustrated in the thematic model shown in Figure 6.10.

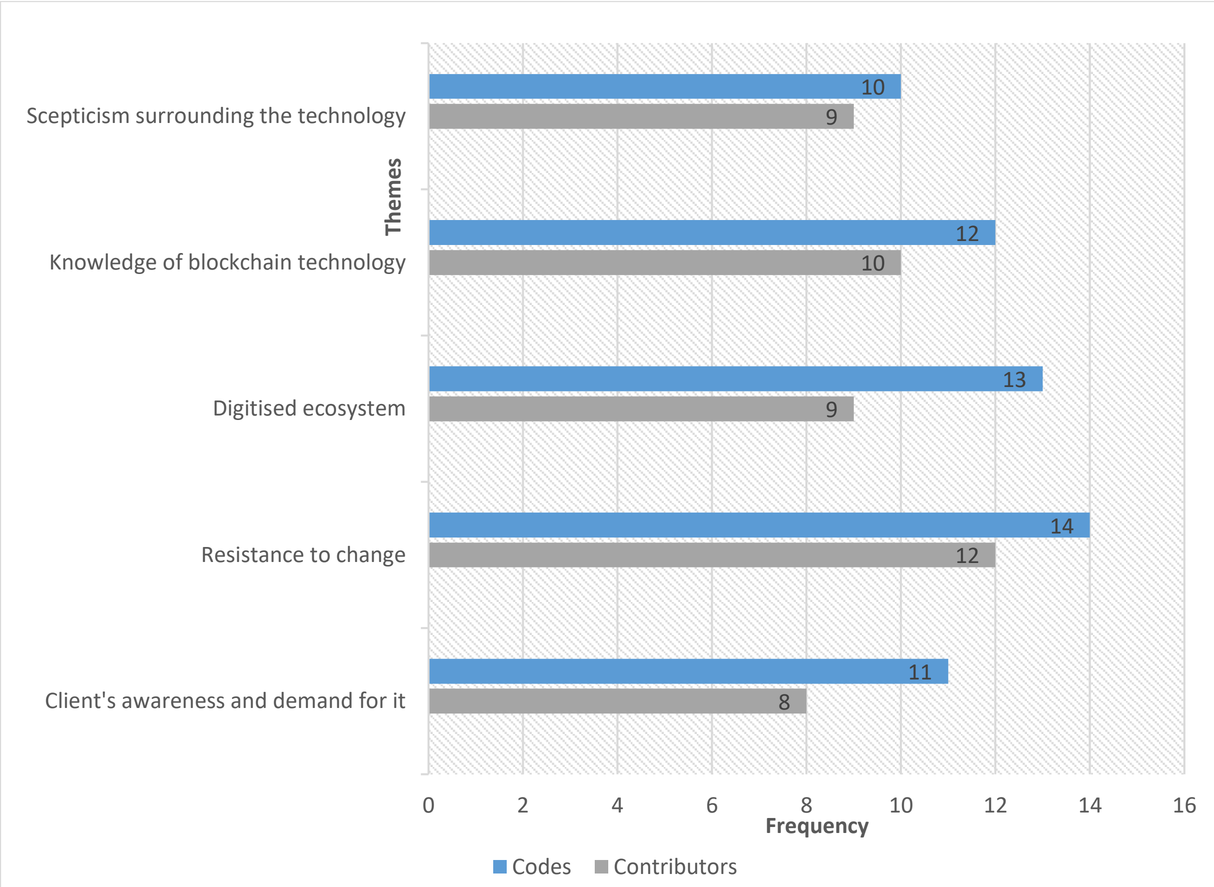

Figure 6.9 Thematic model 8: Factors affecting acceptance and implementation of blockchain

One of the factors that may affect the acceptance and implementation of blockchain as identified by 9 participants was the ***scepticism surrounding the technology*** which recorded 10 codes. PC2 thinks "*there are some companies who are suspicious of the technology, and sceptical about how the data could be used,*" perhaps because of "*hackers and scammers*" adds PC11. The technology is also "currently not as universally accepted as it should be" PES19 stated. Concerning blockchain, PES23 has "*actually become a little bit critical of the tool itself*," he further explained that this is because "*I think there is a lot of hype and I think that some of the things that it promises to solve could also be solved through other technologies that are already available and are less expensive*." Commenting on this, PB28 reports that "*there have been quite a few challenges as I have certainly been involved and put a lot of time and effort into proposals that ultimately due to the lack of trust in the technology, did not go ahead*."

Notwithstanding, some participants also showed optimism regarding the technology, with PES22 stating that "*personally, I have been interested in blockchain since I first heard about it roughly seven years ago*" and PES20, stating that "*a potential solution [to some challenges of the supply chain] such as blockchain is really interesting and I am interested in understanding what those solutions could be*."

As such, 10 participants with 12 codes also suggested that the ***knowledge of blockchain technology*** may determine the level of acceptance and implementation it would enjoy, because "*when some people hear of blockchain, they pull back because it sounds like too much information for them to process, whereas if it was broken down into bits and pieces, they will see that it is not an alien idea*," PC9 said. PC5 thinks blockchain is still "*a little bit mysterious*" and according to PC11, "*a lot of managers of companies may not understand (….) because they may be reluctant in learning new things*," suggesting that "*younger professionals may be able to pick it up faster*." PC8 sums it up well, saying there is a need to "*help people to understand how it really is a trustworthy, provable immutable system. There would be some educating that would have to happen on some level to know that this will accomplish what it says it will.*"

Whilst discussing factors that may affect the acceptance and implementation of blockchain, a common view among participants was that its acceptance and implementation is going to require the presence of a ***digitised ecosystem***, this recorded 13 codes by 9 participants. "*I think everything needs to move with the times and digitalisation*" claims PC6 and "*that is one aspect which might be a little bit tricky considering the reality of infrastructure that needs to be put in place to achieve this*." A view also echoed by PC14 who said, "*the availability of the infrastructure to run these things is not readily available*," citing a this as a disadvantage in a region where electricity supply and the speed of the Internet are still problematic, according to him, "*these are factors that can also contribute to adoption challenges*."

According to PC15, "at the moment, I still do not think it is quite there yet because I feel like there are still a lot more things to come of this before it gets into construction as a normal day-to-day practice," because you can only utilise blockchain with someone who is open to it and has the infrastructure to use it, until then, I think applications will be scarce, PB30 argues. PC12 however notes that "*these days, everything is being digitised*," even firms that did not practice that before are now doing so as one of the many changes induced by COVID-19, so as not to lose opportunities to competitors in the global market. Also, PB28 counsels that "*you have got to look at the future (….) and design to that end because you know that ultimately connectivity will improve and hopefully the cost will come down*." PB30 also warns that we must be careful with blockchain and smart contracts because "*there is a lot of hype at the moment around blockchain and people are exploring it for pretty much everything but just because you can use it does not mean you should.*"

Another factor that may affect the acceptance and implementation of blockchain is the issue of the construction industry's ***resistance to change***, this recorded 14 codes from 12 participants. According to PC15, the construction industry is "*very fearful of change*" and this makes construction industry "*notably a laggard industry, they are one of the last to take advantage of new technologies*." This is evidenced by PC5's comment on blockchain: "*It is an interesting subject that we as an industry have not done as much as we should have done on*."

PC11 notes that "*truly, there are methods that have been working overtime, but people have found loopholes and how to leverage them for theft*." He suggests the "*need to refine these systems*," warning that "*a refusal to change would be tantamount to setting up ourselves to continue the ride downhill as we have seen over the years*." PC15 adds that it may not be very comfortable at the initial stages, maybe because it is different and "*people usually do not like to get out of their comfort zones.*" A view also echoed by PC14 who said that some people do not want to shift away from their comfort zones, and they do not want any changes or upgrade to what they are used to. For example, PC2 explained that everyone is used to the traditional audit process, where experienced auditors audit your finances when it's too late. They will look at past transactions, say what has to be done, take their fees, and leave. Next year, they repeat the same thing. Similarly, PES19 argues that "*another challenge would be the cultural implementation, that is, changing practices and thinking*," because this takes a lot of investment in terms of people, planning and time. As PC9 notes, "*change is something that is always inevitable. Sometimes it is hard to accept, but eventually, you will have to work around it*."

The last factor identified from participant conversations that may affect the acceptance and implementation of blockchain is the ***client's awareness and demand for it***, as recorded within 11 codes from 8 participants. PES18 affirms that "*you tend only to be able to move the industry if the* *client requires it*." A view alluded to by PES20 who said, "*I know that as a large client we are in quite a good position to steer people towards possible blockchain solutions for supply chains*." Usually, "*consultants will say, 'yeah, that's great, but at the end of the day the top priority is whether a client wants us to do it or not',*" PES19 adds. PC1 asserts that "*owners need to understand these advantages, we are not likely to get an architect, engineer or even a construction manager that is going to want to adopt blockchain methodology. It is going to come from the owners or operators."*

6.2.3.3 Personal ethical values

Some participants believed that despite the potential of technology and other measures in place to improve ethics in the CMPSC, the personal ethical values of involved individuals remain a major determinant for their success and the overall improvement of ethics in the CMPSC. This led to the development of the mid-level theme ***personal ethical values*** which produced 18 codes by 12 participants. As PC4 affirms: "*It has great potential for integrity, but again, it does rely heavily on having that entity who is doing the tracking to be an ethical person*." PC5 pointed out that several things in the industry are done based on client demand, so if that happens to be something around ethics, and the client is not asking you about it, "*do you have the values within your organisation to do it anyway because it is the right thing to do or do you just say, 'they are not asking for it, so I am not going to do it'?" People need to "understand that ethics is their responsibility, and it should not be consequent upon the demand of clients,"* said PES19.

In revealing the integral role of personal ethical values, PC6 comments that if you have a mine full of slaves versus one with well-paid and well-cared-for workers, there will be a knock-on effect at some point and "*this is where it then comes down to your personal ethics and whether that bothers you or not."* PC6 further elucidates that if you are buying products and you find cheaper options but to connections with slave labour for half the price. "*You know, if you did not know it before, you would not care; now that you know, you still have a decision to make*."

Some participants also believed that the unethical actions perpetuated by certain people may be due to a more external coercion. "*You know, these are things that potentially, even when people do not want to do them, people get tempted to,*" claims PC14. PES17, an international construction anti-corruption expert with over 40 years of experience in over 18 African countries argues:

> *I do think that people have a natural desire to want to act with integrity and with high professional standards. I have not yet met somebody who said let us lower professional*

standards. So, I think there is a way forward there. I think at the individual level, there is a real desire to do the right thing amongst many people (....) but most people feel that they have no choice but to go along with the way things work, so the system does not allow that free choice (….) For example, I and a colleague were on a project with some engineers in a particular country and we asked the question: 'is it possible for you to manage this project in this country without any corruption?' They said, 'no of course!' (PES17).

In another example, PES17 cited that on a particular construction project that involved a group of engineers where the quality of work done was unacceptable but "*the district officer mounted pressure on the engineers to pay them anyways*."

In summary, these findings present some suggestions to improve ethics in the CMPSC. Firstly, there is need to educate supply chain players, construction professionals and clients on ethics so that it is understood that upholding high ethical standards and spotting breaches is everyone's responsibility. Secondly, beyond the ethical measures and structures, individuals must seek to uphold personal ethical values, even though this may be tantamount to swimming against the current tide of corruption in the industry. Thirdly, the findings also suggest that blockchain has a role to play in the improvement of ethics in CMPSC, but not without overcoming certain challenges. Together, these results provide important insights into how ethics in the CMPSC can be improved.

6.3 Theme 4: Model validation and feedback (phase 1)

As earlier discussed in Section 5.6.2.1 of this study, the layout of interview questions utilised for this research could be broken into three sections. In the third section, the researcher conducts a presentation of the conceptual model and allows for immediate reactions from the participant following the presentation before the researcher begins to ask questions with the goal of validating the model elements and components and evaluate its potential to improve ethics within the CMPSC. This serves as the first phase of the dual-phase validation strategy for the conceptual model, as expert interviews are a way of validating research models and frameworks (Abraham, 2007).

The discussions within the third section of the interview were coded within the high-level theme ***model validation and feedback.*** A variety of perspectives were expressed by all the participants regarding the potential of the model to improve ethics in the CMPSC, the elements and components of the model, factors that may affect its acceptance and implementation, the limitations of the model, suggested adjustments to the model and guidelines for its implementation. These resulted in the following mid-level themes: ***Evaluation of the model's potential to improve ethics*** with 84 codes from 30 participants, ***validation of elements and components*** with 127 codes from 30 participants; ***acceptance and implementation*** with 84 codes from 30 participants; ***limitations of the model*** with 46 codes from 30 participants; ***feedback on the overall model*** with 30 codes from 30 participants and ***Suggested adjustments to model*** with 6 codes from 4 participants. This is further illustrated in the thematic table in Table 6.2.

Table 6.2 Thematic framework: Model validation and feedback - High, medium and low-level themes

High, medium and low-level themes	**Codes**	**Contributors**
4. Model Validation and Feedback	**377**	30
4.1 Evaluation of the model's potential to improve ethics	**84**	**30**
4.1.1 It urges ethicality	30	24
4.1.2 Provision of information	28	21
4.1.2 Transparency and visibility	26	23
4.2 Validation of the elements and components	**127**	**30**
4.2.1 Material and Product Network	48	30
4.2.2 Procurement Network	38	30
4.2.3 Project Network	41	30
4.3 Acceptance and Implementation	**84**	**30**
4.3.1 Cost of implementing the model	20	18
4.3.2 Differing standards across boundaries	12	9
4.3.3 Corruption	23	17
4.3.4 Simplicity in use	11	8
4.3.5 Digitised ecosystem	18	11
4.4 Limitations of the model	**40**	**24**
4.4.1 Ethicality of its oracles	21	17
4.4.2 Not robust enough	4	1
4.4.3 Limited access to technology in lower tiers	15	10
4.5 Feedback on the overall model	**30**	**30**
4.6 Suggested Adjustments to Model	**6**	**4**

The results and findings within the high-level theme ***model validation and feedback*** which culminates into the first phase of the model validation protocol are presented in the next section of this study.

6.3.1 *Evaluation of the model's potential to improve ethics in CMPSC*

The discussion within the mid-level theme ***evaluation of the model's potential to improve ethics*** simply concentrated on discussions and participant feedback on whether the model would be able to help improve ethics within the CMPSC or not. This yielded 84 codes from all 30 participants. Participants generally agreed that the model could indeed help to improve ethics within the CMPSC. While discussing this, there was a sense among the participants that the model's urge for ethicality, the transparency and visibility it helps to achieve, and the information it provides are the major things that would help the model deliver on its value propositions. This resulted in the following low-level themes: ***it urges ethicality*** (30 codes), ***provision of information*** (28 codes) and ***transparency and visibility*** (26 codes). This is illustrated in the thematic model shown in Figure 6.10. Furthermore, the conceptual model developed to improve ethics in the construction materials and products supply chain is also presented in Figure 6.11.

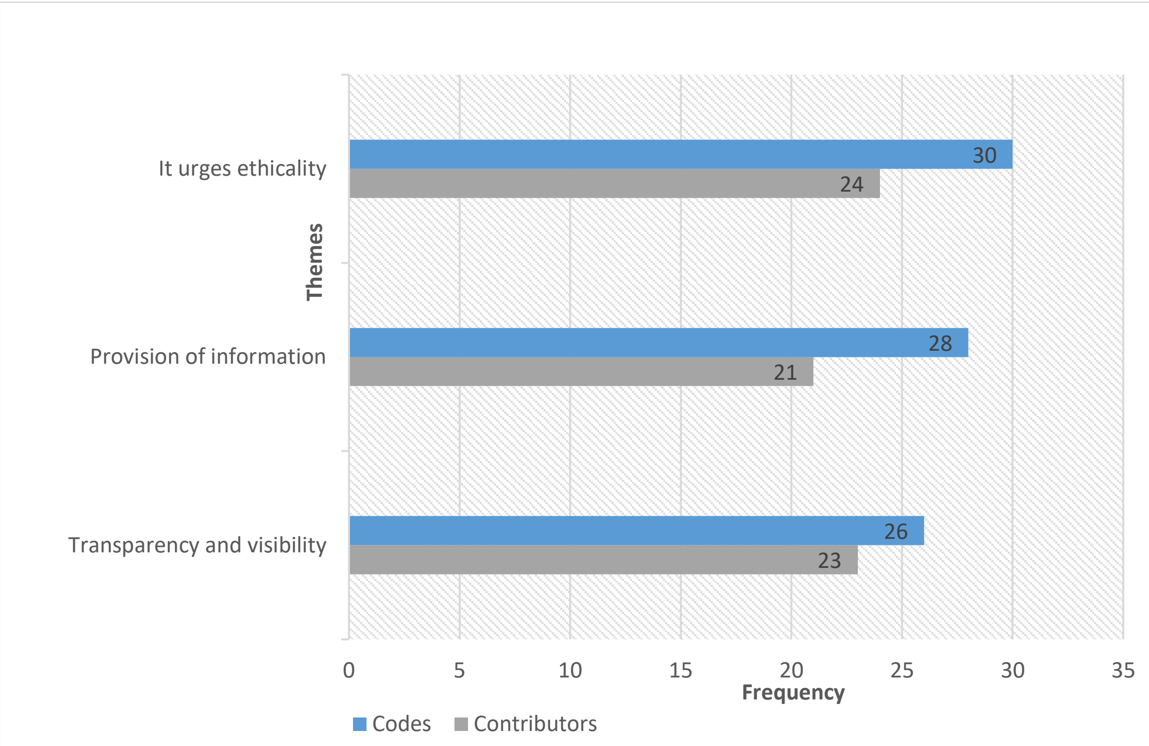

Figure 6.10 Thematic model 8: Validation of model's potential to improve ethics

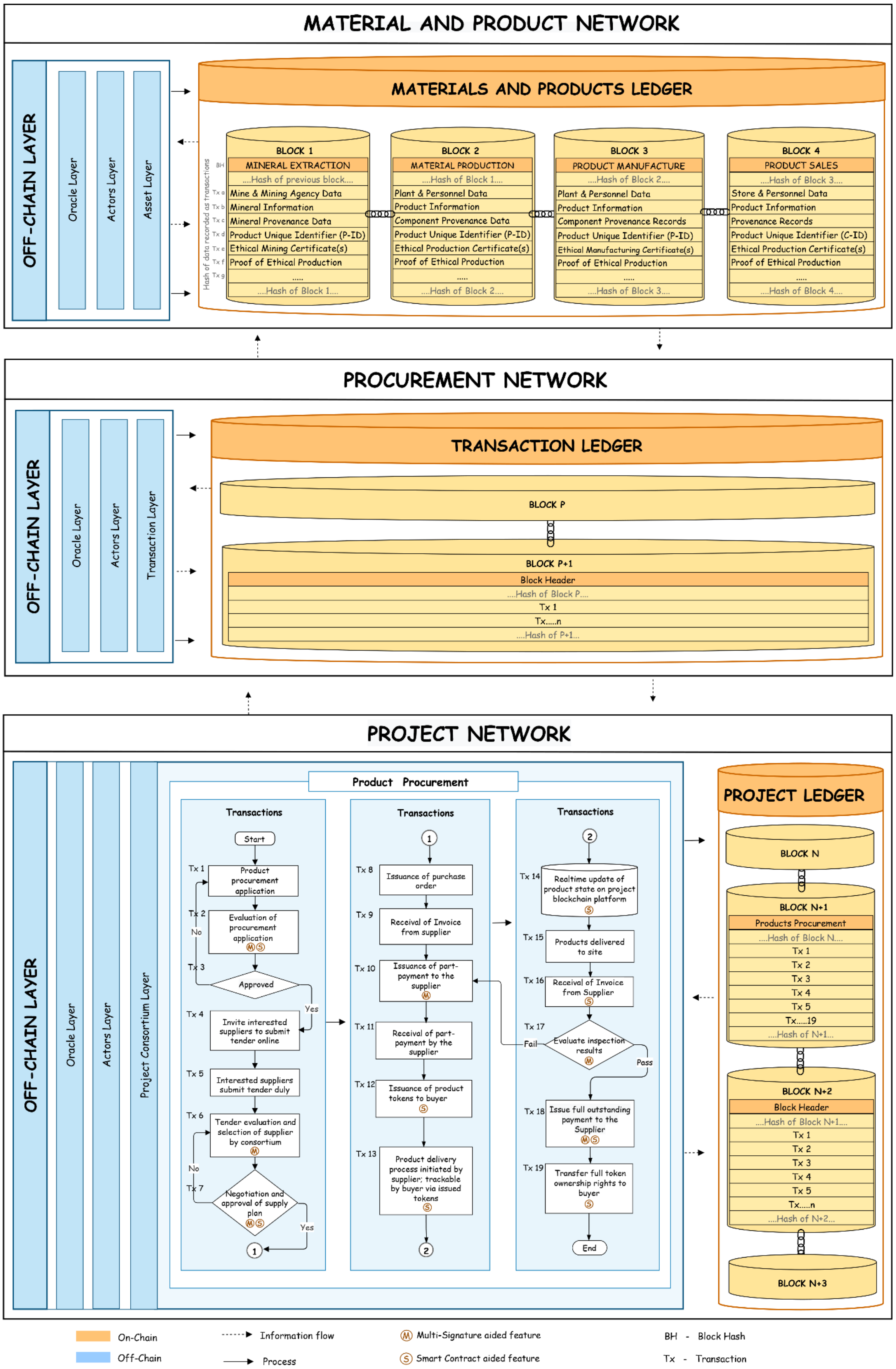

Figure 6.11 Conceptual Model: A model to improve ethics in construction materials and products supply chain

6.3.1.1 It urges ethicality

In validating the model's potential to improve ethics within the CMPSC, a common view among the participants was that the model urges for things to be done ethically within the supply chain. These led to the development of the low-level theme ***it urges ethicality*** which produced 30 codes by 24 participants. As PC8 puts it:

> *I do think this model can improve ethics in CMPSC, but I think it starts even before the daily use of the model, because even before anybody has written anything on the blockchain, the threat of having to have everything provable will force a change that will ripple up and down the supply chain. You know, it is like the old phrase 'shine a light and the cockroaches will run.' This is a light that can be shown into every aspect of CMPSC and just the fact that it exists is a first step toward improving the ethical conduct of operations. (PC8)*

PC13 comments that "*for you to decide to join this network, I think you must be someone who is ready to do the right thing and follow due process in the first place*," and with the "*willingness and the openness to share the information, there is obviously an impetus there to want to act with integrity*," adds PB28. Further explaining, PB28 said that if you have a network of organisations who are willing to cooperate and work together and share information straight away. "*There is a level of trust there that those organisations really want to operate in an ethical manner; otherwise, why would they want to get involved in that?*" PC13 adds that "*with this model, there is an urge to act rightly because you know that it will be less expensive to do the right thing than to cut corners by bribing everybody along the chain."*

As PC4 affirms: "*When people are being watched or know that they can be watched, they act differently generally, and so I think that would instil fair actions into participants*," PB29 further explains that people have the tendency to do the wrong thing if they know people cannot see their acts, but if they know that people can access a trail of their activities, "*it would discourage many of these atrocities from being carried out in the first instance*." PB29 also added that integrity issues will be solved since participants will not want to subject themselves to an environment where their shady deeds would be recorded and instead, strive to ensure that their credibility is protected and sustained.

6.3.1.2 Provision of information

In validating the model's potential to improve ethics within the CMPSC, another common view among the participants was that the information it provides would help the model deliver on its goal. These led to the development of the low-level theme ***provision of information*** which produced 28 codes by 21 participants.

Some participants suggested that ignorance in procurement and supply chain activities are major culprits in the decadent state of ethics in the supply chain today and information is needed to set things right. According to PC6, "*ignorance is probably playing a part in where things are today in terms of ethics*." He explains that sometimes the problem is that of ignorance in procurement. "*For example, I have never really ever thought about going back as far back as block one you know.*" So, one could buy a product that meets all the technical standards et cetera, and that is all one knows because "*sometimes when you are looking at products, you are only going back as far as the information you have,*" "*you don't know, so you don't care,*" he said. However, if one knew that the product came from a mine full of slaves, that would probably change one's mind. This view is also echoed by PC9 who explains that sometimes people do not really know anything about the product they are ordering; they just sign the cheque, so long as something gets delivered. They relegate that duty to someone else, hoping that they would always do the right thing since it is their job.

Commenting on the model, PES25 stated: "*I think it is really useful because you do not know what you do not know and until that becomes visible, you cannot start to address certain issues, so it is really critical*." PES18 said that "*the amount of data that is there is immense, and I think "possibly the fact that it is available might finally get organisations to suddenly start thinking*" about taking ethics in their supply chains more seriously or "*they will bury this research because they do not want to take responsibility for their supply chain but I think it is a great model.*" Also commenting on the model, PC6 said: "*I have never thought that far back, probably because I have never had the information to look at it*" while PES26 also acknowledged: "*You have challenged me to think about stuff I have not really thought about."*

In PC15's view, if this model is implemented, it would be a good step forward for the industry because "*having these different layers of information and transparency would improve the efficiency of the industry.*" PES26's opines that as the industry moves more towards a situation where CSR is more important and is monitored as part of the top line value of a company, "*you are going to need this kind of proof; you are going to need this kind of evidence and traceability of supply chains.*" Because that does exist in other industries, and I was surprised I never really considered that it does not seem to exist in construction. PES19 however cautions that "*it is important to note that this model does not make your supply chain ethical; rather, it provides you with the information to then go into what you* *need to do to ensure you have an ethical supply chain*."

Other participants also suggested that the information provided by this model would aid optioneering in procurement. For example, according to PC10, "*you are able to verify the credibility of each product that you are procuring and then you make an informed decision*." PES 19 also opines that "*from a corporate perspective, I think they would see this as an opportunity to also look at due diligence in their procurement, just using this tool can help to understand where their risks sit up*."

6.3.1.3 Transparency and visibility

In validating the model's potential to improve ethics within the CMPSC, another common view among the participants was that the transparency and visibility the model gives a good assurance that the model will deliver on its value propositions. These led to the development of the low-level theme ***transparency and visibility*** which produced 26 codes by 23 participants.

In discussing how the transparency and visibility the model provides into the CMPSC helps to achieve its goal, PES25 responded saying, *"I think that as a sector, we need to have greater visibility of the content of what we are procuring, and this is a good way of achieving that*." PC5 also comments: "*Yes, I think it would definitely give you more visibility from end to end, which is a lot more than what we have now, so definitely*." PC9 also adds that "*this allows for high transparency because of the availability of certain information (….) Even though not everyone will go through the information that is provided, knowing you have that information is a really good thing*."

As PES19 asserts, from a social perspective, "*it's quite easy to see how this can help improve ethics because you have a long reach into the supply chain*." That could help you understand where all those component parts are from a human rights perspective and the ability to do something like this would be intriguing. When asked if participants thought that the model could improve ethics in the CMPSC, PC9 responded saying "*this allows for high transparency because the availability of certain information (….) even though not everyone will go through the information that is provided, knowing you have that information is a really good thing*." PC6 submits that it is an interesting approach and "*it has certainly opened my eyes a bit more to this sort of things and made me think a little bit more about what we are buying and may even now make me ask a few more questions."*

Other participants also believe that the transparency and visibility provided by the model could help curb fraud and product counterfeiting. To illustrate, PES18 comments:

> *Yes, I think it will help improve ethics, in the sense that it captures the entire transaction. At the top level, right from mines to smelters to manufacturers to sales. And then, in another instance it captures the procurement, payments and approval in the sections below. I think there is obviously a value in capturing all those transactions in one place and I can definitely see that capturing those transactions (....) would make corruption much more difficult.* (PES18)

PES17 also thinks "*it could contribute to that, yes*." With the main benefit being in relation to fraud, "*underlying fraud could be exposed even if not in real time, the fact that the records cannot be changed or lost means that it will be uncovered in the future*," he said. PC8 also said, "*yes, I think it could because if there is a bad actor that aims to get into the system with shoddy materials from unapproved sources, such an actor could be caught more easily.*"

6.3.2 *Validation of the elements and components*

The discussion within the mid-level theme ***validation of the elements and components*** of the model simply concentrated on discussions and participant feedback on whether the elements and components that make up the model help to capture the supply chain, provenance and procurement flows, and if it helps to achieve the model's goal or not. This yielded 127 codes from all 30 participants. Their responses helped in the evaluation and validation of the 3 sub-models represented in the model as networks that make up the whole model. Hence the responses are grouped under the low-level themes: ***material and product network, procurement network*** and ***project network*** which are the main components of the model, recording 48, 38 and 41 codes respectively under each theme. This is illustrated in the thematic model shown in Figure 6.12.

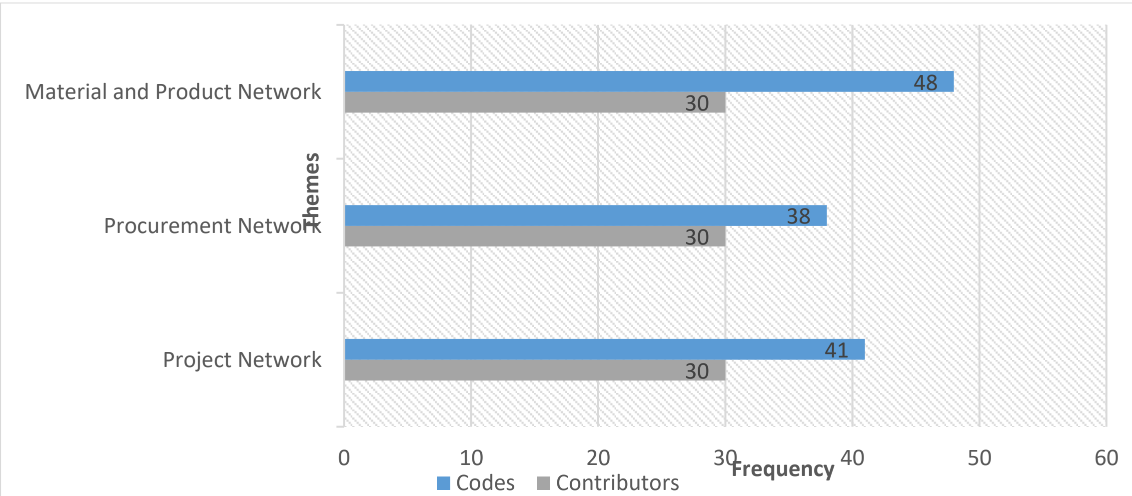

Figure 6.12 Thematic model 9: Validation of model's potential to improve ethics

6.3.2.1 Material and Product Network (MP-Network)

While discussing the elements and components of the model, the feedback for all 30 participants, which led to 48 codes, reveals that the participants generally agree that the material and product network may help to capture provenance and improve ethics within the supply chain and its workings could in fact help improve ethics within the CMPSC. The MP-Network is presented in Figure 6.13.

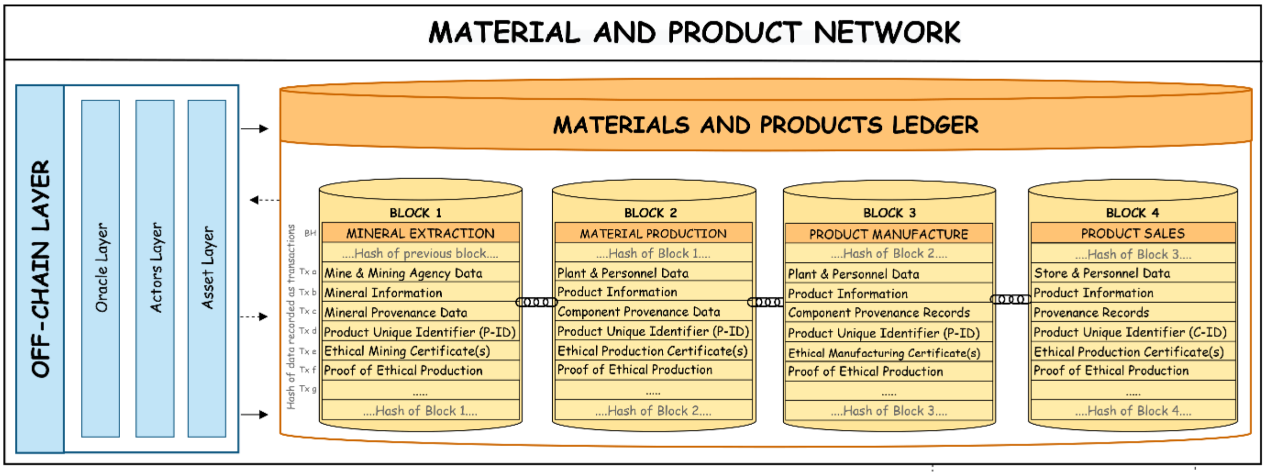

Figure 6.13 Sub-Model 1: The Material and Product Network

This network as PC13 puts it: "*It guarantees quality control to some extent because if those people are certified and licenced by the appropriate bodies, it gives the supplier more credibility and the purchaser an assurance of the quality of the supplies*" and there are "*precepts to be followed for certain actions to be executed so that helps limit the ability of people to cut corners*," adds PC12. PES26 also thinks "*it just creates an enormous amount of opportunity and value for businesses and consumers potentially*."

Commenting on the provenance attributes of the MP-Network, PES18 said that *"I can also see the benefit of showing the provenance*." He cited for example that it may help to prevent an ethical contractor from ignorantly buying iron ore from a war-torn country run by warlords with huge corruption and blood trading. PES18 also adds:

> *I can see that it is very beneficial because you can spot strange companies appearing in the process of production. If you know the provenance of your product, who has bought and sold it, I presume you can identify suspicious activities because if the product is extracted from a mine and then goes to the smelter and Block 2, but between Block 1 and Block 2, if there is a mysterious company, then that transaction would be picked up on the blockchain and you could say 'hang on! who are they? Why is it going via an intermediary company?' If you could*

> *then identify the name of that company from the blockchain, you could conduct ownership searches*. (PES18)

One of the issues the MP-Network aims to solve was also identified by PC5, who complained that "*we deal a lot with products from tiers four, five and six and it gets a little harder to understand where that is all coming from without doing lots of manual research*." Commenting on the elements of the MP-Network, PC10 said, "*the certificates also help to ascertain that the products meet the expected standards,*" and "*I think I would probably be more reliant on the proof of ethical production certificate. If that element is in place, you would have a bit more trust in the product as well*," claimed PC6. Although PES20 stated that, "*to me an ethical production certificate is inadequate, there is quite a lot more information that I would want to know. I would want to know what standards had been used, what external verifying body had done the verification, etc*."

Commenting on the Proof of Authority consensus protocol utilised in the MP-Network, PB29 asserts that it also provides trust within the platform, "*because if anybody is willing to go to the extent of providing an immutable signature on transactions, then they must have done their due diligence,*" in order to also ensure that their own credibility rating does not decrease, "*so they have more reasons to act fairly than otherwise."*

Furthermore, commenting on the dual storage solutions utilised by the model, PB28 said: "*I think the concept of an off-chain is really important as well, so things like certificates are probably a big one (….) You do not want to store images of certificates and things like that on a blockchain*" because, although the immutability is great, it also means that very quickly you start to fill up all your storage and it becomes very expensive.

