A Blockchain-enabled System to enhance Food Traceability in Local Food Supply Chains (FSCs) suitable for Small Co-operatives in South Africa

by

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Declaration

I, Julian Kanjere, declare that this thesis is composed of my original work, it contains no material previously published or written by another person except where due reference has been made in the text. This thesis is submitted to the University of Cape Town for the Master of Philosophy specialising in Financial Technology degree.

Signed by candidate

Signature

February 11, 2021

Date

Abstract

Food is vital to human life. Therefore, ensuring its safety as it moves from producer to consumer in food supply chains (FSCs) is essential. This can be achieved through the use of food traceability technology which enables track and trace of produce within a FSC. Recently, blockchain technology (BCT) has shown great potential to enhance traceability in FSCs, owing to its ability to securely store data in a decentralised and tamper-evident manner. However, it appears that research on blockchain-enabled food traceability exists primarily within the context of large FSCs, whilst scarce for local FSCs in which traceability is often an inefficient and manual process.

Given this background, this exploratory research is carried out, to investigate whether a blockchain-enabled system can be used to improve traceability in local FSCs. To do this, we (i) collaborate with Oranjezicht City Farm Market (OZCFM) - a farmers market in Cape Town, the smallholder farmers that supply OZCFM with fresh local produce and the OZCFM patrons that purchase the produce; (ii) map out the local FSC by conducting observations and running surveys with the aforementioned actors; (iii) design, develop and pilot FoodPrint - a web based and blockchain-enabled food traceability application. During the pilot within the OZCFM-related local FSC, FoodPrint is used to capture data on the harvest, transportation and storage of produce; and reveal produce provenance at destination by scanning of supplier-produce specific quick response (QR) codes.

We find that FoodPrint provides tamper-evident traceability and authentic transparency of produce related data to the local FSC actors. Further, we note that scanning a FoodPrint QR code for produce provenance does not enhance the consumers trust of the local FSC, as it pre-exists. This implies that local FSCs with existing and functional trust mechanisms do not benefit from trust-enhancing mechanisms such as blockchain-enabled traceability. Future work may consider data privacy in FSCs and automating FSC data entry to reduce the risk of fraud.

keywords: blockchain; food supply chain; traceability; transparency;

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Asante sana.

Seek a calling. Even if you don't know what that means, seek it. If you're following your calling, the fatigue will be easier to bear, the disappointments will be fuel, the highs will be like nothing you've ever felt.

— Phil Knight, Shoe Dog: A Memoir by the Creator of NIKE

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Abbreviations and Acronyms

AI .... Artificial Intelligence

AgriTech ...... Agricultural Technology

API .... Application Programming Interface

BCT .... Blockchain Technology

BTC .... Bitcoin

DApp .... Decentralised Application

DARQ .... Distributed Ledger Technology, Artificial Intelligence, Extended Reality and Quantum Computing

DLT .... Distributed Ledger Technology

DBMS .... Database Management System

EU .... European Union

FAQ .... Frequently Asked Questions

FR .... Functional Requirement

FSC .... Food Supply Chain

FoodPrint ..... FoodPrint Traceability Platform

FinTech .... Financial Technology

IoT .... Internet of Things

MSC .... Marine Stewardship Council

NFR .... Non-functional Requirement

OS .... Operating System

OZCF .... Oranjezicht City Farm

OZCFM .... Oranjezicht City Farm Market

PoC .... Proof-of-Concept

REST .... Representational State Transfer

RFID .... Radio Frequency Identification

SaaS .... Software-as-a-service

SC .... Supply Chain

SCM .... Supply Chain Management

SDG .... Sustainable Development Goal

SSL .... Secure Socket Layer

UI .... User Interface

URL .... Uniform Resource Locator

UML .... Unified Modelling Language

UN .... United Nations

WEF .... World Economic Forum

Woolworths ... Woolworths South Africa

1. Introduction

Do you know where your food comes from - how it was grown, whether it is local or not, the conditions under which it was grown and ultimately, whether it is fit for human consumption? This is a question of food provenance and by extension, trust in the authenticity and integrity thereof. The pyramid-shaped hierarchy of needs proposed by Maslow (1943) identifies food as a physiological need - a universal human need and physical requirement for survival. Food is essential to life. However, although food is both, a basic requirement and a basic human right (South African Human Rights Commission n.d.), neither food security nor safety is guaranteed.

In light of growing concerns about food safety as well as an increase in food scandals and unethical labour practices in the production of food, consumers are increasingly becoming interested in their food choices. This interest is not only with respect to the cost of food, but its origin, quality, freshness, effect on health, impact on the local economy and the sustainability of the environment (Hinrichs 2008; Aung and Chang 2014). Consumer need, together with government regulations and trade requirements are key drivers for the increasing expectations in food supply chains (FSCs). Some of these expectations include transparency and traceability, which help to promote food safety and quality (Corallo, Latino, and Menegoli 2019).

1.1 Motivation

It appears that much of the research and innovation in technology solutions for food traceability and transparency has been focused on large FSCs comprised of large scale farmers, agri-processors and retailers. This is possibly due to the larger cost-saving opportunities (e.g. food recall costs and FSC inefficiency costs) being more apparent and/or the availability of resources to experiment with emerging technologies such as blockchain. For example, in 2016, Walmart and their technology partner IBM announced two proof-of-concept (PoC) projects leveraging blockchain technology (BCT) for food traceability - one for tracing the origin of mangos sold in Walmart's American stores and the other, tracing of pork sold in its China stores (Hyperledger 2019).

In addition, small-scale players tend to be excluded from emerging technology innovation due to technology barriers as well as capacity and capital constraints. For example, considering the case of smallholder farmers and food traceability technology, the World Economic Forum and McKinsey & Company (2019) caution that although traceability offers a powerful opportunity to improve information about provenance, safety and sustainability of food, it can unintentionally result in exclusion of small-scale producers who may be unable to engage with such new technologies. This alludes to emerging technology implementations overlooking the needs or on-boarding of small-scale players or firms. Considering the case of more general research and innovation in BCT and traceability, there has been traction in lucrative markets (Bhatia et al. 2019), markets in which small-scale firms do not meet the requirements to participate.

Turning to the South African landscape, it appears that minimal research has been done on use of BCT to improve food traceability for smallholder farmers in South Africa. One such example is the research by Ge et al. (2017), who consider the implications of BCT for food, and develop a pilot for traceability of South African grown table grapes that are exported to European consumers. Section 2.7 of this thesis lists additional related research on AgriTech for South African smallholder farmers. Looking through the lens of digital systems, the majority of the digital systems that are currently used in FSCs are centralised, monopolistic, opaque and laden with high information asymmetry resulting in a natural lack of trust amongst stakeholders (Zhao et al. 2019). Due to this centralised nature, the data in the traceability platforms is easy to tamper with and difficult to monitor (Hong et al. 2018).

Combining all of these considerations and observations, the question then arises, how to enhance traceability and transparency in local FSCs (comprised of smallholder farmers, food co-operatives and consumers) by using emerging and enabling technologies such as blockchain.

1.2 Aim and Objectives

Research Question

The following is identified as the main question for this research:

1. **RQ1**: Can a blockchain-enabled FSC enhance traceability and transparency for smallholder farmers, regional co-operatives and consumers in South Africa?

Research Sub-questions

The main question is further broken down into the following:

1. **RQ1a**: Can a blockchain-enabled FSC be used to enhance food traceability for

smallholder farmers, regional co-operatives and consumers?
2. **RQ1b**: Can a blockchain-enabled FSC be used to enhance transparency for smallholder farmers, regional co-operatives and consumers?
3. **RQ1c**: Can a blockchain-enabled FSC contribute to the advancement of the United Nations (UN) Sustainable Development Goals (SDGs):
   - SDG 2 - Zero hunger[1]
   - SDG 9 - Industry, Innovation and Infrastructure[2]
   - SDG 12 - Responsible Consumption and Production[3]

Research Objectives
The objectives of this research are listed below:
1. Designing a framework for a blockchain-enabled food traceability system for use in local FSCs where smallholder farmers, regional co-operatives and consumers are the main participants.
2. Building a prototype of the system to demonstrate its usefulness in a local FSC.

1.3 Methodology

Research Paradigm
This study explores the design of a blockchain-enabled platform for food traceability and transparency in local FSCs. Specifically, we engage with a local FSC made up of the Oranjezicht City Farm Market (OZCFM) - a farmers market based in Cape Town, the local smallholder farmers that supply them with produce and the market patrons who purchase the produce. Use of BCT for food traceability in FSCs is an unfolding use case, hence the exploratory nature of this research.

Data Collection
We employ a concurrent mixed method design for the research, collecting data through a series of observations coupled with surveys (see Appendix G) of the actors from the OZCFM-related local FSC. This follows the recommendation by Venkatesh, S. A. Brown, and Bala (2013) that if the broad goal of a research endeavour is to understand a phenomenon as it happens, as is the case for a software development project, then

[1] Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture (United Nations 2015b).
[2] Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation (United Nations 2015d).
[3] Goal 12: Ensure sustainable consumption and production patterns (United Nations 2015a).

a concurrent mixed method design approach suffices. In addition, due to the time constraints for undertaking this research, a concurrent mixed method design is preferable over a sequential one. Leech and Onwuegbuzie (2009) describe a concurrent mixed method design as one in which both quantitative and qualitative data are collected and analysed in parallel, whilst a sequential design is one in which the quantitative and qualitative phases occur sequentially.

The mixed method design employed in this research places greater emphasis on the qualitative aspect given the ability to observe the participants of the local FSC over an extended period of time. Hoepfl et al. (1997) state that observational data are used for the purpose of describing settings, activities, people, and the meanings of what is observed from the perspective of the participants. The observations for this research are carried out over a 5 month period.

We make use of surveys as an additional research instrument to establish a baseline on the state of traceability and transparency within the OZCFM-related local FSC, as well as ascertain the requirements of a blockchain-based system for use therein. Kitchenham and Pfleeger (2002) note that surveys can be used when attempting to describe a phenomenon of interest. We survey 4 smallholder farmers supplying fresh produce to OZCFM, as well as 12 consumers from the market. Majority of the constructs in these surveys are measured by a 3-point or a 5-point Likert scale.

Table 1.1 summarises the data collection methods and the associated sources.

Table 1.1: Data collection methods and their associated sources used in this research. Data was collected using observations and surveys, involving the local FSC actors - producers, regional co-operatives and consumers.

Primary Data	**Producer**	**Regional Co-operative (Farmers Market)**	**Consumer**
Observation	✓	✓	✓
Survey	✓	-	✓

Research Outcomes

The outcomes of this research include:

- A cost-effective blockchain-enabled FSC design framework.
- Implementation of a prototype blockchain-enabled FSC application and piloting within the OZCFM-related local FSC. This application is used to:
  - Record and track inventory of harvested farm produce by smallholder farmers.
  - Record storage of produce received from smallholder farmers by the regional co-operative.

– View produce provenance by consumers.

The implemented prototype provides enhanced tamper-evident food traceability, authentic transparency and farm-to-fork provenance of produce.

1.4 Key Concepts

The foundational concepts for this study are defined below:

- **Supply Chain Management** - The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain (SC) as a whole (Christopher 2016).
- **Food Supply Chain** - The series of processes, operations and entities that help to take food from its raw material state to a consumption ready state (Dani 2015).
- **Distributed Ledger Technology** - Umbrella term to designate multi-party systems that operate in an environment with no central operator or authority, despite parties who may be unreliable or malicious (Rauchs et al. 2018).
- **Blockchain** - A type of data structure used in some distributed ledgers which stores and transmits data in blocks that are connected to each other in a digital chain. Blockchains employ cryptographic and algorithmic methods to record and synchronize data across a network in an immutable manner (Natarajan, Krause, and Gradstein 2017).
- **Permissioned Blockchain** - A ledger in which network participants are preselected by the ledger administrator or owner, who in turn controls network access and sets the ledger rules (Natarajan, Krause, and Gradstein 2017).
- **Private Blockchain** - A ledger in which the consensus process can only be achieved by a limited and predefined number of participants (Guegan 2017).
- **Public Blockchain** - A ledger with no preference in access or in managing consensus. All participants (nodes) can read it, use it to carry out transactions and participate in the process of creating the consensus (Guegan 2017), e.g. Bitcoin [4]
- **Private-Permissioned Blockchain** - A permissioned ledger where the data is validated only by a set of participants (Natarajan, Krause, and Gradstein 2017).
- **Public-Permissioned Blockchain** - A permissioned ledger where the data is validated by all participants (nodes) (Natarajan, Krause, and Gradstein 2017), e.g. Ripple which uses the XRP Ledger Consensus Protocol (Chase and MacBrough 2018) and Alastria[5].

[4] Public blockchains are also referred to as permissionless, although given the recent rise of public-permissioned blockchains, public-permissionless is perhaps the more apt term.

[5] https://www.alastria.io/en, https://github.com/alastria/alastria-platform/blob/master/en/Alastria-Core-Technical-Platform.md.

- **Smart Contract** - A smart contract is executable code that runs on the blockchain to execute and enforce the terms of an agreement (Alharby and Moorsel 2017).

1.5 Thesis Outline

The remainder of this thesis is organised as follows:

Chapter 2 — A review of literature on FSCs, UN SDGs, DLT and BCT, as well as blockchain-related initiatives - both local and international.
Chapter 3 — A regional co-operative case study - OZCFM.
Chapter 4 — Design of FoodPrint - a blockchain-enabled food traceability system for local FSCs.
Chapter 5 — Implementation of FoodPrint.
Chapter 6 — Evaluation of FoodPrint.
Chapter 7 — Conclusion and opportunities identified for further research.

2. Background and Related Work

In this chapter, we review literature on farmers markets, FSCs, relevant food system concepts and UN SDGs. With regards to FSCs, we discuss the operations and actors, as well as the pertinent themes of transparency and traceability. From a technology point of view, we review the use of blockchain for food traceability and consider its business case. The chapter concludes with a summary of food traceability and AgriTech initiatives.

2.1 Farmers Markets

South Africa is home to a number of farmers markets, scattered across the major provinces in the country. These include the Oranjezicht City Farm Market (OZCFM) and Wild Oats Community Farmers Market in the Western Cape, Pretoria Boeremark and Bryanston Organic Market in Gauteng, as well as Shongweni Farmers & Craft Market in KwaZulu-Natal, to name but a few. Some of these farmers markets such as the Wild Oats have been running for over 2 decades[1] whilst others such as the OZCFM[2] have been running for a less than a decade. In contrast, farmers markets overseas have existed as far back as the early 20th century, although they briefly declined in popularity as innovations such as refrigeration and retail supermarkets emerged, before re-emerging in the 1960s as consumer interest in healthy eating and freshness of produce began to matter (Hinrichs 2008).

Farmers markets are a direct-to-consumer market where consumers can purchase locally grown produce and products (Polimeni, Iorgulescu, and Miclea 2018). Hinrichs (2000) highlights that farmers markets are settings for exchanges embedded in social ties, based on proximity, familiarity and mutual appreciation. They promise a human connection experience between farmers and consumers that is otherwise not present in retail markets or wholesale commodity markets (Hinrichs 2000). Although the human connection experience is a strong selling point, farmers markets are not always convenient (e.g. physical location or trading hours) and therefore some consumers opt to

[1] Wild Oats was started in 1999, see `http://www.wildoatsmarket.co.za`.

[2] OZCFM was established in 2013, see `https://ozcf.co.za/about/governance`.

rather shop from retail markets instead (Wolf, Spittler, and Ahern 2005).

Catalini and Gans (2020), and Kominers, Teytelboym, and Crawford (2017) indicate that marketplaces should coordinate and facilitate voluntary transactions between participants. This holds true for farmers markets. They are a form of marketplace, seeing as they have infrastructure and rules (Roth 2018). According to A. Brown (2002) and Hinrichs (2008), the core objectives of farmers markets include:

- Bringing the customer and producer closer together.
- Marketing and promoting fresh and high-quality local farm produce at reasonable prices.
- Marketing and promoting unusual and local speciality produce.
- Increasing social cohesion and promoting community well being.
- Encouraging and supporting agricultural diversification and self–reliance.
- Increasing the number of jobs in the related FSC as well as building supporting/related businesses (multiplier effect).
- Increasing farm profitability.
- Serving as business incubators.
- Serving as testing grounds for new products and new technologies.

2.2 Food Supply Chains (FSCs)

SCs are complex adaptive system networks in which organisations exchange information, goods and services (Casado-Vara et al. 2018). FSCs are a type of SC and are central to this research. Zhao et al. (2019) refer to FSCs as agri-food value chains and define them as a complex system responsible for the circulation of agri-food products from the initial stage of production to the final stage of consumption. One of the main differences between FSCs and other types of SCs is the limited time based nature of the SC product qualities, which in the case of fresh produce include freshness, quality and safety.

FSCs are multi-actor based and distributed as produce moves from farm-to-fork (Kamilaris, Fonts, and Prenafeta-Boldu 2019). The actors involved include the farmer (producer), transportation agents, processing agents, retailers and consumers.

Casado-Vara et al. (2018) describe FSCs as complex networks with multiple participants that are not necessarily familiar with each other and subjected to the inherent information asymmetries. One of the implications of this information asymmetry is that traceability along the SC becomes harder given that the minimal transparency, and as a result, food safety and quality become hard to determine.

2.2.1 FSC Operations

FSC management includes the operations from production, distribution, and consumption that are undertaken to keep the safety and quality of various food products under efficient and effective modes (Zhong, Xun Xu, and Wang 2017). Caro et al. (2018) and Dani (2015) identify the actors involved as providers, producers, processors, distributors, retailers and consumers, whose activities overlap with the aforementioned FSC operations.

Figure 2.1 illustrates each of these typical FSC operations, together with the associated actor.

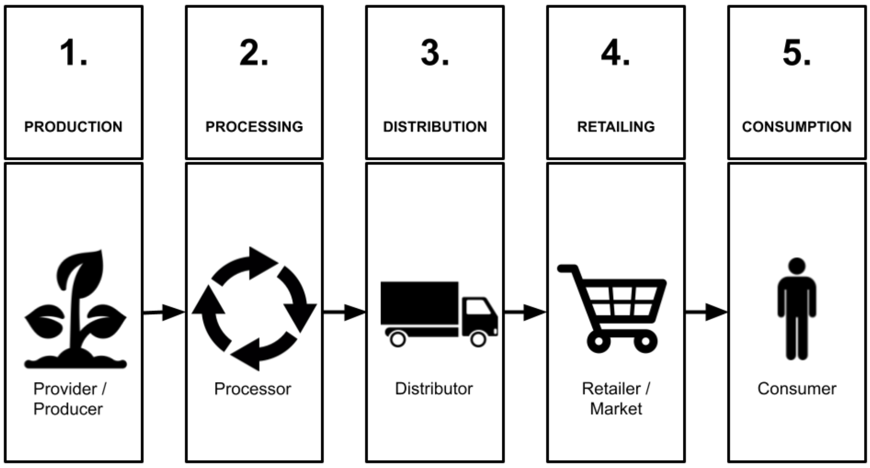

Figure 2.1: An illustration of typical FSC operations and the associated actors (Source: Author). The initial operation is the production of produce by the producer. The produce moves along the FSC until its final destination which is with the consumer.