Also, commenting on the flagging and reporting mechanism within MP-Network, PES18 comments that:

> *I suppose if there is a mine and that mine gets audited to the international standards as to its quality and its manufacturing process. I can see that if that is on the ledger, there would be some sort of continuity plan, which gives you assurance as to their quality, environmental, safety and other standards, and I can see the huge advantage of having that on the blockchain. (PES18)*

Lastly, PES18 comments: "*What you have developed at the top [MP-Network] is new to me, and it is an interesting concept (….) I have not really thought about that before, but I can see the advantages*."

This comment not only illustrates the potential of the MP-Network to help in the fulfilment of the overall goal of the model, but it also points out the novelty of the model.

6.3.2.2 Procurement Network

While discussing the elements and components of the model, the feedback for all 30 participants, which led to 38 codes, reveals that the participants generally agree that the procurement network possesses a good degree of transparency to verify product ethicality and authenticity during procurement; the workings of which could in fact help improve ethics within the CMPSC. According to participants, the network will help level the playing field for both SMEs and large enterprises by providing a level of trust. The procurement network is presented in Figure 6.14.

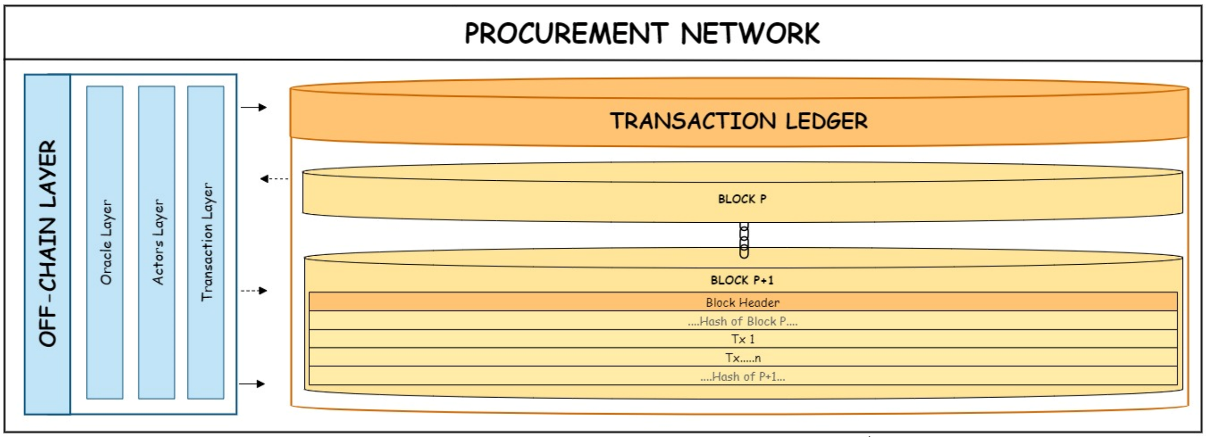

Figure 6.14 Sub-Model 2: The Procurement Network

As PC10 puts it, "*before you procure a product, you are assured that you have access to the necessary information about that product, that removes many blindsides currently existing in today's procurement system*" and "*if this exists and manufacturers are plugged into it and one can quickly see a list of manufacturers and what their scores are right away, it will help optioneering and that is going to be gold to any contractor*" claims PC4. PC10 further added that the procurement network "*gives you a level of oversight on the different options of products, allowing for purchasers to make more informed decisions and not be forced to buy just any product blindly*."

Commenting on how the model helps to improve ethics in procurement, PC13 said that a lot of people falsely claim to be suppliers and unfortunately, most times, there is no way to verify their claims or track the provenance of their supplies, "*so when I went through your model, I found it very interesting because it is going to cut off most of these dubious schemes (….) and it can also improve the credibility* *of the supplier to a large extent."* PC5 also comments that *"the other thing which I think is an important one as well, which may not be necessarily linked to the ethical side is the logistics of knowing where something is at any point in time in the process."* He further explained that it is often quite difficult to see in real time where things are beyond the first couple of tiers, but it is great to have a dashboard indicating their location and developments. PC12 adds that "i*t could help to curb the procurement of substandard materials.*"

Another common view among participants was that the procurement network creates a fair playing ground for both SMEs and large enterprises. As PC11 reports, "*we SMEs are not given the opportunity to play on a level playing field with bigger organisations."* According to PC15, this is because "*the construction industry is like a buddy industry, as soon as you get a good supplier or subcontractor, you always want to stick with them.*" PC11 further adds that, "*most of these projects and contracts are always given to people they already know, not only because they trust them, but because of their years of experience*." Commenting on this, PC15 said, "*people sometimes say it is bad, but I do not really know if that is right or wrong because if those guys have been doing well, so why not let us give them more work?*" He however noted that such a practise also cancels the chances of "*SMEs that could even do probably better or cheaper jobs, but one would never know*" because one keeps procuring from the same supplier.

However, "*with this proposed system, I think it will help level the playing field by providing a level of trust*" (PC11); and "*this model would open up procurement for more people and fairer competition instead of just working with the same people the whole time and keeping your little buddy bubble*" (PC15). A view further supported by PC14, who opines that if there are other people that can offer "*the same level of quality as these large enterprises, then they deserve a fair chance, and I think this model could also help to address that*." PB29 also said that "*this model gives SMEs with a clear ethical track record a fair chance to get the contract*."

6.3.2.3 Project Network

While discussing the elements and components of the model, the feedback for all 30 participants, which led to 41 codes, reveals that the participants generally agree that the project network presents a collaborative environment that helps to capture the flow of transactions among stakeholders within a particular construction project and their interaction with the resources of the project; the workings of which could in fact help improve ethics within the CMPSC. The project network is presented in Figure 6.15.

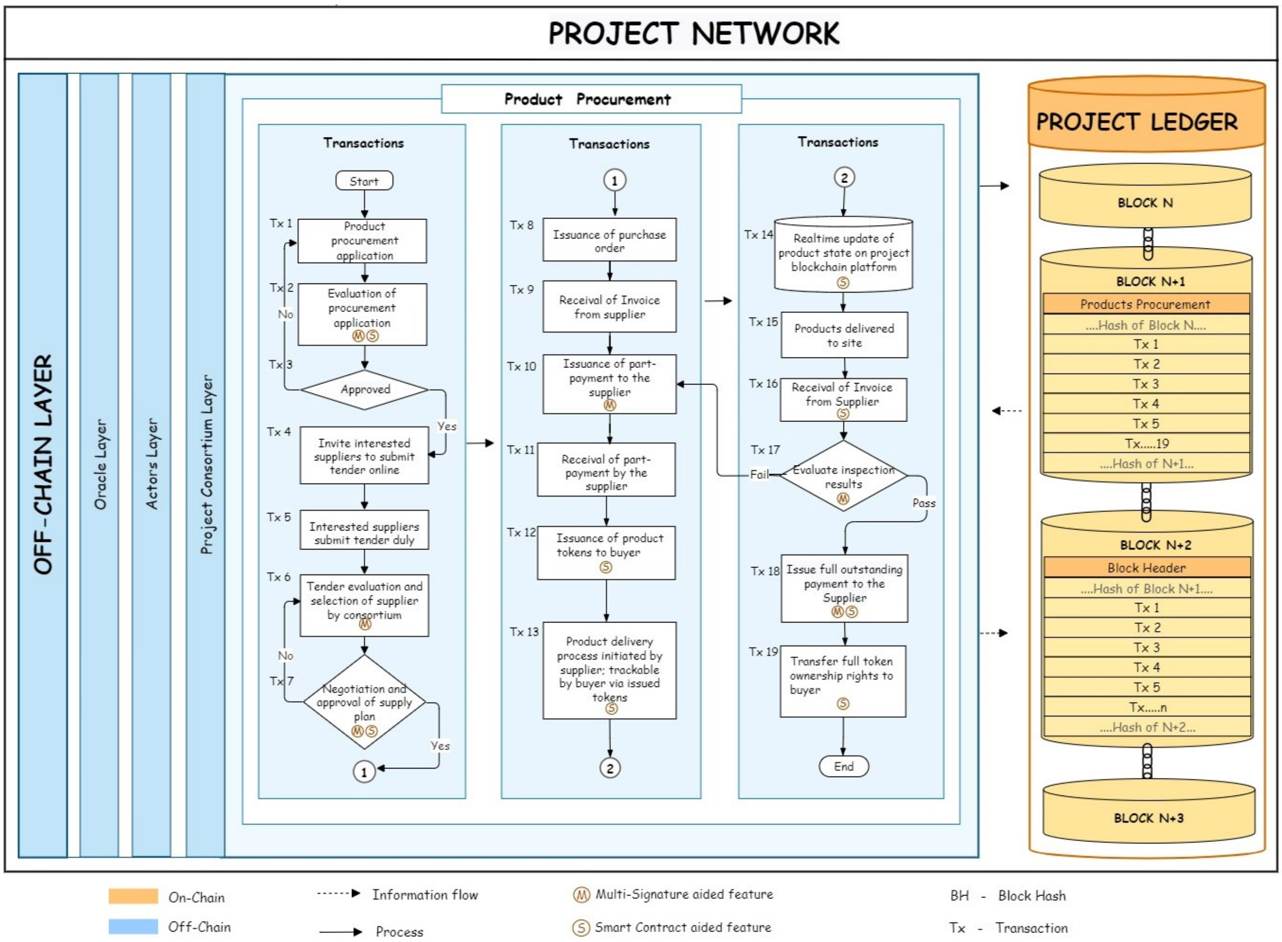

Figure 6.15 Sub-Model 3: The Project Network

There was a sense of familiarity between the workings of the Project Network and the project management systems used within the organisation of some participants. As PES18 said, *"it is an interesting one. I am very familiar with the Project Network of your model in a way, because what you are capturing there is in a typical project management system, but you are taking it to another step*." PC5 also said: "*This bit is what we do really. So that is very familiar to me in terms of the way we go to market, the way we assess the tenders, all of that stuff is very familiar*," further commenting, he said that it is all about collecting data digitally in order to be able to make decisions "*based on the facts that you have in front of you rather than hoping, so I think this is pretty sound actually." A view also supported by PC6 who said, "yeah, I think I would say this is probably the process of what we do, but very loosely without this much detail."* These responses therefore illustrate that the network reflects a practical construction management system that stakeholders can easily understand and relate to.

Also, participants also pointed out the model's prospect of helping improve business ethics through its project network. For example, PC12 affirms that "*it would help improve business ethics as this kind* *of system awakens you to a sense of accountability. You know that transactions are traceable and that you can be sanctioned*." PC13 adds, "*it will actually help in curbing several unethical practices, because of the transparency and permissions, it is easy for the clients and project stakeholders to check and monitor the process*." According to PC9, "*this promotes an integrated project method, where at least one representative member of the key construction groups is involved in the collective decision-making process*" and "*a platform like this would help to keep all stakeholders informed with developments, avoid dubious claims and translate to a better relationship among stakeholders with minimised disputes on site,*" claims PC12. PES23 also added that "*it adds some sort of controls to ensure that certain transactions happen according to the provisions of contracts*."

Commenting on the elements of the Project Network, PC4 opines that "*how the several elements capture the procurement processes within the construction process is pretty accurate as far as the chain of events are concerned*," and PC12 adds: "*I think the model captures well the fundamental activities of the procurement process, although in some cases, there might be a need for some adjustments to fit the certain types of projects.*"

Commenting on the integration of BIM into the Project Network, PC8 affirms: "*I can see the value in connecting this to a BIM system, definitely*." He further explained that there is the whole idea of the single source of truth in construction today that the BIM is supposed to deliver, and "*if you make this part of that technology and they interact with each other, then it becomes part of the single source of truth record."* PES20 suggested that "*if a product's embodied carbon and the certificate of ethical production associated with it could be visible alongside the product in the BIM, that would be very helpful*."

6.3.3 *Acceptance and Implementation of the model*

In validating the model and discussing the role it could play in the improvement of ethics in CMPSC, while most participants express that they would be willing to accept and implement the model and express optimism on its adoption and implementation by that the wider industry, a few participants opined differently. Also, a variety of factors were identified from participants discussions as factors that may affect its acceptance and implementation. This gave rise to the mid-level theme ***acceptance and implementation*** with 84 codes in total being recorded under this theme by 30 participants.

The majority of the participants agree that this model should be accepted and implemented, while a minority thought otherwise. For example, when asked if the participants thought whether the model would be accepted and implemented or not, on one hand, PC6 answered: "*Absolutely, and I think a lot of clients would like to buy into that. The company I work for now is very much interested in this type of solutions…*" PES25 also said that "*with some industry engagement, yes, potentially. I think it is something that I would certainly be quite interested in pursuing*." While on the other hand, PES18 said: "*I have to say I do not know because we have tremendous difficulty getting tools of value to be taken up by government or the industry,*" according to him, the lack of take up maybe "*either because they are complacent, they think they are good and they cannot be bothered, or because they are corrupt*." PC6 also adds that "*not every good product wins in the marketplace*."

Therefore, as earlier stated, while most participants comment that the model should be accepted and implemented in the industry, they also point out factors that would affect its acceptance and implementation which led to the emergence of 5 low-level themes. This is illustrated in the thematic model shown in Figure 6.16.

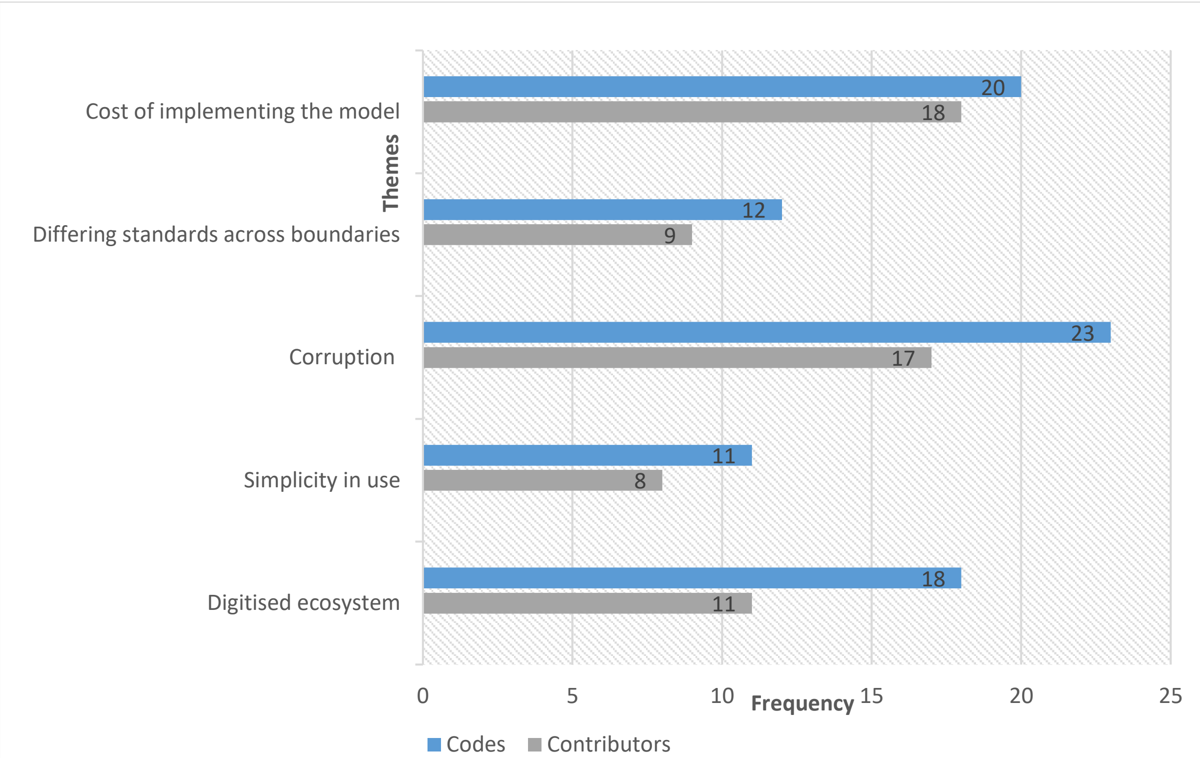

Figure 6.16 Thematic model 10: Acceptance and implementation

One of the factors that would affect the acceptance and implementation of the model as identified by 18 participants was the ***cost of implementing the model,*** which recorded 20 codes. As PC5 said, "*I do not think many people would have a problem with adopting the model. What I think they would have a problem with is how much is it going to cost me to implement the model?"* He argues that due to the low profit margin in the industry, "*budget to invest in new technology and new systems is very difficult to get a sign off on.*" According to PC1, "*oftentimes, what happens is that we hear stakeholders objecting to so many new things. They say, 'it costs me more time and more money'*." PES 18 also adds, "so *we get back to this vicious cycle because what we get from organisations often is, 'we like your ideas, we like your tools, but it is going to cost our company money and time to do this'*." This view is further evidenced by PC6's comment: "*…the company I work for now is very much interested in this type of solutions, it is just that when it comes down to money, sometimes that is the stumbling block."*

Also, PB28 while speaking on the cost of implementation argues that "*for lower cost items, it is really hard to justify the cost to some organisations who are very set in their ways*," further explaining that there are different types of sensors and ways of tracking things, but it comes down to the cost of that versus the cost of the commodity itself in order to justify where it makes sense.

Another factor that could affect the acceptance and implementation of the model as reported by 9 participants was the issue of ***differing standards across boundaries,*** which recorded 12 codes. As PES19 said, "*I think the only thing that would be a huge challenge is actually getting that consistent data set around what standards are required in an international supply chain*." She further explained that in Europe for example, EPD certificates are well understood, but if we travel to Congo to look into conflict minerals and solar panels, things get complex since there is no systematic strategy to standardising that data. PC6 also commented on this by saying, "*because I work for a global company, the biggest issue we have is trying to standardise what we do across different countries*." According to PES25, "O*ne of the greatest challenges that a model like this would have is the alignment of minimum standards across boundaries due to the existence of different social models in different parts of the world,*" she further explained that a model like this would require an alignment of minimum standards across corporate as well as geographic boundaries and that is challenging. As PC12 noted, jurisdictional barriers can stifle the acceptance and implementation of models and standards. PES20 argues that for her, "*local regulation will not be strong enough, what I would need to know is what standards over and above regulation have been applied.*" PES20 further cited an example of a case where a mine met the national Peruvian and local government requirements, but not the criteria of a firm trying to buy ethically.

Furthermore, PES24 also opined that, "this may be hard to implement not in a technological way but in an administrative way," because "several participants may want to host their nodes on the blockchain in a slightly different way because of their own organisational and business structure," PB28 added.

Another common view among participants was that the acceptance and implementation of this model may be stifled by ***corruption***, this recorded 23 codes by 17 participants. As PC1, a leading expert in the built environment digitalisation space through the Digital Twin Consortium, Building 4.0 CRC, AEC Hackathon, etc., with over 40 years of experience in the construction industry said that the corruption in the AEC industry "*is almost by design. It is almost the accepted business model, and that is also the reason why new systems suffer so much pushback, in a bid to maintain the current methods used.*" He further explained that:

> *I think what I see is objections, because this model has the potential to expose poorly placed business models. You know, there are so many two and three step distribution layers that are often not adding any value other than adding cost, and the blockchain will expose these non-value adding segments of the commerce chain. There are just too many under surface activities ongoing that they do not want to have the traceability of blockchain, because that will expose so much of the corruption. I think that is where we have had a lot of challenges with a lot of the improvements that expose unnecessary and or corrupt practices. (PC1)*

A view also supported by PES19, saying that "*they may bury this research because they do not want to take responsibility for their supply chain.*" PB28 also points out that it would be difficult to get unethical corporations to subscribe to a programme that uses blockchain to identify misdeeds, "*so, getting them to be involved in something that could actually come back to bite them, that for me is the bigger challenge*." Similarly, PC11 identifies "*corruption and conflicts of interest*" as his "*only worries*" when it comes to the acceptance and implementation of the model.

Another factor that could affect the acceptance and implementation of the model as reported by 8 participants was the need for ***simplicity in use*** of the model which recorded 11 codes. PC9 warns that "*people would definitely be pushing back if they feel they really do not understand how it works or if they just feel it is too complex*." Hence, PC8 suggests that "*it is important to keep the complexity hidden.*" According to PC8, "*People want to put conscious effort into how to build the building, not how to run the software; so, the simplicity aspect and the continuity are very important*." He further explained that for this to work, it has to be written in such a way that "*anybody in the industry can do exactly what is needed without having to learn a lot of new skills.*" According to PC3, one of the *"big problems"* could be the *"extensive process to have this checked and audited all the way through"* and that sometimes may put people off using it. This is further illustrated by PC14, who commented that as much as he is a proponent of structured and detailed work, a part of him may not want to embrace the model due to the processes when he just wants to do things quickly.

Interestingly, ***digitised ecosystem***, a factor that was initially pointed out whilst discussing factors that could affect the acceptance and implementation of blockchain in the industry was again pointed out by a minority of the participants as a factor that could affect the acceptance and implementation of the model, this recorded 18 codes by 11 participants. According to PC8, "*implementing this model would require an implementation of many other things. You need to have the infrastructure in place to tag the objects to establish what they are and that is a whole other issue.*" PES17 also felt that some basics must be in place first, so "*a lot of this assumes that the capacity is in place to do lots of different activities, including data entry and data capture. While in practice I would just doubt whether that is the case in many situations*." PC10 further opines that the level of digitisation cum development in the country also matters, claiming that for "*developed countries this might be accepted and implemented, but it will take time for developing countries to achieve this based on the sophistication of the infrastructure to be put in place for this model to achieve adoption.*" Furthermore, PC15 argues that currently, blockchain technology "*is not mature enough to get this whole model as you have here from the raw material to the actual building site*," he nevertheless adds that "*but with the fast rate of growth of this technology, it may reach that stage sooner than projected*."

6.3.4 *Limitations of the model in improving ethics in CMPSC*

While discussing the role the model could play in the improvement of ethics in the CMPSC, a variety of concerns were reported by participants as limitations and challenges the model may possess and encounter in its aim to improve ethics in the CMPSC. This gave rise to the mid-level theme ***limitations of the model,*** with 40 codes in total being recorded under this theme by 24 participants and 3 low-level themes as illustrated in the thematic model shown in Figure 6.17.

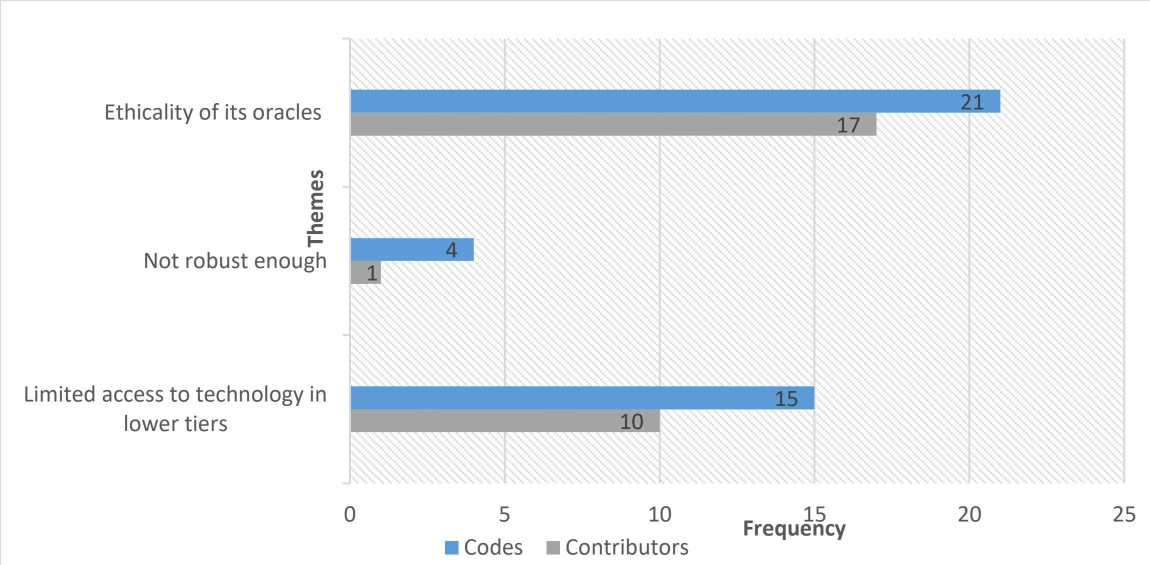

Figure 6.17 Thematic model 11: Limitations and challenges of the model

One of the low-level themes captures a concern raised by 17 participants with 21 codes, this was regarding the ***ethicality of its oracles***. As PB29 puts it, "*how trusted are the oracles, because humans may be required to feed information to some of those oracles and while that may be currently unavoidable, we need to be able to guarantee that they are not compromised*." A view also echoed by PC4, who said that "*it does rely heavily on having that entity who is doing the tracking to be an ethical person and a well-trained person and frankly paid well enough that they are not easily corrupted as well.*" According to PC6, "*the biggest concern would be the policing of all the information, making sure that everything that is entered is correct*." This issue is further exacerbated by the presence of unethical players who may seek to compromise the system with false data. PC9 claimed that "*some bad players already sustain a mindset of perpetrating fraud, and with that kind of mindset, regardless of how straightforward the processes are, they could still find a way of making gains off of this whole thing*." PC6 adds that "*there is always going to be someone trying to buck it in some way or find a loophole." According to PES26, "With IOT, the major issue is the reliability of the things; the devices just sometimes are not reliable,"* further suggesting the *"need to have a way of understanding whether they are working properly all the time and noticing when they have gone offline and when they are sending dodgy data."*

One participant also argued that the model was ***not robust enough*** to tackle the sophisticated nature of unethical activities in the CMPSC. As PES20 reports in her experience of sourcing products, "*I am* *unfortunately aware of the lengths that mines, manufacturers, sales agents can go to camouflage unethical behaviours in supply chains, and I do not think this model addresses those as robustly as I would want.*" As PES17 argued that corruption "*is changing and we must not underestimate it, some corruption is opportunistic, but some are extremely sophisticated.*" To illustrate that certification checks as proof of ethical adherence could sometimes be misleading, PES20 further explained that during the London 2012 Olympics for example, the organizing committee went to great efforts to source responsibly. The games' mascots were made in China, externally verified with certificates and everything seemed good. However, the committee chose not to sell the products after undercover union representatives discovered unacceptable factory occurrences.

Another challenge the model may encounter in its aim to improve ethics in the CMPSC as identified by 10 participants with 15 codes is regarding the ***limited access to technology in lower tiers*** of the supply chain. As PB28 noted, "*You know the mining side of things, when you start to think about the site of some of these organisations when they have actually got no access to technology, how are you going to source information directly from the mine?*" A view also held by PES25 who questioned that "*how accessible is it to people who are so far away from block 1 while we are in Block 4?*" PC4 pointed out that "*those first steps around mining, farming and harvesting activities that are still antiquated*," further explaining that "*the only thing that may be a hindrance is getting that first block, because I think everything after that is already in the technological realm.*"

However, PES26 argues that "*it is not an excuse anymore to not have traceability because of that reason; it is actually potentially simpler now than it ever was before*."

6.3.5 *Feedback on the overall model*

Having discussed on the individual elements and components that make up the model, participants were asked to give overall comments on the model and their responses favour the potential of this model to help improve ethics within the CMPSC. Their feedback resulted in the mid-level theme ***feedback on the overall model*** with 30 codes from all 30 participants. The overall feedback from participants was positive, the following comments help to illustrate this:

"*This is certainly a fascinating model, and I think the assurance of quality and sourcing combined with total transparency is a huge benefit from your proposal. I can see that it is a very interesting approach*." (PES18)

"*I think it is really good and this is probably the clearest I have seen somebody explain it to me (....) I* *have not really seen it broken down into the three individual elements before; it is all just being thrown into one, which is a little bit confusing, so I actually quite like this."* (PC5)

"*I understand this model and it does look to be legit and thorough compared with my experience*." (PC15)

"*I think this is a proposal for a system to create proof of a lot of different things and I think the construction industry is moving more towards that*." (PES 26)

"*The process and outline of the model are familiar, so I found it easy to understand what you are talking about. So it is realistic in that respect. It kind of feels like I know what you are talking about, and I know where you are trying to go."* (PC5)

"*It is totally workable and doable. Although starting might come with some difficulties due to its complexity, but on the user end perspective and the service deliverables, yeah, it is definitely workable."* (PB29)

"*I think your model certainly seems to capture the core procurement and transaction and approval elements. It looks good to me."* (PES18)

"*I can see the principles of it, and I like the interface of the model*." (PES19)

"*It would obviously create a lot of value and it would create a lot of trust*." (PES26)

"*I think it is fantastic and I love the way you have laid it out*." (PB28)

"*I think it is a great idea that if followed properly could be a great tool in a lot of ways to guarantee that the manufacturing and supply of materials is ethical. I can also see how it could provide a secure chain*." (PC4)

"It is realistic enough and I think it will work if used in the intended way." (PC9)

"*It might be very challenging initially, but in the long run, if it is properly implemented it will work, and it is the future really, I must say*." (PC14)

6.3.6 *Suggested adjustments to the model*

While discussing the potential of the elements and components of the model to help deliver the model's overall goal, the participants on the whole believed that the elements and components of the model were sufficient for the model to achieve its overall goal. However, 4 of the participants suggested some adjustments to the model. This led to the generation of the mid-level theme ***suggested adjustments to the model*** with 6 codes.

The participants suggested the need to incorporate an ***interoperability function*** in the model to allow its integration with other existing and future ERP systems and blockchain solutions. As PES20 puts it, "*we would prefer that any linkages be made with existing systems that we use. We would not want to set up a new procurement website purely for this or any specific procurement project.*" PC5 adds that "*some of us have developed our own systems internally, so it is how this would fit into those to compliment what we have already, rather than starting from scratch and asking everybody to move over to a ledger or something*." PES20 also added that "*we monitor and report extensively to our paymasters, so we would want any monitoring and reporting functionality that you have coming from this to be connected to our current monitoring and reporting functionality rather than a new system being created.*" PB27 sums it up by saying, "*there has to be a way that acknowledges the fact that this is not going to be the only one, and I think that is a key element of how this would be architected and deployed*."

The fewness of the suggestions for adjustments to the model indicates that the model was well developed initially and sufficiently comprehensive. As such, only the incorporation of an interoperability function to allow its integration with other existing and future ERP systems and blockchain solutions is required. According to the participants, this would also increase its uptake and ultimately foster the achievement of its overall goal.

6.3.7 *Model revision*

A model provides a means of communication between all parties involved (Robinson, 2008). As the interviews progressed, the researcher learnt more about the dynamic intricacies of the issues surrounding ethics in the industry and the potential of blockchain for the improvement of ethics within the CMPSC from the perspective of experts. This led to the revision of the model to better incorporate the requirements of the end users. This agrees with Chan *et al.* (2015) who posit that as research develops and the modeller learns more from experts and end users, the conceptual model is likely to change. As earlier pointed out in Section 6.3.6 of this study, the change made to the conceptual model was the inclusion of an interoperability function as pointed out in the interview by participants.

Interoperability for blockchains and ERP solutions

Interoperability is the characteristic of a product or system to work with other products or systems. Computer systems or networks that are capable of exchanging and leveraging information mutually with other systems or networks are able to do this through an interoperability function. Similarly, interoperability between blockchains is the concept by which different blockchains communicate and share information with one another. It may also involve the ability to transfer an asset between two or more systems while keeping its state and uniqueness constant.

Enterprise resource programme (ERP) systems seamlessly support business activities by controlling both supply chain operations and relevant information (Dasaklis *et al.*, 2021). The benefits of enterprise blockchain networks will be limited if they are not integrated with existing ERP systems, necessitating the need for blockchain-ERP and blockchain-blockchain interoperability (Monte *et al.*, 2020). Several blockchain interoperability projects are rising as developers seek to accelerate blockchain mass adoption.

Interoperability function utilised by the model

Since blockchain supports API-based integration, it has a high interoperability quotient; however, ERP systems can achieve interoperability more easily than blockchain networks (Buch, 2020). Each blockchain network is a distinct logical entity identifiable by a network ID that validates transactions and updates the ledger using a consensus method that only the nodes belonging to that network understand. Therefore, it must be noted that "*for blockchain interoperability to be implemented in its truest form, it has a long way to go because the current set of blockchain platforms are not built on a common set of standards and specifications*" (Buch, 2020, Conclusion section, para. 2).

Furthermore, an assessment of interoperability approaches by implementing organisations may only be done on a case-by-case basis since different ERP systems and blockchain systems possess different architectures and are set up differently on different platforms, thereby presenting a huge challenge for enterprise level interoperability. Pawczuk and Lele, (2020) suggest three types of systems to connect to and four types of consortia as business context for interoperability needs for interoperability decision making. This is illustrated in Figure 6.18.

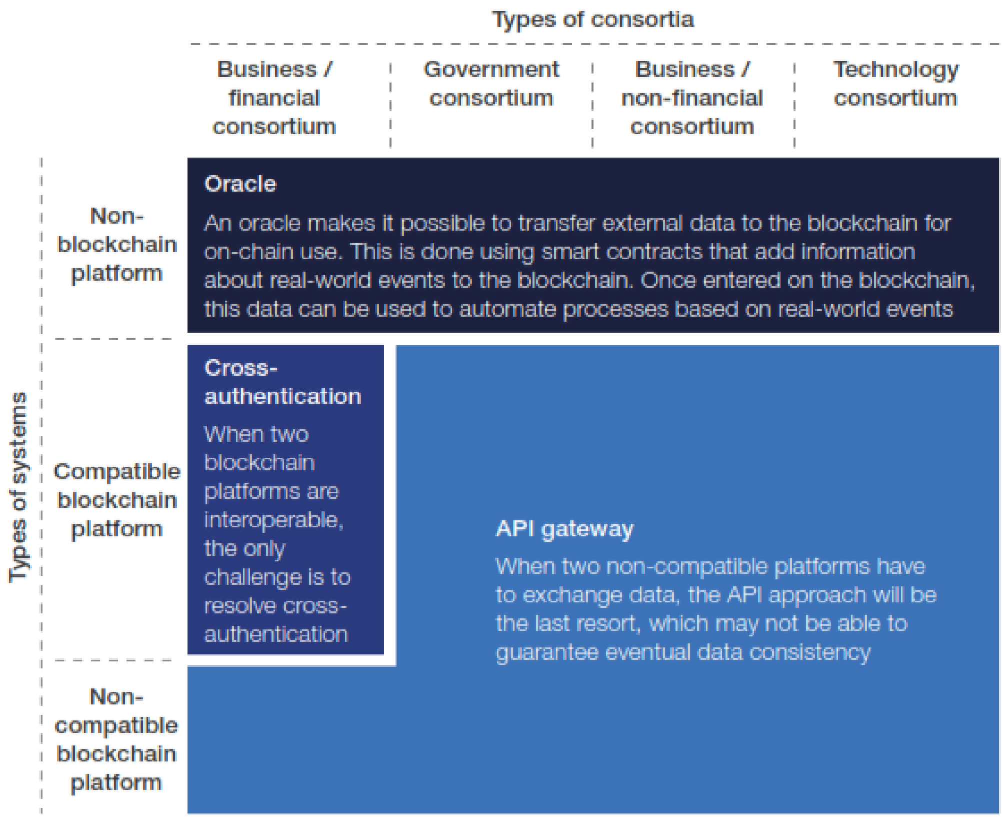

Figure 6.18 Four context dependent approaches to blockchain interoperability. (Source: Pawczuk and Lele (2020))

Therefore, the conceptual model proposes the use of oracle-based communication, relays systems and API based communication to achieve interoperability with ERP and blockchain solutions as suggested by Pawczuk and Lele (2020). This model proposes the utilisation of oracle-based communication through smart contracts that are triggered by events to achieve interoperability for integration with ERP systems which are non-blockchain platforms and therefore have inherently different infrastructure setups than blockchain platforms.

For blockchain platforms that possess a business model, platform and infrastructure that is compatible with the proposed model, relays systems are proposed as the cross-authentication method to achieve interoperability. Relays are systems that can validate and read events and/or states in other blockchains from within one blockchain. This allows one chain to comprehend events occurring on another blockchain platform without the need for a trusted third party.

While for non-compatible blockchain platforms, the model proposes API based communication with each blockchain node in the different networks through a blockchain specific software development kit (via gRPC, HTTP, IPC, etc.) and enables the posting of transactions to the blockchain node (Buch, 2020). Nevertheless, it must be noted that the proposed solutions have their strengths and weaknesses as achieving interoperability with blockchain is still considered an uphill task at the current state of blockchain's development as earlier stated.

Revised version of the model

As earlier pointed out in Section 6.3.6 of this study, the change made to the initial version of the conceptual model goal as pointed out in the interview by participants was the inclusion of an interoperability function to foster acceptance and implementation and to help the model achieve its overall goal. As discussed in Chapter 4 of this study, the verification and validation protocol for each block helps to assure procurers that the products listed on the blockchain have been produced under acceptable standards of ethical environmental and socially aware business practices with a trail of records to prove it. Organisations operating with individual ERP systems and other blockchain solutions can integrate their systems and blockchain solutions with the proposed model to access the ledger and leverage its offerings through the proposed interoperability systems. Organisations will be able to access the solution through an internet platform and make use of an intuitive web user interface and application programming interfaces (APIs) that help enable direct integration with their ERP systems. The revised version of the model captures the inclusion of an interoperability function; this is presented in Figure 6.19, showing the adjustments made to the initial version.

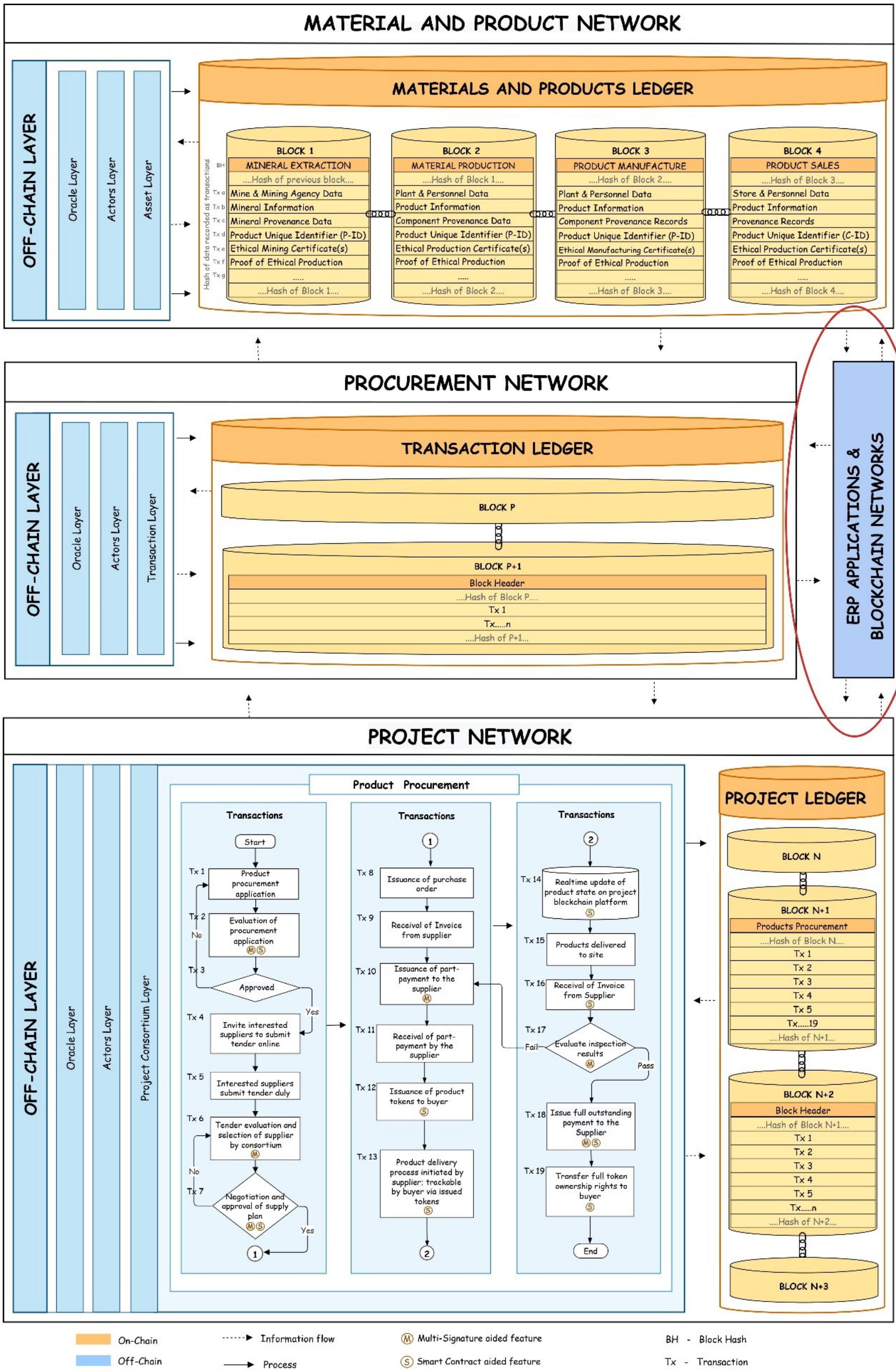

Figure 6.19 Revised Version: A model to improve ethics in the CMPSC

6.4 Focus group: Results and analysis

Following the first phase of the model validation, a focus group consisting of 5 participants, whose profiles are presented in Section 6.2, was used to further validate the model. The validation of this model contributes further to the achievement of Objective 5 of this research. All of the participants had been involved in the in-depth interviews and as such, were already acquainted with the research focus and the model's objectives. The benefits of familiarity were considered to be more important to this study, than any bias that might occur as a result of their involvement.

6.4.1 *Model validation (phase 2)*

A copy of the revised model illustrated in Section 6.14 and some notes to help understand the workings of its elements and components, were emailed to the participants 2 days before the focus group met. This was to give the participants ample time to critically evaluate the model, so as to be able to give rich feedback during the focus group meeting on Microsoft Teams. Once all 5 participants joined the MS Teams meeting via the link provided, the model was verbally and visually presented through Microsoft PowerPoint which lasted for about 20 minutes. The presentation of the model was deemed important to enhance the participants' understanding of the model and its workings. Following this, the participants were asked to evaluate the model's potential to improve ethics within CMPSC, its potential acceptance and implementation, and to consider the validity of the model's elements and components and then the model as a whole.

The data was recorded, transcribed and thematically analysed in order to present the findings. As earlier discussed in Section 5.8, similar to the approach utilised to analyse the interview data, the data from the focus group was also thematically analysed using NVIVO 12 with both inductive and deductive approaches. After coding the data, the codes were then sorted into potential themes and all the relevant coded data extracts within the identified themes were collated. The themes were then reviewed to ensure that the themes were coherent but also distinct from each other. A word frequency analysis was used to construct a 'word cloud' (graphic representation of the word frequency) which can help to see common words in the focus group discussion. This is shown in Figure 6.20.

Figure 6.20 Word frequency analysis of focus group discussion

The overall response was positive; all participants agreed that the developed model with its elements and components was valid. The analysis of focus group data resulted in the development of a thematic framework with high and medium-level themes. The framework is illustrated in Table 6.3.

Table 6.3 Thematic framework: High, medium and low-level themes from focus group findings

High, medium and low-level themes	**Codes**	**Contributors**
1. Evaluation of the model's potential to improve ethics in CMPSC	**27**	**5**
1.1 Environmental Ethics	10	3
1.2 Social Ethics	5	2
1.3 Business Ethics	12	3
2. Validation of elements and components	**21**	**5**
2.1 Material and Product Network	8	3
2.2 Procurement Network	7	2
2.3 Project Network	6	2
3. Acceptance and implementation	**26**	**5**
3.1 Need for Awareness	13	4
3.2 Lack of adequate infrastructure in developing countries	3	2
3.3 Issue of Corruption	6	3
3.4 Cost of procuring the infrastructure	4	2
Overall	**74**	**5**

The analysis of the focus group data resulted in 3 high-level themes and 10 mid-level themes. The total number of codes within all the themes is 74. The high-level theme ***evaluation of the model's potential to improve ethics*** within the CMPSC recorded the highest number of relevant codes with a total of 27 codes. It is then followed by the high-level theme ***acceptance and implementation*** with 26 codes and high-level theme ***validation of elements and components*** of the model with 21 codes. The distribution of the codes across the themes is illustrated in Table 6.5. In the subsequent sections of this chapter, the contents of the themes are explicated in detail.

6.4.2 *Theme 1: Evaluation of the model's potential to improve ethics in the CMPSC*

All participants agreed that the model could indeed help to improve ethics within the CMPSC. PC9 commented that "*if adopted with the adequate technical know-how on how to proceed with this and it is used rightly, yes it will definitely help*," because "*you know that everything that has been done so far till that material or product gets to you has gone through the fundamental ethical approvals and that the products meet the required standard*" PC10 added.

Environmental ethics

Participants generally agreed that the model could indeed help to improve environmental ethics in the CMPSC. PC1 noted that most professionals in the construction industry for a long time have limited their perspectives in that they do not address the full building lifecycle. He stated: "*I think we all need to start thinking in terms of mine to market, to site, to maintenance, to reuse and not cradle to grave, but cradle to cradle, and these are the focal points needed to lead the technological change in the industry,*" further adding that "*blockchain is a great enabler*." PC9 in agreement with this view said, "*I agree that we need to be thinking about these things from cradle to cradle*," which really is not what we are doing right now because "*most times, the main aim is to get whatever material we can get to make this work right now, no one is thinking of the recyclability or the energy spent in producing that material*," further explicating the need for a cradle to cradle approach, he added that it is because the consequence of this processes is "*something that affects not just the construction industry, but the world as a whole*." In conclusion, he affirms: "*I do think we should be thinking about cradle to cradle, and I think this model is a good tool that is able to push us in that direction*."

Commenting on the use of certifications as a tool to help improve environmental ethics in CMPSC, PC9 said that most procurers in the USA seek to verify that their timber is FSC certified to avoid the risk of breaking any ethical rule. "*So, since we have that sort of assurance from your model, that is enough to* *at least give people rest of mind. Assuring them that they are doing the right thing ethically by purchasing that particular product or material*." Furthermore, PC10 commented that "*the idea of bringing in certifications at key phases of the product's production to point to the sustainability of the product also helps to increase the overall sustainability of the building as a whole*."

Business ethics

All participants agreed that the model could indeed help to improve business ethics within the CMPSC. As PC14 puts it, "*the transparency of the model alone can dissuade people from the tendency to act unethically*," he added that this is because "*they know people will be able to audit the transactions, now or in the future, so it not only becomes harder to pull off without being eventually caught but it also weakens the incentive to so do."* A view also shared by PC10 who said that *"the transparency this model provides makes it possible for the stakeholders to monitor what is going on, how the money is being spent, when the materials are to be delivered, and other things like that."* According to PC10, the model *"will drive the appropriate players to ensure that each product that goes into the building project is up to the required standard."* PC14 however cautions that transparency is good, however, "*your transparency may still provide false information if the data are not accurate. So, it boils down to having accurate data and information about every aspect that needs reporting.*"

PC12 also pointed out that "*ignorance is a really huge problem in the industry*," and "*this model will help to eliminate some level of ignorance that is leveraged by unethical players,*" particularly on the part of clients, stating that "*it accommodates the client or his representative as one of the members of the project network, in order to be able to monitor and verify products and processes, checking to see if they conform with what was expected*."

Social ethics

All participants agreed that the model could indeed help to improve social ethics within the CMPSC. PC9 pointed out that with submittals, one is usually caught in a dilemma of verifying if the manufacturers of those products have done the right things in terms of how they treat their workers, which is not easily verifiable. "*However, I clearly see how this model can be leveraged to enhance due diligence and to give a level of assurance as to the adherence of particular producers to social ethical standards within their organisations.*"

PC10 also said, "with this model, the certifications that the players provide are good enough to provide an assurance that things have been done rightly within the supply chain. As such, it would help procurers make a more informed decision in procurement."

6.4.3 *Theme 2: Validation of model's elements and components*

All participants agreed that the elements and components of the model could indeed help to improve ethics within the CMPSC. The data from the interview and focus group reveal that the Material and Product Network (MP-Network), Procurement Network and Project Network all contribute to the achievement of the overarching goal of the overall model.

Material and Product Network (MP-Network)

To illustrate how the MP-Network contributes to the achievement of the overarching goal of the overall model, PC10 said, "*this is really a good job because the model captures the supply chain from the mineral extraction to the final usage of the material and I believe it is holistic enough for its intended usage.*" PC1 also said that "*I really applaud you starting at the mineral for a lot of reasons, that is the only way that we can assure the integrity of the data. If we did not start at that point, there is so much corruption that can happen in the other blocks*," further using the "Chinese drywall" to illustrate, he said that "*it was a problem with substandard products used in gypsum. So, had block one been part of that record in the material procurement phase, that would have never been able to happen*." Commenting on the MP-Network, PC10 added that "*I see that having certifications coming in from the point of mineral extraction to the material production to the product manufacture and the product sales provides a trustable trail of ethics in the provenance of the product*."

Procurement Network

In discussing how the procurement network helps to improve ethics within the CMPSC, PC10 affirms: "*Yes, I believe that this model will be 100% useful in the procurement aspect of our construction projects*," further explaining that since everyone participating at each stage knows that the product and project information are accessible, even if it is not made public, "*this provision would caution sourcing, manufacturing, and project players to operate with integrity*." PC14 pointed out that "*a big problem in how contracts are awarded in the industry is sentiment*." But the procurement network of this model could help "*to actually cut down a whole lot of sentiments and unfair preferences in contract awards, so it then boils down to who is the best fit for the job based on the data available, regardless of social ties*." PC14 further added that it flattens the equity curve for SMEs and large corporations so that experience is not the only factor, as long as you are ready to meet the standards, reducing monopoly. PC9 also commented that "*with this model, one can more easily understand why* *certain products are costlier than others, based on trustable available information*."

Project Network

All participants agreed that the project network of the model could help to improve ethics within the CMPSC. According to PC12, it would help improve business ethics as "*this kind of system awakens you to a sense of accountability. You know that transactions are traceable and the immutable transaction records are not only privy to the contractor but accessible to the client and other project stakeholders*." Further adding, he said that "*the precepts to be followed for certain actions to be executed help limit the ability of people to cut corners."* PC10 notes that *"even though there are respective individuals who would be able to access certain levels of information. I believe that the transparency factor here is still very high as consortium structure enables transparency within project stakeholders."* PC9 also commented that the project network gives a "*high level of oversight and control when compared to the huge paper trail of traditional processes. This system makes it easier for you to keep track or go back to really look at certain transactions."*

6.4.4 *Theme 3: Acceptance and implementation of the model*

In discussing the validity of the proposed model, all the participants agreed that they would be willing to accept and implement the model and that the industry should be able to do likewise. However, they also pointed out a variety of factors that may affect its acceptance and implementation. For example, PC10 said, "*I think generally, this model addresses many aspects of procurement, and it is implementable for both developed and developing countries if they are willing*." PC14 also commented that, "*in a way, this blockchain model is almost like the future. At first it might not be widely accepted, but very soon I believe that it would be a necessity.*" PC9 adds that "*there are a lot of ongoing conversations on blockchain in the construction industry and that could help adoption of blockchain solutions like this in the industry*."

One of the factors that could affect the acceptance and implementation of this model as identified by the participants is the ***need to raise awareness*** about blockchain technology, to encourage uptake and douse the scepticism surrounding the technology. As PC9 puts it: "*I think in order to see a full implementation, we need to educate the professionals and the clients*," and there is a need to "*clarify the myths around blockchain, crypto scams and energy consumption, because all these things will contribute to the level of acceptability of the technology*," adds PC12. PC14 also thinks that "*we need to do a lot of awareness also, because the current level of implementation of BIM in developing* *countries is still at an elementary phase*" and "*that is what we are trying to do with the digital twin consortium and other things; we bring in large constructors in the industry, so as we educate more and more of these institutional owners, adoption grows,*" PC1 added. PC1 further explained that one of the challenges to BIM implementation is that it is considered an expense by consultants even though the owner already paid for it. So, in many of the organisations I have been involved with, we educate the owners because they pay for everything in a building's lifecycle.

PC14 pointed out that "*another great way to get this implemented is by 'catching them young'. One may go into universities for example and show them how this works, letting them know the value it provides*." PC1 responded that even at that, "*the owners are really going to be the ones that can enforce the tools because if the owners do not see the value in them, the rest of the industry is suffering an expense by implementing them*."

Another challenge pointed out by PC10 is the ***lack of adequate infrastructure in developing countries*****.** According to him, implementation for developing countries would take a longer period "*due to the required infrastructure needed, I would say the practicability of implementing the model would be about 25% in developing countries while I see the possibility of an 80% implementation for developed countries in a couple of years*." Further adding, he said that thankfully, in developing countries there are still organisations that are moving towards digitalisation, which would also help to influence others.

However, beyond the lack of infrastructure, another issue that participants suggest could affect the acceptance and implementation of this model is the ***issue of corruption*** in the industry. According to PC12, over and above the challenge of a lack of adequate infrastructure is the problem of corruption, claiming that "*it is even corruption that stops us from having adequate infrastructure in the first place.*" This is further illustrated by PC14's answer when asked whether or not the model would be accepted and implemented, PC14 said: "Y*es, for those that like integrity, transparency, detailed approaches they would gladly accept it. And no, because some people want to steal, cut corners and compromise*." According to PC12, corruption is a concern in developing countries and in the construction industry; a combination of both makes adopting this model difficult. PC1 thinks that there are many similarities, even though there are clear differences between developed and undeveloped countries; "*the corruption just has a different face.*"

Some of the participants also identified the ***cost of procuring the infrastructure*** needed for the implementation of this model as a factor that could affect its acceptance and implementation. PC10 opines that to be able to implement the model, "*you need to put the infrastructure for blockchain and other supporting technology in place, which relates to cost, unfortunately, when professionals in the industry hear 'cost,' the discussion takes a different turn.*" PC1 opines that the only way to justify the infrastructure expenses, or even the industry's shift in attitude, is if we can start putting a price tag on the benefit of deploying blockchain, "*the real value of implementing this and who it transmits to must be defined.*"

6.4.5 *Validated model*

All participants agreed that the proposed model does have a potential to help improve environmental ethics, social ethics and business ethics within the CMPSC. No changes or additions to the model were suggested during the focus group.

As a final comment on the model, one participant said that:

> *This is the first model that I have seen that I feel addresses the digital life cycle in its entirety. When folks discuss it, even in papers and white papers and articles, it is more of a concept of a tool as opposed to the process of how we are going to use it and where; and knowing what benefits we are going to derive from it; I think this is an interesting thing. (PC1)*

Another participant also commented that:

> *Overall, if this model is implemented, it would definitely improve the output of the construction industry, which eventually will promote the contribution of the industry to the general economy, which is a strong reason to drive stakeholders to implement this model for the construction sector. (PC10)*

While another participant summed it up by saying:

> *Knowing how we are all trying to go green, I think the model really plays a big role in making sure that we are taking the right steps, not only in preserving the earth in terms of environmental ethics but that we are also making efforts to curb unethical business practices and to make the supply chain more transparent. (PC14)*

The revised and validated model for improving ethics in the CMPSC is presented in Figure 6.21.

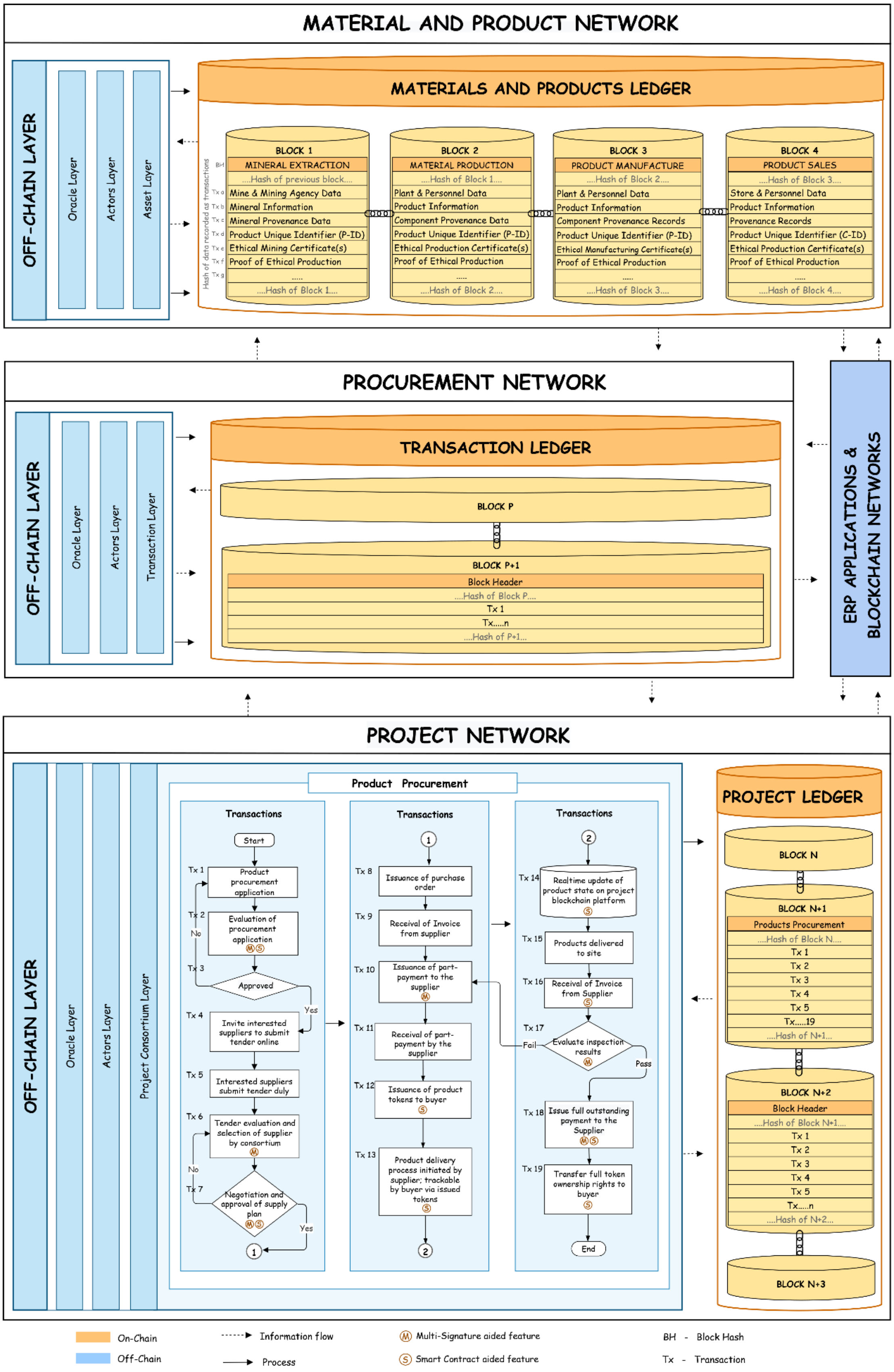

Figure 6.21 The revised and validated model for improving ethics in the CMPSC

6.5 Summary

This chapter presented the results and the analysis of the data, which was systematically and rigorously collected from the interviews and focus group. This chapter helped to fully accomplish Objectives 2, 3 and 4 of this study. Feedback from participants regarding the state of ethics within the construction industry supply chain, the effectiveness of current improvement efforts, the potential blockchain may have for the improvement of ethics within CMPSC and the factors affecting its acceptance and implementation were analysed and presented. The analysis of which resulted in the 4 high-level themes, 15 mid-level themes and 28 low-level themes.

Also, views regarding the validity of the model's elements and components and its feasibility to improve ethics within the CMPSC were presented in this chapter. The feedback from the first phase of the model validation exercise indicated that the proposed model was well developed and sufficiently comprehensive, only the addition of an interoperability function to allow its integration with other existing and future ERP systems and blockchain solutions was suggested by the participants. This informed the revision of the conceptual model, and the revised model was then presented for validation in a focus group in order to consummate the validation protocol. In the final phase, the overall response of the participants was positive, as it was generally agreed that the developed model with its elements and components was valid. A more detailed discussion which entails the interpretation and description of the significance of the findings that emerged in this chapter is carried out in the next chapter.

Chapter 7 Discussion

7.1 Introduction

The goal of this chapter is to reflect, interpret and explain the findings from both the interviews and focus group as presented in Chapter 6, how they are associated with the existing literature and how they address the research questions and objectives posed in Chapter 1 of this study. This chapter also presents arguments to support the entire discussion and to explain the insights that emerged as a result of this study.

7.2 Discussion of findings

The aim of this study was to develop and validate a model for improving ethics in the CMPSC following the TBL construct using blockchain technology. To fulfil this overarching goal, the researcher sort to address the three main research questions posed by the study and their associated sub-questions.

The first research question posed in this study sort to, in part, evaluate the current state of ethics within the construction materials and products supply chain (CMPSC). This was also in tandem with the Objective 1 of this study. To address this question, the research evaluated the state of ethics in the CMPSC within the TBL construct. That is, evaluating the current state of business ethics, environmental ethics and social ethics in the CMPSC. The analyses of the results revealed that the current state of ethics within the CMPSC is weak across the three dimensions examined. This was captured in Theme 1 of the interview findings.

7.3 Theme 1: Current state of ethics in the CMPSC

As earlier indicated, the first research question posed in this study was regarding the current state of ethics in the CMPSC. This was also connected to Objective 1 of this study. To address this question, the research evaluated the current state of environmental ethics, social ethics and business ethics within construction materials and products supply chain.

One of the most obvious findings to emerge from the analysis was that participants seemed to be more concerned and more informed about business dimensions of ethics within CMPSC than its environmental and social dimensions. A possible explanation for this result might be because construction firms are first businesses before they are builders; hence, like most businesses, they also set out with the primary aim of making profits (Laffer Associates, 2004). Given the clear indication that profit in business is linked to the ethical conduct of business operations, firms are likely to pay closer attention to matters that clearly directly translate to profitability than other matters. Although the triple bottom line (TBL) does not have a common unit of measure (Slaper and Hall, 2011), nevertheless, the business component of the TBL is usually monetised and measured in dollars or in the currency of the country within which the business is located, whereas the environmental and social components of the TBL cannot be easily monetised. Therefore, while the state of the business component of the TBL can easily be audited and evaluated through the financial records, the same cannot be said for the other two components. Hence, apart from the profiteering in many construction businesses, the difficulty in auditing/evaluating the environmental and social dimensions of a business could also explain why the stakeholders are more concerned with the more measurable business dimension. This finding reflects that of Dyllick and Hockerts (2002) who also suggest that corporate managers will place greater emphasis on the business case while the natural or societal case will only become relevant if politics or consumers force firms to take notice. Nevertheless, the difficulty in auditing socio-environmental dimensions of CMPSC is also due lack of standardised models, tools and process for auditing the ethical credentials of businesses, as established in literature, which led to the development of a blockchain-based model in this study.

The following sub-sections will explore the findings on the state of ethics in the construction industry from business, environment and social dimensions.

7.3.1 *The state of business ethics in the construction industry*

The results from the evaluation of the state of ***business ethics*** in the construction industry reveal that the state of business ethics in CMPSC is weak. This may be due to the varying perspectives regarding the possibility of achieving ethics in business or its suitability in the business environment. As earlier discussed in the literature review, some researchers opine that the term “business ethics” is an oxymoron (Prasad and Agarwal 2015), claiming that business is intrinsically unethical, or that it is, at best, amoral. For example, Carr (1968) suggests that the “game” of business is not subject to the same moral standards as the rest of society, he claims that deception and lying are perfectly permissible in business. This is a rather out-dated perception of businesses, for clearly, the past decades have witnessed progress on ethical aspects of businesses bordering on the eradication of fraud and bribery in business transactions, as well as matters related to workers’ rights, modern slaver, climate change and sustainability. Subsequently, others like Hamington (2009), Koehn (1997) and Radoilska (2008) argue that it is erroneous to assume that business ethics is naive or idealistic in any way, as there are solid grounds to believe that high ethical standards can be achieved in business.

The findings from this study reveal that the ***issue of corruption*** still holds sway within the construction supply chain today, and like a cankerworm, it continues to eat deep into the fabric of ethics in the industry. Interestingly, the low-level theme issue of corruption recorded the highest codes within ***Theme 1***. This was unsurprising as several studies have shown that the construction industry ranks amidst the most corrupt industries in the world (CoST International, 2016; GIACC, 2020; CIOB, 2006, 2010, 2013, 2018; TI, 2008, 2011).

The results further suggest that the reason why corruption is more serious in construction than in other industries may be due to the fragmented supply chain that typically comprises a huge number of suppliers with little overall oversight, thereby making the entire system very prone to corruption. As identified in the literature review, the supply chain's complex structure, with multiple enterprises competing for high-value contracts with tight profit margins, creates a climate prone to corruption. As a result, unethical practises such as bribery to obtain planning approval, budget overstating, counterfeiting of construction supplies and goods, payment demand abuse, purchasing from unscrupulous players to cut cost etc., have become common in the construction sector.

Further findings suggest that the level of corruption in construction may also be a result of a wider ethical imbalance, which is at varying levels in different countries of the world, thereby inferring the level of corruption in construction to be a function of the level of corruption in that particular country. Interestingly, the literature review did not identify the level of corruption in construction experienced in a country to be a function of the level of corruption in that particular country, although the presence of corruption in every country was identified (Tan *et al.*, 2017), its prevalence in developing countries (Bowen *et al.*, 2007) and in public sector projects (Locatelli *et al.*, 2017).

Another important finding was regarding ***issues at the procurement phase***. This finding suggests that certain unethical issues arise at the procurement phase of the project. Three findings within this theme suggest that the weak state of business ethics in CMPSC is also a result of the issues that arise in the procurement phase. They include the purchase and/or delivery of counterfeit products and materials, total relegation of supply chain due diligence duties to third parties in procurement and unethical activities of some middlemen during procurement. There are several possible explanations for this result.

Firstly, the issue of counterfeits may have surfaced due to the growth of counterfeiting and the proliferation of counterfeit construction materials and products in today's market. As mentioned in the literature review, counterfeiting is one of the world's fastest-growing economic crimes, worth an estimated $600 billion every year (Stevenson and Busby 2015). As Corrugated Metals Inc (2013) notes, a bulk of the materials and products utilised in the construction sector in most countries are from China, a country significantly prone to the production of counterfeit items. This agrees with the findings of Im *et al.* (2018) and Minchin *et al.* (2011), which posit that construction materials and products are extremely prone to counterfeiting.

Secondly, a possible explanation for the issue of total reliance on third parties for due diligence in the supply chain as reported by participants may be due to the difficulty in the visibility of lower tiers in the supply chain. As mentioned in the literature review, CIOB (2018) found that on many sites, responsibility for labour checks often falls to subcontractors that are less well-resourced and less likely to have expertise in spotting fake documents. A prior study by Butner (2010) also revealed that paradoxically, at a time when, generally speaking, information is abundant and connectivity is easier than ever, supply-chain executives still rank visibility as a significant management challenge. This result reflects that of CIOB (2018) who also found that larger companies often have limited visibility of the lower tiers of their long supply chains.

Finally, another possible explanation for the third finding in this low-level theme, (i.e., the unethical activities of middlemen during procurement) is that perhaps some middlemen are simply taking advantage of the fragmented nature of the construction supply chain to perpetuate shady activities. This corroborates the finding of Tezel *et al.* (2020), who maintained that high fragmentation in project procurement is a critical issue in construction supply chains. Also, Dewey et al. (2020) argue that blockchains can help to eliminate unnecessary middlemen in the supply chain, thereby reducing business waste in the supply chain because there will be fewer tiers.

The results of this study also indicate the ***exploitation of loopholes in documentation*** as one of the issues that has stifled business ethics in CMPSC. The results further suggest that it is because some unscrupulous contractors cut their bids to appeal to the prevalent "lowest bid wins" practise with the hope of exploiting loopholes in contract documents to make gains in the future, while others may take advantage of poor record management and weak contractual agreements to cheat the client. These results match the findings of Bowen *et al.* (2012), which submits that most construction professionals in the industry believe that the industry suffers from unfair tendering practises and that negligence also arises mainly from poor documentation in the industry.

7.3.2 *The state of environmental ethics in the construction industry*

The results from the evaluation of the state of ***environmental ethics*** in the construction industry reveal that the state of environmental ethics in CMPSC is weak. The findings suggest that the ***issue of neglect*** of environmental ethical matters in the industry constitutes a barrier to the improvement of environmental ethics. As the findings suggest, a possible explanation for this result may be that professionals and clients are yet to fully understand the overall implications of their (construction materials and products) choices and activities on the environment as a whole.

Earth Watch Institute (n.d.) posits that construction is one of the most resource-intensive and environmentally damaging industries. Although some deny climate change, some claim that the activities of their firms have no environmental impact, while others are unaware of the impact of their production and construction activities on the environment, Mustow (2006) argues that all construction activities indeed impact the environment, even the production of the raw materials for construction. This idea is also shared by Morledge and Jackson (2001), who say that building sites, the making of building materials, and transportation are responsible for 23% of air pollution, 40% of drinking water pollution, and 50% of landfill waste. Also, Karolina (2021) submits that the construction industry consumes 40% of the world's raw stones, gravel and sand and 25% of its virgin timber per year, with half of those resources being non-renewable.

Instead of dwelling in neglect and denial, construction players should strive to balance their environmental impact through deliberate pollution control and remediation procedures. Clients also have a responsibility to demand compliance with this from their suppliers and contractors. WEF (2020) proposes that procurement professionals should seek to conduct business with responsible suppliers that understand the nature of the products and materials they are supplying and recognise their responsibility to protect the environment because the risks caused by environmental impacts are not limited by geography or time; it has an impact on the ecological situations of generations yet unborn.

Although the environmental impact of the construction industry has been hitherto largely neglected by many, however, that narrative is now changing as climate change has become a more pressing concern all around the world today and the ripples of this are being seen in the industry as well. For example, following the 2021 United Nations Climate Change Conference (COP26), as part of the efforts of governments and private firms to attain net-zero goals, “green” or "net zero" clauses in construction contracts and green construction practises related to building construction processes and material production are encouraged (Werdmüller, 2016).

Another important finding was that the ***cost implications*** of imbibing good environmental ethical standards also seemed to hamper the improvement of environmental ethics in the industry. The results suggest that the reason why environmental ethics is not given due consideration in some projects is because some projects do not have enough front-end loading of sustainability from a client perspective and such clients may have chosen to "let sleeping dogs lie" due to the "greener is costlier" factor.