However, not all of the operations shown in Figure 2.1 apply to local FSCs. Local FSCs tend to be shorter, as the link between producers (who are the local farmers) and consumers tends to be more direct, with fewer actors in between. Some of the operations are bundled together (e.g. production and distribution), whilst others are omitted altogether (e.g. processing). For this research, we consider local FSCs to be comprised of local smallholder farmers, regional co-operatives (e.g. farmers markets) and consumers. These are each discussed below.

2.2.2 Local FSC Actors

Smallholder Farmers

The initial supply side actor in a local FSC is the farmer, whose responsibility is that of growing of produce. The Department of Agriculture, Forestry and Fisheries, South Africa (2018) define prominent farming types in South Africa as follows:

- **Subsistence** - self-sufficiency household farming, characterised by resource constraints.[3]
- **Smallholder** - production for household consumption and markets.[4]
- **Semi-Commercial** - farming venture undertaken by an individual or business entity for the purpose of deriving a source of income along the agriculture value chain.[5]
- **Commercial** - farming venture undertaken by an individual or business entity for the purpose of the production and sale of agricultural products to make a profit.[6]

The number of smallholder farmers in South Africa is difficult ascertain. This may be attributed to the seemingly contentious definitions of smallholder farmers. According to the Department of Agriculture, Forestry and Fisheries, South Africa (2016), official South African statistics suggested that less than 231 000 or 2% of households in South Africa practice smallholder agriculture whilst some 2,8 million or 18,4% of households practice subsistence agriculture. In an earlier study, using data from the South African Department of Agriculture, Forestry and Fisheries (DAFF) as well as Statistics South Africa, Pienaar (2013) arrives at approximately 140 000 - 160 000 smallholder farmers and 2.3 million subsistence farmers in South Africa.

Smallholder farmers are often find themselves on the back foot in FSCs due to exposure to risks and insufficient access to market information. Cramer et al. (2019) highlight that although smallholder farmers produce a significant amount of healthy produce, they face numerous market related risks such as a lack of logistic organisation and no access to cold storage facilities. These risks in turn compromise the quality of produce and results in market insecurity. Furthermore, the information asymmetry that is present in FSCs means that smallholder farmers have limited bargaining power and credibility.

Regional Co-operative

In local FSCs, regional co-operatives are positioned in between producers and consumers. Regional co-operatives are responsible for connecting the supply side of the FSC with the demand side. According to the South African Companies and Intellectual Property Commission (n.d.), a co-operative is a distinct form of enterprise that provides services

[3]These producers are not classified as indigents by their municipality. They may market limited surplus production with an annual turnover of less than R50 000.

[4]These are usually the new entrants with an annual turnover ranging from R50 000 - R5 million per annum.

[5]These are established enterprises with an annual turnover ranging from R5 million – R20 million.

[6]These are established enterprises producing for market to make a profit with an annual turnover above R20 million.

and/or products to its members. Considering the FSC context, we consider the regional co-operative to be a local food co-operative providing a service to its members who are the participants in the local food system, both upstream (smallholder farmers) and downstream (consumers). The food co-operative can take various forms such as agri-processors, brokers or farmers markets.

For this research, we are particularly interested in farmers markets as representatives of regional co-operative, given that they:

- are a middleman in local FSCs
- provide the retail operation in local FSCs
- are easily accessible and observable
- are considered to be keystones in building localised food systems (Hinrichs 2008)

Consumer

Consumers are the final actors in FSCs (Dani 2015), they are located on the demand side. Since consumers purchase fresh produce for consumption, it is important that the produce they purchase should be safe, fit for consumption and of acceptable quality. Ramirez (2017) asserts that consumers of today are increasingly demanding access to local food and increased food transparency. As a result, consumer purchase decisions are increasingly being influenced by data points such as food origin, organic status and pesticide status, which gives impetus to the argument for greater food transparency and traceability in FSCs.

In the case of a local FSC that consists of smallholder farmers, and a farmers market, the consumer is a market patron that purchases produce.

2.2.3 Supply Chain (SC) Provenance, Transparency and Traceability

Provenance and Traceability in Traditional SCs

The Merriam-Webster (2020) dictionary defines provenance as "source or origin; or, the history of ownership of a valued object or work of art or literature". According to Westerkamp, Friedhelm, and Küpper (2019), traditional SC systems are capable of uniquely identifying products although their traceability is limited as this information is siloed amongst the participants. Similarly, Corallo, Latino, and Menegoli (2018) note that sometimes the knowledge related to a product and its processing is present in the implicit knowledge of workers. This suggests that the provenance of products in traditional SCs is known more by upstream actors rather than downstream actors, and even then, with limited transparency and traceability. Although this is a general

SC observation, it nonetheless holds for FSCs that are made up of disparate and siloed systems across the different actors.

Transparency and Traceability in Non-Traditional SCs

On the subject of traceability, Dattabot (2019) highlight that transparent data access in agriculture and FSC can result in productivity gains and increased efficiencies, both in the SC and in the market. In terms of traceability, The International Bank for Reconstruction and Development / The World Bank (2011) posit that food traceability systems allow SC actors and regulatory authorities to identify the source of a food safety or quality problem and initiate procedures to remedy it. Transparency and traceability are key to non-traditional SCs. We discuss each of these in turn below.

Transparency

Transparency in the context of SCs involves mapping a SC end-to-end and making the information relevant to each SC operation visible to interested parties. According to Casado-Vara et al. (2018), transparency can be defined as how SC information is communicated to stakeholders. In FSCs, some of this information includes who has been involved in the production and handling of the produce, with the interested parties including trading partners, shareholders, customers, consumers, and/or regulatory bodies. Increasing transparency is an effective way of demonstrating sustainability efforts and openness to stakeholders.

Transparency goes hand-in-hand with trust. In SCs, trust is the willingness that two or more actors are willing to be vulnerable and act in accordance with expectations (Queiroz and Wamba 2019). This is where blockchain, as a mechanism for trust can be of use in SCs. Leong, Viskin, and Stewart (2018) note that the value of blockchain in SC transparency is the ability for each actor to upload information and data about their products using a single platform with near real-time updates. To add to this, the value lies not only in the use of a single shared platform but in its tamper-evident nature as well. Blockchain in SCs is further discussed in Section 2.6.

Traceability

According to the ISO 22005:2007 (2007) standard, traceability is the ability to follow the movement of a feed or food through specified stage(s) of production, processing and distribution. Dabbene, Gay, and Tortia (2014) drill down further to differentiate between traceability and tracking, highlighting the former as following a product upwards to its origin with the latter being the opposite - downwards from raw material to finished product. Tracking requires the capturing of product data along every SC operation, together with its associated actor, from its initial form and source, right through to its final form and destination. This in turn enables the ability to trace a product back to its

initial form and source. For the purposes of this research, we consider traceability to be the tracing of fresh produce back / upwards to its origin.
Benefits of traceability in FSCs include:

- Enhancing of food safety and quality assurance.
- Potential to improve producer revenue, access to market and access to previously unavailable auxiliary services (e.g. financial).
- Enabling food businesses and subscription services to tailor their menus to match seasonally available produce and commit to undervalued produce which counts towards sustainability of the ecosystem (Cramer et al. 2019). This is an example of using traceability technology to influence behavioural change for good.
- Identification of SC inefficiencies.
- Use as a business differentiator.
- Potential to improve customer satisfaction (satisfy the need for food transparency by consumers) and strengthen brand loyalty.

Having considered the benefits of traceability in SCs, it is worth highlighting that some of the hindrances to effective traceability in SCs include poor and manual record keeping, SC complexity and identification lag time (Leong, Viskin, and Stewart 2018).

2.2.4 Issues and Concerns in FSCs

There exists a number of issues in FSCs, which include information asymmetry, food fraud, food safety, food insecurity and food waste. Of these, the first three can potentially be addressed by the tamper-proof record keeping property of BCT, and are briefly discussed below.

Information Asymmetry

As earlier indicated, FSCs are prone to information asymmetry challenges. One of the reasons for the information asymmetry is the fact that the produce-related data along every step of the FSC is primarily centralized to the responsible actor, with minimal to zero visibility for the other actors. In addition, an inverse relationship exists between the number of participants in a SC and the transparency therein - in most cases, a large number of participants is associated with low levels of transparency (Helo and Hao 2019) and increased opaqueness. Furthermore, distributed production and multiple information locations (i.e. information silos) within a SC add to the information asymmetry.

All of these contribute to various issues such as information fraud and unfair treatment of weaker SC actors (Tian 2016). These observations, when applied to FSCs, engender issues and concerns such as food fraud, food safety and food waste.

Food Fraud and Safety

Ge et al. (2017) identifies food fraud as selling unqualified product with high-quality labels or claims - this includes misrepresentation of produce, dilution or even substitution. Food fraud is characterised by deliberate misleading, and/or deception, often with the intention of financial gain. However, apart from being unethical, food fraud can result in public health risks, losses for producers of genuine produce as well as loss in consumer confidence (World Economic Forum and McKinsey & Company 2019).

In addition to food fraud, there are other factors that can impact on food safety, these include global trade, socio-economic and technological development, urbanization and agricultural land use (Tirado et al. 2010). Food safety is about handling, storing and preparing food to prevent infection and help to make sure that food keeps enough nutrients required for a healthy diet (Ministry of Higher Education, Training and Employment Creation, Namibia and Food and Agriculture Organization 2004). Upstream FSC actors not only have a fiduciary duty to uphold food safety but it is also in their best interest to comply with food safety regulations and ensure produce is of an acceptable level of quality as that unlocks access to markets (Leong, Viskin, and Stewart 2018), both local and global. According to the World Health Organization, unsafe food can cause disease[7] and result in death (World Health Organization 2020).

Food integrity is a concept that alleviates the concerns of food fraud and safety. According to Ge et al. (2017), food integrity refers to the fairness and authenticity of food in FSCs both at the physical layer and the digital layer, where the digital layer should provide reliable and trustworthy information on the origin and provenance of food products in the physical layer. Food traceability platforms operate in this digital layer, which is where BCT can be used to enforce integrity. The application of BCT in SCs is further unpacked in Section 2.6.

2.3 United Nations Sustainable Development Goals (SDGs)

The United Nations SDGs[8] are a set of 17 objectives that serve as a call-to-action to achieve global and continuous prosperity, in a manageable and equitable manner. The goals span across a number of themes that include education, clean energy, gender equality, world peace, and alleviating poverty and hunger.

When considering the SDGs from a SC and food traceability perspective, the concept

[7]A good example is the outbreak of listeriosis between 1 January 2017 and 14 March 2017 in South Africa. See `https://www.who.int/csr/don/28-march-2018-listeriosis-south-africa/en`

[8]`https://sdgs.un.org`

of SC sustainability emerges. According to the United Nations Global Compact (2015), SC sustainability is the management of environmental, social and economic impacts, and the encouragement of good governance practices throughout the lifecycles of goods and services. The United Nations SDGs related to food traceability and worth considering when implementing and evaluating technology-related FSC interventions include:

- **SDG 2 Zero Hunger**: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- **SDG 8 Decent Work**: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
- **SDG 9 Industry, Innovation and Infrastructure**: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- **SDG 12 Responsible Consumption and Production**: Ensure sustainable consumption and production.
- **SDG 15 Life on Land**: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

2.4 Food System Concepts

In this section, we discuss food system concepts that are relevant to food traceability and transparency in FSCs.

Food Democracy and Citizenship

Food democracy and citizenship are food system theories that are based on transparency, sustainability and food information needs (Corallo, Latino, and Menegoli 2018; McFadden, Stefanou, et al. 2016). According to Norwood (2015), food democracy emphasizes fulfilment of the human right to safe and nutritious food that has been justly produced, within a local context and championed by local residents as opposed to large corporations. Food democracy is concerned with democratic principles and practices of food governance (Bornemann and Weiland 2019).

Wilkins (2005) defines food citizenship as the practice of engaging in food-related behaviours that support, rather than threaten, the development of a democratic, socially and economically just, and environmentally sustainable food system. It is an active expression of food democracy. One can practice food citizenship by first thinking about the food system implications of how they eat and then by taking appropriate action, which is in stark contrast with an average consumer that is passive and largely uncritical.

Supply Chains and Ethics

Due to the multi-actor nature of SCs, the unfortunate reality is that it cannot be assumed that every actor will have good and honest intentions, and act responsibly. This introduces various concerns which include violation of human rights and labour rights, risks such as reputational and environmental, and additionally, in the case of FSCs, food safety. Furthermore, malpractice by any actor has the potential to do harm, not only to the responsible actor, but to the rest of the actors by virtue of their participation and association in a SC.

For example, in 2013, a building with garment factories collapsed in Bangladesh, resulting in the death of more than 400 people (New 2013). This highlighted the poor conditions that workers in the country's booming garment industry operate under whilst making clothes for global markets. Although this is specific to the clothing SC, it illustrates how SCs, regardless of the industry, can have systemic and hidden unethical practices such as sweatshop labour.

Give this context, the case for ethical considerations in SCs is becoming increasingly relevant. In their 2018 trends report, Accenture Interactive (2018) highlight the ethics economy as an emerging trend in which firms are expected to publicly state their ethical beliefs, which can in turn become a differentiator and potential source of competitive advantage. One way in which firms can communicate their ethical positions is through public disclosure of provenance data related to their value chains or adoption of sustainability-based standards and signalling mechanisms such as the Marine Stewardship Council (MSC) blue label[9] and the European Union (EU) ecolabel[10].

Farm-to-Fork Strategy

The expectation for traceability and transparency in FSCs has contributed to the emergence of the farm-to-fork strategy. Farm-to-fork promises food traceability of produce along the entire FSC, from agricultural production to consumption (Caro et al. 2018). The farm-to-fork[11] strategy is especially embraced in local FSCs given that it promotes consumption of locally sourced, fresh, safe and healthy food produce, often sourced directly from the producer or a local co-operative such as a farmers market. In addition, FSCs that embrace the farm-to-fork approach are deemed to be trustworthy and as a result, win over the discerning food consumers, seeing as trust is essential in commerce.

[9] https://www.msc.org/what-we-are-doing/our-approach/what-does-the-blue-msc-label-mean

[10] https://ec.europa.eu/environment/ecolabel/

[11] Various farm-to-fork like strategies exist with a common thread of sustainable food travelling from source-to-destination. These include bait-to-plate, barrel-to-bottle, beef-to-butcher, bean-to-cup, farm-to-box, farm-to-factory, farm-to-plate, farm-to-table, finished-product-to-consumer, grape-to-bottle, hook-to-cook, pasture-to-plate, paddock-to-plate, ocean-to-plate, rancher-to-retail, seed-to-plate and vineyard-to-table.

This can be used as a unique selling point/differentiator within an agri-business context.

Figure 2.2 illustrates a farm-to-fork mind map, together with its aforementioned constituent components.

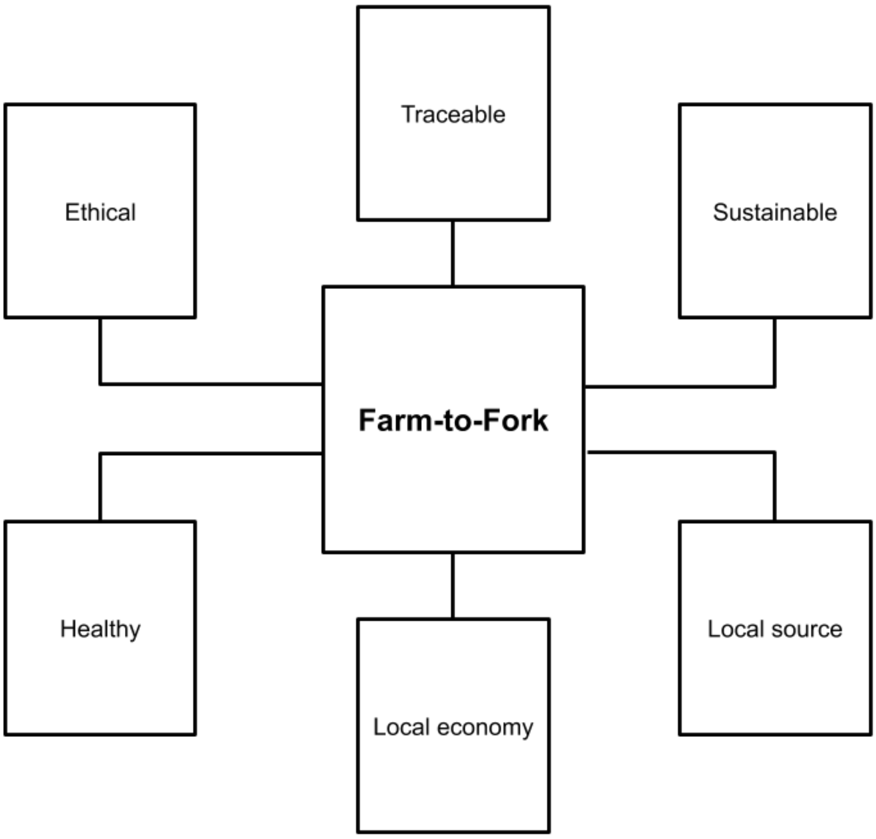

Figure 2.2: A mind map showing the constituents of the farm-to-fork strategy for fresh produce (Source: Author). These constituents include ethics, traceability, sustainability, local sourcing of healthy produce and supporting local economies.

2.5 Distributed Ledger Technology (DLT) and Blockchain

DLT is a broad term which describes all technologies that distribute information across multiple sites, countries or institutions (Treiblmaier 2018). DLT together with Artificial Intelligence, Extended Reality and Quantum Computing (DARQ) technologies are growing in utility and adoption by the day, with leading businesses exploring solutions based on these technologies (Accenture Labs and Accenture Research 2020).

Blockchain is one such technology that falls under the DLT umbrella. Treiblmaier (2018) defines the blockchain as a digital, decentralised and distributed ledger in which transactions are logged and added in chronological order with the goal of creating

permanent and tamper-proof records. The name blockchain stems from its technical structure — a chain of blocks that store a list of transactions, with each block linked to the previous block by means of a cryptographic hash (Wust and Gervais 2018). This distributed ledger is shared across nodes on a public or private network, thus eliminating the single point of failure that is characteristic of centralised systems.
Although blockchain is touted as immutable or tamper-proof, this is somewhat of a misnomer, seeing as a blockchain's records can be modified should the network be sufficiently corrupted by bad actors. A more apt description of the level of data integrity achieved through the use of cryptographic techniques and consensus mechanisms is that blockchains are tamper-evident - they reveal when arbitrary changes have been made after data has been added to the blockchain, but do not prevent them from taking place. However, given this tamper-evident property, a key weakness of blockchain networks is that there is no inherent mechanism to ascertain the validity or truthfulness of data at the point at which it is included in the blockchain. This means that incorrect information can be added to the blockchain, intentionally or unintentionally, and at best, the blockchain can only prove that the data is not tampered with once added. This weakness is also present in database management systems (DBMS).