In a 2020 study conducted by Gemma (2020) of over 2000 adult shoppers in the UK, the results revealed that a quarter of Britons consider shopping green to be too expensive, claiming they cannot afford to be more eco-conscious with their purchases. The study further revealed that shoppers are more likely to consider price ahead of whether a product is sustainable when deciding what to buy. According to MohanaRam *et al.* (2014) one of the approaches utilised to reduce the environmental impact of construction is focused on switching conventional construction materials and products to their green or greener counterparts. However, the greener options are usually more expensive than their conventional counterparts, and this therefore increases the overall cost of the project since material cost is directly connected to the overall cost of the structure.

While it is true that eco-friendly products are more expensive not only because they are greener alternatives but also due to other factors like lack of demand and high manufacturing costs, one of the participants of this research opines that if we built all our houses like that, economics of scale would kick in and it would enable ethical producers to create items more cost-effectively that would in effect cost just as much as conventional products. In addition to this, demand for materials and products that have been produced with minimal environmental impact could also send demand signals that could drive non-sustainable producers to adapt their manufacturing processes to consumer demands. As such, the paradox here seems to be that the quest to win the cost tussle only becomes feasible by embracing some "losses" upfront.

7.3.3 *The state of social ethics in the construction industry*

Furthermore, the results from the evaluation of the state of ***social ethics*** in the construction industry identify a ***lack of concern*** in matters relating to social ethics within the supply chain by construction professionals. The result suggests that people are simply interested in the product and its ability to function as intended, and they are not bothered about how it was produced or whether the people involved in its production were responsibly treated and fairly paid. It seems possible that this may be because most construction professionals may be ignorant of the myriads of modern slavery issues within the supply chain and because social crimes in supply chains are often hidden and hence difficult to detect. As Peter Jacobs, past president of the CIOB puts it, "There would be a bigger outcry if they really knew how some people were being treated by ruthless gangmasters," (CIOB, 2018b).

It is interesting to note that in this study, within the triple bottom line approach under which the state of ethics in CMPSC was evaluated, the social dimension received the lowest feedback and code from the participants of this study, in comparison with the business and ethical dimensions. This itself may be considered as further reason, both for the result and the reason for the same.

In addition, in an interview (CIOB 2018, p.14), Will Kerr, the UK National Crime Agency's director of vulnerabilities said: "*The more we look for modern slavery, the more we find the evidence of widespread abuse of the vulnerable. The growing body of evidence (....) points to the scale being far larger than anyone had previously thought*." Also, as mentioned in the literature review, a 2017 UN Global Compact study on the SDG human rights target, social ethics was found to be the most difficult area for large firms to execute the Ten Principles (UN Global Compact, 2010). Many incidents of modern slavery have gone unnoticed for many years due to a systemic lack of understanding by law enforcement agents and businesses.

Another possible reason for ***lack of concern*** in matters relating to social ethics within the supply chain by construction professionals could be because most contractors typically have little visibility below tiers one and two of their supply chain (CIOB, 2018a); hence making an evaluation of social ethics within their supply chain quite challenging. Several reports have shown that at or below tiers four and five of the supply chain, construction projects are regarded to be the most vulnerable to forced labour infiltration. As Werdmüller (2016) also noted, identifying and addressing the issue of modern slavery in construction is complicated due to the hidden nature of construction supply chains and its complexity.

According to the International Labour Organization (ILO), more than 40 million people are enslaved around the world, with 25 million of them being compelled to work; children make up one in every four victims of modern slavery (ILO, 2021). Also, as indicated in Chapter 2 of this study, more than 20% of total revenues are generated by the construction, agriculture, mining, manufacturing, and utility industries, which employ roughly half of the world's forced labour population (CIPS, 2013).

With the staggering statistics and the work of several anti-slavery organisations worldwide, the ignorance of the presence of modern slavery in supply chains can no longer be a tenable excuse. There is therefore an urgent ***need to improve due diligence*** in the supply chain. Despite the abundance of information and guidance that has been made available by several governmental and non-governmental organisations, some professionals still pay little or no attention to how these resources could be leveraged to reduce or mitigate the modern slavery risk within their organisation's supply chain. To illustrate, in a CIOB (2018) survey, 37% of procurement managers admitted that they had not read the government's modern slavery guidance.

The results of this study suggest that although there has been an improvement in due diligence protocols in the supply chain, a lot of work remains to be done. Results further revealed that many organisations simply rely on the credibility of their suppliers, believing that this is the sole obligation of suppliers. As such, they assume that they must have done their due diligence to ensure there is no trace of modern slavery within their supply chain without any oversight to confirm the supplier's adherence to this obligation. Perhaps due to the "extra" cost of resources that setting up the oversight structure may take up. It is conceived as an extra expense, possibly because it is usually assumed that that is the sole responsibility of the supplier, as earlier noted. Nevertheless, while the major chunk of the risk of a breach in compliance with social ethics standards in the supply chain is borne by the producers and suppliers, procurers and contractors are also not entirely spared from its consequences. For them, the backlash from such breaches in the production of purchased materials and products could lead to reputational damages, which are often considered to be worse than financial losses.

Based on the results presented and discussed under this theme, it can therefore be concluded that the current state of ethics within the CMPSC is weak across the three dimensions examined. Furthermore, the results suggest that the higher level of interest and feedback of participants regarding the business dimension of ethics could be attributed to a perceived direct link between profit in business and the ethical conduct of "business" operations by professionals. The findings help to understand why construction firms seem to be placing greater emphasis on the business component of ethics while the environmental or social component may only receive as much attention if it can be monetised or if internal systems such as directors, stakeholders or external systems such as the government or clients demand for them. As such, it is concluded that construction firms and professionals need to pay more attention to the environmental and social dimensions of ethics within their organisation and supply chain as this makes for a more holistic ethical approach, which may also help to improve business gains in the long run.

7.4 Theme 2: Current improvement measures

As earlier indicated, the first research question posed in this study was also regarding how effective the current measures to improve ethics within the CMPSC have been. This was also connected to Objective 1 of this study. To further address this question, the research evaluated the effectiveness of measures in place to improve ethics within the CMPSC and factors affecting their effectiveness. The analyses of the results revealed that although the measures existed, their effectiveness had been stifled by low implementation and sloppy compliance. This was captured in **Theme 2** of the interview findings.

7.4.1 *Effectiveness of current ethical measures*

In this study, the results from the evaluation of the ***effectiveness*** of current ethical measures in the CMPSC reveal that the measures have been effective to some extent, but much work remains to be done. This result suggests that on one hand, there are companies who have improved their ethical performance and their sustainability performance significantly compared to their contemporaries by utilising some of these ethical measures already identified in the literature review, while on the other hand, there are still companies in construction that act unethically and fail to prevent or control risks relating to environmental or social ethics within their supply chains. The findings further suggest that low implementation and compliance, role of government and denial are three main factors affecting effectiveness of these measures. Some possible explanations for this exist.

7.4.2 *Low implementation and compliance*

Firstly, the issue of ***low implementation and compliance*** which appears to have prevented these measures from yielding their maximum expected results may be due to the absence of systems necessary to ensure that these ethical standards, frameworks, codes of ethics, policies, etc., are adhered to in the industry's everyday operations.

Another possible explanation for the low implementation and compliance could be the fear of missing out on potential contracts. Political scientists (Burdette, 1973; Organski, 1969) claim that when corruption eats deep into a system, most times, one would be required to "grease the wheels" to get things done. Due to the wide spread unethical influence in the industry, many contractors now carry out certain acts in a bid to “grease the wheels,” (Locatelli *et al.*, 2017) and this is even more pronounced in countries with weaker anti-corruption structures (Bowen *et al.*, 2007).

As a result, some firms that may be considering implementing these measures may feel at a disadvantage as their decision to swim against the tide could then become a barrier that automatically impedes them from bidding for certain projects in some places or from corrupt procurement agencies since they are not likely to be fairly considered by the corrupt agents who seek allies to connive with. This may perhaps be the reason for the outright defiance or sloppy implementation of these measures. A position of outright defiance positions an organisation favorably for business with corrupt contract awarding agencies, while a position of sloppy implementation presents opportunities for such organisations to adaptably play the roles of villains and heroes concurrently.

However, if a handful of genuinely ethical organisations decide to take the full plunge despite the seeming repercussions, in practice, they may have to refrain from bidding for certain contracts and that then leaves the door wide open for the unethical organisations to go right through the door. Hence, a greater conundrum arises. It is that the evil of unethical firms will triumph even more as ethical firms step aside. So that whereas in the past, there was a mix of both ethical companies and unethical companies competing for contracts, now you are left with the unethical ones since the ethical firms would be withdrawing. This seems to be a possible explanation for the low implementation and compliance with ethical measures.

7.4.3 *The issue of denial*

Secondly, another finding in this study suggests that the reason for the limited effectiveness of these measures is the outright ***denial*** of the presence of unethical practises within construction and/or supply chain organisations. This suggests that although the problem exists, some do not acknowledge it, perhaps in a bid to protect the public image of their organisation. Or portray them as being disloyal to the organisation and hence stand the chance of being victimised as a result of what was uncovered and made public, as was the case of several Wells Fargo bank managers who were fired after reporting suspected fraudulent behaviour to superiors and a bank ethics hotline (Sbaraini *et al.*, 2011). According to Luke (2020), if an individual realises that the company for which they work is acting unethically, it is their moral responsibility to try to correct the problem and this is something that company loyalty cannot trump. If formal internal escalation is either impossible or ineffective, whistleblowing becomes a moral imperative. Construction News (2019) reported that, although many UK businesses have procedures in place for anonymous reporting, many employees are ignorant of them or do not use them. Furthermore, there have been some examples of senior managers attempting to pay high prices to ascertain the identity of a whistleblower, in violation of their own organization's policies.

Another possible explanation for denial could be to exempt the organisation from the uptake of the measures or from potential scrutiny that may follow disclosure. The popular phrase, “if it ain’t broke, don’t fix it,” suggests that if something is going or working well, there is no need to change it. As such, to declare a supposed ethical risk-free organisation and supply chain is to express no need for the uptake of ethical measures.

7.4.4 *The role of government in fostering the implementation of ethical measures*

Thirdly, another finding in this study was regarding the ***role of government*** in fostering the implementation of ethical measures. The result suggests that the government has a huge role to play for these measures to be well implemented. The government may use its legislative powers to either implement and mandate compliance with certain standards or not. Adetunji et al. (2008) posit that it is widely agreed that because the ideas of sustainability and supply chains are so complicated, the government must take the lead through its spending power and legislative actions. Similarly, Jiang et al. (2022) argue that several standards could easily be relegated to being considered as good advice that people generally would not implement unless they are mandated. The involvement of the government could really be a game changer when it comes to implementation and compliance with measures, standards, policies, etc. For example, BIM implementation in the UK and Singapore has been fostered through government-led approaches. Also, several authors have conducted extensive investigations into BIM implementation and many of them agree that government intervention is a necessary strategy for better uptake and compliance (Liu et al., 2015; Yang and Chou, 2018; Zhou et al., 2019 Smith 2014a).

It can be concluded therefore that although some of the measures set up to improve ethics within the CMPSC have impacted the supply chain positively, the full potential of these measures has been stifled due to low implementation and sloppy compliance. Together, these results provide important insights into the current state of ethics in the CMPSC. Also, these findings may help to understand why unethical activities are still prevalent in the CMPSC, despite the measures put in place to forestall them. Putting together all the results presented and discussed under this theme, it can be further concluded that the current measures to improve ethics in CMPSC have been effective to some extent. However, low implementation and compliance, inability of government to fully play their role in enforcing these measures and the outright denial of the presence of unethical practices within construction and/or supply chain organisations constitute the major obstacles that have impeded these measures from delivering on their full potential.

7.5 Theme 3: Improving ethics in CMPSC

The third research question of this study was regarding whether blockchain can help to improve ethics in the CMPSC within the TBL construct or not. This was also connected to Objectives 2 and 3 of this study. To address this question, blockchain technology and its implementations for ethics were studied, in view of applying the learning to evaluate its feasibility to improve ethics in the CMPSC. Also, in addition to establishing that blockchain technology can help to improve ethics in the CMPSC and the factors that may affect its acceptance and implementation in the construction industry, 2 other major non-technological routes were identified as vital routes to improving ethics in the CMPSC, namely: the need for education and the need to uphold personal ethical values. These results are captured within the ***need for education, personal ethical values*** and ***improving ethics in the CMPSC through blockchain*** medium level themes of **Theme 3** of the interview thematic framework and it reveals how ethics can be improved in the CMPSC, thereby contributing to the overall achievement of Objectives 2 and 3, as well as the answering of Research Question 1.

7.5.1 *The need for education*

The current study found the ***need for education*** as a pivotal ingredient in the improvement of ethics in the CMPSC. The results from this study indicate the need for education among supply chain players, construction professionals, clients and the general public. It suggests that training on ethics should be incorporated into the academic syllabus and professional training so that detecting fraud becomes less of a speciality and more of something anyone can do. The findings indicate that this is required to shift the perspective of professionals into seeing that upholding high ethical standards is their responsibility, whether the client demands for it or not.

A possible reason for this could be the widespread reports of unethical activities by and within construction professionals. As earlier noted in the literature review, several reports have reported numerous business related unethical activities during construction, pointing out construction professionals as the chief culprits in these cases (Agnieszka Pikulicka-Wilczewska, 2018; Remo, 2018). For example, Viator (2019) reported the case of a general contractor who was indicted over the misappropriation of project funds.

As Mark (2017) posits, the ethical way out is not via damage control but through preventive educational measures. He believes that there are certain bodies of knowledge which could be both specific to one's job and general pieces of ethical knowledge that everyone should know, and ignorance of such would be no excuse. A view also supported by the findings of Delaney and Sockell (1992), which reported that the presence of a formal ethics training programme in the workplace is essential to implement an ethics code and awaken workers to the ethical implications and a watchful thinking to ensure that the organisation's activities are ethically right.

The result also further suggests that training should not be limited to supply chain players and construction professionals only, but that clients and owners should also be trained. According to the findings, because most clients and owners do not have a rich understanding of ethics and sustainability, they are unable to demand and hold their contractors accountable to high ethical standards. A possible reason for this is the fact that currently, most changes in the industry is client demand driven. Therefore, clients themselves must first be acquainted with these things to be able to demand them. So doing, several construction players would then be compelled to begin considering how to better mitigate their ethical risks, which may then ultimately result in the improvement of the state of ethics in the CMPSC. For example, Belle (2017) identified the absence of client demand as one of the major perceived barriers holding back the majority of construction firms from establishing a new culture of collaboration and digitalization. Also, Palevich (1997) posits that while companies that see the advantage of supply chain management may be self-motivated to start it, the broader uptake is more likely to be driven by client demand.

Furthermore, on a broader level, the result also stresses that a culture of ethics should be engrained into citizens right from their early learning stages, as it is the citizens of the country that can really drive the needed change.

7.5.2 *Improving ethics in CMPSC through blockchain*

As earlier pointed out, the second research question of this study was regarding whether blockchain can help to improve ethics in construction materials and product supply chain or not. The analysis of the findings revealed that blockchain may help to improve ethics in the CMPSC as most of the participants opined that blockchain may help improve ethics in the CMPSC. Interestingly, two of the four core features of blockchain earlier presented in Chapter 3 of this study were highlighted by most of the participants as features of the technology that could help improve ethics in the CMPSC, namely: transparency and immutability. A possible explanation for this may be due to the learnings of how the participants on blockchain's transparency and immutability features have helped in other supply chains, and as a result, they believe that it may help to shed some light across the hidden tiers of the supply chain materials and products supply chain in construction.

Consistent with literature, ICE (2018) admits that the transparency feature of the blockchain has already offered many competitive advantages in other industries, and it could also be leveraged in the construction industry; since virtually anything of value can be traded and traced on a blockchain network (IBM, 2019). According to Deloitte (2017), organisations can digitise physical assets and generate a decentralised immutable record of all transactions, allowing them to trace assets from manufacture through distribution or use by end users, allowing for more transparent and accurate end-to-end tracking in the supply chain. This improved supply chain openness gives companies and customers more visibility.

Prior studies have indicated the need for more transparency in the supply chain of construction products and materials. The complexity of the construction supply chain and low transparency are weakening the level of trust in the supply chain, particularly in suppliers and subcontractors (Abeyratne, 2016; Hijazi *et al.*, 2019; Perera *et al.*, 2020). Other studies have also noted the relevance of blockchain's transparency and immutability features for the enhancement of supply chain activities (Lanko *et al.*, 2018b; Litke *et al.*, 2019; Smith and O'Rourke, 2019; Tezel *et al.*, 2020). As a matter of fact, Kinnaird *et al.* (2017) posit that similar to the method of tracing products in supply chain management, in a construction project, each asset could be tracked from the extraction/production stage until it is delivered to the site and incorporated into a structure.

Therefore, based on the workings of blockchain, the transparency and immutability features could allow for the recording and protection of data from operations between different parties in the supply chain, which may cover the entire process from "mine to market." Hence, it may be utilised to provide a trail of information that increases supply chain transparency, and in effect, reduces the risk of ethical breaches across the supply chain and potentially enriches the customer experience via the information it provides about their products. These traceable immutable digital records that are created and maintained thereby make it suitable for many supply chains.

Interestingly, while most participants consider blockchain promising in the improvement of ethics in CMPSC, some participants on the contrary considered the immutability feature of blockchain unsuitable for the nature of construction supply chain. The concerns raised were particularly about how the immutability feature of blockchain makes it unsuitable for the variations and reworks that come up during construction. While this points to a construction project scenario rather than a product or material supply chain scenario, the concerns are still considered to be very valid for this study because the component of the developed model is proposed as a construction project solution. Additionally, even in supply chain scenarios, some situations may warrant the need to make changes to an already verified data at some point in the chain.

As earlier mentioned in the literature review, immutability refers to a blockchain ledger's ability to remain unmodified; this is achieved through cryptography and hashing. While not technically immutable because immutability is not an intrinsic feature of a blockchain data structure but an emergent one (Politou *et al.*, 2019), it is still considered to be so because altering transactions that have already been verified and published is difficult (Kassem et al., 2018). This immutability feature aids the recording of data in a secure and transparent way and guarantees data credibility. Some apparent benefits for supply chain management are the tracking of supply chain logistics, including procurement, transportation, and storage of goods and the record of changes made to digital models when connected to BIM (Politou *et al.*, 2019). Despite these positives, blockchain immutability also presents some unintended consequences, such as when erroneous or illegal content is stored in the blockchain and its collision with the GDPRs Right to be Forgotten (Hunhevicz and Hall, 2020).

In addition to managing changes on the blockchain through a combination of on-chain and off-chain technologies, some research work on “pragmatic immutability,” which involves technical workarounds and advanced cryptographic methods to either bypass or remove immutability, has been carried out in a bid to address these challenges and increase blockchain adoption for both permissioned and permissionless blockchains (Politou *et al.*, 2019). Although introducing mutability in permissionless blockchains could be challenging due to the lack of trust among the participants, Meiklejohn (2018) and Swanson (2015) suggest that in permissioned blockchains where the participants are known, introducing mutability is achievable. To illustrate, Accenture has developed a prototype of a new capability that enables blockchain to be edited under extreme circumstances. This allows enterprises to accommodate legal and regulatory requirements, resolve human errors and other issues, while preserving key cryptographic features. The prototype seeks to preserve the qualities of immutability by making it possible to identify blocks that have been edited with an inevitable “scar” that cannot be removed by any party (Accenture, 2017).

While this prototype in certain conditions may strike the right balance between preserving blockchain’s immutability features and adapting it for real-world requirements, seemingly presenting a win-win case for permissioned blockchains, some argue that the concept of a “mutable blockchain” gives in to a fundamental trade-off which undermines the integrity and trustworthiness of the blockchain data (Jeff, 2016).

7.5.3 *Factors affecting acceptance and implementation of blockchain*

The findings further suggest that while blockchain may help to improve ethics in CMPSC, its effectiveness is only going to be as good as its implementation. Hence, some of the factors that may affect the acceptance and implementation of blockchain were identified.

First is the issue of ***scepticism surrounding the technology*** which could be considered to be a function of the second issue, which concerns the ***knowledge of blockchain technology*** people have***.*** The findings of this study suggest that there are individuals and organisations who may be sceptical about the technology based on what they know and consider to be true about the technology. A possible reason for this could be in relation to the activities of scammers and hackers on the web. Which may have been exacerbated by the incessant headlines of crypto-scams and crypto-related Ponzi schemes in the news since the advent of bitcoin. Following the successful launch of bitcoin, cryptocurrencies have gained increasing attention from regulators, investors, entrepreneurs and the public. However, there is still a major concern about cryptocurrency scams (Bartoletti *et al.*, 2021). The pseudonymity features of most cryptocurrencies position them as a very feasible tool for cybercriminals to perpetuate their nefarious activities untraceably.

So, while clear differences exist between different cryptos and between cryptos and blockchain technology, in that each crypto is built differently on the blockchain and only represent one of the many functionalities that can be built on the technology. Many do not seem to see nor understand this dividing line; hence, they consider cryptos synonymous with blockchain and wrongly place cryptos and all other blockchain applications in the same box. As such, they consider every hit on cryptos a direct hit on the underlying technology. For this reason, many associate blockchain with the black web and link cryptocurrencies with criminality as a result of "Silk Road" and other high-profile examples of people exploiting cryptocurrency for nefarious reasons (Rath and Kulnigg, 2019). For this reason, blockchain acceptance and adoption stands the possible risk of being hampered by a backlash of crypto biases, which may be a perspective held by positions from a limited knowledge of what blockchain is and how it works, and as Marsh (2017) observed in her study on BIM adoption, it is the lack of understanding that prohibits or restricts adoption, not the perceived barriers.

However, this cautionary sceptical approach to blockchain is not unfounded. As RICS (2020) reports, since the beginning of 2017, hackers have stolen roughly $2 billion in cryptocurrencies. Also, Yang

(2019) posits that all blockchain implementations are vulnerable to both internal and external threats, and security breaches and malfunctions are very likely before the technology reaches full maturity. Therefore, there are real reasons to warrant such a stance in relation to the technology, and for some, the reason for their scepticism is that they are highly knowledgeable and well aware of the limitations of the technology and the loopholes cyber criminals could exploit.

Another possible reason for the scepticism surrounding the technology may be as a result of the differing regulations surrounding cryptocurrencies and blockchain technology across different countries and the knowledge of the same. According to Wilson (2019), there seems to be a lack of a general governmental consensus on the regulation of cryptos and blockchain technology, so while some governments have issued outright prohibitions on some crypto related activities, others have taken positive steps to legitimate its use, while the rest have decided to watch from the side-lines. While it is commonly stated that cryptocurrencies and blockchain technologies are unregulated, Rath and Kulnigg (2019) argue that cryptocurrencies and blockchain technologies are not unregulated, rather, it is the various approaches taken by different countries, or even different agencies within the same countries (as it is the case within the U.S.) that have left blockchain companies bewildered as to whose jurisdictions and regulatory regimes their products and services will be subject to.

Further results suggest that another factor that may affect the acceptance and implementation of blockchain is the issue of the construction industry's ***resistance to change.*** The industry has a high reputation for being a laggard when it comes to leveraging new technologies and an industry that is resistant to change. The result is in line with prior studies by Hijazi *et al.* (2019), Kassem *et al.* (2018), Li *et al.* (2019) and Zhou *et al.* (2019). Apart from the financial cost effects that come with the implementation of new technology, another possible explanation for this may be due to the changes in practises and organisational culture that may ensue as a result of adopting new technologies. As Mougayar (2016) puts it, the use of blockchain technology in particular has the potential to alter present organisational cultures and replace legacy systems upon which companies have made heavy investments.

Furthermore, as it pertains to blockchain, the resistance to change may also be due to a lack of technical competence and knowledge of blockchain technology. According to (Kifokeris and Koch, 2019) a lack of skilled human resources and a lack of awareness at senior management level present a challenge to the adoption of blockchain in construction. Tezel *et al.* (2020) reported that the use cases of blockchain based asset digitization, supply chain management, procurement, etc., in the construction industry are very limited.

Another factor that may affect the acceptance and implementation of blockchain technology as indicated by the result is the ***client's awareness and demand for it***. A possible reason for this result could be the prevalent client-led innovation approach in the construction industry. Oftentimes, the response of the construction industry to several innovations is usually hinged upon the demand for it by the clients and owners.

This corroborates the findings of Ozorhon (2012) and Loosemore (2015) who found that in the construction industry, clients often play a key role in creating the right conditions for innovation. As reported by Lindblad *et al.* (2020), studies linked to BIM implementation argue that the active involvement of clients demanding the technology in procurement influences its adoption to a large extent. The government and other private clients have used their influence in procurement and demand for BIM to increase its adoption in construction (Jiang *et al.*, 2022). However, clients must first be aware of the offerings of such innovation and how it adds value to their assets to provide strong enough motivation to demand it as part of the project deliverables and pay for it. This was alluded to earlier while discussing the findings concerning the ***need for education*** and ***knowledge of blockchain technology***.

7.5.4 *Personal ethical values*

Regarding the improvement of ethics in the CMPSC, the current study also found that despite the potential of blockchain and all the other measures in place to improve ethics in the CMPSC, the ***personal ethical values*** of involved individuals remain a major determinant for their success and the overall improvement of ethics in the CMPSC. Some possible explanations exist for this result.

Firstly, although the client-led approach has been the main trigger for getting things done in this industry, result suggests that it is important that matters of environmental, social and business ethical concerns are not approached based strictly on client request. Instead, people ought to view the upholding of ethical values as a primary element of their everyday lives and not just as a professional obligation or as part of a one-off job package that is contingent upon the demand of a client. According to the findings from a study on professional ethics in the construction industry conducted by Vee and Skitmore (2003), 93% of the respondents agreed that business ethics should be driven or governed by personal ethics. For a professional, there is an additional responsibility to uphold the values of their profession which may conflict with that of their client or employer. Each person will hold a set of personal ethics which influences their judgement between different options and stakeholders (Fewings, 2008).

Furthermore, while results from this study agrees with prior studies of CIPS (2013) and Kjesbu *et al.* (2017) on the potential of procuring materials and products that have links with ethical breaches due to the ignorance of the procurers or customers. Further results from this study however suggest that having had that knowledge, there is still a choice to be made. As such, certain people may still decide to purchase unethical products instead of ethically produced ones since they usually turn out to be cheaper than their ethically produced counterparts. Therefore, beyond the implementation of systems and structures, individuals always have a choice to make and at that point, the ethical values of the individual in whose court the ball lies become a major determinant.

Furthermore, these findings also suggest that the ethical values of certain individuals may be doused and bullied into subjection by the pervasive and prevalent corruption in the industry. In such cases, individuals may feel utterly handicapped and coerced into comprising and “going with the flow” since “everybody does it” and it seems to be the only way to get by as the prior findings of Burdette (1973), Locatelli *et al.* (2017) and Organski (1969) suggest.

On the contrary, "personal” ethical values may be considered intrinsically subjective and may thus open up grounds for debate about what passes as "ethical" through the personal lenses of different individuals in different circumstances, and may be impedimental to achieving overall ethicality and, in extreme cases, self-defeating. Notably, in a survey of 5,000 Americans, Patterson and Kim (1991) found that 90% of the respondents would determine morality for themselves. About 74% of the participants admitted that they would steal, and 64% admitted that they would lie when it suited them. Even more, Kelly Services (2005) in a survey on ethical behaviour in the workplace that involved 19,000 employees in 12 countries across Europe suggested differing personal ethical standards across different countries. The findings indicated that those residing in the UK had a higher standard of personal ethics than those in other European countries.

These prior findings suggest that the judgement for “personal ethical values” is in many cases subject to the proverbial expression, “one man’s meat is another’s poison,” in which case, what passes as ethically right to one may be considered ethically wrong to another. This appears to be where professional codes of conduct helps to set the minimum expectation and hence provide an “objective” framework of ethical expectations. So that why professionals are not exempt from exhibiting healthy personal ethical values, they are also obligated to uphold and maintain certain standards and behaviours within their profession.

All the same, considering the intricacy of ethical matters, an essential test of ethical behaviour as Lord Justice Moulton puts it, is the degree of "obedience to the unenforceable," (Moulton, cited in Independent Sector, 2002, p.8). According to Moulton, the very best in people and institutions is reflected when they go above and beyond the letter or even the spirit of the law. Thus, suggesting that adherence to obligatory professional codes of conduct is still going to be fundamentally based on the individual's personal ethical values.

From all the results presented and discussed under this theme, it can therefore be concluded that to improve the state of ethics in the CMPSC considerably, supply chain players, construction professionals, clients and the general public should be educated so that everyone understands that upholding high ethical standards and spotting breaches can and should be done by everyone. Also, it can be concluded that blockchain may help to improve ethics in the CMPSC particularly because of its transparency and immutability features, while also noting that its immutability feature may cause significant challenges in implementation, considering the "human factor" and the nature of supply chains generally. Also, it must be noted that the success of the technology in this wise is contingent upon successfully addressing the factors that may affect its acceptance and implementation. Lastly, it can be concluded from the results presented and discussed in this section that the success of blockchain technology and other already existing measures to improve ethics in the CMPSC is largely dependent upon the personal ethical values of people, particularly those who are responsible for feeding data into the system or for ensuring compliance with those measures.

7.6 The developed model

Objective 3 of this study sought to establish how blockchain technology can help to improve ethics in the CMPSC within the TBL construct; Objective 4 sought to determine the factors that may affect the acceptance and implementation of blockchain technology in the CMPSC; while Objective 5 sought to develop and validate a model for improving ethics across the CMPSC following the TBL construct using blockchain technology. These objectives and their related research questions 3 and 4 are also addressed within ***Theme 4*** of this study. To address these questions, having examined how blockchain technology has assisted in the supply chains of several industries and identified how blockchain technology can help to improve ethics in the CMPSC, the learnings were applied to develop a model for improving ethics in the CMPSC. Following this, a dual-phase validation strategy through interviews and focus group discussion was utilised to validate the model (including its elements and components), evaluate its potential to improve ethics within the CMPSC, and investigate its potential acceptance and implementation in the industry.

The results captured within ***Theme 4*** of the interview data and ***Themes 1, 2 and 3*** of the focus group data, which have been separately presented in Chapter 6 are now triangulated using the different data sets from the multiple methods. The intention is that the outcome of the triangulation will provide a more accurate evaluation of the model and help to enhance the validity and credibility of the findings (Denscombe, 2008).

Having identified and extensively discussed the workings of the elements and components of the model and how its networks integrate to achieve the model's overall goal in Chapter 4. In Chapter 6 of this study, the results and analysis of the interview and focus group data were presented. The data presented under ***Theme 4.1*** of the interview thematic framework and ***Theme 1*** of the focus group thematic framework***: Evaluation of the model's potential to improve ethics*** in CMPSC both revealed that the model could help to improve environmental ethics, social ethics and business ethics in CMPSC. Similarly, the analysis of the results presented under ***Theme 4.2*** of the interview thematic framework and ***Theme 2*** of the focus group thematic framework***: Validation of model's elements and components*** both revealed that the Material and Product Network, Procurement Network and Project Network all contribute to the achievement of the overarching goal of the overall model.

In this section, two very interesting themes are discussed. First is ***Theme 4.3**** which refers to the triangulated data from ***Theme 4.3*** of the interview thematic framework and ***Theme 3*** of the focus group thematic framework, which both deal with the ***Acceptance and Implementation*** of the developed model. Theme 4.3* is here discussed in relation to the theoretical framework underpinning the developed model, as presented in Section 4.3 of this study. Second is **Theme 4.4** which deals with the ***limitations and challenges of the model*** is also discussed.

7.6.1 *Model Validation: Acceptance and implementation of the model*

Following the results from the evaluation of the model's potential to improve ethics in CMPSC and the feedback from the validation of the model's elements and components, the potential acceptance and implementation of the model was then evaluated. The fulfilment of which contributes to addressing Research Question 4 and the achievement of Objective 4 of this research, which was regarding the identification of factors that may affect the acceptance and implementation of blockchain technology in the construction industry. On one hand, results show that most participants would be willing to accept and implement the model, which suggests that the construction industry should be willing to accept and implement it. On the other hand, results also show that although the participants express that the model is valuable, it may fall through in the implementation and acceptance phase if certain factors are not addressed. These factors that may affect the acceptance and implementation of the model as earlier identified by participants are further discussed in this section.

The cost factor

The ***cost of implementing the model,*** which is also related to the ***cost of procuring the infrastructure*** were both identified as factors that may affect the acceptance and implementation of the model in the interviews and focus group discussion respectively. This suggests that while many may like to adopt the model based on its value propositions, the cost of procuring the infrastructure on which the blockchain system that houses the model would run may be inhibitive. Several of the previous studies evaluating the barriers to innovation faced by organisations identify high cost of innovation as a major barrier (Pellegrino, 2018; Segarra-Blasco *et al.*, 2008), particularly for SMEs (Cordeiro and Vieira, 2011).

According to Coinbase (2019), setting up blockchain networks calls for a lot of technical know-how, time, money, and robust underpinning technology, including dependable and scalable hardware, updated software, and a steady internet connection to participate in the blockchain network. A view also supported by Isler (2022), who claimed that blockchain is more than simply computer code and blockchain implementation must include a robust hardware and software blockchain infrastructure in order to run a node effectively.

While this is true, it is important to note that most of the concerns regarding the cost of setup and infrastructure are more applicable when the blockchain solution is being set up as a traditional on-premises solution where the service is deployed, hosted, and maintained on hardware at an organization's building or campus. In such cases, businesses incur a lot of costs by having to buy and manage hardware. On-premises services are deployed, hosted, and maintained on hardware at an organisation's building or campus, hence the required heavy start-up cost. However, today, cloud-based services models that allow businesses to use IT infrastructures, platforms, software, and applications via the Internet now exist, offering different levels of autonomy and control to suit different business needs. These cloud-based service providers do the heavy lifting, allowing interested users to simply pay a subscription fee to access the solution. As alluded to in Chapter 4, this model proposes the utilisation of a Blockchain-as-a-Service (BaaS) solution which is based on the Software-as-a-Service (SaaS) solution which transfers the cost of setting up and keeping the infrastructure operational to the cloud-based service provider, and users can leverage the cloud-based solutions to build, host, and operate their own nodes.

Nonetheless, apart from blockchain infrastructure related costs, there is also the cost of tracking technologies utilised by the model to reconcile and update the digital world with real world occurrences. The achievement of the traceability potential of the model relies heavily on oracles, like IOT and some tagging solutions. The cost of implementing these tracking solutions would usually be set up by the individual members of the supply chain implementing the model and as a result, lead to an increase in the price of their materials and products. Also, in some cases, it may be hard to justify the implementation of such tagging solutions for lower cost items. In such a case, one may have to consider the cost of tagging the item versus the cost of the commodity itself in order to decide usage.

At the same time, according to Rosoff (2015), a research by the US Bureau of Labor Statistics that tracked prices for broad categories of commodities over 18 years revealed a massive decline in prices in almost every major area, with computer hardware being the steepest. Therefore, it can be concluded that as technology gets more advanced, the cost of both the blockchain infrastructure and the tracking technologies should reduce.

Asides the cost of the technology infrastructure, obtaining other elements of the model, such as ecolabels and certifications attracts costs too. Jelse and Peerens (2018) expresses that conducting an LCA is time and resource intensive, which means that for SMEs, cost is often seen as a barrier to starting such studies. Consequently, SMEs with limited resources cannot always justify the cost, and since manufacturers are not obligated to produce EPDs, they may prefer not to have LCA or EPD data available.

The corruption factor

The issue of ***corruption*** was identified as a factor that may affect the acceptance and implementation of the model in construction from both the interviews and focus group discussion. Having extensively discussed how the "issue of corruption" in construction affects ethics in CMPSC, this section focuses on discussing how the issue of corruption may inhibit the acceptance and implementation of the developed model. As earlier pointed out, corrupt activities are still prevalent in the construction supply chain today, and this finding suggests that as a result, the model may not be accepted, knowing that it has the capacity to either prevent or even expose some unethical activities. As one of the participants put it, "*they may bury this research because they do not want to take responsibility for their supply chain.*"

As prior studies have noted, a major challenge to the implementation of anti-corruption efforts is that even though the solutions are known and available, the people who have the capacity to implement them have refused to because they are also benefiting from the corruption (GIACC, 2020; Locatelli *et al.*, 2017). This is further evidenced by the comment of one of the participants in this study, who stated that:

> *Sadly, a lot of the ministers and civil servants responsible for placing contracts are benefiting corruptly from the contracts everywhere in the world, but they are also the people who could bring about change (…..) What we find a lot is that our systems get applauded and welcomed. We get invited to the country to provide training on our systems, and often we get met by the minister of infrastructure, who shakes us warmly by the hand, and sometimes the TV cameras suddenly appear. Then the Minister gives a brave speech and then vanishes, and we are left with the implementers who tell us that they have no power and no authority to implement anything.*

Also, Ameyaw *et al.* (2017) found that despite the numerous anti-corruption initiatives, the extensive network of political relationships and the personal financial rewards that corrupt activities in construction provide make it difficult to eradicate, particularly because government officials are implicated.

Further findings in this study indicated that the potential for the adoption of the developed model in developing countries is further weakened due to the higher prevalence of corruption in such countries. Suggesting that when corruption in developing countries meets with corruption in construction (due to the innate vulnerability of the industry to corruption), it presents an environment that further fosters corrupt activities and as such, hostile to all anti-corruption strategies and approaches, such as the developed model, thereby constituting a major challenge to its acceptance or implementation.

The digitised ecosystem factor

The emergence of the ***digitised ecosystem*** theme under ***Theme 3*** and ***Theme 4*** of the interview thematic framework and its relationship to the ***lack of adequate infrastructure in developing countries*** theme from the focus group discussion thematic framework indicates its high importance in the acceptance and implementation of not only this model but of blockchain technology generally.

This result suggests that for this model to be implemented, some fundamentals must first be in place, and while the model assumes that all of the fundamentals required for complete implementation are present, in actuality, they are not. Indicating that applying this model would necessitate the implementation of many other things, such as the infrastructure required for the robust tagging solution proposed by the model, which may not be readily available.

Blockchain itself needs an ecosystem of digital technologies to thrive maximally, all of which are powered by electricity, as such, constant power supply and internet service are needed to keep the servers, oracles and nodes live. Also, blockchain works best when cross-enterprise workflows are automated, facilitating business processes and data sharing across organisational boundaries. However, to do so successfully calls for a digital ecosystem with a group of parties interconnected through information technology resources functioning as a unit (WEF 2018). The developed model requires the participation of several actors in the construction materials and products supply chain to enrich and sustain the digital network. This requires such players to be ones who digitise their workflows and businesses. The challenge with this is that many of the players who constitute the supply chain of construction materials reside in developing countries where basic social amenities may not yet be a given, much less access to internet services. Many developing countries do not yet have the needed social amenities (such as constant electricity, security, schools, housing, communication, etc.). As such, they lack the infrastructure needed to build a rich digital ecosystem which individuals and organisations in such countries can leverage to do business comfortably with the wider world. This suggests that possible acceptance and implementation of the model in developing countries may still take several years.

Apart from the need for a digitised wider supply chain ecosystem, the model also requires a digitised construction industry ecosystem. Although digitization is widely considered as the solution for the optimization and automation of processes in the construction industry, while Turk and Klinc (2017) note that almost all planning and design work is now done digitally, and information is shared and exchanged in a digital format through BIM. Ye *et al.* (2020) on the other hand argues that the current building project practise still relies on paper contracts and traditional communications, which are time-consuming and opaque. Nonetheless, one thing is certain, construction in many developing countries is yet to achieve widespread digitisation due to the absence of some fundamental amenities and infrastructure earlier stated. These findings suggest that possible implementation of the developed model in developing countries would take a longer period of time than in developed countries due to the unavailability of the required infrastructure.

While these results may portray the model to be somewhat ahead of its time with regard to the availability of the digital ecosystem required for the model to thrive, one must also consider that the rate of digitisation across all sectors and countries has exponentially grown over the past few years. Much of this surge has been due to the changes brought about by the COVID-19 pandemic. Shortly after the epidemic, internet traffic in some nations soared by up to 60%, and to sustain operations and revenue streams, several businesses have adopted digital business models (OECD, 2020). A McKinsey (2021) survey finds that responses to COVID-19 have accelerated the adoption of digital technologies by several years, and the proportion of items in their portfolios that are either digital or digitally enabled has increased by seven years. Therefore, with the growth of emerging technologies related to virtual reality, augmented reality, robots, big data, artificial intelligence, drone technology, metaverse, etc., it can be concluded that the world is moving towards a digitised end at a very fast pace, which could inadvertently foster the building and strengthening of the environment that blockchain requires to thrive.

At the same time, this finding admittedly suggest that the current level of digitisation globally is not be sufficient enough to fully host and run the model. As such, it may take some more time before widespread implementation becomes plausible. Also, apart from the need for digitisation across the global supply chain, the acceptance and implementation of this model requires blockchain technology to become more mature and mainstream both in the construction industry and amongst the general public than it is today. As Construction Blockchain Consortium (2020) posits, full-scale adoption of blockchain could take years because the majority of use cases are in test phases.

The differing standards factor

The issue of ***differing standards*** was identified as a factor that may affect the acceptance and implementation of the model in the interviews. This suggests that while many may like to adopt the model based on its high potential, the inconsistency in data set around required standards in different parts of the world and differing standards across geographical boundaries represents a huge challenge.

A possible explanation for this may be due to the differing standards within and across (ethics) measurement tools since the proposed model relies on labels and certifications to indicate ethicality. While this approach possesses certain potential effectiveness, it does not represent a total solution, one of its challenges being the inconsistency in the data set of the elements of some standards. This is seen for example in EPDs and LCAs. A common means of quantifying the potential environmental impact of construction elements or construction works in developing countries is LCA and EPD. Nonetheless, Iraldo *et al.* (2020) argue that a challenge related to communicating LCA and EPD information is the variation in LCA and EPD elements. The first step in creating an EPD is defining the product, using the appropriate Product Category Rules (PCR), and even though the European Committee for Standardization published EN 15804, which sets common PCR for EPD development, the challenge of the adaptation of non-uniform PCR still exists. As Ingwersen and Subramanian (2014) posit, the challenge of differing standards of data for EPDs is revealed in the diverse range of PCRs that exist, according to the geographical scope of the product. Thus, the adaptation of differing PCRs for the same product would result in fallacious and varying EPDs.

Furthermore, several LCA software solutions each have their own databases of preloaded datasets and processes. As such, results from the same LCA expert using various software and databases can be significantly different (Buildings Performance Institute Europe, 2021). Lasvaux *et al.* (2013) opines that different interpretations of EPDs for similar products result from a lack of agreement on specific aspects and from considering only general aspects while excluding more specific aspects. Therefore, the differing standards within the elements of product assessment tools, which by extension also serve as a means with which ethicality is indicated in the proposed model, could pose a challenge to the acceptance and implementation of the model.

Another possible explanation for this result may be as a result of differing standards across geographical boundaries due to jurisdictional differences. Also Iraldo *et al.* (2020) submits that ecolabels have faced significant difficulties in ensuring and enhancing their capacity to satisfy high environmental sustainability criteria in globally diversified supply chains. Since products are seldom produced solely for national markets, certain standards, ecolabels or certifications considered relevant at a local or national level may be considered inadequate in the larger international market. Iraldo *et al.* (2020) suggests a strengthening the cooperation among ecolabels worldwide and a harmonisation of standards to foster trade and commerce.

Again, while EPDs and LCAs are being used outside Europe, it largely remains a European based program, but it may well be considered as a well-developed construction product assessment tool. For all that, even in Europe, the provision of EPDs by manufacturers is not presently a requirement across board except in France where it is required if manufacturer wants to communicate on environmental aspect not already regulated (Michalak and Michałowski, 2021). Similarly, Harrison (2007) reported a decline in green consumerism, and because the premise of most of the ethical indicators rely on consumer altruism, Harrison (2007) proposed that they should be seen as a complement to, rather than a substitute for, traditional regulatory instruments. In many developing countries, governments have set up different regulatory frameworks on ethics are often adhered to due to their obligatory nature more than voluntary ethical schemes. However, due to individual jurisdictional and contextual differences, these frameworks may lack international harmonisation. That is, what may be permissible by the legislation of a certain region may be unacceptable to the standards upheld in other regions or as stipulated by more internationally embraced standards. To illustrate, one of the participants cited an example of a case where a mine met the national Peruvian and local government requirements but not the criteria of a firm trying to buy ethically.

The simplicity in use factor

The need for ***simplicity in use*** of the model was identified as a factor that may affect the acceptance and implementation of the model from the interview data. The result suggests that it may suffer a pushback if people do not understand how it works or if they just feel it is too complex, so the complexity of the system must be hidden so that anybody in the industry can easily do what is needed without having to learn a lot of new skills.

Kumar and Swaminathan (2003) point out that an innovation is too complex if it is relatively difficult to understand and use by its intended users. Extant literature also reveals that innovations that are simple and straightforward to use have a higher chance of being adopted (Ahuja *et al.*, 2016; Ayinla and Adamu, 2018). Despite the rapid advancements in IT and the invention of numerous IT applications for the construction sector, a number of problems continue to prevent the widespread use of these systems. Codinhoto *et al.* (2022) expresses that, previous studies on factors affecting BIM adoption reported technical complexity in the difficulty in using BIM tools as one of the main factors, for example, in the studies by Ahuja *et al.* (2016) and Doumbouya *et al.* (2016). Based on this result, it may therefore be concluded that the model stands a higher chance of acceptance and implementation if its workings can be easily understood and executed by all the intended users with minimal training.

7.6.2 *Limitations of the model in improving ethics in CMPSC*

This study highlighted 3 main ***limitations of the model*** in its quest to improve ethics in the CMPSC. This indicates that, just like other models and frameworks, the proposed model developed in this study to improve ethics in the CMPSC is not a panacea. The highlighted limitations of the model include ***ethicality of its oracles***, concern that the model is ***not robust enough,*** and the ***limited access to***

technology in lower tiers of the supply chain. There are some possible explanations for this.

Firstly, the concern expressed about the ***ethicality of its oracles*** could be regarding the "human factor" in the blockchain model, as the model utilises human, software and hardware oracles. The results suggest that although blockchain can play a major role in improving ethics in the CMPSC, the human aspect would always come in because you still need a human being to feed data or information into the system, and as long as that remains the case, "humans will always be humans" and there is still a possibility of someone doing the wrong thing intentionally. This agrees with the finding of Wegrzyn and Wang (2021), who posit that there is still the possibility of human error or purposeful wrongdoing when entering the data onto the blockchain.

As discussed in Chapter 3, unlike most digital currencies on the blockchain which exist in a fully digitised self-contained ecosystem, blockchain for supply chain integrations does not. Supply chains are made up of physical products and materials independent from their ledgers. As such, they rely on the inputs of oracles, which could be software, hardware or human actors to keep the physical and digital worlds in sync. As a result, some believe that the integrity of the data could be jeopardised due to human error or intentional misconduct and therefore, the information such a system provides cannot be fully guaranteed. Wegrzyn and Wang (2021) argue that although blockchain technology could help pinpoint where in the supply chain the fraudulent data was entered, it would not prevent it from entering the blockchain and the traditional immutability of the blockchain also raises a concern there.

Another possible reason could be the reliability of hardware and software oracles. For example, further findings reveal that a major issue with the implementation of the Internet of Things (IoT) is the reliability of the things and the possibility that the devices could be hacked by malevolent actors, which will result in compromised data. This was also reported by Varga *et al.* (2017), who submit that one of the biggest issues with IoT is addressing security concerns, and there are also issues related to the connection within the physical component and the networking domain of the IoT. This begs the need to ensure that a mechanism is put in place to ensure that the devices are functional and benign at all times.

Secondly, the concern that the model is ***not robust enough*** to tackle the sophisticated nature of unethical activities in the CMPSC. Interestingly, only one participant raised this concern, which indicates that other participants believe that the model captures the essential elements needed to achieve its goal. As the participant said, "*I am unfortunately aware of the lengths that mines,* *manufacturers, sales agents can go to camouflage unethical behaviour in supply chains, and I do not think this model addresses those as robustly as I would want.*" This suggests that the developed model may not be robust enough to tackle the evolving sophistication of corruption in supply chains.

It is important to note however that the overall aim of the model is not to exhaustively tackle all forms of unethical behaviour in the CMPSC. To make that claim would be to be over ambitious and to be fictitious about the capabilities of the model. Instead, the model provides a socio-technical system that seeks to improve the current state of ethics in the CMPSC through technological systems and human collaboration. As such, blockchain or any technological implementation for that matter can only fully deliver on its value propositions when it is treated as not just another digital tool but as a system designed to re-engineer networks and processes. The effects of which are not only limited to the online ecosystem but also spills into the offline space, causing a shift in the way things have been hitherto done (Mehra and Dale, 2020).

In any case, to effectively combat corruption, one must use a comprehensive approach that closes all gaps and modifies incentives and erroneous rules (Yang, 2019). As such, no singular model, framework, policy, standard, or legislation for that matter may be capable of entirely tackling the unethical activities in the CMPSC on its own. Murray (2008) writes that the Egan Report does not consider that technology on its own can provide the answer to the need for greater efficiency and quality in construction. Similarly, Yang (2019) affirms that blockchain by itself cannot produce significant transformational results. It may at most improve the integrity of the IT system and trust in the on-chain records, but because corruption involves dishonest behaviour in the real off-chain world, human agency will always be required.

Lastly, the third limitation of the model as indicated in the result is regarding the ***limited access to technology in lower tiers*** of the supply chain. The result suggests that getting the data for block one (which may include data from mining, fishing, harvesting, etc.) may be an uphill task because those organisations are usually located on sites where internet connections are inaccessible or totally unavailable.

As already extensively discussed in "The Digitised Ecosystem Factor" in section 7.6.1 of this study, blockchain itself requires an ecosystem of digital technologies to thrive maximally, all of which are powered by electricity. As such, constant power supply and internet service are needed to keep the servers, oracles and nodes live. Unfortunately, many of the players at the base of the supply chain work in remote regions where basic social amenities such as constant electricity, security, schools, housing, communication are not available and as such, these workers may have little or no access to the technology required to participate in the network. Furthermore, due to the shortage of schooling facilities in these regions, many of the workers on these sites may not even have the level of education required to input the required data into the network or to even understand how it works in the first place. Boersma and Nolan (2020) and Tezel et al. (2020) warn that it is crucial that workers have the ability to participate in the network as unequal access may compromise the validity of the validation process, and a digital gap caused by a lack of resources (financially or technologically) could marginalise employees (even more). As a result, Yang (2019) suggests that due to the current maturity level of blockchain and the low degree of digitalisation in many countries, it might be more practical and affordable for organisations in such countries to focus more on improving their compliance with current conventional measures for ethics in their supply chains, while blockchain and other associated technologies could be utilised to reinforce the system after a culture of ethics has been built, and the maturity of blockchain and global digitalisation has increased.

Nevertheless, further results in this study indicates that it is in fact simpler now than it has ever been before, and it is therefore no longer a valid excuse to not have traceability because of limited technology in lower tiers. As a matter of fact, there have been several blockchain for supply chain traceability pilot programmes that have successfully overcome this barrier. For example, in the food sector, blockchain was successfully used to enable end-to-end supply chain traceability across four commodities: beef, soy, wild-caught tuna, and farmed shrimp (IBM, 2019). However, as Leong *et al.* (2018) suggest, to reap the full benefit of blockchain, there needs to be a level of digital capabilities across the supply chain, including traceability applications that can be integrated with blockchain, and internet connectivity to help the base of the supply chain in rural areas close the digital divide.

7.6.3 *How the theoretical framework drives acceptance, implementation and success of the model*

As earlier discussed in section 4.3, this study utilises the theory of collective action as the theoretical framework that underpins the conceptual model developed to improve ethics within the CMPSC through blockchain. The model was developed to incorporate the principles of collective action to improve ethics in the CMPSC whilst leveraging the core features of blockchain. Collective action, which is a group theory that investigates the actions undertaken by individuals or groups for a collective purpose posits that when individuals have a shared goal and will profit from collaboration, they will establish a group to work together for the greater good (Gillinson, 2004). As clearly revealed in this study, the construction industry has shared goals which may only be achieved by collaboration. This study considers the goal of improving environmental, social and business ethics in the CMPSC as one which may only be achieved through the collaboration of all involved parties.

With respect to environmental ethics, the construction industry has a shared goal of reducing emissions to net zero by 2050. Buildings are not only responsible for emissions during their use phase but also for emissions arising from manufacturing and processing of building materials. The sector consumes 40% of the world's raw stones, gravel and sand and 25% of its virgin timber per year, with half of those resources being non-renewable (Karolina, 2021). Concrete, steel, and timber are the most widely used construction materials and products worldwide (Monteiro *et al.*, 2017; World Steel Association, 2018). However, concrete and steel production have huge impacts on the environment (Jonathan Watts, 2019; Kjesbu *et al.*, 2017), and many criticise the construction industry as major culprits of deforestation (Akwada *et al.*, 2018; Chimeli *et al.*, 2011). As a result, climate change is becoming a more pressing concern in construction, particularly following the 2021 United Nations Climate Change Conference (COP26), as both governments and private firms strive to attain their own net-zero goals. However, McKinsey (2022) reports that no single player can achieve this goal alone; it will require companies from across the ecosystem to commit to decarbonization.

Also, with respect to social ethics, Stronger Together (2019) reported that according to the Global Slavery Index, there are 29.8 million people in modern slavery around the world (Stronger Together, 2019). At or below layers four and five of the supply chain, construction projects are regarded to be the most vulnerable to forced labour infiltration. However, modern slavery is a threat not just to the labour force of the construction industry, but also to the supply chains for its raw materials and finished goods (CIOB, 2010). Supply chain transparency is currently relatively low in the construction industry because, due to the complex supply chains, determining whether items are ethically sourced and produced becomes more difficult. Modern slavery is difficult to combat as it is disguised in fragmented supply chains. Hence, organisations will not be able to end slavery by acting alone; they must band together and begin making difficult decisions (Sam Eastwood et al., 2020). Baldwin and Bordolli (2014) suggest that to address these issues, the industry must collaboratively think and act as a whole.

Furthermore, regarding business ethics, Transparency International (2006, 2008, 2011) revealed that the construction industry ranks among the most corrupt industries in the world, primarily attributable to the fragmented nature of the construction industry (involving clients, designers, contractors, consultants, producers, suppliers, etc.), which makes it difficult to track payment and information

(Kenny 2009), and the tremendous expansion of the global construction sector after the turn of the century. Further studies identify Bribery and fraud as the most common forms of corruption in construction (OECD, 2015; Sohail and Cavill, 2006; Tl, 2011). Other misconducts primarily takes the forms of misinformation, deceit and theft (Fourie and Malan, 2021; Yang, 2019). Bowen *et al.* (2007) found that deceit and misinformation are the most common forms of fraud in construction. De Jong *et al.* (2009) suggests that improved openness and transparency of decision-making processes from procurement to work performance by all parties involved in a project, including clients, consultants, contractors, material and product suppliers and regulators is a major approach to improving business ethics in construction.

Having met the requirements for collective action according to group theorists (Jordan, 1999; LaVaque-Manty, 2006; Verba *et al.*, 2000), which are the presence of shared goals from which individuals will profit if they collaborate, this model is therefore built on the premise that since cooperation is socially optimum, everyone will cooperate since it is clearly in everyone's best interests to collaborate.

At the same time, Mancur Olson, in his major paper, "The Logic of Collective Action," argues that if society is made up of many rational people, collective action would be undermined as people will free ride if they believe they can get the benefits of cooperation without contributing to the expense. According to him, we only cooperate when certain conditions are met. Although his model of the "rational" individual is criticised because it sees collaboration as merely a by-product of narrowly conceived individually rational activities, group theorists believe that it provides genuine considerations for collective action (Gillinson, 2004). While numerous examples of successful cooperation today that do not meet his criteria for "when" we should cooperate have been earlier discussed in section 4.3.1 of this study, this section further highlights how the developed model addresses Olson's conditions for collective action.

Olson (1965) presents three conditions and argues that cooperation can only happen when one or more of the three conditions are met. Firstly, he posits that cooperation can only happen when free riding would be detected because the group is small. In the proposed model, free riding would be detected and inhibited because of the model's validation protocol and the workings of the underlying blockchain technology; sets of rules and conditions could be coded into smart contracts to help mitigate free riding (Marquardt and Pohlmann, 2021). Interestingly, the larger the group grows, the lesser the technological chances for free-riding (Kinnaird *et al.*, 2017), thereby helping to foster collective action.

Secondly, Olson (1965) argues that cooperation can only happen when we are compelled to do so. Having argued that cooperation may be achieved without coercion and having cited vivid examples of successful collaborations with no iota of coercion whatsoever, such as the emergence of open-source software developments, crowdfunding platforms, social demonstrations, etc. Nevertheless, the research also acknowledges that altruism may not be a sufficient incentive for uptake without some form of (client or government based) coercion. This is further reflected in one of the findings of this study, which indicates that a client's demand for the model will determine its acceptance and implementation. As earlier discussed, clients (private and public) appear to be major “movers and shakers” in the construction industry, making them the “compellers” of innovation in the industry. Thus, it is assumed that the rising demand for an ethical and more traceable supply chain may compel and foster the acceptance and implementation of the model.

Thirdly, according to Olson (1965), cooperation can only happen when selective incentives are being used to persuade people to collaborate. Like in most industries, economic gains and financial incentives are considered major motivational forces for business in the construction industry. While there is a tonne of proof that these incentives can spur increased performance and productivity, Grant et al. (2011) argue that intrinsic motivation should be encouraged over financial incentives as a motivational force in business. They further added that the risk of financial incentives lies in reducing intrinsic motivation due to the over-justification effect, which occurs when an expected external incentive such as money or prizes decreases a person's intrinsic motivation to perform a task (Garland and Staff, 1979)**.** The researcher is of the opinion that fundamentally, response to matters regarding ethics ought to be morally intrinsically motivated and the offering of an “incentive” in form of tokens or a direct financial reward to persuade people to collaborate may result in the over-justification effect, which may then undermine the primary goal of the model, making it another profit driven venture instead of purpose driven. However, the developed model proposes a financial compensation for validators, but that to reward their time and professional services, and not to incentivise their participation or benign actions on the network, as it is the case with most permissionless blockchain platforms. The subscription fees paid by the actors in the MP-Network fund this as well as the maintenance of the blockchain infrastructure.

To conclude, the theory of collective action lies at the core of the model developed in this study to improve ethics in the CMPSC. This implies that participants must act collectively to fulfil their individual functions on the proposed network for the model to fully deliver its goal of improving ethics within the CMPSC. As earlier indicated, this model is not alone in the pursuit of collective action for global good. The United Nations Global Compact's new 2021–2023 strategy that aids firms globally in achieving sustainable and responsible business operations throughout their supply chain was developed with a strong emphasis on collective action. Other international organisations are also promoting this approach (OECD, 2020; SDGs, 2018; UN Global Compact, 2010).

From all the results presented and discussed under this theme, it can therefore be concluded that although the validated proposed model has been judged valid and capable of delivering on its value propositions through the feedback from the interviews and focus group, there remain some limitations and challenges to be addressed for the model to enjoy acceptance and implementation and to fully realise its potential. Despite these challenges, it can also be concluded based on the findings that the model possesses sufficient potential value to warrant and justify the rigors that its uptake may require. Furthermore, the model sufficiently addresses the conditions necessary for collective action to take place successfully according to group theorists and the other constructs that stemmed from Olson’s critique of the initial constructs for collective action, thereby indicating a high likelihood of success in the collective action approach this model utilises.

7.6.4 *Recommendations for implementing the proposed model*

To implement the developed model for the construction materials and products supply chain, six key steps are recommended. The recommendations for ensuring that the implementation of the model can lead to the required results are presented below.

1. Assemble a Setup and Implementation Team (SIT): The members of the Setup and Implementation Team (SIT) would largely be drawn from relevant fields, such as the field of blockchain and information technology, ethics and sustainability, academics, and construction supply chains (e.g., contractors, consultants, producers, miners, suppliers, etc.). They would set implementation goals with timelines for when such goals or targets should be met and put systems in place to monitor and measure such targets and make interventions when needed. The SIT will organically make up the first Registrar-actors of the network with permissions and authority to define, manage, register and assign unique identities to subsequent actors on the network. They would also be charged with the duty of contracting the Blockchain-as-a-Service (BaaS) providers that would help to build the network, creating a software specific representation of the conceptual model.

2. Setup Testnet: The BaaS providers set up the test blockchain network to run and test the functionalities of the networks, as well as monitor their performance before the blockchain networks are ready to be launched. This would allow SITs to run tests and simulations on the network. Other potential users and actors on the network would also be invited to run simulations and demos on the testnet to understand how the protocol would function on the mainnet itself without incurring transaction costs. This would also allow the BaaS providers to tweak the setup, troubleshoot any issues and fix any bugs. Considering that whilst the network is in its testing phase, blockchain knowledge and maturity as well as global digitisation would also be growing concurrently, thereby setting the stage for a softer landing for the mainnet and helping to build momentum for mainstream adoption of the technology.

3. Education: The current study found the need for education as a pivotal ingredient in the improvement of ethics in the CMPSC. Many are unaware and unable to spot ethical breaches in supply chains and the knowledge of blockchain that is held by most people is limited to its cryptocurrency application. Hence, training and awareness sessions on blockchain and ethics (in the supply chain) must emerge among supply chain players, construction professionals, clients and the general public. Such trainings may be incorporated into the academic syllabus and professional training programmes.

4. Cultural Change: The adoption of blockchain technology may require changes in the practises and organisational culture of organisations. According to Mougayar (2016), the use of blockchain technology in particular has the potential to alter present organisational cultures and replace legacy systems upon which companies have made heavy investments. The more prevalent competitive and adversarial attitudes of people within the supply chain must change to one that is more collaborative, where people are willing to work together, share information and collaborate with other players. As discussed in Chapter 3, blockchain is a team sport, and in Chapter 4, it is revealed that the success of the proposed model relies hugely on the willingness of people to collaborate. Aside from education, the required change may also be achieved through legislation, as the findings of this study reveal that one of the three main factors affecting the effectiveness of current ethical measures is the role of government.

5. Develop and Launch Mainnet: Following extensive simulations and testing of the networks on the testnet, the mainnet deployment is the stage that logically comes after the completion of all the necessary trials on the testnet. It is expected that application developers and early users would have experimented with the features, protocols and functions of the elements of the network in different settings and any emanating issues or challenges would have been addressed by the relevant parties. It is also assumed that while on one hand, the networks are being developed and the networks are being tested on the testnet, on the other hand, the maturity and uptake of blockchain as well as global digitisation would also be growing concurrently, thereby making the development, adoption and implementation of a real main network, which is the original and fully functional blockchain network where actual transactions will take place more feasible.

6. Onboarding and Uptake: Based on a finding from this research which indicates that uptake of innovation in the industry is based on demand, internal or external, therefore, in addition to the invitational voluntary uptake achieved by the SITs working their way upstream, encouraging the relevant organisations to participate and submit relevant data. A demand-led snowballing downstream to upstream approach could also be utilised to give the acceptance and implementation of the model some teeth. For example, with regard to the MP-Network, clients who are both knowledgeable in blockchain and ethics-conscious, who through their interaction with the model in the testnet consider it valuable for the improvement of ethics, can then demand its implementation from their suppliers. The supplier may then in turn demand the same from the producers, who in turn demand the same from the manufacturers of their raw materials, and the "chain of demand" grows and goes on from there.

7.7 Summary

In this chapter, the findings from both the interviews and focus group, how they are associated with the existing literature and how they address the research questions and objectives of this study are interpreted and explained thematically. Also in this chapter, arguments to support the entire discussion and to explain the insights that emerged as a result of this study were presented. In the first theme, the state of ethics in the CMPSC is discussed with the triple bottom line construct. It was concluded that the current state of ethics in the CMPSC is weak across the three dimensions examined. From the results, it appears that the industry is more concerned about the business dimension of ethics. The discussion of the findings in this theme help to understand why construction firms seem to be placing greater emphasis on the business component of ethics, while the environmental or social component may only receive as much attention if it can be monetised or if it is demanded. In discussing theme 2, it was concluded that the effectiveness of current ethical measures in the CMPSC has been limited. Due to low implementation and compliance, the inability of the government to fully play their role in enforcing these measures and the outright denial of the presence of unethical practises within construction and/or supply chain organisations.

In theme 3, it is concluded that in addition to educating professionals and the general public alike on ethics, blockchain may also help to improve ethics in the CMPSC particularly because of its transparency and immutability features. Although, findings also admittedly suggest that the current level of digitisation globally may not be sufficient to fully host and run the model, therefore widespread implementation may only be plausible in the future. It is also concluded that the overall success of any measure to improve ethics in the CMPSC is largely dependent upon the personal ethical values of individuals. Finally, based on the results presented and discussed in theme 4, it was concluded that the developed model is valid and capable of helping to improve ethics in CMPSC within the TBL construct. Although it also still possesses its own limitations and challenges that must be addressed for the model to enjoy acceptance and implementation. Nonetheless, it is concluded that the model possesses sufficient potential value to warrant and justify the rigors that its uptake may require.

Chapter 8 Conclusions and recommendations

8.1 Introduction

This chapter presents the overall conclusions and recommendations drawn from the entire research. It begins with a reiteration of how the research objectives and questions were achieved and addressed respectively by highlighting the significant findings, followed by the contribution to knowledge and research limitations. Finally, recommendations for further work are made.

8.2 Achievement of research aim and objectives

This research has achieved its overall aim of developing and validating a model for improving ethics across the CMPSC following the TBL construct using blockchain technology. The 5 research objectives and 4 research questions are restated below to highlight how well they were met during the different stages of the research.

8.2.1 Conclusions related to objective 1

Research objective 1: To evaluate the current state of ethics in the CMPSC following the TBL construct and how effective the current ethical measures have been.

Research question 1: *What is the current state of ethics in the CMPSC and how effective are the current measures to improve ethics in the CMPSC?*

The first objective was achieved by an in-depth review of relevant literature, which was conducted in Chapter 2. It provided a detailed understanding of the nature of the construction industry and takes a holistic TBL approach to evaluate the current ethical state of its materials and products supply chain to help understand how effective the current ethical measures have been. From the reviewed literature, it was seen that the current state of ethics in the CMPSC is weak across the three dimensions examined, as unethical practises in the CMPSC are still prominent. This was again confirmed by the main empirical study in Chapter 6. Based on literature, evidence of unethical environmental, social and business practices is still abundant in the CMPSC. People-related issues are known to have a poor record in construction, particularly for health and safety. The industry and its clients have also been accused of operating unethically, such as obtaining timber from unsustainable sources and extracting minerals in a way that results in human rights violations. Findings from this study also revealed that although the increasing emphasis on corporate social responsibility, fair payments, responsible supply chain management, moral judgements, sustainability and the environment in construction has urged companies to apply ethical standards to their activities, industry players still place greater emphasis on the business dimension of ethics, while the environmental or social component may only receive as much attention if it can be monetised or if it is demanded.

Extant literature also revealed that although several measures to improve ethics in the industry have already been proposed and employed with varying degrees of implementation across various countries, the effectiveness of these current ethical measures in the CMPSC has been limited mainly due to corruption, defragmentation and the complexity of the CMPSC. The empirical study in Chapter 6 also confirmed this and identified other causes for the limited effect of the current measures to improve ethics in the CMPSC. Hence, the need for the development of systems that can help to further improve ethics in the CMPSC.

8.2.2 Conclusions related to objective 2

Research objective 2: To study blockchain technology and its implementations for ethics within the TBL construct, in view of applying the learnings to evaluate its feasibility to improve ethics in the CMPSC.

Research question 2: *Is blockchain technology capable of impacting ethics in supply chains across the TBL construct?*

The second objective was achieved by an in-depth review of relevant literature, which was conducted in Chapter 3 to study the workings of blockchain technology and its implementations for ethics. It revealed that based on the features of blockchain technology, it indeed has the potential to improve current ethical levels within the TBL construct by acting as a digital enabler across the supply chain. It also showed that blockchain is currently helping to improve ethics within the supply chain use cases where it is being utilised to meet ethical goals. The study of literature revealed that blockchain shows the potential to tackle global environmental challenges and help with addressing issues like climate change, energy, biodiversity conservation, water security, ocean sustainability, and air pollution; and it is currently being promoted by some energy businesses for green energy implementations.

With regard to social ethics, the study also showed that blockchain technology has the potential to enhance the sustainability of social supply chains since its traceability and security promote sustainability through improved assurance of human rights and fair, safe work practises. Concerning business ethics, the study revealed that the technology can help to mitigate potential opportunistic behaviours in business environments through its features. It revealed that due to its features, it can help provide transparency and prevent fraud between transacting business parties, foster integrity in bureaucracies, track the flow of funds and assets, remove payment bottlenecks, register assets and secure registries, notarize and enforce contract terms, etc. As a result, several blockchain projects are being developed, mostly in the financial and supply chain sectors to improve business ethics within their organisations and supply chains.

However, the study also revealed that blockchain is not a panacea for addressing ethical concerns and that instead of relying on a technology as a remedy for a complicated problem, successful approaches would require an understanding of the plethora of elements that indicate and contribute to ethical risk and seek to mitigate it in every way possible. The study also helped to identify some challenges and barriers that must be addressed for the successful implementation of the technology for supply chains, which were also confirmed and further enriched by the empirical study in Chapter 6. The in-depth understanding of the nature of the CMPSC as discussed in Chapter 2, coupled with a rich understanding of the workings of blockchain technology and its potential to impact ethics across the TBL as discussed in Chapter 3 led to the development of a model to improve ethics in the CMPSC, which is presented and discussed in Chapter 4 and validated in Chapter 6 of this study.

8.2.3 Conclusions related to objective 3

Research objective 3: To establish how blockchain technology can help to improve ethics in the CMPSC within the TBL construct.