Lastly, there are many different types of blockchains (e.g. Ethereum, Hyperledger Fabric), with very different properties.

2.5.1 Applications of Blockchain

Although the focus of blockchain has largely been focused on bitcoin, the latter is simply one of the applications of BCT, it is not the only one (Carson et al. 2019; Treiblmaier 2018). Blockchain and bitcoin were introduced by one or more individuals under the pseudonym Satoshi Nakamoto (Nakamoto 2008). Blockchain, although still emerging is more of a foundational technology whilst bitcoin is a blockchain cryptocurrency application. Referring to bitcoin as blockchain is therefore somewhat of a misnomer.

Blockchain has uses beyond fintech due to the reduction of agency and auditable traceability (D. Miller et al. 2019). Alternative applications of blockchain include stable-value currencies, decentralised file storage, decentralised autonomous organizations, financial services using smart contracts as well as identity and reputation systems (Buterin et al. 2014).

Applications that are built on top of a blockchain or DLT are referred to as decentralised applications (DApps). DApps utilize smart contracts to persist or retrieve data on the blockchain. The Financial Stability Board (2017) defines a smart contract as a programmable distributed application that can trigger financial flows or changes of ownership if specific events occur. A more generalised description for a smart contract is that of a self-executing and deterministic contract, with the terms written in code, that can trigger a state change on the blockchain. Some of the advantages of using smart contracts include increased efficiency, transparency and built-in security.

One can therefore view blockchain as the underlying framework and infrastructure that enables these varied applications that can be categorised as either record keeping or transactional.

2.5.2 Blockchain Categories

Public vs Private vs Consortium Blockchain

Blockchains can be categorised as public or private. Public and private permissioned blockchains differ in that the former allows anyone to read the contents of the chain and thus verify the validity of the stored data, whilst the latter only allows a limited number of participants to read the chain, and write permissions are kept centralised to one organization (Wust and Gervais 2018). Buterin (2015) describes fully private blockchains as akin to a traditional centralised system with a degree of cryptographic auditability attached. According to Natarajan, Krause, and Gradstein (2017), public blockchains do not require the network participants to be vetted by a ledger administrator. Examples of public blockchains include Bitcoin[12] and Ethereum[13].

The main criticisms associated with public blockchains include the limited data privacy and scalability limits such as size of data on the blockchain, slow transaction processing rate and latency of data transmission (Xiwei Xu et al. 2017; Wust and Gervais 2018). These criticisms do not hold for private blockchains.

Consortium blockchains are somewhere between public and private blockchains, they are semi-private and work across multiple different organizations. According to Buterin (2015), they provide a hybrid between the "low-trust" provided by public blockchains and the "single highly-trusted entity" model of private blockchains. Examples of these blockchains include Quorum by JP Morgan[14], Hyperledger Fabric by IBM [15], and Corda by R3[16].

Permission-less vs Permissioned Blockchain

Blockchains can also be viewed from consensus perspective, in which case they are considered to be permissioned or permision-less. A consensus mechanism in blockchain

[12] https://bitcoin.org/en
[13] https://ethereum.org
[14] https://www.goquorum.com
[15] https://www.ibm.com/blockchain/hyperledger
[16] https://www.r3.com/corda-platform

is the process for determining what blocks get added to the chain and what the current state is. Examples of consensus mechanisms include Proof of Work and Proof of Stake.

Permission-less public blockchains are completely open - new users can join the network, validate transactions, and mine blocks. In Bitcoin's permissionless blockchain, any writer and reader can join at any time. This is not the case for permissioned blockchains where only an authorized set of entities is allowed to write and read the respective blockchain and is therefore similar to a centralised database in this regard. In a permissioned blockchain, the participants are in a sense pre-selected and their are known by the ledger administrator. The ledger administrator, as the central entity decides and attributes to individual peers, the right to participate in the write or read operations of the blockchain. Carson et al. (2019) suggest that blockchain does not have to be a dis-intermediator (in the sense of a permission-less blockchain) to generate value and therefore permissioned blockchains can have valid use-cases, particularly in controlled environments where the permissioned blockchain supports existing business processes, instead of replacing them. Examples of permissioned blockchains include Hyperledger Fabric and Corda.

2.5.3 When to use Blockchain as a Technology Solution

Considering the parallels between blockchain and DBMS, one could describe blockchain as a distributed database system that is used for transacting or record keeping amongst multiple entities in an environment that is devoid of trust. This description, together with the technical complexity and limited awareness with regards to BCT, particularly when contrasted with existing DBMS raises the question of what circumstances warrant the implementation of a BCT solution.

Lapointe and Fishbane (2019) have put together an ethical design framework for blockchain that is a useful point of departure prior to commencing blockchain related projects. The framework includes a generic checklist that can be used to answer the question of when to use blockchain, see Figure 2.3.

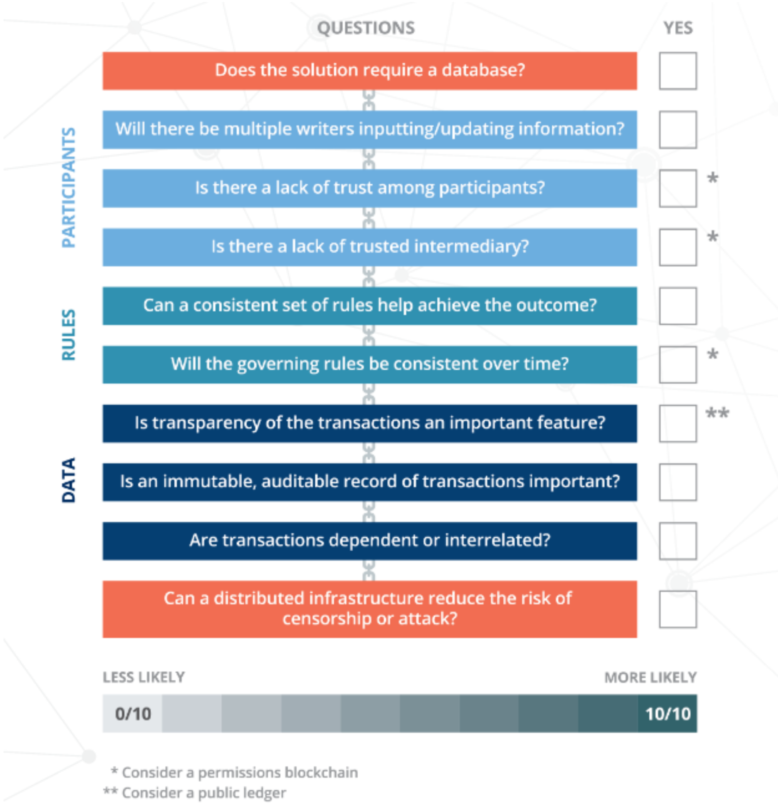

Figure 2.3: Checklist by Lapointe and Fishbane (2019) to determine viability of blockchain as a technology solution to a problem.

This framework is later referred to in Section 4 during blockchain-enabled traceability system design considerations.

2.6 Blockchain in SCs

Although blockchain is largely considered to still be an immature technology in a nascent market (Carson et al. 2019), one of the promising domains in which there may be notable value-add from employing blockchain-enabled solutions is in SCs. It can provide a secure, distributed way to perform transactions among different untrusted parties (Yuan et al. 2019; Pearson et al. 2019) and allows information to be verified and value to be exchanged without having to rely on a third-party authority (Carson et al. 2019). According to Pearson et al. (2019), DLT can provide a cryptographically secure and immutable record of transactions and associated metadata (origin, contracts, process steps, environmental variations, microbial records, etc.) linked across whole supply chains. These blockchain characteristics and nature position it well to track provenance and establish trust in a SC environment - an environment with shared information across multiple actors.

Tribis, El Bouchti, and Bouayad (2018) conduct a systematic review of the uses of BCT in SC and identify three main areas:

1. Physical traceability of goods with trusted information thereby increasing transparency as well as enhancing the quality and safety of the products.
2. Information security of supply chain management (SCM) system using privacy and immutability features of BCT.
3. SC finance in which claims and movement of funds can be automated and tracked using smart contracts.

Blockchain-enabled traceability in SCs can be useful in multiple contexts, such as reduction of product counterfeiting, tracking regulatory compliance and enhancing food safety and quality through traceability. For example, Bhatia et al. (2019) explore how blockchain-enabled traceability can be used to stamp out counterfeit goods across a products life cycle (production, sales and after-sales). They find that blockchain, coupled with IoT can be a source of both financial and competitive advantage, especially in luxury goods markets. In a different study, Biswas, Muthukkumarasamy, and Tan (2017) propose a blockchain-based wine SC traceability system to reduce counterfeiting, adulteration, and use of excessive preservatives and hazardous chemicals in the production of wine.

Blockchain in Food Supply Chains (FSCs)

In FSCs, blockchain can be used to track and verify produce origin.[17] The ability to timestamp FSC operation entries onto the blockchain is useful for creating an audit trail of each participant in the SC - particularly the producer, transporter and broker. In addition, the immutable nature of data on the blockchain guarantees data integrity, which has the effect of increasing trust and transparency. The timestamping and data integrity ultimately help prevent food fraud, improve food safety and quality, thereby addressing some of the earlier mentioned issues in FSCs. As put forth by Kshetri (2018) who proposes applying BCT to track end-to-end actions in a SC, blockchain improves SC dependability by exerting pressure on SC partners to be more responsible and accountable for their actions .

However, as correctly put by Wust and Gervais (2018), SCM has the inherent problem of the interface between the digital and the physical world - a human, or some machine under the control of a single writer, typically is required to register that a certain good has arrived in a warehouse, and if for example its quality is appropriate. If there is no trust in the operation of these employees, then the whole SC is technically compromised

[17] We refer to these as blockchain-enabled FSCs.

as any data can be supplied by a malicious writer. This problem exists not only in FSCs, but in the broader context of SCs in general.

It must also be noted that BCT is not the only means available for tracking and verifying produce in FSCs. Therefore, as aptly put by Leong, Viskin, and Stewart (2018), blockchain is simply another arrow in the quiver.

2.6.1 The Business Case for Blockchain-enabled Food Traceability

Blockchain-enabled food traceability solutions appear to be worth considering in scenarios where:

- Sustainability is a fundamental value to the FSC actors.
- A trust deficit exists in the FSC.
- The impact of food traceability related risk (e.g. food recalls or non-compliance penalties) is of material value to one or more SC actors.
- Tamper-evident traceability provides access to markets.
- Economic incentives exist for the FSC actors.
- Transparency and fraud controls such as auditability are required (Uhlmann 2017).

However, as stated by Leong, Viskin, and Stewart (2018), blockchain solutions must provide demonstrable business value and incentives for each participant in the blockchain ecosystem. Westerkamp, Friedhelm, and Küpper (2019) highlight that implementation of SC traceability systems based on smart contracts raises various questions regarding deployment and maintenance costs. Therefore, given that the cost structure of technology projects tends to consist of implementation costs and on-going operational costs, in order for them to be worthwhile, the economic benefits (revenue increase or cost savings) must exceed their economic costs. This is echoed by the World Economic Forum and McKinsey & Company (2019) who propose that cost-saving opportunities need to be weighed against the capital expenditures of acquiring technology, together with the operational costs involved. Bhatia et al. (2019) suggest that firms must look across key markets and segments and examine buying behaviours and channel characteristics in order to evaluate the overall cost-benefit of a blockchain solution.

2.7 Related Research in South Africa

In this section, we list related research around the themes of BCT, FSCs, traceability and smallholder farming in South Africa. See below:

- PoC for blockchain-enabled traceability of South African grown table grapes that are exported to Europe by Ge et al. (2017).
- Blockchain for financial inclusion in South African small-scale agriculture in South Africa by Chinaka (2016).
- SC risks and smallholder fresh produce farmers in the Gauteng province by Louw and Jordaan (2017).

2.8 Food Traceability and AgriTech Initiatives

General AgriTech Initiatives

Table 2.1 shows a brief summary of generalised AgriTech initiatives in South Africa that range from use of artificial intelligence and drones for crop disease detection to fish traceability for small-scale fishers. These initiatives are not presently known to use BCT.

Table 2.1: General AgriTech initiatives in South Africa. These initiatives are not known to presently employ blockchain technology (BCT).

Name	Description (URL)	Location
Aerobotics	Early pest and disease detection enabled by drone imagery and artificial intelligence. (https://www.aerobotics.com)	South Africa
Khula	Online market place for farm produce. (http://www.khula.co.za)	South Africa
Abalobi	Suite of mobile applications for small-scale fisheries governance. Abalobi promotes traceable, storied seafood by empowered small-scale fishers from hook to cook. (http://abalobi.info)	South Africa
BuyFresh	Online marketplace for ordering fresh produce from local farmers and artisanal food producers. (https://buyfresh.co.za)	South Africa

Cramer et al. (2019) provide a similar and longer list of existing applications in the South African farmer space.

BCT Initiatives for Traceability

Globally, there a a number of different initiatives that are using BCT for traceability. Some of these are using BCT for traceability of produce and livestock in FSCs (refer to Appendix A, Section A.1), whilst others are solving traceability requirements outside of FSCs (refer to Appendix A, Section A.2).

3. A South African Regional Co-operative Case Study - Oranjezicht City Farm Market (OZCFM)

For this food traceability research project, we engage with OZCFM who are representative of a regional co-operative in a local FSC. As a farmers market, OZCFM are central to the local FSC of interest, given that they interface directly with the other equally important actors of the local FSC - the smallholder farmers that supply the market, together with the market patrons who are responsible for the final purchase of produce from OZCFM. The view of equally important actors is suggested by A. Brown (2002), who notes that a successful market meets the needs of farmers and consumers, and cannot exist without either party.

In this chapter, we discuss the mechanics of OZCFM, how it interfaces with the smallholder farmers and consumers, as well as some of the observations the OZCFM-related located FSC.

3.1 Overview of OZCFM

OZCFM is a farmers market that is located in Granger Bay at the V & A Waterfront precinct in Cape Town, South Africa. The market is an extension of the Oranjezicht City Farm (OZCF) - a non-profit urban farming project in Cape Town (see Figure B.1 in Appendix B for an image taken at the entrance of OZCF).

According to Ozinsky and Ackermann (2014), the objectives of the OZCF include:

- Improving under-utilised green spaces by creating urban farming gardens.
- Community building.
- Small scale organic food production education.

- Promoting food sustainability.
- Increasing access to nutritious fresh produce in the Western Cape province of South Africa.

OZCFM

OZCFM supports over 30 smallholder local farmers in the Western Cape by purchasing fixed quantities of their locally grown, fresh and seasonal produce. This produce is then sold to market patrons on market days. According to Louw and Jordaan (2017), smallholder fresh produce farmers are exposed to post-harvest and marketing risks as low market prices, lack of access to markets, lack of transport, competition, poor produce quality and a lack of packaging material. Therefore, by purchasing the produce directly from the farmers, the market takes on the market-related risk of not selling all of the produce, guarantees the farmers some revenue and reduces some of the farmers post-harvest risk. By buying produce from farmers and selling it on to consumers, OZCFM earns revenue through trading spread - earning the difference between the price paid to buy the produce and price earned from selling the produce. Trading spread is one of the viable revenue models that is identified by Eisenmann and Kominers (2018) during their discussion of revenue models for markets.

OZCFM currently places orders for produce directly with the farmers. The farmers then fulfil the order by delivering the produce to the market, typically one day before the market is opened to the public. When the produce is delivered, it is kept in cold storage until market day. In addition to supporting farmers, OZCFM also supports artisanal food producers who man individual booths and operate as market traders. OZCFM earns revenue from these traders through a hybrid of membership fees and transaction fees.

Similar to the observation by Wolf, Spittler, and Ahern (2005), OZCFM not only serves the local community but is also a tourist attraction. This is due to the well-crafted consumer experience coupled with the increase in consumer demand for fresh farm produce.

3.2 Participants of the OZCFM-related local FSC

The OZCFM-related local FSC consists of three core actors - the local smallholder farmers (also referred to as suppliers or producers), the market itself as the regional co-operative and the market patrons as the consumers. These are illustrated in Figure 3.1 on the next page.

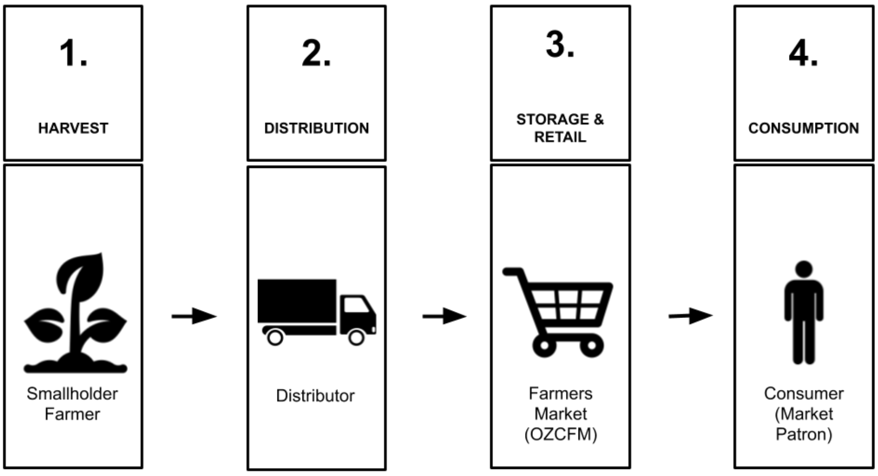

Figure 3.1: Visualisation of the OZCFM-related local food supply chain (FSC) (Source: Author). The local FSC is made up of the smallholder farmers, the market and the market patrons. The smallholder farmers are responsible for the supply of produce to the market (and often double up as distributors). The market provides cold storage for the produce and the retail operation. The market patrons who purchase produce from the market are the consumers.

In the next section, we discuss each of these participants - their role, observations recorded during the period of research as well as the inferences drawn.

3.2.1 Regional Co-operative (The Market)

Ordering Produce

As noted in Section 3.1, OZCFM orders produce from smallholder farmers, which it then sells to the consumers. These orders are placed via email or telephonically, in advance of the market days, according to the markets weekly requirements and expectations of consumer demand.

Delivery of Produce

The farmers deliver the ordered produce in advance of the market days. The deliveries arrive at the OZCFM weigh and pay station, typically in light duty pickup trucks, with the produce in non-standard crates or boxes. Cold foods are transported in styrofoam packaging or in mini refrigerated trucks.

When the produce is delivered to the market, an OZCFM administrator weighs the produce, confirms the quantities and quality, and produces a credit note/receipt, formally acknowledging the handover and commercial obligation to the farmer. At this point, the food produce is then stored in an on-premise cold storage facility until market day when it is placed on display for consumers.

When the produce is put on display on market days, it is labelled as either organically grown[1] or conventionally grown[2]. This labelling of produce is crucial as it reduces information asymmetry, which in turn can steer consumers towards making a purchase, thereby avoiding an information-driven market failure (Kominers 2019).

Market Day

OZCFM is open to the public for trading on Saturdays and Sundays, as seen in Figure 3.2.[3]

Figure 3.2: Trading times for the Oranjezicht City Farm Market (OZCFM) (Photo: Author). The market is open to patrons on Saturdays and Sundays.

At the official start of a market day, the market administrator welcomes the consumers by announcing over the public-address system and highlights some of the produce that is available for purchase on the day - often incorporating a personal and seasonal touch to the message. The produce itself is laid out in an aesthetically pleasing manner against a natural materials and greenery backdrop as seen in Figure 3.3.

[1] Organic farming is based on natural techniques such as bio-diversity and composting.

[2] Conventional farming is based on chemical intervention for pest and weed control as well as plant nutrition.

[3] During the summer season, OZCFM is also briefly open to the public on Wednesdays, late-afternoon to early evening.

Figure 3.3: A picturesque display of fresh produce for sale on a market day at the Oranjezicht City Farm Market (OZCFM) (Photo: Author).

As the market progresses, the market administrator regularly advertises produce that the consumers should not miss out on and gives an indication of remaining quantities so as to induce a feeling of fear-of-missing-out, which ideally translates into subsequent purchases by the consumers. At the close of the market day, it is OZCFM tradition to ring a bell. When the bell is rung, the market patrons and traders clap their hands in response. This tradition helps to create a strong sense of community between the market, traders and consumers.

Attendance and Purchase Patterns

One of the fundamental objectives for OZCFM is to increase the spend per market patron/consumer. When observing the interactions at the market through the lens of this objective, attendance and purchase patterns became of interest.

A. Brown (2002) identifies the location of the market as an important factor in the composition of the customer base of a farmers market as markets draw primarily from the neighbourhoods that they are located in. OZCFM is located in the upmarket Granger Bay precinct of the V & A Waterfront, as earlier indicated. We perceive this to be beneficial for OZCFM on two fronts. Firstly, this naturally draws the local residents in and around the area. Secondly, the V & A Waterfront area is a natural tourist magnet and OZCFM benefits from this as a visit to the market is low hanging fruit for tourists planning on spending some time at the V & A Waterfront.

From our observations, most fresh produce is purchased on Saturday mornings.

These consumers purchasing produce appear to be the regular market patrons who plan for their Saturday morning shop, budget accordingly and often have hand-written shopping lists. In contrast, produce purchases on the other market days tend to be fewer and slower. On Sundays, activity around the produce stalls increases during the last hour of the market day as consumers seek to take advantage of the discounted produce prices, including flat-fee bundled produce boxes. It is also worth noting that not all of the market patrons purchase fresh produce, some visit the market for social purposes.

Another key observation is that the busiest months for the market are November, December and January. This is because of the large influx of tourists who visit Cape Town for the summer season and end of year holidays. This period coincided with the pilot of the food traceability system which is one of the artefacts of this research. Further, our engagement with some of the international tourists who visited the market revealed that they too are interested in food traceability.

3.2.2 Smallholder Farmers

The fresh produce supplied to OZCFM by the local smallholder farmers includes oranges, apples, green beans, cucumbers, fennel and beetroot. The farmers perform their own deliveries or else outsource to small-scale transportation agents. Most of these farmers harvest to order in a bid to avoid produce wastage, although sometimes they do suffer from produce wastage as the market cannot absorb all the produce from the farmers if it is in excess supply.

The surveys we ran suggest that the farmers trust OZCFM and similar markets that they supply. They trust that the markets act in their best interest and pay fair rates for procurement of the farmers produce. The trust stems from years of working together in a mutually beneficial manner and the sense of community that is associated with farmers markets. This beneficial and long-running engagement between OZCFM and the farmers resonates with the remark by A. Brown (2002) that farmers engage with markets because of the perceived value and benefit of the channel for selling of produce. A. Brown (2002) also notes that smallholder farmers are more likely to participate in farmers markets as compared to large-scale farmers because the economics of farmers markets are favourable for smallholder farmers instead of large scale farmers.

The interactions with the smallholder farmers also revealed that they have limited access to financial services. This is largely due to the significant guarantees such as immovable assets, guarantors or government guarantees that are required by the lenders/financial institutions.

Technology and Data Management

With regards to technology and produce related data management, our interactions with the farmers reveal the following:

- Majority of them have access to reliable internet on their farms and in-turn also have internet-enabled devices such as mobile phones at their disposal.
- The capture, storage and processing of operational data (such as produce planting dates, pesticide application dates and harvest data) is largely done on paper logbooks or Microsoft Excel spreadsheets. The challenges with paper logbooks are numerous - they are difficult to store, version control is difficult to enforce, legibility is not guaranteed and ultimately searching through historic records is difficult as highlighted by Moore, Goudard, and Hardy (2008). Similarly with spreadsheets, inefficiencies arise as spreadsheets tend to become scattered over time and similar concerns of enforcing version control and audit trails apply. Additionally, a side effect of using offline data management tools such as Microsoft Excel is that the sharing of inventory information becomes a time intensive, costly and inefficient operation. This means that the search costs - the costs of looking for information (Goldfarb and Tucker 2019), are in this instance higher as OZCFM has to call the farmers one by one to discover available produce and subsequently place orders.
- Analytics on farming data appears to be under-utilised, if utilised at all. This is because the data is often very segmented and stored in an unstructured manner.

Given these considerations, we infer that by digitizing their operations, the farmers have the potential to improve their operational effectiveness, make crop yields more efficient (e.g. reduce risk of produce over-supply), and ultimately improve their revenue generation.

3.2.3 Market Patrons (Consumers)

According to A. Brown (2002), consumers patronise farmers markets because they find it socially beneficial to do so and feel that the markets provide high-quality produce at reasonable prices. At OZCFM, the market patrons visit for a number of reasons, which include socialising, touring and purchasing of produce. The social and tourism aspects are exemplified by the large amounts of foot traffic at the produce stands from patrons seeking to capture picture perfect shots for their social media profiles.

The consumers (market patrons who purchase produce) are of greater importance to this study. The consumers that purchase produce early in the morning display an intrinsic incentive to buy the best and freshest produce, hence the early arrivals. On the other hand, consumers that wait until the last hour on the last market day of the week to buy produce are seemingly driven by an internal incentive to get the most amount of produce for the least amount of cost.

Perceived Consumer Interest in Traceability Information

Our engagement with consumers at OZCFM indicated that although the consumers are interested in traceability information (as it provides provenance and closes the food loop), majority of them do not appear willing to pay a premium for it. One consumer indicated that paying for access to traceability information suggests profit motives by the information provider which in turns undermines consumer trust in them. This, the consumer described, would be akin to OZCFM charging an entrance fee which would appear contradictory to their agenda of supporting the local farmers and community.

4. FoodPrint Design

In order to demonstrate the usefulness of a blockchain-enabled FSC solution for farm-to-fork traceability, we design and implement a hybrid web/blockchain application called FoodPrint[1]. The design and implementation of FoodPrint takes into consideration the remark by Corallo, Latino, and Menegoli (2018) that the real strength of a traceability system is in the creation of a big-data platform where all the collected data is merged, maintaining its paternity with respect to the SC operator and traceability towards the products.

This chapter discusses the design of FoodPrint - the requirements, design considerations and concludes with the conceptualised data models to represent the FSC *harvest* and *storage* operations.

4.1 Functional Requirements

Functional requirements (FRs) define what a system must be able to do, they pertain to a functional concern (Glinz 2007). During the design of FoodPrint, the personas of the main FSC participants - the smallholder farmer, food market administrator and consumer are created in order to better understand their needs, experiences and goals; and in turn translate these into the core features, functionality and user experience of the application. These personas are shown in Appendix C.1.

The distilled FRs for FoodPrint together with the corresponding system actor are listed in Table 4.1 on the next page.

[1] https://www.foodprintapp.com

Table 4.1: The core functional requirements identified for the development of the FoodPrint Traceability platform. These requirements are listed together with their corresponding system actors. The actors are the smallholder farmer, food market administrator and consumer.

Functional Requirement	System Actor
User Authentication	System Admin, Farmer, Market Admin
Generation of supplier-produce specific QR codes	System Admin
Master data configuration	System Admin
Logging of harvest produce information to a SQL database	Farmer
Logging of harvest produce information to an Ethereum blockchain network	Farmer, System Admin
Logging of storage information to a SQL database[2]	Market Admin
Logging of storage information to an Ethereum blockchain network	Market Admin, System Admin
Efficient tracing of produce (trace produce / produce search)	Market Admin
Verifying of harvest and storage data on blockchain (blockchain explorer)	Market Admin
Viewing of weekly produce list	Consumer
Viewing of produce provenance by scanning of a supplier-produce specific and system generated quick response (QR) code	Consumer
Expose FSC data via APIs for actors and/or interested parties to flexibly integrate into external systems[3]	System Admin

Further, according to El-Attar and J. Miller (2007), use case modelling is often used to drive the design phases of a software project because it is very simple to use to effectively describe the functional requirements of a system. A use case diagram consists of use cases (depicted as ovals) and actors - it summarises the interaction between the actors and the use cases as well as the relationships between the use cases themselves. The use case diagram shown in Figure 4.1 on the next page summarises the core FRs identified for FoodPrint.

[2] Storage information includes receipt of produce from a farmer and its subsequent delivery into storage.
[3] Huang, Wu, and Long 2018.

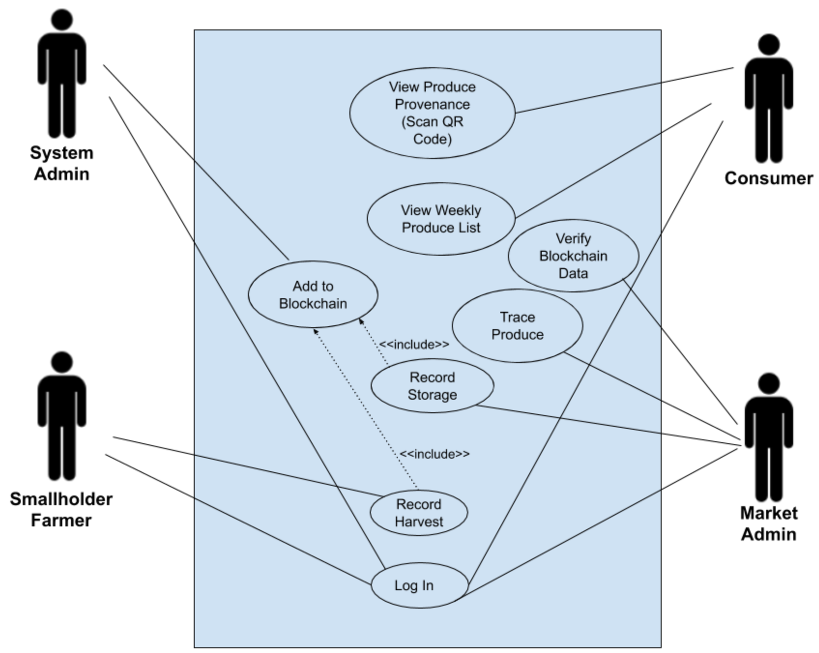

Figure 4.1: A use case diagram illustrating the interactions between the FoodPrint system actors and the core system functionality. This functionality includes the logging of produce-related operational data and the viewing of produce provenance information.

4.2 Non-functional Requirements

Non-functional requirements (NFRs) relate to performance, quality or a constraint of a solution space beyond what is necessary to meet the core requirements (Glinz 2007). Table 4.2 on the next page lists the identified NFRs for FoodPrint based on the concern-based taxonomy suggested by Glinz (2007).

Table 4.2: The non-functional requirements identified for the development of the FoodPrint Traceability platform. These constraints which relate to the performance, quality and design of the platform are primarily categorised as attributes or constraints.

NFR type	NFR subtype	NFR	Description
Attribute	Performance	Speed	The traceability application should be responsive and scalable regardless of network traffic. When Axiom Zen innovation studio launched CryptoKitties[4] on the Ethereum blockchain network, the popularity of the game resulted in transaction congestion and delays on the network, highlighting its lack of scalability[5,6]. Since blockchain may not be ready for scale, the use of hybrid solutions involving traditional database technologies and blockchain is a valid consideration.
	Quality	Good User Experience	The success of a digital product depends on more than the utility alone. In the design of the traceability application, consideration should be given to its ease of use and accessibility, both on a web browser and on a mobile device.
		Security	Online platforms tend to have higher perceived risks by users as compared to conventional commerce platforms. As such, use of trust-enhancing mechanisms for online platforms is necessary for the application. One such mechanism is the use of secure socket layer (SSL) certificates.
		Availability	The application should be available even if there is an issue with blockchain network.
		Modularity	Modular applications are easier to maintain. The application needs to be modular in nature, similar to the IBM Food Trust solution - a modular blockchain platform for the food industry and all players in the ecosystem. The IBM Food Trust solution modules include - Trace & Recall, Data Entry & Access, Certificate Management (IBM Food Trust 2019).
Constraint	Design and Implementation	QR codes should be scannable by modern mobile device cameras	The QR codes generated by the application should be readable by cameras on modern mobile devices running the most popular Operating Systems (OS) at the time of writing - iOS and Android OS.
		Minimal technical barriers to trade	According to Pearson et al. (2019), applications such as FoodPrint should enhance trust and enable trade, instead of becoming technical barriers to trade (due to specific and perhaps complex digital infrastructure requirements). This is accomplished by designing pragmatic, low cost and accessible DLT solutions that allow access to DLT via low cost hardware (smartphones/tablets). In addition, the software solutions should be independent of farm size and suitable for all farmers and smallholders.

[4]CryptoKitties 2020.

[5]BBC News 2017.

[6]One common concern about Ethereum is the issue of scalability. Like Bitcoin, Ethereum suffers from the flaw that every transaction needs to be processed by every node in the network (Buterin et al. 2014).

4.3 System Design Considerations

From PoC to Technical Prototype and Pilot

Before developing the FoodPrint technical prototype, a PoC is created to demonstrate the ability to write to the Ethereum blockchain for basic harvest and storage operations. A PoC is used in the initial stages of design and generally involves minimal effort (Ullman 2009). Following the PoC, the engagement with the OZCFM-related FSC becomes more frequent and participatory, with the FSC actors actions considered in the development of the technical prototype, and the actors themselves participating in the pilot.

The implementation of the technical prototype is discussed in Chapter 5 (FoodPrint Implementation), whilst the evaluation of the prototype is discussed in Chapter 6 (FoodPrint Evaluation).

Is BCT Appropriate for Food Traceability in local FSCs?

Whilst considering the appropriateness of a blockchain-enabled solution to enhance traceability and transparency in the local FSC, we answer the questions posed in Figure 2.3, and provide a comment for each. This can be seen in Table 4.3 on the next page.

Table 4.3: A completed checklist to establish whether blockchain technology (BCT) is appropriate for food traceability in the local FSC of interest for this research. The answer to 8 out of the 10 questions is *yes*, suggesting the viability of a public blockchain such as Ethereum to enhance food traceability within the local FSC in question. The checklist is by Lapointe and Fishbane (2019).

Category	Question	Response (Yes/No)	Comment
Data Persistence	Does the solution require a database?	Yes	The harvest and storage operations require persistent storage for traceability and analytics.
Participants	Will there be multiple writers inputting/updating information?	Yes	Smallholder farmers and market administrators.
	Is there a lack of trust among participants?	No	Although unknown at onset of the research, survey of consumers suggests a primary trust in OZCFM as the intermediary and by association, trust in their suppliers - the smallholder farmers.
	Is there a lack of trusted intermediary?	No	Although unknown at onset of the research, survey of consumers suggests a primary trust in OZCFM as the intermediary between the farmers and the consumers.
Rules	Can a consistent set of rules help achieve the outcome?	Yes	Standardised information capture will be speed up traceability and enhance transparency.
	Will the governing rules be consistent over time?	Yes	The procedure for capturing harvest and storage information will be consistent.
Data	Is transparency of the transactions an important feature?	Yes	Transparency of the harvest and storage information is vital to the consumer.
	Is an immutable, auditable record of transactions important?	Yes	This is necessary to provide traceability and assurance that information is not altered after the initial data entry operation.
	Are transactions dependent or interrelated?	Yes	A FSC storage operation requires a preceding harvest operation.
Censorship and Attacks	Can a distributed infrastructure reduce the risk of censorship or attack?	Yes	The information asymmetry that inherently exists in FSCs poses a very real risk of censorship. Once FSC operational data is captured on blockchain, it becomes visible to all observers and is harder to tamper with after the fact.

Given that the answer to 8 out of the 10 questions in Table 4.3 are in the affirmative (*yes*), coupled with the assertion by Abelseth (2018) that by using a blockchain-based SC, the tracking of produce is secure, irreversible and auditable, we deduce that use of BCT is a viable option for enabling food traceability in the local FSC in question. A permissioned blockchain such as Hyperledger Fabric appears to be a reasonable choice of BCT to use given that OZCFM is a trusted intermediary and there is a level of trust amongst FSC participants.

However, we decide to use the public Ethereum blockchain given that:

- Transparency of transactions is an important requirement for the research.
- Solidity[7], an object-oriented, high-level language for implementing Ethereum based smart contracts is well documented and makes use of syntax that is similar to some of the mature programming languages such as C++, Python and JavaScript.
- The Ethereum developer ecosystem is growing and includes development frameworks (e.g. Truffle[8]), local testing environments (e.g. Ganache[9]), cryptocurrency wallets (e.g. MetaMask[10]) and gateways/APIs to Ethereum networks (e.g. Web3.js[11], Infura[12]).
- Test Ether for testing smart contracts is freely available via network specific faucets. A faucet is a service that dispenses funds in the form of free test ether that can be used on a testnet (Antonopoulos and Wood 2018). [13]
- It is relatively straightforward and cost-effective to deploy to an Ethereum testnet. A testnet (test network) is a network used to simulate the behaviour of the main Ethereum network (Antonopoulos and Wood 2018). [14]

Produce Identification Mechanism

FoodPrint is designed to support the harvest and storage FSC operations, which each have associated quality, logistics and transaction data. In order to track this data for each produce type as it moves along every stage of the FSC from farm-to-market, an identification mechanism is required. The ISO28219:2017 standard defines guidelines for creating globally valid identifiers that are enforced by utilizing bar codes or two-dimensional symbols, such as QR codes and alternative radio frequency identification (RFID) tags, to project physical goods onto digital systems (Costa et al. 2013). Similarly, Westerkamp, Friedhelm, and Küpper (2019) highlight that an identification mechanism is fundamental to ensuring the coupling between physical and digital representations.

Building on this, we ascertain that a system-generated identifier that is specific to the supplier-produce-date combination needs to be generated at the first FSC operation (harvest) and carried through for each subsequent operation, with respect to produce that has been harvested. In addition, a static, customer-facing identifier that is unique

[7] https://solidity.readthedocs.io
[8] https://www.trufflesuite.com/truffle
[9] https://www.trufflesuite.com/ganache
[10] https://metamask.io
[11] https://web3js.readthedocs.io
[12] https://infura.io
[13] An example faucet for the Ethereum Rinkeby testnet is https://faucet.rinkeby.io.
[14] Testnets are preferred for testing as the ETH used in testnets has no value and is generally freely available from faucets. The common Ethereum testnets include Ropsten, Kovan and Rinkeby. The main Ethereum network is referred to as the mainnet and on this network, Real Ether (ETH) (with real value) is used.

to the supplier-produce combination is required that links back to the system-generated supplier-produce-date identifier.