Research question 3: *How can blockchain help to improve ethics in the CMPSC within the TBL construct?*

Based on the learnings from Chapters 2 and 3, this study establishes how blockchain technology can help to improve environmental ethics, social ethics and business ethics in Chapter 4. This was also corroborated by the findings from the empirical study in Chapter 6 of this research. The study revealed that, to improve environmental ethics in the CMPSC, blockchain can act as a digital enabler to grow a network of ethical players whose products and services meet fundamental environmental ethical standards throughout their life cycle: from raw material extraction to production, distribution, use and recycle. The study reveals that blockchain can help to improve environmental ethics in the CMPSC by helping to foster ethical environmental production across the various stages and actors in the

CMPSC, demonstrate respect for environmental ethics in production, sustain continuity of commitment to environmental ethical standards, curb greenwashing, foster environmental ethics through transparency and foster circular construction through trust.

While it remains difficult to address modern slavery issues within supply chains, this study reveals that blockchain can help to improve social ethics in CMPSC when the technology is utilised to track ethical claims and fair-trading practices. This can be achieved by setting up a permissioned network on blockchain consisting only of supply chain actors who adhere to anti-modern slavery standards within their organisation. Such a network can foster due diligence within the supply chain through its "trustable data and network", help to ensure that member organisations sustain adherence to social ethical standards within their organisation, assure customers of adherence to social ethical standards and urge a demand for the same from other supply chain actors outside the network.

The study revealed that unethical activities in the construction industry take many forms, including bribery to secure planning approval, budget overstating, counterfeiting of construction materials and products, payment demand abuse, and purchasing from unethical players to save costs. The study affirms that blockchain can help to address some of these issues and as a result, help to improve business ethics in the CMPSC. This can be achieved by setting up a consortium network on blockchain consisting of project stakeholders and clients with improved transparency and recording of decisions and transactions. Such a network can help to deter and detect unethical business activities through its immutable history of commitments, achieve required oversight to curb unethical business activities through its four-eyes protocol, ensure fair payment through smart contracts, track BIM modification provenance and curb the purchase of counterfeits through asset digitization and supply chain transparency.

8.2.4 Conclusions related to objective 4

Research objective 4: To determine the factors that may affect the acceptance and implementation of blockchain technology in the CMPSC.

Research question 4: *What factors may affect the acceptance and implementation of blockchain technology in the construction industry?*

The literature reviewed in Chapter 3 as well as the primary data from the interviews and focus group analysed and presented in Chapter 6 of this study help to fulfil the fourth objective of this study and to address its attendant research question. The findings reveal that although blockchain holds promising potential for improving ethics in the CMPSC, certain factors that may affect the acceptance and implementation of technology in the CMPSC exist. As discussed in Section 3.9, the factors identified in the literature review are summarised and grouped into three main categories, namely: factors related to the blockchain system, factors related to the construction industry and factors related to external barriers. This list was broadened by the analysis of findings from the interviews and focus group presented in Chapter 6 to include other factors, such as: scepticism surrounding the technology, knowledge of blockchain technology, digitised ecosystem, resistance to change, client's awareness and demand for it, cost of implementing the model, differing standards across boundaries, simplicity in use, digitised ecosystem, need for awareness, lack of adequate infrastructure in developing countries, issue of corruption and the cost of procuring the infrastructure.

8.2.5 Conclusions related to objective 5

Research objective 5: To develop and validate a model for improving ethics in the CMPSC following the TBL construct using blockchain technology.

This objective was achieved through the development of a conceptual model to improve ethics in the CMPSC within the TBL construct. The findings from the previous stages of the research study were taken into consideration in the development of the model. As presented and discussed in Chapter 4, the model is underpinned by the theory of collective action, and it seeks to leverage blockchain technology to improve ethics in the CMPSC following the TBL construct. It proposes a sociotechnical solution to improve ethics in the CMPSC via a collective action approach that seeks to bring together the multiple parties involved in the construction materials and products supply chain, organisations that help to drive ethics in production and supply chain, customers who procure construction materials and products and stakeholders involved in the delivery of a construction project to work collaboratively to improve ethics within the TBL construct in the CMPSC. The model was refined and validated via a dual phase approach.

8.3 Summary of research conclusions

The following conclusions can be drawn from this study.

1. The current state of environmental ethics, social ethics and business ethics in the CMPSC is weak and inadvertently nurtures some unethical practices. A technologically driven approach could help businesses with their TBL without trade-offs which favour profitability to the detriment of socio-environmental dimensions.
2. Supply chain actors and construction firms need to pay more attention to the environmental and social dimensions of ethics within their organisation and supply chain as this makes for a more holistic ethical approach, which may also help to improve business gains in the long run.
3. The current measures to improve ethics within the CMPSC have impacted the supply chain positively. However, their full potential has been stifled by low implementation and sloppy compliance, the inability of the government to fully play their role in enforcing these measures and the outright denial of the presence of unethical practises within organisations.
4. To improve the state of ethics in the CMPSC considerably, supply chain actors, construction professionals, clients and the general public must be educated on ethics so that breaches can be easily spotted and addressed.
5. Blockchain possesses high potential to improve ethics within the TBL construct in the CMPSC, but the success of the technology in this wise is contingent upon successfully addressing the factors that may affect its acceptance and implementation.
6. The personal ethical values of individuals remain a major determinant for the success of both new and current ethical measures and the overall improvement of ethics in the CMPSC. No matter the sophistication of the technology or process, it is people who collaborate and as long as their personal value system is tending towards unethical or corrupt practices, the industry will continue to suffer.
7. Finally, the model developed in this study was validated and judged capable of improving ethics in CMPSC within the TBL construct. However, the model on its own cannot produce significant transformational results and its goals can only be fully realised when it is not simply treated as just another digital tool but as a system designed to re-engineer actions and processes, used in integration with other elements of the digital ecosystem by willing players.

8.4 Contribution to knowledge

This research makes both theoretical and practical contributions in the fields of construction management, ethics and sustainability, blockchain and information technology. The contributions made are presented in this section.

Practical contribution

The main contribution of this thesis to knowledge is the model developed to improve ethics in the CMPSC within the TBL construct using blockchain technology. This model provides practical clarity on how the technology may be implemented to improve ethics within fragmented supply chains. It also has a vital role in helping the intended users and actors improve their knowledge of the technology and how blockchain can help to improve ethics in the CMPSC and to also understand their roles and responsibilities on the network. The model was developed based on the existing literature, an understanding of blockchain technology and the CMPSC, and it was refined and validated by inputs from professionals in relevant fields, who also belong to the pool of the intended users of the model, such as actors from the fields of blockchain and information technology, ethics and sustainability, and construction supply chain. As such, the model possesses a valid understanding of the systems under investigation and provides the Setup and Implementation Team (SIT) with sufficiently comprehensive prerequisite guidance for insightful discussion, collaboration and agreement by the relevant stakeholders.

In addition, the model provides a significant understanding of a socio-technical approach to addressing the issue of ethics within construction supply chains. Also, it provides a considerable comprehension of the needs of the relevant stakeholders, which is needed for the development of the Testnet and Mainnet by Blockchain-as-a-Service (Baas) providers. Therefore, it serves as a framework and prerequisite guidance for the BaaS providers in the development of the blockchain network, without which the comprehension of the expectations of the Setup and Implementation Team (SIT) will be limited and the resulting network unsatisfactory.

Theoretical contributions

Firstly, while previous research mainly focused on the sustainability concerns ensuing from the activities of the construction industry (Akwada *et al.*, 2018; CIOB, 2018a; Ibrahim *et al.*, 2010; Omran and Schwarz-Herion, 2020; Stronger Together, 2019) and on blockchain technology in general and its implementation in other sectors (Boersma and Nolan, 2020; Hijazi *et al.*, 2019; Tezel *et al.*, 2019; Zheng *et al.*, 2017), this study takes an unconventional socio-technical approach to provide clarity on how these three dimensions of ethics can be improved in the construction materials and products supply chain through the emerging blockchain technology and collective action theory.

Secondly, by reviewing and capturing data on the current state of ethics in the CMPSC following the TBL construct, this research provides the knowledge required for understanding the effectiveness of current ethical measures, how their bottlenecks can be addressed, and it establishes 3 major routes to the improvement of ethics in the CMPSC, involving both technological and non-technological solutions, namely: through education, through blockchain technology and through the upholding of personal ethical values.

Finally, the findings of this thesis have demonstrated new evidence and insights and contributed to the existing body of knowledge by further advancing the discussion on the role of the blockchain in the construction industry with the model developed for improving ethics in the CMPSC across the TBL. It is also believed that the developed model forms a good basis for deepening the current body of knowledge on blockchain implementations for ethics in supply chains.

8.5 Research limitations

It is acknowledged that this study possesses some limitations in addition to the constraints in time and resources.

1. Regarding methodology, while the basis for the qualitative approach used in this research has been sufficiently justified. It is however acknowledged that the use of only qualitative methods results in methodological limitations that might impact the generalisability of the research findings. As findings from qualitative approaches may not be extended to wider populations with the same degree of certainty that quantitative analysis provides.

2. The findings of this study are based on the information provided by 30 participants, comprising of 16 construction industry professionals, 10 professionals in the ethics/sustainability in construction and 4 blockchain experts. However, the participants did not include upstream actors in the construction supply chain, such as miners, forestry managers, product manufacturers, recyclers, etc. Whereas the study would have likely benefitted from the input of a more balanced representation of the construction materials and products supply chain. Therefore, a possible limitation regarding the lack of interviews

with construction supply chain upstream actors is recognised.

3. Another limitation is the nascent nature of blockchain technology itself. The technology upon which the proposed model sits is still maturing. Hence, some of the assumptions held about the technology today may change in the future. As a result, the rapid pace of change in this field could impact the components and subcomponents of the model, particularly with the introduction of mutability in blockchains and the developments in quantum computing.

8.6 Future research

The use of blockchain-based tokenized payment systems in construction supply chains: As earlier discussed in the literature review, a major form of unethical practise in the construction supply chain is related to the misappropriation of funds. While the developed model proposes a token/digital currency agnostic solution, which implies that there is no preference built into the platform for any currency over any other and all digital currencies may be supported, the researcher also acknowledges that the use of a platform-based token as a means of payment, particularly on the Project Network and Procurement Network may enhance the traceability of funds flow within construction projects. Also, with de-cashing and tokenization becoming a reality all over the world today, and with the rapid growth of cryptocurrencies, Central Bank Digital Currencies (CBDC), network and platform-based tokens, etc., it is expected that future research could explore the use of blockchain-based tokenized payment systems in the construction supply chain, and its potential benefits and challenges. As IFoA (2018) suggests, tokenization impacts core market processes and the prospect of de-cashing the construction supply chain to any degree may constitute a fundamental economic and societal change that poses substantial risks and issues.

Blockchain interoperability: Another is regarding blockchain agnosticism, which is considered by some as a necessity for blockchain's future as it may allow organisation's different business solutions to be built or operated from different underlying blockchain technologies. Results from the first validation phase of the model revealed that interoperability between the model and existing and future ERP systems and blockchain solutions was highly desirable. Having refined the model to accommodate this feature, substantial challenges still exist in the interoperability of blockchain-blockchain and blockchain-ERPs as pointed out in Section 6.3.7. Furthermore, literature on blockchain interoperability and reports from real-life use cases is currently very sparse. Therefore, further research is needed to address the complexities of interoperability of blockchains and other more traditional systems and technologies.

Future evaluations and revisions of the model as the technology matures: Also, as earlier indicated, blockchain technology upon which the model is developed is still an emerging technology. As a result, the rapid pace of change in this field could impact the components and subcomponents of the proposed model. However, the time and scope of this research did not permit conducting a longitudinal study and evaluation of the model to this effect. As such, it is hard to foresee how participants' perspectives may shift during the course of a longitudinal study of the model or the implementation of the networks that might result from it. Therefore, it is suggested that the model be subjected to future evaluations and revisions both in organisational and academic environments as the technology matures to remain a relevant and useful solution for the industry.

Development of a sectoral roadmap to assist the adoption of blockchain for addressing the ethical challenges facing the sector: Finally, as earlier pointed out, unethical practices in the construction industry is still widespread and the industry still takes on a laggard approach to the uptake of new technology. Having developed a model with the potential to checkmate some of these unethical practices through blockchain and other associated technologies, there is therefore an imperative need to develop a sectoral roadmap to assist the industry in the adoption of blockchain and other associated technologies with a view to addressing various ethical challenges facing the sector.

References

101 Blockchains (2019) Introduction to Permissioned Blockchains. Available from: https://101blockchains.com/permissioned-blockchain/ [Accessed 17 August 2022].

Abere, S. A. and Opara, J. A. (2012) Deforestation and Sustainable Development in the Tropics : Causes and Effects, *Journal of Educational and Social Research*, 2 (January), pp. 105–110. Available from: https://www.richtmann.org/journal/index.php/jesr/article/view/11917/11522 [Accessed 25 February 2022].

Abeyratne, S. A. (2016) Blockchain ready manufacturing supply chain using distributed ledger, *International Journal of Research in Engineering and Technology*, 05 (09), pp. 1–10. DOI:10.15623/ijret.2016.0509001.

Abraham, J. (2007) Differentiating between and synthesizing quantitative, qualitative, and longitudinal research on polarized school cultures: A comment on Van Houtte (2006), *Taylor & Francis*, 39 (5), pp. 597–602. DOI:10.1080/00220270701487624.

Abrishami, S. and Elghaish, F. (2019) Revolutionising AEC financial system within project delivery stages : A permissioned blockchain digitalised framework Revolutionising AEC financial system within project delivery stages : A permissioned blockchain digitalised framework, (September). Available from: https://www.researchgate.net/publication/335892493 [Accessed 23 January 2020].

Abrishami, S., Goulding, J. S., Rahimian, F. P. and Ganah, A. (2014) Integration of BIM and generative design to exploit AEC conceptual design innovation, *Journal of Information Technology in Construction*, 19 (September), pp. 350–359.

Accenture (2017) Editing the Uneditable Blockchain - Accenture. Available from: https://www.accenture.com/us-en/insight-editing-uneditable-blockchain [Accessed 20 June 2022].

Adams, R., Kewell, B., Parry, G. C., Parry, G., Adams, R., Kewell, Á. B., Kewell, B., Strategy, G. P. and Management, O. (2017) Blockchain for good? Digital ledger technology and sustainable development goals, *Springer*, pp. 127–140. DOI:10.1007/978-3-319-67122-2_7.

Adetunji, I., Price, A. D. F. and Fleming, P. (2008) Achieving sustainability in the construction supply chain, *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, 161 (3), pp. 161–172. DOI:10.1680/ensu.2008.161.3.161.

Aggarwal, N. and Floridi, L. (2019) The Opportunities and Challenges of Blockchain in the Fight against Government Corruption, *19th General Activity Report, GRECO*, 82 (March), pp. 22–25. Available from: https://bitcoin.org/bitcoin.pdf [Accessed 21 February 2020].

Agnieszka Pikulicka-Wilczewska (2018) What happened to Ukraine's border wall against Russia? | Russia News | Al Jazeera, *Aljazeera News*,

Ahuja, R., Jain, M., Sawhney, A. and Arif, M. (2016) Architectural Engineering and Design Management Adoption of BIM by architectural firms in India: technology-organization-environment perspective. DOI:10.1080/17452007.2016.1186589.

Akanbi, O. A., Amiri, I. S. and Fazeldehkordi, E. (2014) *A Machine-Learning Approach to Phishing Detection and Defense*, *A Machine-Learning Approach to Phishing Detection and Defense*. Elsevier Inc. DOI:10.1016/c2014-0-03762-8.

Akwada, D. R., Akinlabi, E., Akwada, D. R. and Akinlabi, E. T. (2018) Bamboo an alternative wood to reducing tropical deforestation in Ghana, *Researchgate.Net*, pp. 11–13. Available from: https://www.researchgate.net/profile/Damenortey-Akwada/publication/327230922_-_Bamboo_an_alternative_wood_to_reducing_tropical_deforestation_in_Ghana/links/5b824165a6fdcc5f8b6889d5/Bamboo-an-alternative-wood-to-reducing-tropical-deforestation-in-Ghana.pdf [Accessed 4 February 2022].

Al-Breiki, H., Rehman, M. H. U., Salah, K. and Svetinovic, D. (2020) Trustworthy Blockchain Oracles: Review, Comparison, and Open Research Challenges, *IEEE Access*, 8, pp. 85675–85685. DOI:10.1109/ACCESS.2020.2992698.

Al-Jaroodi, J. and Mohamed, N. (2019) Blockchain in Industries: A Survey, *IEEE Access*, 7, pp. 36500–36515. DOI:10.1109/ACCESS.2019.2903554.

Amaratunga, D., Baldry, D., Sarshar, M. and Newton, R. (2002) Quantitative and qualitative research in the built environment: application of "mixed" research approach, *Work Study*, 51 (1), pp. 17–31. DOI:10.1108/00438020210415488.

Ameyaw, E. E., Pärn, E., Chan, A. P. C., Owusu-Manu, D.-G., Edwards, D. J. and Darko, A. (2017) Corrupt Practices in the Construction Industry: Survey of Ghanaian Experience, *Journal of Management in Engineering*, 33 (6), pp. 05017006. DOI:10.1061/(ASCE)ME.1943-5479.0000555.

Andrew, C., Dirk, M., Sarah, G. and Laura, S. (2019) *Business Ethics: Managing Corporate Citizenship and Sustainability* . Available from: https://books.google.co.uk/books?hl=en&lr=&id=fcSbDwAAQBAJ&oi=fnd&pg=PP1&dq=coopertae+ethics&ots=MsfdkvnZKB&sig=xmV9hNDXR5-q4WKnteptidw8cSc&redir_esc=y#v=onepage&q&f=false

Androulaki, E., Barger, A., Bortnikov, V., Muralidharan, S., Cachin, C., Christidis, K., *et al.* (2018) Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains, in: *Proceedings of the 13th EuroSys Conference, EuroSys 2018*.2018-Janua,.

Ansari, S., Hameed Panhwar, A., Akbar Mahesar, G., Panhwar, A. H., Akbar, G. and Ariel, M. / (2016) *Mixed Methods Research: Ontological, Epistemological and Methodological underpinnings*, *ARIEL An International Research Journal of Language and Literature*. Vol. 27. Available from: http://sujo.usindh.edu.pk/index.php/ARIELhttp://sujo.usindh.edu.pk/index.php/

Anthony Bowen, P., Edwards, P. J., Cattell, K. and Anthony Bowen Ã, P. (2012) Construction Management and Economics Corruption in the South African construction industry: a thematic analysis of verbatim comments from survey participants Corruption in the South African construction industry: a thematic analysis of verbatim comments , *Construction Management and Economics*, 30. DOI:10.1080/01446193.2012.711909.

Archibald, M. M., Ambagtsheer, R. C., Casey, M. G. and Lawless, M. (2019) Using zoom videoconferencing for qualitative data collection: perceptions and experiences of researchers and participants, *Journals.Sagepub.Com*, 18. DOI:10.1177/1609406919874596.

Arnold, U., Neubauer, J. and Schoenherr, T. (2012) Explicating factors for companies' inclination towards corruption in Operations and supply chain management: An exploratory study in Germany, *International Journal of Production Economics*, 138 (1), pp. 136–147. DOI:10.1016/j.ijpe.2012.03.011.

Auditchain (2018) Decentralized Continuous Audit & Reporting Protocol Ecosystem Whitepaper, pp. 0–21.

Autodesk (2020) *Scope of Blockchain in BIM*. Autodesk University. Available from: https://www.autodesk.com/autodesk-university/article/Scope-Blockchain-BIM-2020

Automated Trading (2014) History of Trading Systems – Automated Trading. Available from: https://www.automatedtrading.com/2014/01/13/history-trading-systems/ [Accessed 24 April 2020].

Ayinla, K. O. and Adamu, Z. (2018) Bridging the digital divide gap in BIM technology adoption, *Engineering, Construction and Architectural Management*, 25 (10), pp. 1398–1416. DOI:10.1108/ECAM-05-2017-0091/FULL/HTML.

Aziz, Z., Anumba, C. and Peña-Mora, F. (2009) A road-map to personalized context-aware services delivery in construction, *Electronic Journal of Information Technology in Construction*, 14, pp. 461–472.

Aziz, Z., Riaz, Z. and Arslan, M. (2017) Leveraging BIM and Big Data to deliver well maintained highways, *Facilities*, 35 (13–14), pp. 818–832. DOI:10.1108/F-02-2016-0021/FULL/PDF.

Baldwin, A., & Bordolli, D. (2014) *A handbook for project planning and scheduling.*

Baliga, A. (2016) The Blockchain Landscape Office of the CTO, *Persistent Systems Ltd*, pp. 21. Available from: https://www.persistent.com/wp-content/uploads/2016/03/The-Blockchain-Landscape-.pdf [Accessed 30 January 2020].

Baliga, A. (2017) *Understanding Blockchain Consensus Models*. Available from: www.persistent.com

Banerjee, S. and Kashyap, N. (2018) *Rogue Trade: The AML & KYC Challenge in Monitoring Virtual Currencies*.

Baranwal, P. R. (2020) Avoiding Counterfeits and Achieving privacy in Supply Chain : A Blockchain Based Approach Avoiding Counterfeits and Achieving privacy in Supply Chain : A Blockchain Based Approach, (December), pp. 0–6.

Bartoletti, M., Lande, S., Loddo, A., Pompianu, L. and Serusi, S. (2021) Cryptocurrency scams: Analysis and perspectives, *IEEE Access*, 9, pp. 148353–148373. DOI:10.1109/ACCESS.2021.3123894.

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C. M. and Crowther, T. W. (2019) The global tree restoration potential, *Science*, 364 (6448), pp. 76–79. DOI:10.1126/SCIENCE.AAX0848/SUPPL_FILE/AAX0848_BASTIN_SM_DATA-FILE-S2.CSV.

Belle, I. (2017) The architecture, engineering and construction industry and blockchain technology, in: Research Gate,.

Beniiche, A. (2020) A Study of Blockchain Oracles. Available from: https://arxiv.org/abs/2004.07140v2 [Accessed 7 March 2022].

Bentley, A. F. H. (1967) The Process of Government, *The Process of Government*. DOI:10.4159/HARVARD.9780674733657/PDF.

Bheemaiah, K. (2017) *The Blockchain alternative: Rethinking macroeconomic policy and economic theory*, *The Blockchain Alternative: Rethinking Macroeconomic Policy and Economic Theory*. Apress Media LLC. DOI:10.1007/978-1-4842-2674-2.

Blengini, G. A. and Shields, D. J. (2010) Green labels and sustainability reporting: Overview of the building products supply chain in Italy, *Management of Environmental Quality: An International Journal*, 21 (4), pp. 477–493. DOI:10.1108/14777831011049115/FULL/PDF.

Blismas, N., information, A. D.-B. research & and 2003, undefined (2010) Computer-aided qualitative data analysis: panacea or paradox?, *Taylor & Francis*, 31 (6), pp. 455–463. DOI:10.1080/0961321031000108816.

Blummer, T. and Bohan, S. (2018) *ABOUT HYPERLEDGER*. Available from: https://wiki.hyperledger.org/groups/pswg/performance-and-scale-wg%0Ahttps://www.hyperledger.org/wp-content/uploads/2018/07/HL_Whitepaper_IntroductiontoHyperledger.pdf

Boersma, M. and Nolan, J. (2020) Can Blockchain Help Resolve Modern Slavery in Supply Chains?, *AIB Insights*, 20 (2), pp. 2–5. DOI:10.46697/001c.13542.

Bowen, P. A., Edwards, P. J. and Cattell, K. (2012) Corruption in the South African construction industry: A thematic analysis of verbatim comments from survey participants, *Construction Management and Economics*, 30 (10), pp. 885–901. DOI:10.1080/01446193.2012.711909.

Bowen, P., Akintoye, A., … R. P.-C. and 2007, undefined (2007) Ethical behaviour in the South African construction industry, *Taylor & Francis*, 25 (6), pp. 631–648. DOI:10.1080/01446190701225707.

Branca, T. A., Colla, V., Algermissen, D., Granbom, H., Martini, U., Morillon, A., Pietruck, R. and Rosendahl, S. (2020) Reuse and recycling of by-products in the steel sector: Recent achievements paving the way to circular economy and industrial symbiosis in europe, *Metals*, 10 (3). DOI:10.3390/met10030345.

Brancalion, P. H. S. and Holl, K. D. (2020) Guidance for successful tree planting initiatives, *Journal of Applied Ecology*, 57 (12), pp. 2349–2361. DOI:10.1111/1365-2664.13725.

Braun, V. and Clarke, V. (2006) Using thematic analysis in psychology, *Qualitative Research in Psychology*, 3 (2), pp. 77–101. DOI:10.1191/1478088706qp063oa.

BREEAM (2018) Is it really green? Available from: www.greenbooklive.com [Accessed 25 October 2021].

Brown, R. G. (2018) The Corda Platform: An Introduction, *Corda Platform White Paper*, pp. 1–21. Available from: https://www.corda.net/wp-content/uploads/2018/05/corda-platform-whitepaper.pdf [Accessed 14 February 2020].

Bryman, A., Becker, S. and Sempik, J. (2008) Quality criteria for quantitative, qualitative and mixed methods research: A view from social policy, *International Journal of Social Research Methodology*, 11 (4), pp. 261–276. DOI:10.1080/13645570701401644.

Buch, H. (2020) Enterprise Integration and Interoperability of Blockchain | Network Computing. Available from: https://www.networkcomputing.com/network-security/enterprise-integration-and-interoperability-blockchain [Accessed

Buildings Performance Institute Europe (2021) Addressing the hidden emissions in buildings.

Burdette, F. L. (1973) Tradition and Authority, *History: Reviews of New Books*, 1 (3), pp. 66–66. DOI:10.1080/03612759.1973.9945870.

Butner, K. (2010) The smarter supply chain of the future, 38 (1), pp. 22–31. DOI:10.1108/10878571011009859.

Cameron, R. (2009) A sequential mixed model research design: Design, analytical and display issues, *International Journal of Multiple Research Approaches*, 3 (2), pp. 140–152. DOI:10.5172/mra.3.2.140.

Carey Wodehouse (2020) What Will Blockchain Mean for Data Storage? Blockchain Data Basics. Available from: https://blog.purestorage.com/perspectives/what-will-blockchain-mean-for-data-storage/ [Accessed 7 March 2022].

Castiglione, F., Mancini, E., Pedicini, M. and Jarrah, A. S. (2018) Quantitative modelling approaches, in: *Encyclopedia of Bioinformatics and Computational Biology: ABC of Bioinformatics*. Elsevier,1–3, pp. 874–883.

CH Alliance (2019) *Crypto Assets, a New Frontier for KYC*.

Chan, K. V, Moon, I., K Roeder, T. M., Macal, C., Rossetti, M. D., Robinson Gilbert Arbez Louis Birta, S. G. and Tolk Gerd Wagner, A. (2015) *CONCEPTUAL MODELING: DEFINITION, PURPOSE AND BENEFITS*.

Chartered Institute of Building (2016) Building a fairer system: tackling modern slavery in construction supply chains, pp. 1–60. Available from: https://policy.ciob.org/wp-content/uploads/2016/07/CIOB_Modern_Day_Slavery_WEB.pdf [Accessed

Chaum, D. L. (1982) *Computer Systems Established, Maintained and Trusted by Mutually Suspicious Groups*. University of California, Berkeley.

Chimeli, A., Boyd, R., Economics, D. A.-A. and 2012, undefined (2011) International timber markets and tropical deforestation: the evidence from prices, *Taylor & Francis*, 44 (10), pp. 1303–1314. DOI:10.1080/00036846.2010.539545.

Christine Kim (2019, October 21) Bitcoin News Roundup for April 15, 2020 - CoinDesk, *Coindesk*. Available from: https://www.coindesk.com/bitcoin-news-roundup-for-april-15-2020 [Accessed 24 April 2020].

CIOB (2010) *A REPORT EXPLORING PROCUREMENT IN THE CONSTRUCTION INDUSTRY*. Available from: www.ciob.org

CIOB (2018a) Construction and the Modern Slavery Summary Report.

CIOB (2018b) TACKLING EXPLOITATION IN THE UK.

CIPS (2013) Ethical and Sustainable, *Chartered Institute of Purchasing and Supply*, 2013, pp. 32.

Claybaugh, Z. (2006) Research Guides: Organizing Academic Research Papers: Types of Research Designs. Available from: https://library.sacredheart.edu/c.php?g=29803&p=185902 [Accessed 2 December 2020].

Clement, D., Aliabadi, A. A., Mackey, J., Thé, J. and Gharabaghi, B. (2021) Dust Emissions Management Model for Construction Sites, *Journal of Construction Engineering and Management*, 147 (8), pp. 04021092. DOI:10.1061/(ASCE)CO.1943-7862.0002121.

Codinhoto, R., Li, H., Ullah, K., Witt, E. and Lill, I. (2022) The BIM-Based Building Permit Process: Factors Affecting Adoption. DOI:10.3390/buildings12010045.

Cohen, L. (1985) Strategy or identity: New theoretical paradigms and contemporary social movements, *JSTOR*. Available from: https://www.jstor.org/stable/40970395 [Accessed 17 February 2022].

Cole, R., Stevenson, M. and Aitken, J. (2019) Blockchain technology: implications for operations and supply chain management, *Supply Chain Management: An International Journal*, 24 (4), pp. 469–483. DOI:10.1108/SCM-09-2018-0309.

Coleman, E. A., Schultz, B., Ramprasad, V., Fischer, H., Rana, P., Filippi, A. M., *et al.* (2021) Limited effects of tree planting on forest canopy cover and rural livelihoods in Northern India, *Nature Sustainability 2021 4:11*, 4 (11), pp. 997–1004. DOI:10.1038/s41893-021-00761-z.

Concrete Sustainability Council (2020) Concrete Sustainability Council Technical Manual Version 2.1.

Consensys (2018) Blockchain Payments: Project i2i Case Study. Available from: https://consensys.net/blockchain-use-cases/finance/project-i2i/ [Accessed 15 April 2020].

Construction Blockchain Consortium (2020) *Financing & Procurement Working Group Construction Blockchain Consortium Blockchain & Construction Cash Flow White Paper 1 Revision 1.0 CONSTRUCTION BLOCKCHAIN CONSORTIUM (CBC) WHITE PAPER SERIES CONSTRUCTIONBLOCKCHAIN.ORG*.

Construction News (2019) Whistleblowing: Construction can't forever lag behind other industries | Construction News. Available from: https://www.constructionnews.co.uk/agenda/opinion/expert/whistleblowing-construction-cant-forever-lag-behind-industries-02-08-2019/ [Accessed 16 June 2022].

Conti, M., Gangwal, A. and Todero, M. (2019) Blockchain trilemma solver algorand has dilemma over undecidable messages, *ACM International Conference Proceeding Series*. DOI:10.1145/3339252.3339255.

Cordeiro, A. and Vieira, F. (2011) Barriers to innovation amongst small and medium-sized enterprises (SMEs) in Portugal.

Corrugated Metals Inc (2013) *The Cost of Counterfeit Metal Construction Materials About the Author*.

CoST International (2016) *Strategic Review of the Construction Sector Transparency (CoST) Initiative Final Report Construction Sector Transparency Initiative*.

Creswell (2009a) Mixed Methods Procedures.

Creswell, J. C. (2009b) *Choosing a Mixed Methods Design*, *Designing and Conducting Mixed Methods Research*. Available from: http://www.antle.iat.sfu.ca/courses/iat834/resources/Creswell&Clark_Chap4&5.pdf

Crunchbase [no date] Bimchain - Crunchbase Company Profile & Funding. Available from: https://www.crunchbase.com/organization/bimchain [Accessed 12 February 2022].

Dabbagh, M., Sookhak, M. and Safa, N. S. (2019) The evolution of blockchain: A bibliometric study, *IEEE Access*, 7, pp. 19212–19221. DOI:10.1109/ACCESS.2019.2895646.

Dakhil, A. J. (2017) *Building Information Modelling (BIM) maturity-benefits assessment relationship framework for UK construction clients*.

Dangel, U. (2016) *The World's Forests*, *Turning Point in Timber Construction*. DOI:10.1515/9783035608632-002.

Das, M., Luo, H. and Cheng, J. C. P. (2020) Securing interim payments in construction projects through a blockchain-based framework, *Automation in Construction*, 118, pp. 103284. DOI:10.1016/j.autcon.2020.103284.

Dasaklis, T. K., Voutsinas, T. G. and Mihiotis, A. (2021) Integrating blockchain with Enterprise Resource Planning systems: Benefits and challenges, *ACM International Conference Proceeding Series*, pp. 265–270. DOI:10.1145/3503823.3503873.

Dave, B., Buda, A., Nurminen, A. and Främling, K. (2018) A framework for integrating BIM and IoT through open standards, *Automation in Construction*, 95, pp. 35–45. DOI:10.1016/J.AUTCON.2018.07.022.

de Freitas Netto, S. V., Sobral, M. F. F., Ribeiro, A. R. B. and Soares, G. R. da L. (2020) Concepts and forms of greenwashing: a systematic review, *Environmental Sciences Europe*, 32 (1). DOI:10.1186/S12302-020-0300-3.

De Jong, M., Henry, W. P., And, P. E. ; and Stansbury, N. (2009) *Eliminating Corruption in Our*

Engineering/ Construction Industry, *Leadership Manage. Eng*.

De La Pena, J. and Papadonikolaki, E. (2019) From relational to technological trust: How do the Internet of Things and Blockchain technology fit in?, *Proceedings of the 2019 European Conference on Computing in Construction*, 1, pp. 415–424. DOI:10.35490/ec3.2019.153.

Delmas, M. A. and Burbano, V. C. (2011) The drivers of greenwashing, *California Management Review*, 54 (1), pp. 64–87. DOI:10.1525/CMR.2011.54.1.64.

Deloitte (2017) *Continuous interconnected supply chain Using Blockchain & Internet-of-Things in supply chain traceability Introduction 03*.

DeMarrais, E. and Earle, T. (2017) Collective Action Theory and the Dynamics of Complex Societies, *Https://Doi.Org/10.1146/Annurev-Anthro-102116-041409*. DOI:10.1146/ANNUREV-ANTHRO-102116-041409.

Denzin, N. K., Lincoln, Y. S. and Giardina, M. D. (2006, November 1) Disciplining qualitative research, *International Journal of Qualitative Studies in Education*. DOI:10.1080/09518390600975990.

DEV Community (2017) Blockchain: what is in a block?- . Available from: https://dev.to/damcosset/blockchain-what-is-in-a-block-48jo [Accessed 27 January 2022].

Dewey, J. N., Llp, K., Wright, A., Alliance, E. E., Weinstein, J., Cohn, A., *et al.* (2020) Blockchain & Cryptocurrency Regulation.

Di Francesco Maesa, D. and Mori, P. (2020) Blockchain 3.0 applications survey, *Journal of Parallel and Distributed Computing*, 138, pp. 99–114. DOI:10.1016/j.jpdc.2019.12.019.

Djamba, Y. K. and Neuman, W. L. (2002) *Social Research Methods: Qualitative and Quantitative Approaches*, *Teaching Sociology*. Vol. 30. DOI:10.2307/3211488.

Doumbouya, L., Gao, G. and Guan, C. (2016) Adoption of the Building Information Modeling (BIM) for Construction Project Effectiveness: The Review of BIM Benefits, *American Journal of Civil Engineering and Architecture*, 4 (3), pp. 74–79. DOI:10.12691/ajcea-4-3-1.