We find that QR codes are suitable for use as the static, customer-facing produce identification mechanism for FoodPrint. QR codes encode specific identifiers that can be printed and added to physical products, which in turn can be scanned by a smartphone running the traceability solution (Westerkamp, Friedhelm, and Küpper 2019).

System Data Model Design Iterations

The design of the core FoodPrint harvest and storage data models is carried out in two iterations in which the models are initially conceptualized and then improved upon. The data models are fundamental entities representing the FSC operational data that is persisted in the relational database, and on the blockchain via a smart contract. These iterations are described below:

- **Iteration 1 - Initial Harvest and Storage Data Models for the PoC** - After minimal engagement with the local FSC actors, the initial data models are created with the view of establishing the feasibility of capturing and representing the corresponding harvest and storage operations in their most basic form, using a blockchain-enabled food traceability solution.
- **Iteration 2 - Updated Harvest Data Model for the Technical Prototype and Pilot** - The data models from Iteration 1 are improved upon by incorporating the feedback and observations resulting from a more interactive and routine engagement with the local FSC actors. Iteration 2 exhibits a SC vertical collaboration in which the entire SC is involved, from producers to customers (World Economic Forum and McKinsey & Company 2019). The updated data models are reflected in the technical prototype which is used for the pilot at OZCFM.

Table 4.4 shows the updated produce harvest and storage data models which are used for the technical prototype and pilot. The elements marked with an asterisk (*) are added during Iteration 2, whilst the rest of the elements are carried over from Iteration 1.

Table 4.4: Updated data models for the FoodPrint technical prototype and pilot. These models are specific to the produce harvest and storage operations which are supported by FoodPrint. The elements marked with an asterisk (*) are added during the second design iteration, whilst the rest of the elements are carried over from the first iteration.

Supply Chain Operation	**Data Field**	**Description**	**Example**
(1) Harvest	Harvest ID	Unique ID for harvest entry	1b26557b-20f3-4ea2-81d2-e54c5a9a40f7
	Supplier Produce ID	Unique ID for harvest entry (per supplier-produce combination)	OZCF_Apples
	Supplier ID	Unique ID for supplier	OZCF
	Supplier Address	Supplier street address	Pier Road, Waterfront, Cape Town, Western Cape, 8001
	Produce Picture Hash	Hash of photo stored in relational database	abc01...
	*Harvest Geolocation	Geographical location of where the produce is harvested	-33.961059,18.4110411
	*Growing Conditions	Claims related to growing conditions e.g. Organic vs Conventional,	'greenhouse':'no', 'organic':'yes'
	*Harvest Description	Harvest specific comment	Baby Marrows with soft skin and buttery flesh. [Organic]
	*Harvest Quantity	Harvest specific comment	Baby Marrows with soft skin and buttery flesh. [Organic]
	*Harvest Unit of Measure	Harvest specific comment	Baby Marrows with soft skin and buttery flesh. [Organic]
	*Harvest User	Harvest specific comment	Baby Marrows with soft skin and buttery flesh. [Organic]
	Harvest Timestamp	Date and time at which produce is harvested	20190620 16:10:55
	Harvest Data Entry Timestamp	Date and time at which data captured in FoodPrint	20190620 17:10:55
	Harvest Table Name	Table name for harvest entry in relational database	harvest
(2) Storage	Harvest ID	Unique ID for harvest entry	1b26557b-20f3-4ea2-81d2-e54c5a9a40f7
	*Storage ID	Unique ID for storage entry	c3541cd7-82e7-477b-9a17-b0f910bf7098
	Market ID	Unique ID for market	OZCFM
	Market Address	Market street address	Pier Road, Waterfront, Cape Town, Western Cape, 8001
	Produce Quantity	Number of units received	20
	Produce Unit of Measure	Type of unit e.g. weight, number of produce units, bunches	grams
	*Storage Description	Storage specific comment	Stored in cold room at 10 degrees Celsius
	Storage Timestamp	Date and time at which produce is received at the market	20190621 16:10:55
	Storage Data Entry Timestamp	Date and time at which data captured in FoodPrint	20190621 17:10:55
	Storage Table Name	Table name for storage entry in relational database	storage

4.4 Mapping of local FSC to FoodPrint

Figure 4.2 below displays the mapping of the FSC operations to the proposed FoodPrint application & data, and blockchain layers. The mapping takes into consideration the appropriateness of BCT for the enhancing of produce traceability in the OZCFM-related local FSC, the produce identification mechanism and the updated data models.

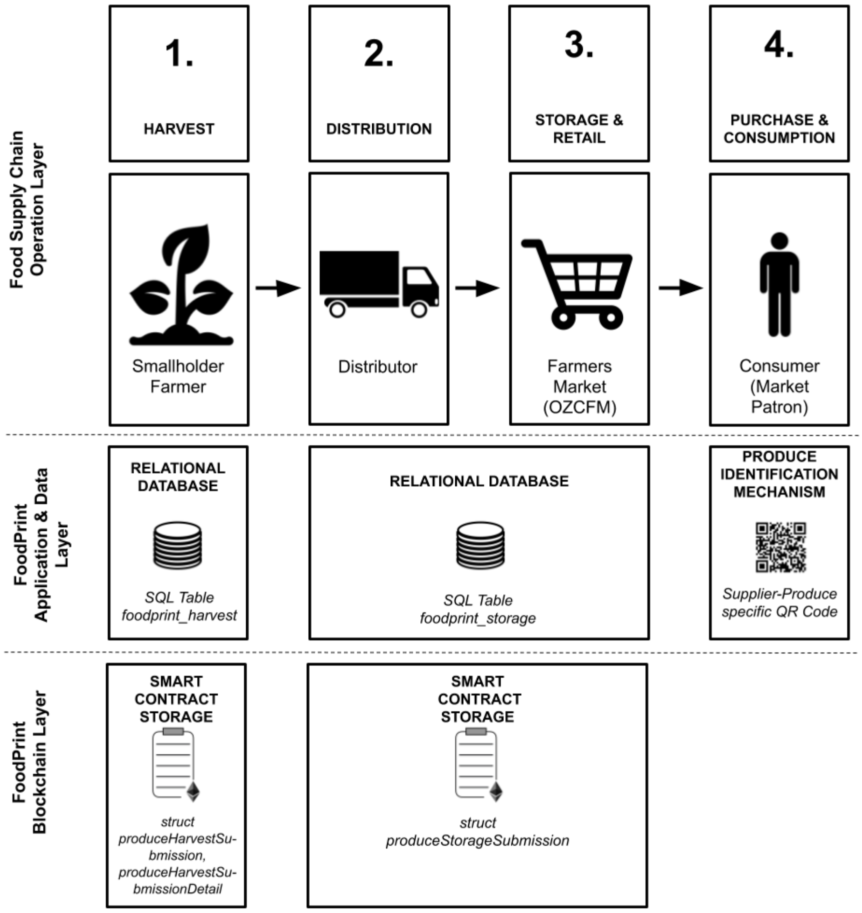

Figure 4.2: Mapping of the local food supply chain (FSC) to the FoodPrint Application & Data, and Blockchain Layers (Source:Author). The mapping shows the FSC operations, the actors and the corresponding digital layer components. The local FSC consists of the Oranjezicht City Farm Market, the smallholder farmers supplying it with produce and the produce consumers who are the market patrons.

This mapping serves as the basis for the FoodPrint architecture which is discussed in the next chapter.

5. FoodPrint Implementation

This chapter discusses the implementation of the FoodPrint Traceability platform which is a hybrid web/blockchain application built. FoodPrint is deployed onto the Heroku[1] cloud application platform, making it publicly accessible[2] to users in a software-as-a-service model (A. Singh et al. 2015). The links to the FoodPrint source code and deployed application can be found in Appendix F.

5.1 System Features

The main features of the FoodPrint traceability platform together with their brief descriptions are listed below:

- **Harvest Logbook** - Log produce harvest details. The Harvest logbook is used by farmers.
- **Storage Logbook** - Log produce storage details after receipt of produce from farmers. The Storage logbook is used by food co-operative administrators.
- **Blockchain Integration** - Record harvest and storage data onto the Ethereum blockchain.
- **QR code Scanning for Produce Provenance** - Scan a supplier-produce QR code to view the produce provenance.
- **Produce Search** - Search for historical produce harvest and storage records in the relational database. This feature is used by food co-operative administrators.
- **Blockchain Explorer** - Search historical produce records on the blockchain using the relevant identifier (Harvest ID or Storage ID). This feature is used by food co-operative administrators.
- **Food Production Systems Education** - Food 101 section on FoodPrint website with definitions for common food-conscious terms e.g. organic vs pesticide free.
- **Blockchain and Technology Education** - Technology 101 section on FoodPrint website with definitions to increase awareness on BCT, together with other tech-

[1] https://www.heroku.com
[2] https://www.foodprintapp.com

nology that are relevant in FSCs.

The educational features(Food 101 and Technology 101) are inspired by the observations from the local FSC and the pilot that suggested a misunderstanding of some of the key terms pertaining to produce growing conditions as well as a lack of awareness of use of BCT for food traceability.

The screenshots of all of the features are displayed in Section D.1 of Appendix D. Similarly the links to access the system features in the deployed application are listed in Section F.3 of Appendix F .

5.2 System Architecture

High Level System Overview

Figure 5.1 displays a high level system architecture diagram of FoodPrint.

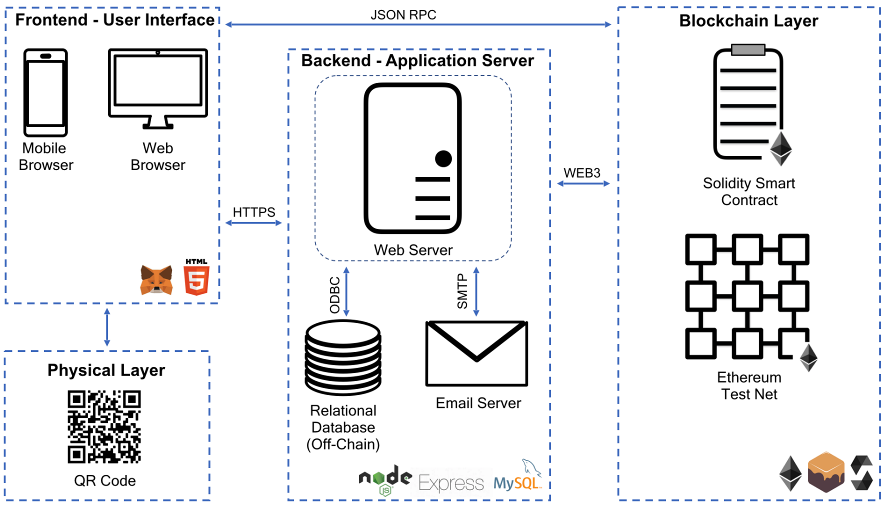

Figure 5.1: High level system architecture diagram of the FoodPrint platform. The modular architecture consists of the application server, the blockchain layer, front end user interface as well as the physical layer. The application server is the core engine with the application logic. The blockchain layer is comprised of the FoodPrint smart contract for persistence of produce operations on the Ethereum blockchain network. The front end consists of the user interface which users see when accessing the platform and the physical QR codes that the users scan in order to see produce provenance information.

The key components of the architecture include:

- **Frontend - User Interface** - The frontend is the part of the FoodPrint system that a user interacts with. It consists of:
  - Web Interface - An HTML5 user interface (UI) with dynamic features powered by JavaScript. The UI is used for data collection (harvest and storage logbook), data search and displaying provenance information. Although

  the UI works on modern browsers, the blockchain functionality specifically requires that the browser be Web3-enabled with access to the blockchain network (e.g. via MetaMask).
  - Mobile Interface - A responsive version of the web interface.
- **Physical Layer** - This layer serves as a bridge between physical produce and their unique digital representations. The layer consists of:
  - QR Code - A FoodPrint generated QR code that is unique to a supplier-produce combination.
- **Back-end - Application Server** - The server-side of the FoodPrint application (that users do not see), consisting of:
  - Web Server - A Node.js server running the Express.js web application framework. The web server performs user management, configuration data management (e.g. system parameters) and FSC operational data management (i.e. harvest and storage logbooks). The web server also integrates with the database server, email server, blockchain network and exposes the FoodPrint REST API which serves traceability data for both internal and external use (i.e. allowing 3rd party integration).
  - Database Integration - Integration with a relational SQL database (MySQL) for storing metadata (e.g. configuration) and redundant storage of FSC produce harvest and storage operations data for quick search and retrieval.
  - Email Integration - Integration with an SMTP[3] email server for sending notifications to SC actors when SC operations are carried out.
- **Blockchain Layer** - This layer is encompasses the integration of the FoodPrint web application to the Ethereum blockchain network. The components of interest in the FoodPrint Architecture diagram are:
  - Blockchain Network - Integration with the Ethereum blockchain via the *web3.js*[4] Ethereum JavaScript API.
  - Smart Contract - Solidity smart contract for capturing and persisting FSC produce harvest and storage operations data in blockchain storage.

Since FoodPrint connects to a smart contract for storing produce harvest and storage information on the Ethereum blockchain, it can also be referred to as a DApp.

[3]Simple Mail Transfer Protocol (SMTP) standard - https://tools.ietf.org/html/rfc5321
[4]https://web3js.readthedocs.io

Additionally, the following aspects of the modular FoodPrint architecture are worth noting:

- Combination of On-chain and Off-chain Data Storage - Xiwei Xu et al. (2017) discuss splitting of computation and data storage between on-chain and off-chain components. FoodPrint implements a similar hybrid and redundant data storage layer for storing of the local FSC produce harvest and storage data, both in a relational database (private off-chain data) and on blockchain storage (public on-chain data). All the produce harvest and storage data is stored off-chain, whilst the core components are stored on-chain (see Appendix F, Section F.2.) This hybrid architecture is a trade-off since the BCT advantages are often diminished by the associated performance and cost overheads, which in turn are countered by use of alternative data storage option such as relational databases (Carson et al. 2019). The decision to store only the core (and not the entire) components of the produce harvest and storage data acknowledges the smart contract design constraints of the Ethereum blockchain (e.g. limited number of variables that can be passed to a function) and to reduce cost associated with storing data on-chain. The cost consideration is inline with the suggestion by (X. Zheng, Zhu, and Si 2019) to store a sub-set of data on-chain in a bid to minimise operational costs.
- Blockchain Fault-tolerance - By using a combination of a SQL database and blockchain, the application is designed to remain functional even in the unlikely event that the blockchain network experiences some form of downtime.
- Database Agnosticism - FoodPrint can be used with any ANSI-SQL compliant relational database engine.
- Encrypted communication - FoodPrint makes use of SSL[5] certificates to create an encrypted connection between a web server (FoodPrint) and a browser (end-user), and to establish trust. Internet users can determine that a web application is SSL-secured when the URL is prefixed with https rather than http and the website address bar displays a locked padlock icon or is green in colour. The SSL padlock is an example of trust seals that electronic markets have successfully adopted to enhance consumer trust (Vos et al. 2014). See Section D.2 in Appendix D for a before-SSL and after-SSL comparison of the address bar when loading the FoodPrint application in a web browser.

FoodPrint Smart Contract

An Ethereum smart contract called *TheProductV2* is developed for the FoodPrint blockchain layer. The purpose of the smart contract is to store the core elements

[5] `https://www.digicert.com/ssl`

of the harvest and storage data that is captured in the respective FoodPrint logbooks. Figure F.1 in Appendix F displays a Unified Modelling Language (UML) class diagram for the *TheProductV2* smart contract. UML class diagrams are visual summaries of a program's static structure (El-Attar and J. Miller 2007).

FoodPrint QR Codes

FoodPrint uses QR codes as a mechanism for retrieving the most recent uniquely identifiable provenance information for a type of produce. The FoodPrint QR codes are unique to a supplier-produce combination and when scanned, return the corresponding provenance information, provided there is data that has been captured on the platform within the last 7 days counted from the most recent Monday from the date of scanning a QR code. If there is no recent data, a no data message is returned. The FoodPrint QR codes can be scanned by most modern smartphones as their native camera applications have embedded QR code reading functionality. Figure 5.2 below is an example of a FoodPrint QR code used during the pilot at OZCFM.

Figure 5.2: An example of a FoodPrint supplier-produce specific QR Code. These QR codes are printed and placed next to the corresponding physical produce at the Oranjezicht City Farm Market.

5.3 How it Works

Figure 5.3 illustrates the use of the FoodPrint Traceability platform to log produce harvest and storage data (step 2 and 4) as well as reveal produce provenance (step 6) in a local FSC.

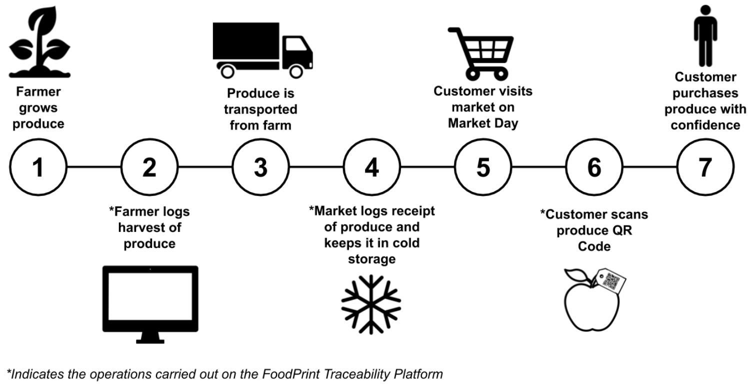

Figure 5.3: A visual representation of how the FoodPrint platform works in a local food supply chain (Source:Author). The produce harvest and storage operations data are logged onto the platform as produce moves from the farmer to the market. Once the produce is displayed for sale at the market, a consumer scans a supplier-produce specific QR code to reveal the produce provenance, from farm-to-fork.

In particular, the following steps relate to the FoodPrint platform:

- Step 2 - A registered farmer logs the harvest of produce onto FoodPrint. The harvest data (as per Table 4.4) is persisted in a SQL database and the blockchain. [6]
- Step 3 and 4 - After harvesting, the farmer transports the produce to the market as per order. An official handover takes place and a market administrator captures the handover/storage operation on the FoodPrint platform. The storage data (as per Table 4.4) is persisted in a SQL database and the blockchain.
- Step 6 - Once a customer scans the supplier-produce QR code using their mobile device[7], a unique URL is decoded from the QR code. This opens up a web page on the mobile device which displays the provenance information if available. The provenance information is collated across the different nodes of the FSC (Westerkamp, Friedhelm, and Küpper 2019), from farm-to-market and is linked by a combination of the supplier-produce-date identifier, unique harvest identifier and unique storage identifier, similar to the use of the unique product ID in the Wine SC implementation by Biswas, Muthukkumarasamy, and Tan (2017). See Appendix D.3 for a screenshot of an example FoodPrint provenance timeline visualisation.

The next chapter evaluates FoodPrint prototype and discusses considerations of blockchain-enabled traceability in FSCs based on insights gleaned from the pilot and related literature.