Drisko, J. W. (1997) Strengthening Qualitative Studies and Reports, *Journal of Social Work Education*, 33 (1), pp. 185–197. DOI:10.1080/10437797.1997.10778862.

Dyllick, T. and Hockerts, K. (2002) Beyond the business case for corporate sustainability, *Business Strategy and the Environment*, 11 (2), pp. 130–141. DOI:10.1002/BSE.323.

Earth Watch Institute [no date] Biodiversity and construction industry. Available from: http://www.businessandbiodiversity.org/construction.html [Accessed

Easterby-Smith, M., Thorpe, R. and Jackson, P. (2012) *Management research*. Available from: https://books.google.com/books?hl=en&lr=&id=3VJdBAAAQBAJ&oi=fnd&pg=PP1&dq=Easterby-Smith+et+al.,+2012)+interviews&ots=AknppoG9VC&sig=-OwLqDEguRVmHRC8WAJRock_V9E

Easton, G. (2010) Critical realism in case study research, *Industrial Marketing Management*, 39 (1), pp. 118–128. DOI:10.1016/j.indmarman.2008.06.004.

Eastwood Sam, Ford James and Reynolds Libby (2020) Transparency in supply chains – modern slavery: holding business and public bodies to account | Perspectives & Events | Mayer Brown. Available from: https://www.mayerbrown.com/en/perspectives-events/publications/2020/09/transparency-in-supply-chains-modern-slavery-holding-business-and-public-bodies-to-account [Accessed 29 June 2022].

EBRD (2007) Fraud and corruption - definitions and guidelines for private sector operations, *European Bank of Reconstruction and Development*.

El-Haggar, S. M. (2007) Sustainability of Construction and Demolition Waste Management, *Sustainable Industrial Design and Waste Management*, pp. 261–292. DOI:10.1016/B978-012373623-9/50010-1.

Elangovan, N. and Rajendran, R. (2015) Conceptual Model: A Framework for Institutionalizing the Vigor in Business Research, *Third National Conference on Indian Business Management - The Emerging Management Paradigm in Indian Business*, (April), pp. 1–55. DOI:10.13140/RG.2.1.2164.8484.

Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y. M. and Milo, R. (2020) Global human-made mass exceeds all living biomass, *Nature 2020 588:7838*, 588 (7838), pp. 442–444. DOI:10.1038/s41586-020-3010-5.

Engebø, A., Kjesbu, N., Lædre, O., engineering, J. L.-P. and 2017, undefined (2015) Perceived consequences of counterfeit, fraudulent and sub-standard construction materials, *Elsevier*. Available from: https://www.sciencedirect.com/science/article/pii/S1877705817330709 [Accessed 8 February 2022].

Erol, I., Ar, I. M., Ozdemir, A. I., Peker, I., Asgary, A., Medeni, I. T. and Medeni, T. (2021) Assessing the feasibility of blockchain technology in industries: evidence from Turkey, *Journal of Enterprise Information Management*, 34 (3), pp. 746–769. DOI:10.1108/JEIM-09-2019-0309.

Esmaeilian, B., Sarkis, J., Lewis, K. and Behdad, S. (2020) Blockchain for the future of sustainable supply chain management in Industry 4.0, *Resources, Conservation and Recycling*, 163, pp. 105064. DOI:10.1016/J.RESCONREC.2020.105064.

Eugene Tarasenko (2020) How to Use Blockchain to Store Data - Merehead. Available from: https://merehead.com/blog/how-to-use-blockchain-to-store-data/ [Accessed 7 March 2022].

Falazi, G., Hahn, M., … U. B.-2019 I. 23rd and 2019, U. (2019) Process-based composition of permissioned and permissionless blockchain smart contracts, *Ieeexplore.Ieee.Org*. Available from: https://ieeexplore.ieee.org/abstract/document/8945020/?casa_token=jSovd3nrbgQAAAAA:FsH0VwfXAWw4OjMgPGk-LDPkxuo1nVFPPQsTqPc_c1diRF2Jfd-X9fEJqd4-zdUg6pLjTN9aoNE [Accessed 29 January 2022].

Feilzer, M. Y. (2010) Doing Mixed Methods Research Pragmatically: Implications for the Rediscovery of Pragmatism as a Research Paradigm, *Journals.Sagepub.Com*, 4 (1), pp. 6–16. DOI:10.1177/1558689809349691.

Fellows, R. and Liu, A. M. M. (2013) Construction Management and Economics Use and misuse of the concept of culture Use and misuse of the concept of culture, *Taylor & Francis*, 31 (5), pp. 401–422. DOI:10.1080/01446193.2013.794296.

Fenergo (2019) *Solving the KYC & AML challenge for cryptocurrencies, tokens & ICOs*. Available from: www.regtechinsight.com

Fewings, P. (2008) Ethics for the built environment, *Ethics for the Built Environment*, 9780203926, pp. 1–377. DOI:10.4324/9780203926901.

Fleischman, F., Basant, S., Chhatre, A., Coleman, E. A., Fischer, H. W., Gupta, D., *et al.* (2020) Pitfalls of Tree Planting Show Why We Need People-Centered Natural Climate Solutions, *BioScience*, 70 (11), pp. 947–950. DOI:10.1093/BIOSCI/BIAA094.

Flick, U. (2013) *The SAGE Handbook of Qualitative Data Analysis Uwe Flick*. Available from: https://books.google.co.uk/books?hl=en&lr=&id=R-6GAwAAQBAJ&oi=fnd&pg=PP1&dq=flick+2011+methodology&ots=L61j--v6Li&sig=2jz4eia3W4XQEQDE7PEuhtc2MBY

Forest News (2020) Tree planting is critical for sustainable future but can't fix climate change on its own - CIFOR Forests News. Available from: https://forestsnews.cifor.org/67447/tree-planting-critical-for-sustainable-future-but-cant-fix-climate-change-on-its-own?fnl=en [Accessed 4 February 2022].

Fourie, D. and Malan, C. (2021) Technological Approach to Ensure Ethical Procurement Management, *Factoring Ethics in Technology, Policy Making, Regulation and AI*. DOI:10.5772/INTECHOPEN.98650.

Gad, G. M. and Shane, J. S. (2014) Trust in the Construction Industry: A Literature Review, (May), pp. 2136–2145. DOI:10.1061/9780784413517.217.

Gao, S. and Low, S. P. (2014) Research Methodology, in: *Lean Construction Management*. Singapore: Springer Singapore, pp. 143–153.

Garland, H. and Staff, P. E. (1979) The overjustification effect, *Motivation and Emotion*, 3 (1), pp. 35–49. DOI:10.1007/bf00994159.

Gemma Francis (2020) Quarter of Britons say shopping green is too expensive | The Independent, *Independent*. Available from: https://www.independent.co.uk/news/uk/home-news/shoppers-britons-green-sustainability-poll-uk-b694630.html [Accessed 13 June 2022].

Gencer, A. E., Basu, S., Eyal, I., van Renesse, R. and Sirer, E. G. (2018) Decentralization in Bitcoin and Ethereum Networks, in: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*.10957 LNCS, pp. 439–457.

Gibbs (1997) Focus groups, *Social Research*. Available from: https://openlab.citytech.cuny.edu/her-macdonaldsbs2000fall2015b/files/2011/06/Focus-Groups_Anita-Gibbs.pdf [Accessed 8 April 2022].

Gilad, Y., Hemo, R., Micali, S., Vlachos, G. and Zeldovich, N. (2017) Algorand: Scaling Byzantine Agreements for Cryptocurrencies, *SOSP 2017 - Proceedings of the 26th ACM Symposium on Operating Systems Principles*, pp. 51–68. DOI:10.1145/3132747.3132757.

Gill, P., Stewart, K., Treasure, E. and Chadwick, B. (2008) Methods of data collection in qualitative research: interviews and focus groups, *British Dental Journal 2008 204:6*, 204 (6), pp. 291–295. DOI:10.1038/bdj.2008.192.

Gillinson, S. (2004) *Why Cooperate? A Multi-Disciplinary Study of Collective Action*.

Global Enviromental Facility (2019) Harnessing Blockchain Technology for the Delivery of Global Environmental Benefits A STAP Document, (March 2021). DOI:10.13140/RG.2.2.31542.63048.

Global Forest Resources (2020) Global Forest Resources Assessment 2020, *Global Forest Resources Assessment 2020*. DOI:10.4060/ca8753en.

Global Infrastructure Anti-Corruption Centre (2020, April) Procurement controls . Available from: https://giaccentre.org/procurement-controls/ [Accessed 4 February 2022].

GoChain (2019) GoChain: Blockchain at Scale. Available from: https://www.digitalcoindata.com/whitepapers/gochain-whitepaper.pdf [Accessed 10 February 2022].

Grant, A., Singh, H., Schweitzer, M., Useem, M. and Cappelli, P. (2011) The Problem with Financial Incentives - and What to Do About It - Knowledge at Wharton. Available from: https://knowledge.wharton.upenn.edu/article/the-problem-with-financial-incentives-and-what-to-do-about-it/ [Accessed 30 June 2022].

Grant, C. (2014) UNDERSTANDING, SELECTING, AND INTEGRATING A THEORETICAL FRAMEWORK IN DISSERTATION RESEARCH: CREATING THE BLUEPRINT FOR YOUR 'HOUSE'. DOI:10.5929/2014.4.2.9.

Gräuler, M. and Teuteberg, F. (2014) Greenwashing in Online Marketing-Investigating Trust-Building Factors Influencing Greenwashing Detection. Available from: https://www.researchgate.net/publication/258507737 [Accessed 22 January 2022].

Gurzawska, A. and Nl, M. G. (2019) Towards Responsible and Sustainable Supply Chains – Innovation, Multi-stakeholder Approach and Governance. DOI:10.1007/s40926-019-00114-z.

Hamann, R. and Kapelus, P. (2004) Corporate Social Responsibility in Mining in Southern Africa: Fair accountability or just greenwash?, *Development 2004 47:3*, 47 (3), pp. 85–92. DOI:10.1057/PALGRAVE.DEVELOPMENT.1100056.

Hamington (2009) Business is not a game: The metaphoric fallacy, *Journal of Business Ethics*, 86 (4), pp. 473–484. DOI:10.1007/s10551-008-9859-0.

Harrison, K. (2007) Environmental Politics Racing to the top or the bottom? Industry resistance to eco-labelling of paper products in three jurisdictions. DOI:10.1080/09644019908414496.

Hauge, J. (2020) Industrial policy in the era of global value chains: Towards a developmentalist framework drawing on the industrialisation experiences of South Korea and Taiwan, *World Economy*, 43 (8), pp. 2070–2092. DOI:10.1111/TWEC.12922.

Hede, A. J. and Bullen, R. B. (1982) Research Methodology, *Journal of Sound and Vibration*, 82 (1), pp. 39–49. DOI:10.1016/0022-460X(82)90541-7.

Helliar, C. V., Crawford, L., Rocca, L., Teodori, C. and Veneziani, M. (2020) Permissionless and permissioned blockchain diffusion, *International Journal of Information Management*, 54. DOI:10.1016/j.ijinfomgt.2020.102136.

Helo, P. and Shamsuzzoha, A. H. M. (2020) Real-time supply chain—A blockchain architecture for project deliveries, *Robotics and Computer-Integrated Manufacturing*, 63 (November 2019), pp. 101909. DOI:10.1016/j.rcim.2019.101909.

Hijazi, A. A., Perera, S., Alashwal, A. M., Alashwal, A. and Calheiros, R. N. (2019) *Blockchain Adoption in Construction Supply Chain: A Review of Studies Across Multiple Sectors Venturing Of Malaysian Construction Firms Into International Market View project Risk Management in the Abandoned Housing Projects in Malaysia View project Block*, *CIB World Building Congress*. Available from: https://www.researchgate.net/publication/333879452

Houben, R. and Snyers, A. (2018) Cryptocurrencies and blockchain: Legal context and implications for financial crime, money laundering and tax evasion, *European Parliament*. Available from: www.europarl.europa.eu/cmsdata/150761/TAX3 Study on cryptocurrencies and blockchain.pdf [Accessed

Howlett, M. (2021) Looking at the ‘field’ through a Zoom lens: Methodological reflections on conducting online research during a global pandemic, *Qualitative Research*. DOI:10.1177/1468794120985691.

Hunhevicz, J. J. and Hall, D. M. (2020) Do you need a blockchain in construction? Use case categories and decision framework for DLT design options, *Advanced Engineering Informatics*, 45. DOI:10.1016/j.aei.2020.101094.

IBM (2019) *Blockchain for trade: Examples and Lessons from real world implementations*.

IBM (2020) *Blockchain 3rd IBM Limited Edition*. Available from: http://www.wiley.com/go/permissions.

Ibrahim, A. R. Bin, Roy, M. H., Ahmed, Z. and Imtiaz, G. (2010) An investigation of the status of the Malaysian construction industry, *Benchmarking*, 17 (2), pp. 294–308. DOI:10.1108/14635771011036357/FULL/PDF.

IFoA (2018) *Cash and digital payments in the new economy* . Available from: https://www.actuaries.org.uk/documents/cashless-society-world-motion-2017-addendum

Im, H., Minchin, R. E., Zhang, Y. and Tian, Y. (2018) Research on Counterfeit Materials and Products in Construction Supply Chains, (September), pp. 0–12.

Independent Sector (2002) Ethics and the Nation's Voluntary and Philanthropic Community. Available from: www.IndependentSector.org. [Accessed 23 June 2022].

Ingwersen, W. W. and Subramanian, V. (2014) Guidance for product category rule development: Process, outcome, and next steps, *International Journal of Life Cycle Assessment*, 19 (3), pp. 532–537. DOI:10.1007/S11367-013-0659-0.

Institute of Civil Engineers (2018) Blockchain Technology in the Construction Industry - Digital Transformation for High Productivity, *Institute of Civil Engineers (ICE) Publication*, (December).

Iraldo, F., Griesshammer, R. and Kahlenborn, W. (2020) The future of ecolabels. DOI:10.1007/s11367-020-01741-9.

IRMA (2018) IRMA Standard for Responsible Mining. Available from: www.responsiblemining.net [Accessed 23 February 2022].

ISO (2000) ISO 14020:2000 - Environmental labels and declarations — General principles. Available from: https://www.iso.org/standard/34425.html [Accessed 7 February 2022].

ISO (2017) ISO and construction.

It, P. (2018) Permissioned vs Permissionless Blockchains : Understanding the Differences, pp. 1–6. Available from: https://blockonomi.com/permissioned-vs-permissionless-blockchains/ [Accessed 30 January 2020].

Jabbari, A. and Kaminsky, P. (2018) *Blockchain and Supply Chain Management*.

Jacobsson, M., Linderoth, H. C. J. and Rowlinson, S. (2017) The role of industry: an analytical framework to understand ICT transformation within the AEC industry, *Construction Management and Economics*, 35 (10), pp. 611–626. DOI:10.1080/01446193.2017.1315148.

Jeff, J. (2016) Accenture's Plan to Edit Blockchain Is Causing Some Controversy | Fortune. Available from: https://fortune.com/2016/09/20/accenture-blockchain/ [Accessed 20 June 2022].

Jelse, K. and Peerens, K. (2018) Using LCA and EPD in Public Procurement Within the Construction Sector, *Designing Sustainable Technologies, Products and Policies*, pp. 499–502. DOI:10.1007/978-3-319-66981-6_55.

Jiang, R., Wu, C., Lei, X., Shemery, A., Hampson, K. D. and Wu, P. (2022) Government efforts and roadmaps for building information modeling implementation: lessons from Singapore, the UK and the US, *Engineering, Construction and Architectural Management*. DOI:10.1108/ECAM-08-2019-0438.

John Kuada (2012) Chapter 9 Quantitative Data Collection Methods and Techniques, *Research Methodology: A Project Guide for University Students*, pp. 103–115.

Jonathan Watts (2019) Concrete: the most destructive material on Earth | Cities | The Guardian, *The Guardian*. Available from: https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth [Accessed 22 October 2021].

Jordan, G. (1999) The relevance of Bentley for group theory: Founding father or mistaken identity?, *History of the Human Sciences*, 12 (1), pp. 27–54. DOI:10.1177/09526959922120144.

Jordan Tuwiner (2019) 10 Best and Biggest Bitcoin Mining Pools 2019 (Comparison), *buybitcoinworldwide.com*. Available from: https://www.buybitcoinworldwide.com/mining/pools/ [Accessed 23 April 2020].

Jugder, N. (2019) The thematic analysis of interview data : an approach used to examine the influence of the market on curricular provision in Mongolian higher education institutions, (January 2016).

Karolina, D. (2021) How Does Construction Affect The Environment?, *Archdesk*. Available from: https://archdesk.com/blog/how-does-construction-affect-the-environment/ [Accessed

Kassem, M., Lia, J. and Greenwood, D. (2018) Blockchain in the built environment: analysing current applications and developing an emergent framework, in: pp. 59–66.

Kawabara, T. and Acharya, M. (2020) Blockchain Technology and Environmental Sustainability, *UN Environment Foresight Brief*, 19, pp. 1–9. Available from: https://wedocs.unep.org/bitstream/handle/20.500.11822/34226/1/FB019.pdf [Accessed

Kealey, D. J. and Protheroe, D. R. (1996) The effectiveness of cross-cultural training for expatriates: An assessment of the literature on the issue, *International Journal of Intercultural Relations*, 20 (2), pp. 141–165. DOI:10.1016/0147-1767(96)00001-6.

Keane, R., Holsinger, L., … M. M.-R. and 2017, undefined (2016) Evaluating future success of whitebark pine ecosystem restoration under climate change using simulation modeling, *Wiley Online Library*, 25 (2), pp. 220–233. DOI:10.1111/rec.12419.

Keister, O. R. (1963) Commercial Record-Keeping in Ancient Mesopotamia, *The Accounting Review*. American Accounting Association. DOI:10.2307/242928.

Khalfan, M. M., McDermott, P. and Swan, W. (2007) Building trust in construction projects, *Supply Chain Management*, 12 (6), pp. 385–391. DOI:10.1108/13598540710826308.

Kifokeris, D. and Koch, C. (2019) Blockchain in construction logistics: state-of-art, constructability, and the advent of a new digital business model in Sweden. DOI:10.35490/EC3.2019.163.

Kinnaird, C., Geipel, M. and Bew, M. (2017) *Blockchain technology: How the inventions behind Bitcoin are enabling a network.* Available from: https://scholar.google.com/scholar_lookup?title=Blockchain Technology&author=C. Kinnaird&publication_year=2017

Kitzinger, J. (1995) Qualitative Research: Introducing focus groups, *BMJ*, 311 (7000), pp. 299. DOI:10.1136/bmj.311.7000.299.

Kjesbu, N. E., Engebø, A., Lædre, O. and Lohne, J. (2017) Counterfeit, fraudulent and sub-standard materials: The case of steel in Norway, *IGLC 2017 - Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, pp. 805–812. DOI:10.24928/2017/0124.

Klitgaard, R. (1997) Cleaning up and invigorating the civil service, *Public Administration and Development*, 17 (5), pp. 487–509. DOI:10.1002/(sici)1099-162x(199712)17:5<487::aid-pad981>3.0.co;2-1.

Koehn, D. (1997) Business and game-playing: The false analogy, *Journal of Business Ethics*, 16 (12–13), pp. 1447–1452. DOI:10.1023/A:1005724317399.

Kubba, S. (2012) *Handbook of green building design and construction: LEED, BREEAM, and Green Globes*. Available from: https://books.google.com/books?hl=en&lr=&id=y5OOtNjk4QoC&oi=fnd&pg=PP1&dq=S.+Kubba,+Handbook+of+Green+Building+Design+and+Construction&ots=gi0uW6WGFM&sig=ESVyF7vyXjbjpligkY1qszGL1tM

Laffer Associates (2004) Does Corporate Social Responsibility Enhance Business Profitability.

Lai, X., Lu, C. and Liu, J. (2019) A synthesized factor analysis on energy consumption, economy growth, and carbon emission of construction industry in China, *Environmental Science and Pollution Research*, 26 (14), pp. 13896–13905. DOI:10.1007/S11356-019-04335-7.

Lambert, S. D. and Loiselle, C. G. (2008) Combining individual interviews and focus groups to enhance data richness, *Journal of Advanced Nursing*, 62 (2), pp. 228–237. DOI:10.1111/j.1365-2648.2007.04559.x.

Lamport, L. (1978) Time, Clocks, and the Ordering of Events in a Distributed System, *Communications of the ACM*, 21 (7), pp. 558–565. DOI:10.1145/359545.359563.

Lamport, L., Shostak, R. and Pease, M. (1982) *The Byzantine Generals Problem*.

Lanko, A., Vatin, N. and Kaklauskas, A. (2018a) Application of RFID combined with blockchain technology in logistics of construction materials, in: *MATEC Web of Conferences*.170,.

Lanko, A., Vatin, N. and Kaklauskas, A. (2018b) Application of RFID combined with blockchain technology in logistics of construction materials. DOI:10.1051/matecconf/201817003032.

Lasvaux, S., Leroy, Y. and C Briquet (2013) International Survey on Critical Review and Verification Practices in LCA with a Focus in the Construction Sector, *Hal.Archives-Ouvertes.Fr*. Available from: https://hal.archives-ouvertes.fr/hal-01785909/ [Accessed 27 June 2022].

LaVaque-Manty, M. (2006) Bentley, Truman, and the study of groups, *Annual Review of Political Science*. DOI:10.1146/annurev.polisci.9.072004.085705.

Lavikka, R., Kallio, J., Casey, T. and Airaksinen, M. (2018) Digital disruption of the AEC industry: technology-oriented scenarios for possible future development paths, *Construction Management and Economics*, 36 (11), pp. 635–650. DOI:10.1080/01446193.2018.1476729.

Le, Y., Shan, M., Chan, A. P. C. and Hu, Y. (2014) Overview of corruption research in construction, *Journal of Management in Engineering*, 30 (4). DOI:10.1061/(ASCE)ME.1943-5479.0000300.

Leong, C., Viskin, T. and Stewart, R. (2018) *Tracing the Supply Chain - How blockchain can enable traceability in the food industry*, *Accenture*. Available from: https://www.accenture.com/t20190115T192110Z__w__/us-en/_acnmedia/PDF-93/Accenture-Tracing-Supply-Chain-Blockchain-Study-PoV.pdf

Levers, M. J. D. (2013) Philosophical paradigms, grounded theory, and perspectives on emergence, *SAGE Open*, 3 (4). DOI:10.1177/2158244013517243.

Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A. and Koch, A. (2019) Restoring natural forests is the best way to remove atmospheric carbon, *Nature*, 568 (7750), pp. 25–28. DOI:10.1038/d41586-019-01026-8.

Li, J., Greenwood, D. and Kassem, M. (2019) Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases, *Automation in Construction*, 102, pp. 288–307. DOI:10.1016/j.autcon.2019.02.005.

Liang, Y., Liu, L., Tan, X., Huang, Z., Dang, J. and Zheng, W. (2016) The effect of self-esteem on corrupt intention: The mediating role of materialism, *Frontiers in Psychology*, 7 (JUL). DOI:10.3389/FPSYG.2016.01063/FULL.

Lindblad, H., Guerrero, J. R. and Rudolphsson Guerrero, J. (2020) Construction Management and Economics Client's role in promoting BIM implementation and innovation in construction Client's role in promoting BIM implementation and innovation in construction.

DOI:10.1080/01446193.2020.1716989.

Linderoth, H. C. J. (2017) From visions to practice – The role of sensemaking, institutional logic and pragmatic practice, *Construction Management and Economics*, 35 (6), pp. 324–337. DOI:10.1080/01446193.2016.1250930.

Litke, A., Anagnostopoulos, D. and Varvarigou, T. (2019) Blockchains for Supply Chain Management: Architectural Elements and Challenges Towards a Global Scale Deployment, *Logistics*, 3 (1), pp. 5. DOI:10.3390/logistics3010005.

Lobe, B., Morgan, D. and Hoffman, K. A. (2020) Qualitative Data Collection in an Era of Social Distancing:, *Https://Doi.Org/10.1177/1609406920937875*, 19. DOI:10.1177/1609406920937875.

Locatelli, G., Mariani, G., Sainati, T. and Greco, M. (2017) Corruption in public projects and megaprojects: There is an elephant in the room!, *International Journal of Project Management*, 35 (3), pp. 252–268. DOI:10.1016/J.IJPROMAN.2016.09.010.

Lu, S. and Sexton, M. (2004) *Appropriate research design for investigating innovation in small knowledge-intensive professional service firms*, *Heriot Watt University. Association of Researchers in Construction Management*. Vol. 2. Available from: http://www.arcom.ac.uk/-docs/proceedings/ar2004-0733-0739_Lu_and_Sexton.pdf

Luke Andreski (2020, February 7) Ethics in the workplace: whistleblowing and transparency | HRZone. Available from: https://www.hrzone.com/lead/culture/ethics-in-the-workplace-whistleblowing-and-transparency [Accessed 16 June 2022].

Luo, H., Das, M., Wang, J. and Cheng, J. C. P. (2019) Construction payment automation through smart contract-based blockchain framework, *Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019*, (Isarc), pp. 1254–1260. DOI:10.22260/isarc2019/0168.

M N N Rodrigo, Srinath Perera, Sepani Senaratne, Xiaohua Jin, Rodrigo, M. N. N., Perera, S., *et al.* (2018) Blockchain for Construction Supply Chains : a Literature Synthesis, *ICEC-PAQS Conference 2018*, (January 2019), pp. 18–20. Available from: https://www.researchgate.net/publication/329607336 [Accessed

MacIntosh, J. A. (1993) Focus groups in distance nursing education, *Journal of Advanced Nursing*, 18

(12), pp. 1981–1985. DOI:10.1046/J.1365-2648.1993.18121981.X.

Marcel Isler (2022) Blockchain Infrastructure Requirements (Software & Hardware). Available from: https://imiblockchain.com/blockchain-infrastructure-requirements/ [Accessed 24 June 2022].

Mark Putnam (2017) Ethics and Ignorance - 4 Things You Should Know | LinkedIn. Available from: https://www.linkedin.com/pulse/ethics-ignorance-4-things-you-should-know-mark-s-putnam/ [Accessed 16 June 2022].

Marquardt, T. and Pohlmann, N. (2021) ANALYSIS OF LARGE-SCALE DECISION MAKING TOOLS USING A DECENTRALI-ZED ARCHITECTURE TO GOVERN COMMON POOL RESOURCES.

Marsh, D. B. (2017) *Building Information Modelling (Bim) and the Uk Quantity Surveying Organisation: a Framework for Value Creation*. Liverpool John Moores University.

Matt Rosoff (2015) Why is tech getting cheaper? | World Economic Forum. Available from: https://www.weforum.org/agenda/2015/10/why-is-tech-getting-cheaper/ [Accessed 24 June 2022].

McKinsey (2021) Achieving sustainable procurement. Available from: https://www.mckinsey.com/business-functions/operations/our-insights/buying-into-a-more-sustainable-value-chain [Accessed 2 November 2021].

McKinsey (2022) Decarbonizing the built environment: Takeaways from COP26 | McKinsey. Available from: https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/decarbonizing-the-built-environment-takeaways-from-cop26 [Accessed 29 June 2022].

McKinsey Global Institute (2019) China and the world Inside the dynamics of a changing relationship. Available from: www.mckinsey.com/mgi. [Accessed 17 January 2022].

Medium (2018) Blockchain: What are nodes and masternodes? . Available from: https://medium.com/coinmonks/blockchain-what-is-a-node-or-masternode-and-what-does-it-do-4d9a4200938f [Accessed 27 January 2022].

Mehra, A. and Dale, J. (2020) How Humanitarian Blockchain Can Deliver Fair Labor to Global Supply Chains, *Reliefweb*. Available from: https://reliefweb.int/report/world/how-humanitarian-blockchain-can-deliver-fair-labor-global-supply-chains [Accessed

Meiklejohn, S. (2018) Top ten obstacles along distributed ledgers path to adoption, *IEEE Security and*

Privacy, 16 (4), pp. 13–19. DOI:10.1109/MSP.2018.3111235.

Merkle, R. C. (1979) *Secrecy, Authentication, and Public Key Systems*. STANFORD UNIVERSITY.

Merton, R. K. and Kendall, P. L. (1946) The Focused Interview, *American Journal of Sociology*, 51 (6), pp. 541–557. DOI:10.1086/219886.

Michalak, J. and Michałowski, B. (2021) Understanding of Construction Product Assessment Issues and Sustainability among Investors, Architects, Contractors, and Sellers of Construction Products in Poland. DOI:10.3390/en14071941.

Mik-meyer, N. (2021) Multimethod qualitative research Final version before publishing . Full reference : Mik-Meyer , N . (2020) Multimethod qualitative research . In : D . Silverman (ed .) Qualitative Research . London : SAGE , pp . 357- Copenhagen Business School , Denmar, *ResearchGate*, (November 2020).

Miller (2019) Permissioned and permissionless blockchains, *Books.Google.Com*. Available from: https://books.google.com/books?hl=en&lr=&id=dhaMDwAAQBAJ&oi=fnd&pg=PA193&dq=permissioned+or+permissionless+blockchain&ots=QU1hidItnt&sig=SEe6Y_6WVPsydrbRFXEYbxKGxps [Accessed 29 January 2022].

Miller, A., Litton, J., Pachulski, A., Gupta, N., Spring, N., Bhattacharjee, B. and Levin, D. (2015) Discovering Bitcoin's Public Topology and Influential Nodes.

Minchin, R. E., Pan, J., Walters, R. C. and Fang, D. (2011) Counterfeit Construction Products From Low-Cost Sourcing Countries, *Management and Innovation for a Sustainable Built Environment*, (June), pp. 1–12. Available from: http://resolver.tudelft.nl/uuid:07740538-269a-44fd-b19f-a8cc9218df73 [Accessed

MinchinJr., R. E., Lucas, E. D., Walters, R. C., Pan, J., Issa, R. R. A. and Singla, G. (2016) Counterfeiting in the Construction Industry: Analysis of Sino-American Differences in Perception, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 8 (4), pp. B4516002. DOI:10.1061/(ASCE)LA.1943-4170.0000194.

MohanaRam, M., Prasad, S., Ayothi, T. and Chart, S. K.- (2014) Shape Makes Building Greener, *Ijnrd.Org*. Available from: https://www.ijnrd.org/papers/IJNRD170124.docx [Accessed 13 June 2022].

Mohite, A. and Acharya, A. (2018) Blockchain for government fund tracking using Hyperledger, *Proceedings of the International Conference on Computational Techniques, Electronics and Mechanical Systems, CTEMS 2018*, pp. 231–234. DOI:10.1109/CTEMS.2018.8769200.

Monte, G. Del, Pennino, Di. and Pizzonia, M. (2020) Scaling blockchains without giving up decentralization and security: A solution to the blockchain scalability trilemma, *CRYBLOCK 2020 - Proceedings of the 3rd Workshop on Cryptocurrencies and Blockchains for Distributed Systems, Part of MobiCom 2020*, pp. 71–76. DOI:10.1145/3410699.3413800.

Monteiro, P. J. M., Miller, S. A. and Horvath, A. (2017) Towards sustainable concrete, *Nature Materials 2017 16:7*, 16 (7), pp. 698–699. DOI:10.1038/nmat4930.

Moodley, K., Smith, N., and, C. P.-C. M. and 2008, undefined (2008) Stakeholder matrix for ethical relationships in the construction industry, *Taylor & Francis*, 26 (6), pp. 625–632. DOI:10.1080/01446190801965368.

Morecroft, M. D., Duffield, S., Harley, M., Pearce-Higgins, J. W., Stevens, N., Watts, O. and Whitaker, J. (2019) Measuring the success of climate change adaptation and mitigation in terrestrial ecosystems, *Science.Org*, 366 (6471). DOI:10.1126/science.aaw9256.

Morgan, D. (2012) Planning and Research Design for Focus Groups, in: *Focus Groups as Qualitative Research*. pp. 31–45.

Morledge, R. and Jackson, F. (2001) Reducing environmental pollution caused by construction plant, *Environmental Management and Health*, 12 (2), pp. 191–206. DOI:10.1108/09566160110389933/FULL/HTML.

Morse, J. M. (2010) Simultaneous and sequential qualitative mixed method designs, *Qualitative Inquiry*, 16 (6), pp. 483–491. DOI:10.1177/1077800410364741.

Moss, M., Hume, J. and Newcomen, D. (2000) Bridge Building Achievements of P. & W. MacLellan & Co.,(1850–1914), *Taylor & Francis*, 72 (2), pp. 179–202. DOI:10.1080/03720187.2000.12023612.

Mougayar, W. (2016) *The business blockchain: promise, practice, and application of the next Internet technology*. Available from: https://books.google.com/books?hl=en&lr=&id=X8oXDAAAQBAJ&oi=fnd&pg=PR9&dq=Mougayar,+W.+2016.+The+Business+Blockchain:+Promise,+Practice,+and+Application+ofthe+Next+Internet+Te

chnology.+Hoboken:+John+Wiley+%26&ots=jfYYDY1N2B&sig=OP2Q_7BjNS9IBq7U1jwmbsYdSZQ

Murray, M. (2008) Rethinking Construction: The Egan Report (1998), *Construction Reports 1944–98*, pp. 178–195. DOI:10.1002/9780470758526.CH13.

Mustow, S. E. (2006) Procurement of ethical construction products, *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, 159 (1), pp. 11–21. DOI:10.1680/ENSU.2006.159.1.11/ASSET/IMAGES/SMALL/ENSU159-011-F2.GIF.

Nakamoto, S. (2008) *Bitcoin: A Peer-to-Peer Electronic Cash System*. Available from: www.bitcoin.org

Nanayakkara, S., Perera, S. and Senaratne, S. (2019) *Stakeholders' Perspective on Blockchain and Smart Contracts Solutions for Construction Supply Chains*, *CIB World Building Congress*.

National Research Council (2000) Surviving Supply Chain Integration: Strategies for Small Manufacturers, *Surviving Supply Chain Integration*. DOI:10.17226/6369.

Nobrega, S., Ghaziri, M. El, Giacobbe, L., Rice, S., Punnett, L. and Edwards, K. (2021) Feasibility of Virtual Focus Groups in Program Impact Evaluation:, *Https://Doi.Org/10.1177/16094069211019896*, 20. DOI:10.1177/16094069211019896.

Nye, J. S. (1967) Corruption and Political Development: A Cost-Benefit Analysis, *American Political Science Review*, 61 (2), pp. 417–427. DOI:10.2307/1953254.

O'Brien, W. J., Formoso, C. T., Vrijhoef, R. and London, K. A. (2008) *Construction supply chain management handbook*, *Construction Supply Chain Management Handbook*. DOI:10.1080/01446190903222361.

O'Grady, K. (2019) *Can the industry effectively deploy the technology for projects and people BLOCKCHAIN FOR CONSTRUCTION W E M A K E P O S S I B L E*. Available from: www.meedmashreqindustryinsight.com

OECD (2015) Implementing The OECD Anti-Bribery Convention, *European Journal of Political Research Political Data Yearbook*, 54 (1), pp. 309–315. DOI:10.1111/2047-8852.12112.

OECD (2020) Financing Climate Futures KEY FINDINGS Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure Why blockchain ?

Ofori, G. (2019) Construction in developing countries: Need for new concepts, *Journal of Construction in Developing Countries*, 23 (2), pp. 1–6. DOI:10.21315/JCDC2018.23.2.1.