[6]For data to be added to the Ethereum blockchain, a valid Ethereum account and wallet software is required.

[7]iPhones and most modern smartphones running Android OS have in-built QR code scanners accessed by opening the native camera application and focusing on a QR code.

6. FoodPrint Evaluation

This chapter evaluates the objectives of the research against the outcomes, following the development and pilot of the FoodPrint Traceability platform. The pilot is conducted over a period of 6 weeks at OZCFM, with 2 participating smallholder farmers and 8 produce types (see Appendix E). In addition, we discuss general observations and resulting considerations, as well as the benefits of using FoodPrint for the FSC actors.

6.1 Research Objectives

6.1.1 Objectives Review and Validation

Below is a recap of the objectives of this research:

- **RQ1**: Can a blockchain-enabled FSC enhance traceability and transparency for smallholder farmers, regional co-operatives and consumers in South Africa?
- **RQ1a**: Can a blockchain-enabled FSC be used to ensure food traceability for smallholder farmers, regional co-operatives and consumers?
- **RQ1b**: Can a blockchain-enabled FSC be used to ensure transparency for smallholder farmers, regional co-operatives and consumers?
- **RQ1c**: Can a blockchain-enabled FSC contribute to the advancement of the UN SDG 2, SDG 9 and SDG12?

These objectives are validated below:

- **RQ1**: The FoodPrint Traceability platform is implemented as a hybrid web/blockchain application that provides tamper-evident traceability and transparency of produce from farm-to-fork in the OZCFM-related local FSC.
- **RQ1a**: FoodPrint ensures tamper-evident traceability through a combination of linked produce harvest and storage entries, persisted on the blockchain, coupled with the produce search functionality (see screenshots of the FoodPrint features in Appendix D.1).
- **RQ1b**: FoodPrint brings transparency to the local FSC by revealing the produce

harvest and storage data to all the FSC actors (see Table 4.4 for the data elements, Figure D.3 for a screenshot displaying a produce provenance entry and Figure F.1 for a class diagram showing the related blockchain smart contract). This harvest and storage data is stored both in a centralised database (for efficient access) and on a public blockchain for authenticity and immutability.

- **RQ1c**: FoodPrint contributes to the advancement SDG 2, SDG 9 and SDG 12 (further discussed in Subsection 6.2.1).

In addition, the implementation and functionality of FoodPrint aligns with the definition of a traceability system according to the ISO 22005:2007 (2007) standard, which states that a traceability system is a technical tool to assist an organization to conform with its defined objectives and is applicable when necessary to determine the history, or location of a product or its relevant components.

6.2 General Discussion

6.2.1 Food Traceability and SDGs

According to the World Economic Forum and McKinsey & Company (2019), traceability is a SC improvement that contributes towards the advancement of the following SDGs:

- SDG 2 - Zero hunger as traceability can reduce food loss by identifying inefficiencies in the SC and also promotes sustainable agriculture.
- SDG 8 - Decent Work and Economic Growth [1] as traceability can enable access to financial services.
- SDG 9 - Industry, Innovation and Infrastructure as traceability helps identify and eliminate inefficiencies in the SC.
- SDG 12 - Responsible Consumption and Production as traceability unlocks ability to measure and track various externalities such as economic, health and environmental.
- SDG 17 - Partnerships for the goals as traceability can improve data collection to complement food data initiatives used in planning and decision making.

Considering these SC traceability-related SDGs, we find that the FoodPrint implementation advances SDG 2, SDG 9 and SDG 12, as further discussed below:

- **SDG 2 - Zero Hunger**. According to United Nations (2015b), one of the targets of this goal is "By 2030, ensure sustainable food production systems and implement

[1] Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all (United Nations 2015c).

resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality." The provenance information that is revealed by scanning a FoodPrint QR code includes the conditions under which the produce is grown and substances that may have been applied.

During the FoodPrint pilot, consumers at the market indicate a preference for healthier produce[2] which is the produce that is grown naturally without use of synthetic pesticides and fertilisers. Synthetic pesticides and fertilisers can contaminate soil and water as well as be toxic to organisms such as birds, fish and beneficial insects (Aktar, Sengupta, and Chowdhury 2009). In turn, knowing that consumers have access to information on the conditions under which the produce is grown and having an idea of the consumer preferences, farmers using FoodPrint are incentivized to grow produce that is inline with these consumer preferences (assuming the consumer preferences are ethical and in favour of resilient agricultural practices). This results in a favourable outcome for all FSC actors, one that also includes a more sustainable food production system, thereby contributing positively towards the aforementioned SDG target.

- **SDG 9 - Industry, Innovation and Infrastructure**. According to United Nations (2015d), innovation and technological progress are key to finding lasting solutions to both economic and environmental challenges, such as increased resource and energy-efficiency. FoodPrint uses BCT to reliably store and reveal on-demand, the journey travelled by produce in a FSC, from farm-to-market. Using BCT to establish provenance of produce in a SC is an emerging use case for blockchain and therefore can be categorised as technological innovation. In addition, given BCTs ability to increasingly streamline SCs (Helo and Hao 2019), we envisage that use of FoodPrint will also result in operational-efficiency gains in FSCs (e.g. faster produce tracing using shared real-time data).
- **SDG 12 - Responsible Consumption and Production**. According to United Nations (2015d), one of the targets for this SDG is "By 2030, achieve the sustainable management and efficient use of natural resources". These natural resources include water, air and land. FoodPrint displays produce origin which can persuade consumers to purchase local produce instead of produce with higher food mileage. Food mileage refers to the distance food travels from its production location to its consumption location. In this context, when consumers purchase produce directly

[2]The preference of consumers that are food secure is for healthier produce although the indication is that it is often times costs more than conventional produce. This cost can be prohibitive.

from the market, lower food mileage implies less air pollution and reduced greenhouse gas emissions. However, this implication is predicated on the assumption that the carbon emission per unit of locally grown produce over the entire transport chain (including the transport mode and distance travelled by the consumer) is overall lower when compared with produce that is not locally grown and has likely travelled a longer distance, possibly in larger quantities. This concept of carbon emission per unit of produce over the transport chain is discussed by Coley, Howard, and Winter (2009) in their comparison of farm shop and mass distribution approaches for food products.

The potential persuasion of consumers as a result of using the FoodPrint platform supports responsible consumption, similar to the assertion by Relihan (2018) that "The idea of a responsible SC is really simple: 'My dollar should not go to anyone who's profiteering off of slavery or worker exploitation or destroying the environment'". FoodPrint therefore encourages responsible sourcing by food co-operatives together with responsible consumption by consumers.

6.2.2 Considerations on Blockchain-enabled Food Traceability and Transparency in local FSCs

Blockchain-enabled food traceability and transparency platforms increase SC visibility (authentic transparency from a single, shared source of truth), enhance traceability (by adding tamper-evident assurance) and enable enforcement of SC specific required practises. FoodPrint, an example of a blockchain-enabled food traceability and transparency platform, is used to record produce harvest and storage logs, as well as establish chain of custody for produce (audit trails). FoodPrint records produce data in a centralised database and on the Ethereum blockchain.

In this subsection, we note considerations on how blockchain-enabled food traceability and transparency, both generally and from a FoodPrint point-of-view, can impact on local FSC actors - smallholder farmers, markets and consumers.

Consumers

Blockchain-enabled food traceability and transparency can impact consumers in the following ways:

- Promote food democracy and citizenship.
- Improve food safety and quality.
- Reduce the risk of produce counterfeiting and other fraudulent actions (Blossey, J. Eisenhardt, and Hahn 2019).

- Potentially increase customer trust (Casado-Vara et al. 2018), (Kraft, Valdés, and Y. Zheng 2019).
- Promote responsible consumption by consumers given the access to trusted produce provenance information. This deduction is drawn from the observation from the FoodPrint pilot that food conscious consumers desire traceability information.
- Encourage tech-savvy consumers to start demanding trusted sources for the produce they consume given their access to trustworthy provenance. We identify tech-savvy consumers as consumers falling within the 25 - 40 years old age demographic as this demographic expressed most interest in scanning produce for traceability during the FoodPrint pilot.
- Empower consumers to review the quality of produce from various dimensions, such as environmental and labour standards (Westerkamp, Friedhelm, and Küpper 2019), from a source that has the necessary controls to be reliable.
- Enhance the farm-to-fork experience for the consumer given their access to trustworthy produce provenance information.

Farmers

Blockchain-enabled food traceability and transparency can impact smallholder farmers in the following ways:

- Result in better prices paid to farmers for their produce and ultimately a more sustainable food eco-system (Yadav and A. R. Singh 2019).
- Self-selection and repeat purchases of produce from specific farmers by consumers as a result of increased transparency and subsequent performance monitoring. Further, the increases transparency increases equity through the FSC as there is a clearer and more open understanding of how value is added as the produce moves and is transformed along the FSC (Pearson et al. 2019).
- Standardise FSC operation data collection through use of the produce harvest and storage logbooks (or similar standardised data collection mechanisms) instead of the combination of paper-based and disparate tracking systems that the farmers have been known to use. Standardised and historic data records on the blockchain lead to traceable and trustworthy transaction records, which in turn have the potential to unlock access to auxiliary services and/or commercial opportunities. Respective examples of auxiliary services and commercial opportunities include access to credit and participation in formal bids for supply of produce. On access to credit, Chod et al. (2019) discuss financing benefits of SC transparency and BCT, and note that BCT reduces the information asymmetry that previously limited access to credit. In addition, the capturing of standardised produce harvest and storage data on the blockchain can accelerate convergence on a local/regional

standard for handling produce data.

- Provide an opportunity for smallholder farmers to be on the cutting edge of innovation in AgriTech. Having said that, an observation from the FoodPrint pilot is that technology-related change management is difficult for farmers as they are change-averse. However, embracing new and enabling technology positions smallholder farmers to benefit from innovation that can improve crop yields, unlock access to auxiliary services (e.g. financial) and access to markets, amongst other future possibilities.
- Provide a new channel for customer engagement (Leong, Viskin, and Stewart 2018). The traceability platform keeps track of the number of scans per supplier-produce type, which together with the option for a consumer to message a farmer gives the farmer visibility into previously opaque consumer preferences. This in turn can allow for the tailoring of produce growing and related service to enhance consumer experiences.
- Enhance trustworthiness reputation (Harbet 2020), not only for farmers but markets as well. However, it is worth cautioning that enhancing trust does not automatically equate to an increase in revenue. In an incentivised, human-subject laboratory experiment and casual mediation analysis to investigate how a firm's investment in SC visibility impacts consumer trust, Kraft, Valdés, and Y. Zheng (2019) find that although increased visibility into SCs does bolster consumer trust, this does not necessarily generate a revenue benefit as this depends on the consumers trust beliefs and care for others well-being.
- Enable farmers to reliably demonstrate their operating procedures to potential buyers in other markets.

Markets

Blockchain-enabled food traceability and transparency can have an impact on markets (and other types of food co-operatives) in the following ways:

- Enable markets to perform more efficient, standardised and provable supplier due diligence.
- Promote responsible sourcing by markets, resulting in better quality produce for consumers. However, it must be noted that technology alone cannot ensure responsible sourcing practices, it requires firms contracting with suppliers to enforce penalties for irresponsible behaviour and foster relationships that encourage ethical action (Relihan 2018). In the case of the OZCFM-related local FSC, OZCFM can enforce such penalties to uphold the benefit from the responsible sourcing benefit derived from the FoodPrint solution.
- Translate into a reputational boost, seeing as firms making investments in SC

transparency earn points with socially-conscious buyers and sceptical buyers too (S. Brown 2019).

- Enable consumer-oriented marketing strategies that promote buying locally produced fresh produce (e.g. confirmation bias based marketing campaigns, potentially yielding favourable outcomes for the upstream local FSC actors and the local economy(Arsil et al. 2014)). Confirmation bias is the tendency to seek evidence that is partial to existing beliefs (Nickerson 1998). When used in a marketing campaign by a farmers market, if consumers believe that such a market stands for freshness and quality, their confirmation bias will reinforce evidence (i.e. use of a blockchain-enabled food traceability and transparency platform by the market) that supports their belief and mitigate examples that contradict it (Mayer 2020).
- Enable markets to market foods with subtle or undetectable quality attributes (Aung and Chang 2014).
- Empower markets as upstream actors in a local FSC to act as gatekeepers given their access to trustworthy and shared produce provenance information. Using BCT enables them to effectively enforce quality assurance measures and prevent produce that does not meet the required standards from entering the FSC (Helo and Hao 2019).
- Enhance the tourist experience value proposition of local farmers markets. A. Brown (2002) remarks that markets draw tourists. This is consistent with an insight gleaned from the FoodPrint pilot that some tourists visit OZCFM as part of their sight-seeing itinerary.
- Enable markets to meet the customer demand for provenance and ethical consumerism (Leong, Viskin, and Stewart 2018), in a demonstrable and open manner.

6.2.3 Cost-benefit of Blockchain-enabled Food Traceability

Based on the FoodPrint implementation and the pilot at OZCFM, we narrow down the scenarios under which blockchain-enabled food traceability implementations can be viable. These include:

- Cases where strict legal traceability requirements exist (implying an associated cost with ensuring compliance) and non-compliance penalties are significant.
- Operating environments in which an agent (the food co-operative in a local FSC) has both a fiduciary responsibility to ensure product safety and reliability (Bhatia et al. 2019), as well as an incentive to uphold its brand image.
- Tracking of high value produce (produce that is a delicacy or has high value per

unit relative to to other produce types). [3]

- SCs with a large number of tiers and/or actors. Naturally, the more tiers/actors, the more the co-ordination complexity and potential for high opaqueness, resulting in a notable value add by a blockchain-enabled traceability platform.
- Use cases in which there exists a trust-deficit and the desired transparency requirements exceed the threat of losing competitive advantage by disclosing internal information (Westerkamp, Friedhelm, and Küpper 2019).

Considering these scenarios, we do not find a direct cost-benefit from implementing blockchain-enabled food traceability at OZCFM given that the regulation around fresh produce in South Africa is not draconian, OZCFM sells a variety of produce types that range from low value to high value and most importantly, there is no perceived trust-deficit in the OZCFM-related local FSC.

6.2.4 Blockchain and Trust in FSCs

According to K. Eisenhardt (1989), agency theory is concerned with resolving two problems that can occur in agency relationships - the first is the agency problem that arises when (a) the desires or goals of the principal and agent conflict and (b) it is difficult or expensive for the principal to verify what the agent is actually doing. Applying the agency theory in the context of FSCs that are devoid of trust, we note that:

- The agent (food market) is privy to information - both internal (e.g. quality processes) and external (information from farmers, customers as well as the operating environment).
- Due to the information asymmetry that exists, the principal (consumer or smallholder farmer) does not have the complete picture and therefore is required to implicitly trust the agent, especially in the absence of suitable alternative agents.

According to D. Miller et al. (2019) and Harbert (2019), blockchain is a new mechanism of trust, one that enables trustworthy shared information among suppliers that may not trust each other. Therefore, in theory, the introduction of blockchain in such a trust-deficient FSC results in information flows that are transparent and accessible to both, the principal and agent, negating the need for implicit trust in a SC actor (Treiblmaier 2018).

During the observations of the OZCFM-related FSC and conducting of the pilot, we establish that there exists a strong level of trust between the consumers and the market, and by extension, the consumers and the smallholder farmers. The consumers

[3] For example, as observed during the FoodPrint pilot, cherries are one such example of high value produce that are ideal for traceability given that they are seasonal, tend to run out within the first 2-3 hours on OZCFM market days and have a high price per unit ratio as compared to other types of fresh produce - a 1 kilogram box of cherries (Selina Wamucii n.d.[a]) costs on average 3-times the cost of 1 kilogram of cucumbers (Selina Wamucii n.d.[b]).

specifically indicate that purchasing of produce directly from the smallholder farmers, although ideal, is not practical as it is time consuming, costly and inefficient. Therefore, purchasing from OZCFM is the next best and notably trustworthy option as compared to buying from retail markets.

The consumer trust arises from the following:

- One degree of separation between the farmers and the market, as well as the market and the consumer (short SC).
- The long term and mutually beneficial relationship enjoyed with the market.
- The outstanding reputation of the market.
- The sense of community that the market facilitates and cultivates.
- The reasoning that both the market and the farmers have more to lose from false claims (e.g. reputational damage) unlike a large retailer with incentives to be profitable, meet shareholder expectations and can afford to spend on well crafted marketing campaigns.

As a result, the addition of blockchain-enabled traceability does not increase trust in this OZCFM-related local FSC as anticipated. The local FSC does not appear to have a principal-agent problem. Furthermore, it is plausible that even in the absence of the existing trust between the consumers and the market, blockchain-enabled traceability may not have been an immediate trust-enhancing mechanism due to the mixed responses on the use of BCT in FSCs observed and gathered during the undertaking of this research.

6.2.5 Challenges with Introducing Blockchain in FSCs

During the FoodPrint implementation and pilot at OZCFM, we note the following general challenges with introducing BCT in FSCs:

- A lack of awareness expressed by the farmers and consumers on the use BCT for food traceability. In a study comprised of food quality assurance professionals and a coconut water export company in Thailand, Tipmontian, Alcover, and Rajmohan (2020) show that the customer awareness level with regards to food safety and traceability is an important factor in a producers decision to implement blockchain traceability. This suggests that it cannot be assumed that local FSCs actors have an awareness of emerging technology and its FSC related uses.
- Blockchain-enabled traceability requires adoption of emerging technology. This means that there is a need for collaboration and buy-in from all FSC actors to ensure successful implementation of blockchain-enabled food traceability. As indicated by (Casado-Vara et al. 2018), an individual's motivation to use a new technology is related to their perceived advantages of the technology in their

everyday work routine. This is especially important when considering how to communicate the benefit to farmers as they often do not have visibility of the final activities in the FSC that involve the consumer, and the minute nudges that can influence the consumers purchase decisions. In addition, with respect to implementation of blockchain related projects, Harbert (2019) suggests that it helps to have a dominant company driving the adoption. We find that food co-operatives such as OZCFM are central in local FSCs and therefore wield some influence to drive the adoption of technology enabled solutions, both with the smallholder farmers and the consumers.

- Ensuring that the initial data entry into a blockchain platform is truthful. Although the immutability of a blockchain ensures that the data cannot be tampered with, Jabbari and Kaminsky (2018) question how to prevent a party from committing fraud when capturing data into a blockchain-enabled supply chain. In our opinion, the data integrity assurance in the implemented FoodPrint platform is weakest at the point of initial data entry (logging of produce harvest data). After the initial data entry, the actors in the OZCFM-related local FSC can detect anomalies during subsequent FSC operations by using the FoodPrint produce data timestamps and quantities for verification. In addition, there is an expectation that the OZCFM-related local FSC actors are truthful in their use of the FoodPrint platform given that their established reputations within the FSC are at stake, although this is admittedly not a robust control. The possibility of fraudulent data entry exists, especially in the absence of a trusted 3rd party trust anchor (e.g. a produce verifier/inspector) and risk of collusion amongst actors (Jabbari and Kaminsky 2018).