Oguntona, O. A., Aigbavboa, C., Btech, O. A. O. and Aigbavboa, C. O. (2016) Promoting biomimetic materials for a sustainable construction industry, *Icevirtuallibrary.Com*, 6 (3), pp. 122–130. DOI:10.1680/jbibn.16.00014.

Oguntona, O. A. and Aigbavboa, C. O. (2019) The Role of Product Eco-Labels in Realising the Greening Agenda of the Construction Industry, pp. 139–144. DOI:10.3311/CCC2019-021.

Olson, M. (1965) *The logic of collective action*. Available from: https://books.google.com/books?hl=en&lr=&id=bH_fN60W85UC&oi=fnd&pg=PA1&dq=The+Logic+of+Collective+Action'+(Olson+1965&ots=SEefX7HqMc&sig=qzI7XX2rBx60Q4qupIMg_ZWHcRs

Olson, M. (1989) Collective Action, in: *The Invisible Hand*. London: Palgrave Macmillan UK, pp. 61–69.

Omran, A. and Schwarz-Herion, O. (2020) Deforestation in Malaysia: The Current Practice and the Way Forward, *Sustaining Our Environment for Better Future*, pp. 175–193. DOI:10.1007/978-981-13-7158-5_11.

Onwuegbuzie, A. J., Dickinson, W. B., Leech, N. L. and Zoran, A. G. (2009) A Qualitative Framework for Collecting and Analyzing Data in Focus Group Research:, *Http://Dx.Doi.Org/10.1177/160940690900800301*, 8 (3), pp. 1–21. DOI:10.1177/160940690900800301.

Organski, A. F. K. (1969) Political Order in Changing Societies. By Samuel P. Huntington. (New Haven: Yale University Press, 1968. Pp. 448. $12.50.), *American Political Science Review*, 63 (3), pp. 921–922. DOI:10.1017/s000305540025870x.

Ostrom, E. and Walker, J. (2003) *Trust and reciprocity: Interdisciplinary lessons for experimental research*. Available from: https://books.google.com/books?hl=en&lr=&id=cfkWAwAAQBAJ&oi=fnd&pg=PR7&dq=.+Ostrom+and+J.+Walker,+Eds.,+Trust+and+Reci%3Fprocity:+Interdisciplinary+Lessons+for+Experi%3Fmental+Research,+Russell+Sage+Foundation,++2003&ots=WSX_azi2si&sig=WyOSY_tSoAX2IDqzro9UNNW4voI

Palevich, R. F. (1997) Supply chain management, in: *Annual International Conference Proceedings -*

American Production and Inventory Control Society. pp. 1–5.

Palmer, C. E. (2001) The extent and causes of illegal logging: an analysis of a major cause of tropical deforestation in Indonesia. Available from: https://discovery.ucl.ac.uk/id/eprint/17588/ [Accessed 4 February 2022].

Palmer, C., Mcshane, K. and Sandler, R. (2014) Environmental Ethics. DOI:10.1146/annurev-environ-121112-094434.

Palombini Maria (2017) The Other Side of Blockchain: We Choose What We Want to See - IEEE SA. Available from: https://beyondstandards.ieee.org/side-blockchain-choose-want-see/ [Accessed 13 February 2022].

Patterson, J. and Kim, P. (1991) The day America told the truth: What people really believe about everything that really matters. Available from: https://ixtheo.de/Record/27647922X [Accessed 23 June 2022].

Pawczuk, L. and Lele, N. (2020) Interoperability, *Deloitte's 2020 Global Blockchain Survey*, pp. 1–13.

Pei, M., Petäjäniemi, M., Regnell, A. and Wijk, O. (2020) Toward a fossil free future with hybrit: Development of iron and steelmaking technology in Sweden and Finland, *Metals*, 10 (7), pp. 1–11. DOI:10.3390/MET10070972.

Pellegrino, G. (2018) Barriers to innovation in young and mature firms, *Journal of Evolutionary Economics*, 28 (1), pp. 181–206. DOI:10.1007/S00191-017-0538-0.

Perera, S., Nanayakkara, S., Rodrigo, M. N. N., Senaratne, S. and Weinand, R. (2020) Blockchain technology: Is it hype or real in the construction industry?, *Journal of Industrial Information Integration*, 17 (January), pp. 100125. DOI:10.1016/j.jii.2020.100125.

Politou, E., Casino, F., Alepis, E. and Patsakis, C. (2019) Blockchain Mutability: Challenges and Proposed Solutions.

Postmes, T. and Brunsting, S. (2002) Collective action in the age of the internet: Mass communication and online mobilization, *Social Science Computer Review*, 20 (3), pp. 290–301. DOI:10.1177/089443930202000306.

Powell, R. A. and Single, H. M. (1996) Focus Groups, *International Journal for Quality in Health Care*, 8 (5), pp. 499–504. DOI:10.1093/INTQHC/8.5.499.

Prentice, R. (2019) Just compensation? The price of death and injury after the rana plaza garment factory collapse, *Research in Economic Anthropology*, 39, pp. 157–178. DOI:10.1108/S0190-128120190000039008.

Provenence (2019) Every product has a story | Provenance, *Every product has a story | Provenance*. Available from: https://www.provenance.org/ [Accessed 16 April 2020].

PWC (2020) Time for trust The trillion-dollar reasons to rethink blockchain.

Qian, X. (Alice) and Papadonikolaki, E. (2020) Shifting trust in construction supply chains through blockchain technology, *Engineering, Construction and Architectural Management*, (April). DOI:10.1108/ECAM-12-2019-0676.

Radoilska, L. (2008) Truthfulness and business, *Journal of Business Ethics*, 79 (1–2), pp. 21–28. DOI:10.1007/S10551-007-9388-2.

Rath, U. and Kulnigg, T. (2019) *Blockchain & Cryptocurrency Regulation*, *Global Legal Insights*. Available from: https://www.acc.com/sites/default/files/resources/vl/membersonly/Article/1489775_1.pdf

Remo, A. R. (2018) Construction on the rise in Q2,

RICS (2020) Blockchain: an emerging opportunity for surveyors?, (February). Available from: www.rics.org [Accessed 5 May 2020].

Ripple (2020) Instantly Move Money to All Corners of the World. Available from: https://ripple.com/ [Accessed 15 April 2020].

RNLI (2015) Royal National Lifeboat Institution - Saving Lives at Sea. Available from: https://rnli.org/ [Accessed 17 February 2022].

Robinson, S. (2008) Conceptual modelling for simulation Part I: definition and requirements, *Journal of the Operational Research*, 59 (3), pp. 278–290. DOI:10.1057/palgrave.jors.2602368.

Rocco, S. T. and Plakhotnik, S. M. (2009) Literature reviews, conceptual frameworks, and theoretical frameworks: Terms, functions, and distinctions, *Human Resource Development Review*, 8 (1), pp.

120–130. DOI:10.1177/1534484309332617.

Rozas, D., Tenorio-Fornés, A., Díaz-Molina, S. and Hassan, S. (2021) When Ostrom Meets Blockchain: Exploring the Potentials of Blockchain for Commons Governance, *SSRN Electronic Journal*. DOI:10.2139/SSRN.3272329.

Russell, K. (2010) The Art of Being a Scientist: A Guide for Graduate Students and their Mentors by Roel Snieder, Ken Larner, *International Statistical Review*, 78 (1), pp. 159–159. DOI:10.1111/j.1751-5823.2010.00109_28.x.

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L. (2019a) Blockchain technology and its relationships to sustainable supply chain management, *International Journal of Production Research*, 57 (7), pp. 2117–2135. DOI:10.1080/00207543.2018.1533261.

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L. (2019b) Blockchain technology and its relationships to sustainable supply chain management, *International Journal of Production Research*, 57 (7), pp. 2117–2135. DOI:10.1080/00207543.2018.1533261.

SAI [no date] Social Accountability International Standard. Available from: https://sa-intl.org/programs/sa8000/ [Accessed 7 February 2022].

Saini, M. and Shlonsky, A. (2012) *Systematic synthesis of qualitative research*. Available from: https://books.google.com/books?hl=en&lr=&id=wEajcxKOEYYC&oi=fnd&pg=PP1&dq=M.+Saini+and+Shlonsky+(2012)+&ots=YXplsb4cSD&sig=wuRQ2VRq3YNX8o6d0MyxdmvJPJc

Samsung Newsroom (2021) Samsung to Plant Millions of Trees to Fight Climate Change - Samsung US Newsroom. Available from: https://news.samsung.com/us/samsung-veritree-plant-millions-trees-fight-climate-change/ [Accessed 10 February 2022].

San, K. M., Choy, C. F. and Fung, W. P. (2019) The Potentials and Impacts of Blockchain Technology in Construction Industry: A Literature Review, *IOP Conference Series: Materials Science and Engineering*, 495 (1). DOI:10.1088/1757-899X/495/1/012005.

Sarkar, S., Chauhan, A., Kumar, R. and Singh, R. P. (2019) Impact of Deadly Dust Storms (May 2018) on Air Quality, Meteorological, and Atmospheric Parameters Over the Northern Parts of India, *GeoHealth*, 3 (3), pp. 67–80. DOI:10.1029/2018GH000170.

Saunders, M. (2012) *Research methods for business students*. 6th ed. Harlow England ;;New York: Pearson.

Sbaraini, A., Carter, S. M., Evans, R. and Blinkhorn, A. (2011) How to do a grounded theory study: A worked example of a study of dental practices, *BMC Medical Research Methodology*, 11. DOI:10.1186/1471-2288-11-128.

Schneider, F. B. (1990) Implementing Fault-Tolerant Services Using the State Machine Approach: A Tutorial, *ACM Computing Surveys (CSUR)*, 22 (4), pp. 299–319. DOI:10.1145/98163.98167.

SDGs (2018) Corruption and supply chain management toward the sustainable development goals era, *Corporate Governance (Bingley)*. DOI:10.1108/CG-01-2018-0031.

Sedex (2019) Sedex Members Ethical Trade Audit (SMETA) Best Practice Guidance.

Segarra-Blasco, A., Garcia-Quevedo, J. and Teruel-Carrizosa, M. (2008) Barriers to innovation and public policy in Catalonia, *International Entrepreneurship and Management Journal*, 4 (4), pp. 431–451. DOI:10.1007/S11365-008-0086-Z.

Seitz, S. (2016) Pixilated partnerships, overcoming obstacles in qualitative interviews via Skype: a research note, *Qualitative Research*, 16 (2), pp. 229–235. DOI:10.1177/1468794115577011.

Seymour, D., Crook, D. and Rooke, J. (1998) The role of theory in construction management: Reply to Runeson, *Construction Management and Economics*, 16 (1), pp. 109–112. DOI:10.1080/014461998372655.

Seymour, F. (2020) Seeing the Forests as well as the (Trillion) Trees in Corporate Climate Strategies. DOI:10.1016/j.oneear.2020.05.006.

Shan, M., Le, Y., Yiu, K. T. W., Chan, A. P. C. and Hu, Y. (2017) Investigating the Underlying Factors of Corruption in the Public Construction Sector: Evidence from China, *Science and Engineering Ethics*, 23 (6), pp. 1643–1666. DOI:10.1007/s11948-016-9865-z.

Shapiro, D. M., Li, J. and Feng, C. M. (2020) Exploring the Liability of Origin: Lessons from Smithfield Foods and Meat Processing in the US During COVID-19, *AIB Insights*. DOI:10.46697/001C.18164.

SHAZLY, S. M. E., ABDELMAGEED, A. M. and NOBI, G. Y. H. A. B. (2021) CONSTRUCTION OF AN OPTICAL DEVICE FOR MEASURING ATMOSPHERIC DUST EXTINTION, *MAUSAM*, 43 (1), pp. 110–112.

DOI:10.54302/MAUSAM.V43I1.3346.

Sheldon, M. (2022) Tracking Tangible Asset Ownership and Provenance with Blockchain, *SSRN Electronic Journal*. DOI:10.2139/ssrn.3669326.

Sherman, A. T., Javani, F., Zhang, H. and Golaszewski, E. (2018) *On the Origins and Variations of Blockchain Technologies*.

Silverman, D. (2013) *Doing qualitative research: A practical handbook*. Available from: https://books.google.co.uk/books?hl=en&lr=&id=LySjM0tY-tEC&oi=fnd&pg=PP2&dq=silverman+2013+doing+qualitative+research&ots=kG-9sHOFwZ&sig=-BN6XKYp5Tnm1GkV9Knxf6Bbjo8

Skocek, J., Zajac, M. and Ben Haha, M. (2020) Carbon Capture and Utilization by mineralization of cement pastes derived from recycled concrete, *Scientific Reports 2020 10:1*, 10 (1), pp. 1–12. DOI:10.1038/s41598-020-62503-z.

Slaper, T. and Hall, T. (2011) The Triple Bottom Line : What Is It and How Does It Work?, *Indiana University Kelley School of Business*, pp. 4–8. Available from: http://www.ibrc.indiana.edu/ibr/2011/spring/article2.html [Accessed 9 June 2022].

Smith, S. and O'Rourke, L. (2019) Exploring the potential of Blockchain technology for the UK Construction industry - 2019, (April).

Sohail, M. and Cavill, S. (2006) *Corruption in construction projects*. Available from: https://dspace.lboro.ac.uk/

Sprenger, P. and Balsiger, F. (2019) *Anti-Money Launderi ng i n ti mes of cryptocurrenci es Cryptocurrencies-game changers in many ways*. Available from: https://www.coindesk.com/global-aml-watchdog-to-step-up-

SSAB (2021, August) The world's first fossil-free steel ready for delivery. Available from: https://www.ssab.co.uk/news/2021/08/the-worlds-first-fossilfree-steel-ready-for-delivery [Accessed 4 February 2022].

Stronger Together (2019) stronger2gether.org, (November).

Swanson, T. (2015) Consensus-as-a-service: a brief report on the emergence of permissioned, distributed ledger systems., *World Agriculture*, 1 (May), pp. 1–9. Available from: https://www.the-blockchain.com/wp-content/uploads/2016/04/Permissioned-distributed-ledgers.pdf [Accessed 20 June 2022].

Szabo Nick (1994) Smart Contracts. Available from: http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html [Accessed 24 April 2020].

Tan, A. and Ngan, P. T. (2020) A proposed framework model for dairy supply chain traceability, *Sustainable Futures*, 2, pp. 100034. DOI:10.1016/j.sftr.2020.100034.

Tan, X., Liu, L., Huang, Z., Psychology, W. Z.-P. and 2017, undefined (2017) Working for the hierarchical system: The role of meritocratic ideology in the endorsement of corruption, *Wiley Online Library*, 38 (3), pp. 469–479. DOI:10.1111/pops.12341.

Tang, M. and Omega, H. L. (2021) From conventional group decision making to large-scale group decision making: What are the challenges and how to meet them in big data era? A state-of, *Elsevier*. Available from: https://www.sciencedirect.com/science/article/pii/S0305048319307285 [Accessed 17 February 2022].

Tashakkori, A., research, C. T.-I. journal of social and 2003, undefined (2010) Issues and dilemmas in teaching research methods courses in social and behavioural sciences: US perspective, *Taylor & Francis*, 6 (1), pp. 61–77. DOI:10.1080/13645570305055.

Tashakkori, A. and Teddlie, C. (2010) Putting the human back in ‘human research methodology’: The researcher in mixed methods research, *Journal of Mixed Methods Research*, 4 (4), pp. 271–277. DOI:10.1177/1558689810382532.

Terrachoice (2007) The "Six Sins of Greenwashing TM " A Study of Environmental Claims in North American Consumer Markets.

Tezel, A., Papadonikolaki, E. and Yitmen, I. (2019) Preparing Construction Supply Chains for Blockchain: An Exploratory Analysis, *CIB World Building Congress*, (June), pp. 17–21. Available from: http://www.diva-portal.org/smash/get/diva2:1327247/FULLTEXT01.pdf [Accessed 23 January 2020].

Tezel, A., Papadonikolaki, E. and Yitmen, I. (2020) Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. DOI:10.1007/s42524-

020-0110-8.

The Bureau of International Labor Affairs (ILAB) (2014) List of Goods Produced by Child Labor or Forced Labor | U.S. Department of Labor. Available from: https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-goods-print [Accessed 20 July 2022].

The Chartered Institute of Building (2006) Corruption in the UK Construction Industry, (September).

The Chartered Institute of Building (2013) Corruption in the UK Construction Industry, (September).

The Royal United Services Institute (2019) What's in a Name? Corruption and Fraud in the UK. Available from: https://rusi.org/explore-our-research/publications/occasional-papers/whats-name-corruption-and-fraud-uk [Accessed

Tong, K. (2017) If blockchain is difficult to be hacked, how does Bitcoin get hacked multiple times? - Quora. Available from: https://www.quora.com/If-blockchain-is-difficult-to-be-hacked-how-does-Bitcoin-get-hacked-multiple-times [Accessed 28 January 2020].

TradeLens (2020) Data Sharing Specification - TradeLens Documentation, (March). Available from: https://docs.tradelens.com/reference/data_sharing_specification/ [Accessed

Transparency International (2008) *Transparency International - Bribe Payers Index*. Available from: www.transparency.org

Transparency International, Hardoon, D. and Heinrich, F. (2011) *Bribe payers index 2011*. Transparency International.

Trochim, W. and Donnelly, J. (2001) *Research methods knowledge base*. Available from: https://www.researchgate.net/profile/William-Trochim/publication/243783609_The_Research_Methods_Knowledge_Base/links/55db837008aed6a199ac6246/The-Research-Methods-Knowledge-Base.pdf

Turk, Ž. and Klinc, R. (2017a) Potentials of Blockchain Technology for Construction Management, in: *Procedia Engineering*. Elsevier Ltd,196, pp. 638–645.

Turk, Ž. and Klinc, R. (2017b) Potentials of Blockchain Technology for Construction Management, in: *Procedia Engineering*. Elsevier Ltd,196, pp. 638–645.

UK Finance (2019) *The definitive overview of payment industry fraud*.

UN Global Compact (2010) *Fighting Corruption in the Supply Chain: a guide For Customers and Suppliers*. Available from: www.unglobalcompact.org

UNISON (2013) Branch guide to ethical procurement, pp. 1–12. Available from: https://www.unison.org.uk/content/uploads/2013/06/On-line-Catalogue212793.pdf [Accessed

United Nations Global Compact (2017) 2017 United Nations Global Compact Progress Report: Business Solutions to Sustainable Development, pp. 99. Available from: https://www.unglobalcompact.org/docs/publications/UN Impact Brochure_Concept-FINAL.pdf [Accessed

Vajpeyi, D. (2001) *Deforestation, environment, and sustainable development: a comparative analysis*. Available from: https://books.google.com/books?hl=en&lr=&id=JWf4X2apWMYC&oi=fnd&pg=PP5&dq=sustainable+deforestation&ots=w7DGkapnn9&sig=rJ7ggoAnyTQ7RC37NqOA2_oc0a4

Varga, P., Plosz, S., Soos, G. and Hegedus, C. (2017) *Security Threats and Issues in Automation IoT*. DOI:10.1109/WFCS.2017.7991968.

Vee, C. and Skitmore, Cm. (2003) Professional ethics in the construction industry, *Engineering, Construction and Architectural Management*, 10 (2), pp. 117–127. DOI:10.1108/09699980310466596.

Verba, S., Schlozman, K. L. and Brady, H. E. (2000) Rational action and political activity, *Journal of Theoretical Politics*, 12 (3), pp. 243–268. DOI:10.1177/0951692800012003001.

Verhoeven, P., Sinn, F. and Herden, T. (2018) Examples from Blockchain Implementations in Logistics and Supply Chain Management: Exploring the Mindful Use of a New Technology, *Logistics*, 2 (3), pp. 20. DOI:10.3390/logistics2030020.

Verité (2015) Strengthening Protec ons Against Traffi cking in Persons in Federal and Corporate Supply Chains. Available from: www.verite.org%7C+1.413.253.9227www.verite.org%7C+1.413.253.9227 [Accessed 20 July 2022].

Vian, T. (2020) Anti-corruption, transparency and accountability in health: concepts, frameworks, and approaches, *Global Health Action*, 13 (sup1). DOI:10.1080/16549716.2019.1694744.

Viator, M. (2019) General Contractor Indicted Over Misuse of Funds | zlien, *Levelset*. Available from: https://www.levelset.com/blog/general-contractor-misusing-funds-is-indicted/

Viriyasitavat, W. and Hoonsopon, D. (2019) Blockchain characteristics and consensus in modern business processes, *Journal of Industrial Information Integration*, 13, pp. 32–39. DOI:10.1016/j.jii.2018.07.004.

Wang, J., Wu, P., Wang, X. and Shou, W. (2017) The outlook of blockchain technology for construction engineering management, *Frontiers of Engineering Management*, 4 (1), pp. 67. DOI:10.15302/j-fem-2017006.

WEF (2020) *Redesigning Trust: Blockchain Deployment Toolkit Supply Chain Focus EXPERIENCE THE INTERACTIVE VERSION AT: wef.ch/blockchain-toolkit*. Available from: www.weforum.org

Wegrzyn, K. and Wang, E. (2021) Blockchain Use in Supply Chain Leads to Greater Benefits. Available from: https://www.natlawreview.com/article/pros-and-cons-blockchain-supply-chain [Accessed 21 June 2022].

Weinstein, J. and Cohn, A. (2019) Promoting innovation through education: The blockchain industry, law enforcement and regulators work towards a common goal, in: *Blockchain & Cryptocurrency Regulation 2020*.

Werdmüller, J. (2016) Hidden in Plain Site: Modern Slavery in the Construction Industry, *LexisNexis*, pp. 14. Available from: https://bis.lexisnexis.co.uk/pdf/whitepapers/Modern_Slavery_in_Construction_Full.pdf [Accessed

Williams, A. D., Vargas, R. V., Conforto, C., Oumarou, T. A. and Blockchain, " (2019) *Blockchain and the Project Management Office: A Distributed Platform for Strategy Delivery and Organizational Transformation*. Available from: www.blockchainresearchinstitute.org/contact-us,

Wilson, C. (2019) Cryptocurrencies: The Future of Finance?, *Contemporary Issues in International Political Economy*, pp. 359–394. DOI:10.1007/978-981-13-6462-4_16.

Wong, E. (1977) Retrieving Dispersed Data from SDD-1, in: *Berkeley Workshop on Distributed Data Management and Computer Networks*. California: University of California, pp. 217–235.

World Counts (2021) Environmental Impact of Steel. Available from: https://www.theworldcounts.com/challenges/planet-earth/mining/environmental-impact-of-steel-production/story [Accessed 18 January 2022].

World Economic Forum (2020) Sustainable procurement policy, *Joutnal of Sustainable Procurement*, 2 (December 2011), pp. 1–10.

World Economic Forum (2021) A free-tree scheme in the Netherlands is proving to be a sustainable success | World Economic Forum. Available from: https://www.weforum.org/agenda/2021/12/tree-climate-change-replanting-forest/ [Accessed 4 February 2022].

World Steel Association (2018) Steel Facts, *SteelFACTS*, pp. 23.

World Trade Organization (2018) Can Blockchain revolutionize international trade? Available from: www.wto.org [Accessed 31 January 2022].

Xiaoning, Q. and Papadonikolaki, E. (2019) The Influence of Blockchain Technology on Trust in construction Supply Chain Management, *In: (Proceedings) 36th CIB W78 2019 Conference. CIB (International Council for Research and Innovation in Building and Construction) (2019) (In Press).*

Yaga, D., Mell, P., Roby, N. and Scarfone, K. (2018) Blockchain Technology Overview - National Institute of Standards and Technology Internal Report 8202, *NIST Interagency/Internal Report*, pp. 1–57. DOI:10.6028/NIST.IR.8202.

Yaga, D., Mell, P., Roby, N. and Scarfone, K. (2019) Blockchain Technology Overview. DOI:10.6028/NIST.IR.8202.

Yang, C. (2019) *Is There a Role for Blockchain for Enhancing Public Procurement Integrity?*

Yar, M. (2005) The Novelty of 'Cybercrime': An Assessment in Light of Routine Activity, *European Journal of Criminology*, 2, pp. 407. DOI:10.1177/147737080556056.

Ye, X., Sigalov, K. and König, M. (2020) Integrating BIM- and Cost-included Information Container with Blockchain for Construction Automated Payment using Billing Model and Smart Contracts, *Proceedings of the 37th International Symposium on Automation and Robotics in Construction (ISARC)*, (Isarc). DOI:10.22260/isarc2020/0192.

Żak, A. (2015) Triple bottom line concept in theory and practice, *Prace Naukowe Uniwersytetu*

Ekonomicznego We Wrocławiu, (387). DOI:10.15611/pn.2015.387.21.

Zambrano, R., Young, A., Verhulst, S. and Alden, A. (2018) B LO C KC H A N G E Connecting Refugees to Aid through Blockchain-Enabled ID Management: World Food Programme's Building Blocks.

Zarkada-Fraser, A., & M. S.-C. M. and 2000, undefined (2000) Decisions with moral content: collusion, *Taylor & Francis*, 18 (1), pp. 101–111. DOI:10.1080/014461900370997.

Zhang, S. and Lee, J. H. (2019) Analysis of the main consensus protocols of blockchain, *ICT Express*. DOI:10.1016/j.icte.2019.08.001.

Zheng, Z., Xie, S., Dai, H., Chen, X. and Wang, H. (2017) An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends, *Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017*, pp. 557–564. DOI:10.1109/BigDataCongress.2017.85.

Zhou, Q., Huang, H., Zheng, Z. and Bian, J. (2020) Solutions to Scalability of Blockchain: a Survey, *IEEE Access*, 8, pp. 16440–16455. DOI:10.1109/ACCESS.2020.2967218.

Zhou, Y., Yang, Y. and Yang, J. Bin (2019) Barriers to BIM implementation strategies in China, *Engineering, Construction and Architectural Management*, 26 (3), pp. 554–574. DOI:10.1108/ECAM-04-2018-0158/FULL/HTML.

Zouina, M. and Outtai, B. (2019) Towards a distributed token based payment system using blockchain technology, in: *2019 International Conference on Advanced Communication Technologies and Networking (CommNet)*. IEEE, pp. 1–10.

Appendices

Appendix 1- Sample of debriefing sheet

Appendix 2: Sample of participant information sheet

Appendix 3: Sample of participant consent form

Appendix 4: Sample of semi-structured interview questions

Appendix 5: Sample of focus group discussion questions

Appendix 1: Sample of debriefing sheet

DEBRIEFING SHEET

Improving ethics in construction materials and products supply chain through blockchain

Thank you for your interest in this research and the willingness to share your insights.

The overall aim of this study is to develop and validate a model for improving ethics in the construction materials and products supply chain (CMPSC) following the triple bottom line (TBL) construct using blockchain technology. To achieve the stated aim, I seek to achieve the following objectives:

1. To evaluate the current state of ethics in the CMPSC following the TBL construct and how effective the current ethical measures have been.
2. To explore blockchain technology and its implementations for ethics following the TBL construct, in view of applying the learning to evaluate its feasibility to improve ethics in the CMPSC.
3. To establish how blockchain technology can help improve ethics in the CMPSC within the TBL construct.
4. To determine the factors that may affect the acceptance and implementation of blockchain technology in the CMPSC.
5. To develop and validate a model for improving ethics across the CMPSC following the TBL construct using blockchain technology.

Please feel free to ask any questions at any time. You can also e-mail me on kolawoo6@lsbu.ac.uk if you have any further questions. I can assure you that your data will be treated in the strictest of confidence and no personal data will be shared outside of the research team. This study has been reviewed and approved by the Built Environment and Architecture Ethics Committee of London South Bank University

Please keep this part of the sheet for reference.

Appendix 2: Sample of participant information sheet

Participant Information Sheet

Study title

Improving ethics in construction materials and products supply chain through blockchain

I have invited you to take part in this research study. Please take time to read the following information carefully to understand why the research is being done and what it will involve. You may also ask questions if anything you read is not clear or if you would like more information.

What is the purpose of the study?

The overall aim of this study is to develop and validate a model for improving ethics in the construction materials and products supply chain (CMPSC) following the triple bottom line (TBL) construct using blockchain technology.

Why have I been invited to participate?

You have been chosen to share your insights as a suitably qualified participant for this research because you work either within or in tandem with one or more of the underlisted fields.

1. Construction industry
2. Construction materials and products supply chain
3. Ethics / Sustainability in Construction
4. Blockchain implementors, blockchain developers & researchers / enthusiasts

Do I have to take part?

It is up to you to decide. If you do decide to take part, you will be given this information sheet to keep and you would be asked to sign a consent form. Moreover, you are still free to withdraw up until the research report is submitted and without giving a reason. To do this, you can notify the researcher via email. Contact details are available at the end of this form.

What will happen to me if I take part?

Nothing will happen to you. We will not refer to any participants by name. Participants will be referred to by an anonymised naming system. The information you provide will be used to further the research as outlined here. The method of data collection is through interviews and focus group. All data from Participants would be requested and gathered virtually and remotely without the need for person-person contact. The interview would last for about 1 hour.

What are the possible benefits of taking part?

Your participation will be a valuable addition to this research and the findings could lead to a novel approach on how the age long menace of unethical practices in public procurement can be curbed. You will also be provided with early access to the findings of this research after completion upon request.

Will the data collected in this study be kept confidential?

All information which will be collected during the course of this research will be kept strictly confidential, and all research inputs will be anonymised. If you withdraw from the study, I will delete the data from the interview. Audio/video recordings from the interview will be deleted as soon as I have a clear transcript of the interview.

What should I do if I want to take part?

On deciding to take part in this study, participant should please finish up reading the information sheet, debrief sheet, sign the consent form and then proceed to participate in the interview to the best of their capacity.

What will happen to the results of the research study?

The research study information will be presented in the form of a university thesis. It may also be published in a condensed version, as a paper in a professional or academic journal. You will not be identified in any publication/material personally. All information collected will be anonymised. Also, participants can obtain a copy of the published research by contacting the researcher via the details stated at the end of this form.

Who is organising and funding the research?

I am conducting the research as a student of the School of The Built Environment and Architecture at London South Bank University. This research is funded solely by the researcher and by no external bodies.

Who has reviewed the study?

The research has been approved by the Built Environment and Architecture Ethics Committee of London South Bank University. The research study has been conducted under constant supervision Dr. Adamu Zulfikar who is an Associate Professor of Strategic IT in Construction and Dr. Daniel Fong, an Associate Professor in the Division of Construction, Property and Surveying at London South Bank University.

Contact for Further Information

	Researcher details	Supervisor details	Ethics panel
Name	Oluwatobi .M. Kolawole	Dr. Adamu Zulfikar	Dr Yamuna Kaluarachchi
Email ID	Kolawoo6@lsbu.ac.uk	adamuz@lsbu.ac.uk	Yamuna.Kaluarachchi@lsbu.ac.uk

If you have any other concerns about the way in the research has been conducted, then you can contact Dr. Yamuna Kaluarachchi

If you are happy to participate in the research and contribute your experience for the benefit of this research, please sign the consent form below. Please send a copy of the signed form back to the researcher and keep a copy for yourself.

Signature of research participant

Date

I believe the participant is giving informed consent to participate in this study

Signature of researcher

01/08/2021

Date

Researcher: Oluwatobi .M. Kolawole

Appendix 3: Sample of participant consent form

Consent Form

Full title of Project: A model for ethical procurement of materials & products in construction through blockchain

Name, position and contact details of Researcher:
Oluwatobi .M. Kolawole _ PhD Student _ kolawoo6@lsbu.ac.uk

Taking part (please tick the box that applies)	Yes	No
I confirm that I have read and understand the information sheet/project brief and I have had the opportunity to ask questions.	☐	☐
I understand that my participation is voluntary and that I am free to withdraw as explained in the information sheet, without providing a reason.	☐	☐
I agree to take part in the above study.	☐	☐
Use of my information (please tick the box that applies)	**Yes**	**No**
I understand my personal details will not be revealed to people outside the project.	☐	☐
I agree to the use of anonymised quotes in potential publications and presentations	☐	☐
I would like my real name to be used in the above	☐	☐
I agree for the data I provide to be stored (after it has been anonymised) in a specialist data centre and I understand it may be used for future research.	☐	☐
I agree to the interview being audio recorded.	☐	☐
I agree to the interview being video recorded.	☐	☐
I agree to the use of anonymised quotes in publications.	☐	☐

By ticking the 'Yes box' below, I confirm that I agree to take part in the study

Yes ☐
Name:

Please send a copy of the filled form back to the researcher

Project contact details for further information:
Project Supervisor
Dr. Adamu Zulfikar
020 7815 6132
adamuz@lsbu.ac.uk

Appendix 4: Sample of semi-structured interview questions

SEMI-STRUCTURED INTERVIEW QUESTIONS

Section 1: *These questions are introductory; easing the participant into the interview whilst helping to get participant understanding of blockchain.*

1. What is your job title, and how long have you been in this role?
2. How conversant are you with blockchain and its applications?
3. Do you or your organisation use blockchain technology? If no, jump to Section 2
4. Please explain what 'Blockchain' means to you/your organization.
5. What does your organisation use blockchain technology for and how is it implemented?
6. Can you describe the key drivers that have fuelled the need for implementing blockchain initiatives in your project/organization?

Section 2: *Evaluation of the current state of ethics in construction materials and products supply chain and the feasibility of improving it with blockchain.*

1. What are your thoughts on the impact of the activities of the construction materials and products supply chain on the environment.
2. What are your thoughts on the current state of social ethics in construction materials and products supply chain.
3. What are your thoughts on the current state of business ethics in construction materials and products supply chain.
4. What is your opinion, on the effectiveness of the current measures to curb unethical practices in construction supply chains.
5. Do you think blockchain can help to improve ethics in construction supply chains? If so, how?

Section 3: *Model evaluation and validation*

Researcher would do an introductory walk through of the model before questions are asked.

The next few questions will focus on evaluating and validating the proposed model.

1. Before, I begin asking for specific feedback on the model, what are your thoughts in general on the model I have just presented
2. Do you think the elements of this model and their interconnections help to capture the essential information necessary for ethical oversight in the construction materials & product supply chain? If so, how?

3. Do you think this model can help to make the construction materials and products supply chain more ethical? If so, what aspects of unethical practices do you think it can help eliminate.
4. Do you think it will be accepted and implemented in the construction industry?
5. Could you please share other concerns or comments you have about the model?

Appreciation

Appendix 5: Sample of focus group discussion questions

FOCUS GROUP QUESTIONS

Model Validation

The questions focus on evaluating and validating the proposed model, how it may impact ethics in the construction materials and products supply chain and its potential acceptance and implementation.

Researcher does an introductory walk through of the model before questions are asked and discussions ensue.

1. What do you think of this model as a socio technical approach to achieve environmental ethics
2. What do you think of this model as a socio technical approach to achieve social ethics
3. What do you think of this model as a socio technical approach to achieve cooperate ethics
4. How much do you think a socio-technical approach like this can achieve in improving ethics in construction?
5. What are your thoughts on the practicality and feasibility of this model.
6. How well rounded do you think this approach for providing an ethical oversight in the construction materials & product supply chain?
7. Do you think it will be accepted and implemented in the construction industry?
8. What do you think could be the limitations of this approach?
9. What are your other concerns about the model?
10. Closing comments on the model from each participant

Appreciation