We additionally note the following technical challenges with implementing BCT in FSCs:

- Lack of technical expertise (Min 2019).
- Blockchain scalability issues (Min 2019; Westerkamp, Friedhelm, and Küpper 2019; Carson et al. 2019).
- Non-intuitive blockchain key management (especially when compared to traditional email-password authentication schemes).

7. Conclusion and Future Work

7.1 Conclusion

Blockchain-enabled traceability in local FSCs has the potential to positively transform food systems by improving food safety, promoting sustainable agriculture, growing local economies and increasing produce sales for smallholder farmers. This stems from BCTs ability to increase FSC operational data visibility and enhance trust (particularly when there is a trust-deficit) amongst FSC actors, combined with the improvement in food safety and quality as a result of robust food traceability.

In order to demonstrate blockchain-enabled traceability within the context of local FSCs in South Africa, we engage with OZCFM (regional co-operative), the smallholder farmers supplying OZCFM with produce and the market patrons purchasing the produce (consumers). During the course of the engagements with these local FSC actors, we develop FoodPrint - a hybrid web/blockchain traceability application, and subsequently pilot the prototype at OZCFM. Using the FoodPrint platform, produce harvest and storage data is captured and persisted in a SQL database and on an Ethereum blockchain. In turn, by scanning unique supplier-produce FoodPrint QR codes that are related to the captured data, consumers purchasing produce on market days establish the produce provenance.

We find that FoodPrint brings authentic transparency to the local FSC by unlocking visibility into previously opaque and ring-fenced FSC produce-related information and operational data, for all actors, especially consumers. In addition, the FoodPrint platform provides a mechanism for the food co-operative administrators to trace the tamper-evident chain-of-custody (and associated conditions) for produce in a much faster and more structured manner than before. Moreover, the ability to view provenance by scanning the FoodPrint QR codes provides a rewarding experience for consumers, positively distinguishes the market (for providing the service) and promotes support of local economies.

Considering FSC actor dynamics, we find that blockchain-enabled traceability is not a trust-enhancing mechanism in the OZCFM-related local FSC due to the preexisting trust amongst the FSC actors. Further, we note that BCT implementations are analogous to team sports, requiring the FSC actors to work together to realise a successful implementation.

The FoodPrint pilot shows that by using a blockchain-enabled FSC, the question - *"Do you know where your food comes from?"* can be reliably answered. Using FoodPrint, it is possible for all FSC actors to reliably establish the source of food produce - how it was grown, whether it is local or not, the conditions under which it was grown and its fitness for human consumption. In addition, it can be used to successfully trace produce to its source and promote environmental sustainability - contributing towards meeting UN SDG 2, SDG 9 and SDG 12.

7.2 Research Gaps and Limitations

The gaps and limitations from this research are listed below:

- In conducting this research, produce shoppers from retail shops were not surveyed.
- FoodPrint has been tested in one farmers market. Further testing in local food markets both nationally and internationally will help determine whether the findings can be generalized across South Africa and beyond.
- FSC data privacy has not been actively considered in this implementation. As such, there exists the possibility of privacy leakage (Helo and Hao 2019). An option to consider is that of storing an encrypted version the FSC data together with its hash on the blockchain, similar to the Work-History Fraud prevention blockchain implementation by Sarda et al. (2018). Alternatively, statistical information such as quantities of sale can be removed from the smart contract as noted in (Huang, Wu, and Long 2018).
- FSC operations have been limited to produce harvest and handover/storage operations.
- Although the FoodPrint architecture is modular, only the Ethereum blockchain is currently supported. Minimal effort will be required to make FoodPrint blockchain agnostic or to integrate with an alternative blockchain. In their Blockchain Deployment Kit, the World Economic Forum (2020) suggest that technology silos should be avoided and instead, flexible and interoperable solutions are lower risk and preferred.
- The sample size for this study is small due to time constraints.

7.3 Possible Future Work

Future work on blockchain-enabled food traceability arising from this research includes:

- Automating FSC data entry in blockchain-enabled food traceability platforms through use of sensors, scanners and IoT devices in order to enhance the richness of the data (e.g. automated real-time geo-locations and timestamps) as well as increase the trust and integrity of information sourced from the various SC participants (Dujak and Sajter 2018; Hong et al. 2018; Yusuf et al. 2018). This stems from the fact that information shared by SC participants in the blockchain-enabled traceability solutions cannot necessarily be outright trusted (Tian 2016). Whilst blockchain is useful for establishing integrity of on-chain information, the integrity of information at the point of entry into the blockchain is only as good as the existing trust mechanisms in place.
- How to rectify incorrect blockchain data entries ex-post.
- Use of standardised and tamper-evident packaging (Uhlmann 2017) for harvesting and transporting of produce as it moves along a blockchain-enabled FSC, in order to enhance produce safety, produce data integrity and trust since. The packaging used by the farmers in this research for harvesting and subsequent transportation of produce is not currently standardised.
- How to use a blockchain-enabled food traceability platform to:
  - Comprehensively track the different FSC operations beyond produce harvest and storage, such as planting and growing (Caro et al. 2018; Uhlmann 2017).
  - Process FSC operation related payments such as produce purchases by the market from the farmers, as well as market patron produce purchases. Kamilaris, Fonts, and Prenafeta-Boldu (2019) highlight that digital payments are better than cash transactions because the latter lack traceability, which ultimately hinders the ability of small and medium-sized farmers in developing countries to access credit, new markets and to grow.
  - Secure credit financing for smallholder farmers in South Africa.
  - Support regulatory actors with permanent system-wide permissions to access all traceability data - both on-chain and off-chain (Pearson et al. 2019). Inclusion of regulators is useful to ensure the activities of the network participants are compliant and using best practises.
  - Increase visibility and improve labour conditions at smallholder farms in the Western Cape (SDG 8: Decent Work).
  - Reduce food waste (SDG 2: Zero Hunger).
  - Track sustainability metrics (e.g. carbon emissions) (SDG 2: Zero Hunger).

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A. Global Initiatives using Blockchain Technology (BCT) for Traceability

This appendix shows a summary of global technology initiatives that are using BCT for traceability. Section A.1 highlights food traceability related BCT use cases whilst Section A.2 highlights other BCT uses cases beyond food traceability.

A.1 Global Initiatives using Blockchain Technology (BCT) for Food Traceability

Table A.1 on the next page shows a summary of global AgriTech initiatives that are using BCT for food traceability.

Table A.1: Summary of global AgriTech initiatives that are known to use blockchain technology (BCT) for food traceability.

Name	Description (URL)	Location
IBM Food Trust	Modular web application that uses BCT to improve transparency, standardization and efficiency throughout the food supply chain. Solving visibility across the food supply chain using blockchain (IBM Food Trust 2019). (https://www.ibm.com/blockchain/solutions/food-trust)	Global
FoodLogiQ	Software-as-a-service (SaaS) solutions to connect the world's FSC, promoting food safety through traceability and sustainability. (https://www.foodlogiq.com)	Global
ripe.io	FSC platform for accessing transparent and reliable information on the origin, journey and quality of food. (http://www.ripe.io)	United States of America
BeefLedger	Integrated provenance, blockchain security and payments platform for beef supply chains. (https://beefledger.io)	Australia, China
BeanLedger	Using Blockchain to improve traceability throughout the coffee industry. (https://beanledger.org)	Australia
Happerley	Applying BCT to passport the entire journey of every food output, from farm to plate. (https://www.happerley.co.uk)	United Kingdom
HerdX	HerdX specializes in building blockchain-based livestock verification tools for farmers, grocers and restaurants. (https://herdx.com/retail)	Global
te-food	Farm-to-table food traceability solution using BCT. (https://www.te-food.com) on blockchain	Germany
BeefChain	Creating a new "rancher-centric" supply chain utilizing blockchain technology to ensure blockchain verified beef and sheep. (https://beefchain.com)	United States of America
Traseable Solutions	Blockchain-ready software-as-a-service platform for end-to-end digital traceability for seafood and agriculture products. (https://www.traseable.com)	Fiji
Treum	Blockchain-based platform for modelling business processes, tracking assets and building trusted supply chains. (https://treum.io)	Global
Provenance	Blockchain-enabled platform for transparency. (https://www.provenance.org, White Paper - https://www.provenance.org/whitepaper)	Global
Modum	Creating trusted digital ecosystems for sensitive goods using BCT. (https://modum.io)	Switzerland
TraceFood	Blockchain solutions for the FSC. (https://tracefood.io)	Global
OriginTrail	Ecosystem dedicated to making global supply chains work together by enabling a universal, collaborative and trusted data exchange, powered by BCT. (https://origintrail.io, White Paper - https://origintrail.io/storage/documents/OriginTrail-White-Paper.pdf)	Slovenia, Serbia, Hong Kong
AgriDigital	Cloud-based, blockchain-enabled commodity management application. (https://www.agridigital.io/blockchain)	Australia
HARA	Blockchain-based data exchange for the food and agriculture sector. (https://haratoken.io)	Indonesia
Skuchain	Blockchain-based platform for food traceability and attestation of quality, safety and sustainability of food sourcing. (https://www.skuchain.com)	United States

A.2 Initiatives using Blockchain Technology (BCT) for Traceability beyond FSCs

Table A.2 below shows a summary of technology initiatives that are using BCT for traceability beyond the food traceability use case. The initiatives marked with an asterisk (*) have solutions that work both for and beyond FSC traceability.

Table A.2: A list of solutions that are using blockchain technology (BCT) beyond the food traceability use case. The initiatives marked with an asterisk (*) have solutions that work both for and beyond food traceability.

Name	Description (URL)	Location
*Treum	Blockchain-based platform for modelling business processes, tracking assets and building trusted supply chains. (https://treum.io)	South Africa
*Provenance	Blockchain-enabled platform for transparency. (https://www.provenance.org, White Paper - https://www.provenance.org/whitepaper)	Global
*Modum	Creating trusted digital ecosystems for sensitive goods using BCT. (https://modum.io)	Switzerland
*OriginTrail	Ecosystem dedicated to making global supply chains work together by enabling a universal, collaborative and trusted data exchange, powered by BCT. (https://origintrail.io, White Paper - https://origintrail.io/storage/documents/OriginTrail-White-Paper.pdf)	Slovenia, Serbia, Hong Kong
Chronicled	Automating business rule enforcement in the life sciences industry through the blockchain-powered MediLedger Network - a decentralised network for the pharmaceutical industry (https://www.mediledger.com), (https://www.chronicled.com)	United States of America
Everledger	Enterprise-grade blockchain platform for tracking provenance, transfer ownership and registry for high value assets such as gem stones and jewellery. (https://www.everledger.io)	United Kingdom
ubirch	blockchain technology designed to capture information from IoT sensors. (https://ubirch.de/en)	Germany

B. Images from the local FSC

This appendix displays images taken at OZCF and OZCFM.

Figure B.1: An image taken outside the Oranjezicht City Farm (OZCF) in Cape Town, South Africa (Photo: Author). A variety of fresh produce is grown at OZCF.

(a) Produce Delivery at OZCFM

(b) Beetroot QR Code on Display at OZCFM

Figure B.2: Screenshots of images from the Oranjezicht City Farm Market (OZCFM). a)Delivery of produce to the market prior to market day (Photo: Author). b)A FoodPrint supplier-produce specific QR Code on display during a market day at OZCFM (Photo: Author).

C. Prototype Design Considerations

This appendix contains the personas used in the design of the FoodPrint prototype.

C.1 FoodPrint User Personas

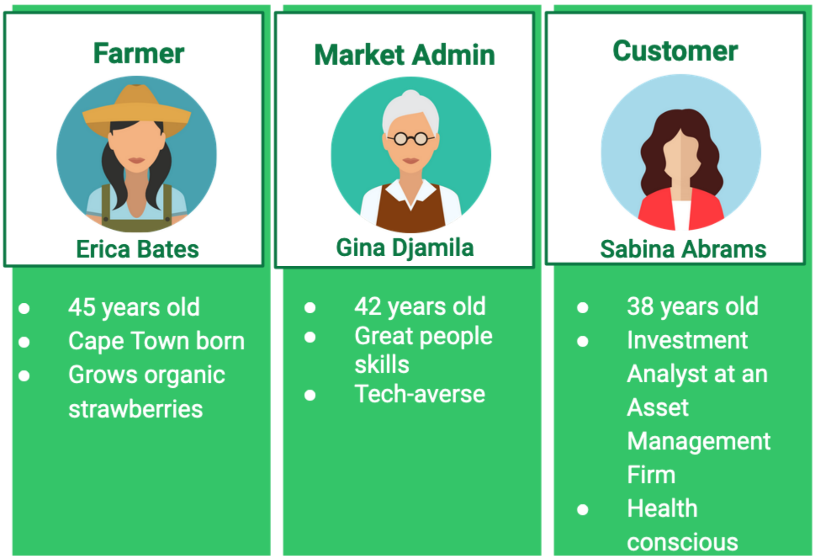


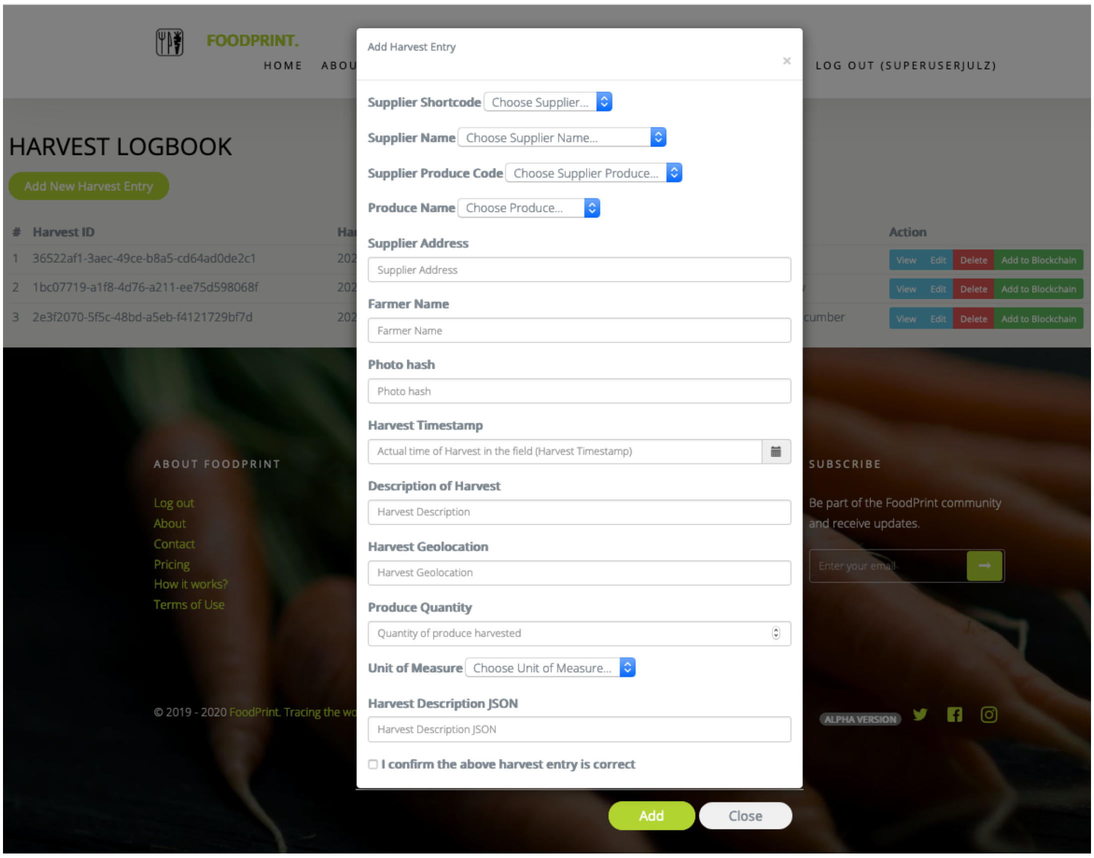
Figure C.1: Personas created during the FoodPrint system design process. These personas correspond to the local FSC actors, namely the smallholder farmers, the farmers market and the market patrons.

D. Prototype Implementation

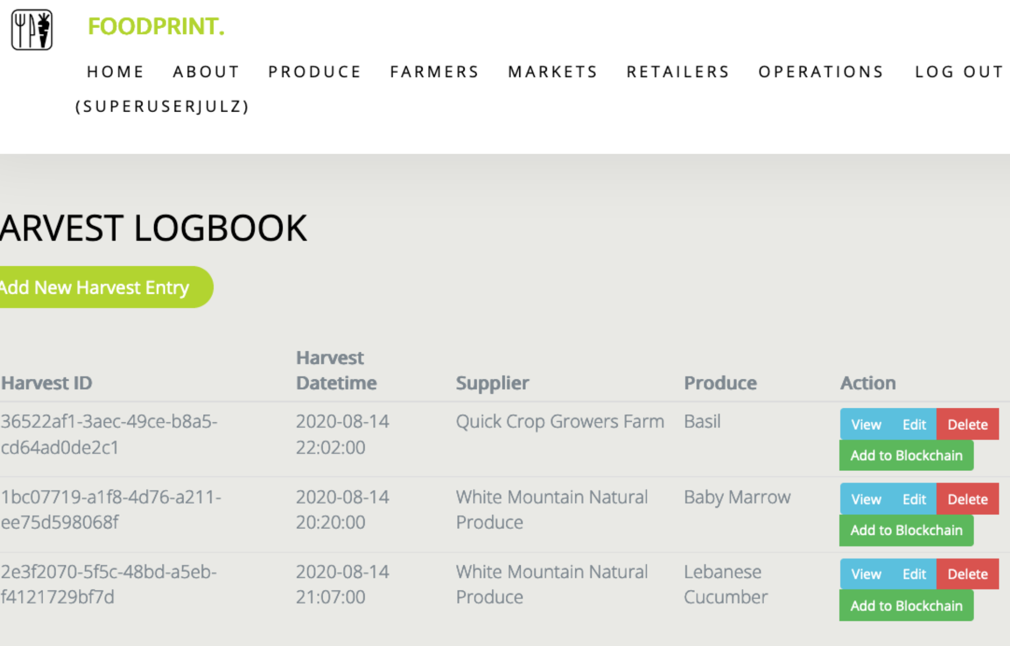
This appendix displays screenshots of FoodPrint features as well as other design related considerations.

D.1 FoodPrint Features

Screenshots of the FoodPrint Harvest Logbook, Storage Logbook, QR Code Scan Results, Produce Search, Blockchain Explorer as well as Definitions/Frequently Asked Questions (FAQs) pertaining to fresh produce and technology in FSCs are shown on the following pages.

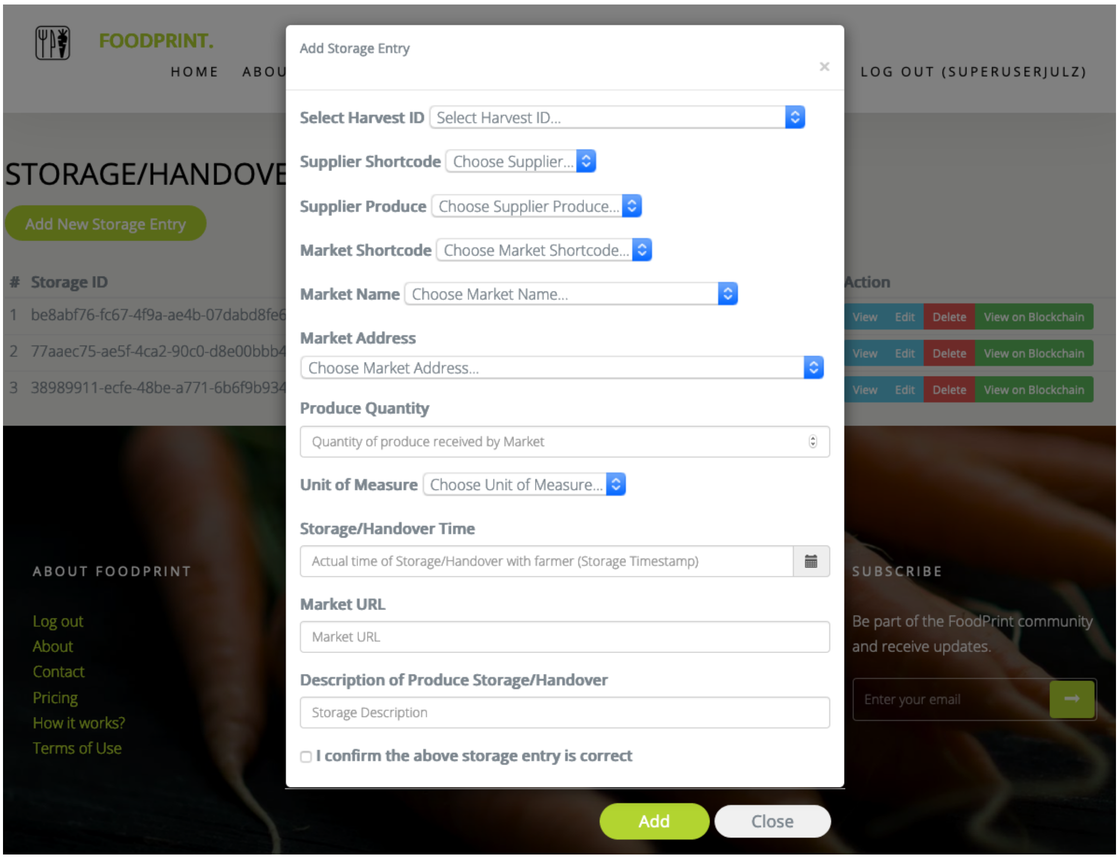


(a) Harvest Logbook - Add Harvest Entry

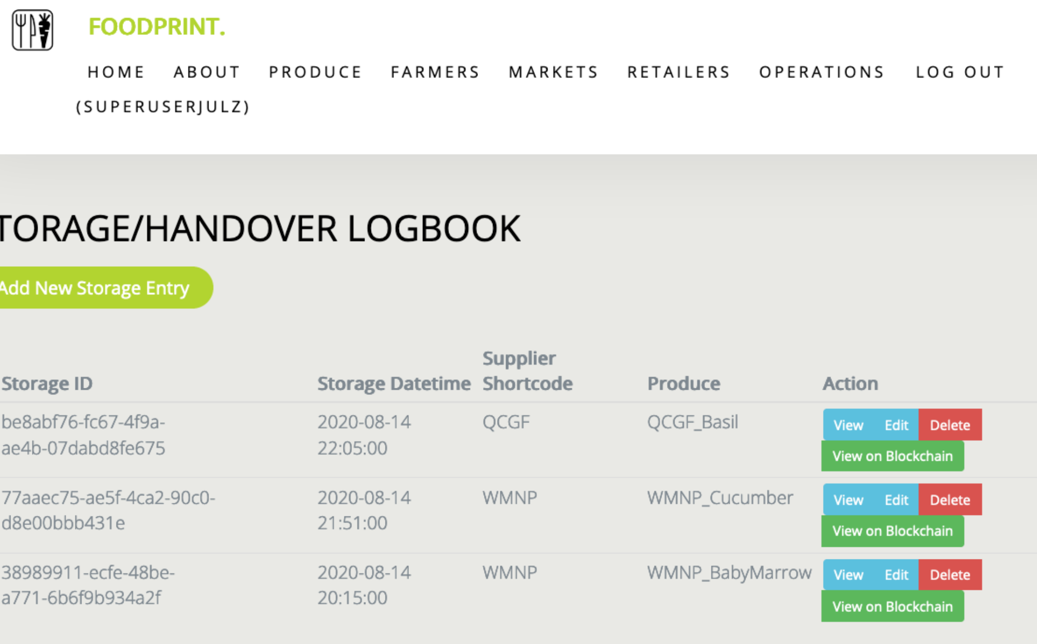


(b) Harvest Logbook - List View of Harvest Entries

Figure D.1: Screenshots of the FoodPrint Harvest Logbook. a)The form that is displayed when a farmer selects the Add Harvest Entry option in the FoodPrint application. b)The list of harvest entries previously entered into the FoodPrint application. The Harvest Logbook feature corresponds with step 2 of Figure 5.3.



(a) Storage Logbook - Add Storage Entry



(b) Storage Logbook - List View of Storage Entries

Figure D.2: Screenshots of the FoodPrint Storage Logbook. a)The form that is displayed when a market administrator selects the Add Storage Entry option in the FoodPrint application. b)The list of storage entries previously entered into the FoodPrint application. The Storage Logbook feature corresponds with step 3 & step 4 of Figure 5.3.

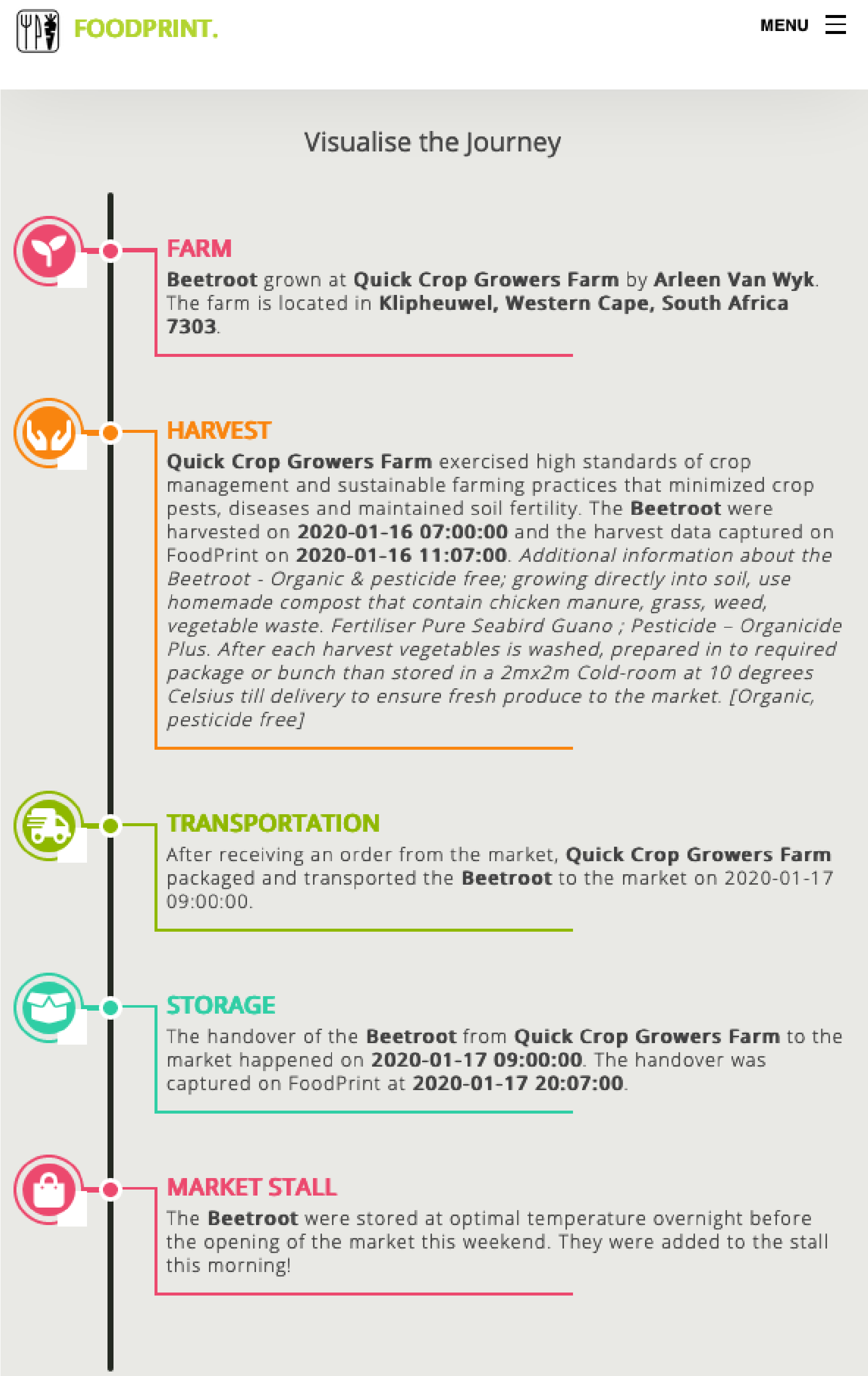
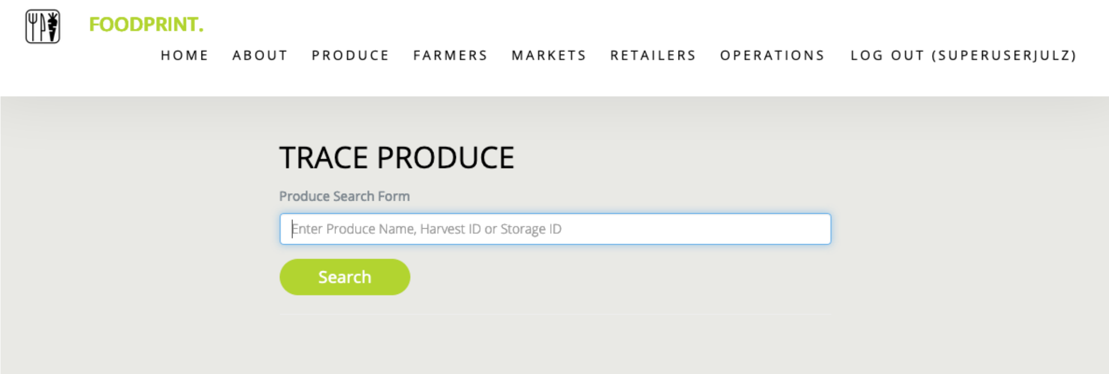
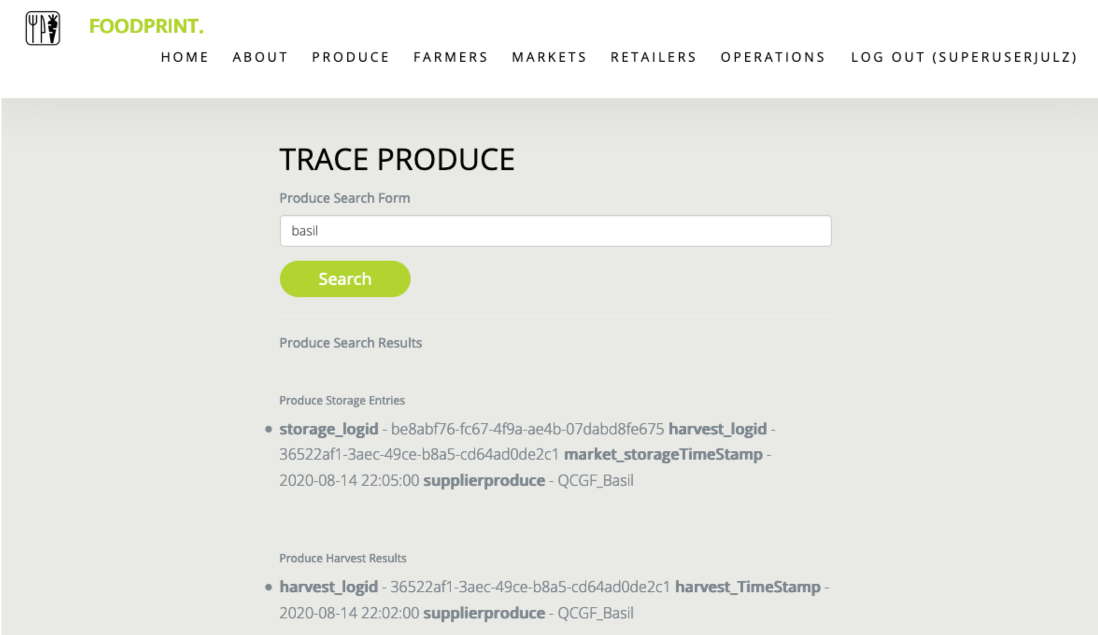


Figure D.3: A screenshot of a produce timeline view that a user sees after scanning a FoodPrint supplier-produce specific QR code. This corresponds with step 6 of Figure 5.3. The provenance information is displayed in the form of a comprehensive timeline visualization that reveals the source of the produce, the actors involved, the possession changes (traceability) together with any additional and relevant information.

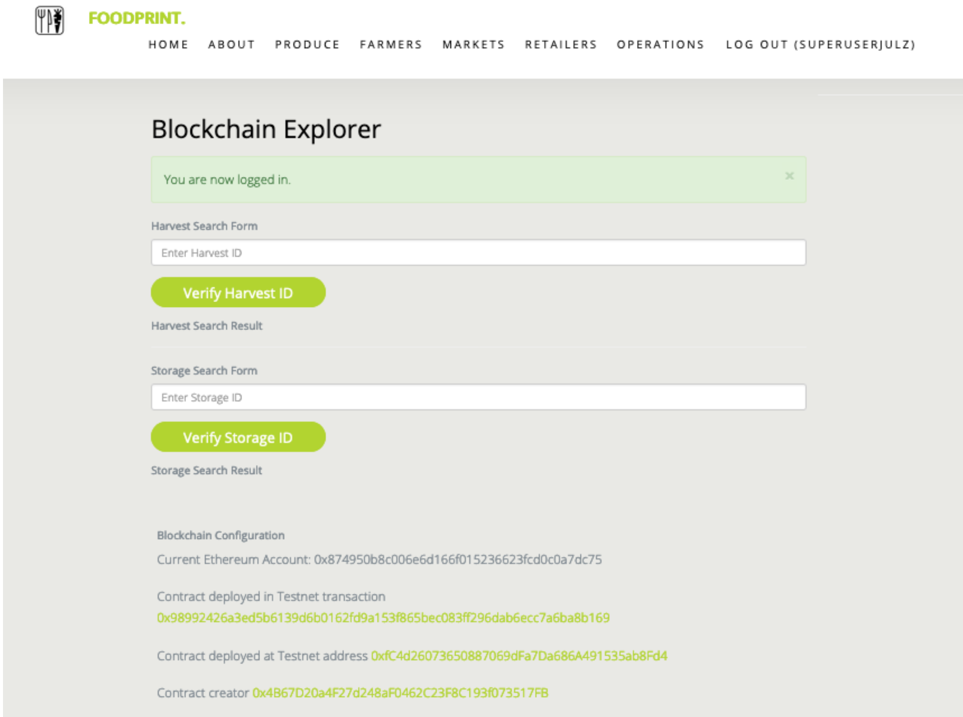


(a) Trace Produce - Produce Search Form

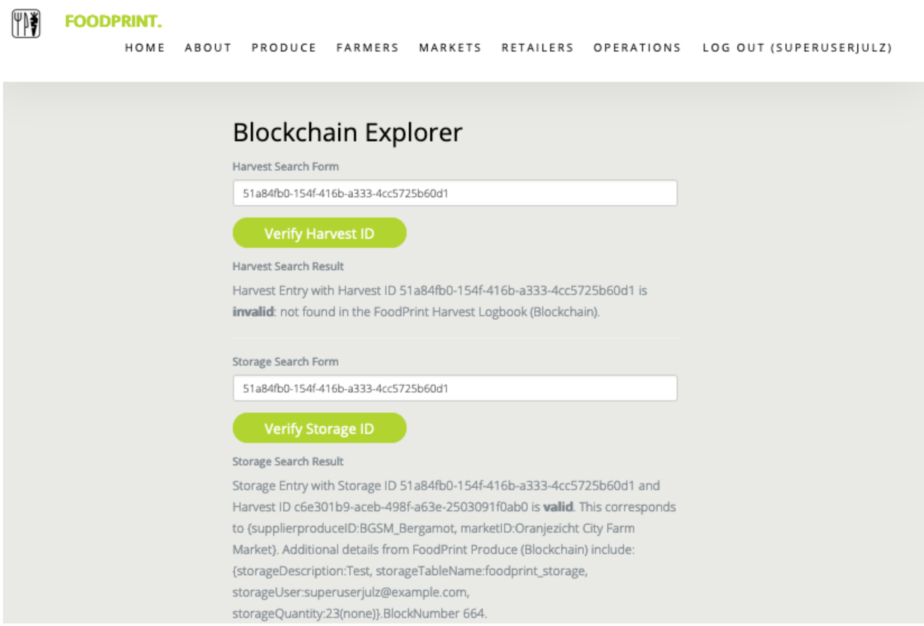


(b) Trace Produce - Produce Search Results

Figure D.4: Screenshots of the FoodPrint Trace Produce functionality. a)The Trace Produce page showing an empty form. Produce can be traced by name or a relevant identifier. b)The Trace Produce page displaying search results.



(a) Blockchain Explorer - Harvest & Storage Search Form



(b) Blockchain Explorer - Harvest & Storage Search Form Results

Figure D.5: Screenshots of the FoodPrint Blockchain Explorer functionality. a)The Blockchain Explorer page showing an empty Harvest Search Form and Storage Search Form. Using the Blockchain Explorer, a user can search for produce harvest and storage entries existence on the Ethereum blockchain by querying using the Harvest ID or Storage ID respectively (from the Harvest and Storage Logbook entries). The Blockchain Explorer also shows the relevant Blockchain Configuration details such as the currently active Ethereum wallet address and the address of the deployed smart contract. b)The Blockchain Explorer page displaying search results. Harvest Search Form - The Harvest ID searched for is not found on the blockchain. Storage Search Form - The Storage ID searched for is found on the blockchain and the results displayed to the user.

FAQS & DEFINITIONS

Food Facts 101

Organic Produce - A form of agriculture in which the use of synthetic/man-made pesticides and artificial fertilisers are prohibited.

Organic Animal Farming - Animal farming in which the use of antibiotics and/or growth hormones is prohibited. In addition, all feed must be organically produced.

Conventional Farming - Farming which uses synthetic chemicals and fertilizers to maximize the yield of a particular crop or set of crops, which can also be genetically modified. Conventional farming requires a significant amount of chemical and energy input, and weakens the ecology of a landscape.

GMO Produce - GMO is short for genetically modified organism. GMO foods are foods produced from organisms that have had changes introduced into their DNA using genetic engineering methods as opposed to traditional cross breeding. GMO produce is also known as genetically engineered food or bio-engineered food.

GMO-free Produce - Usually means that the genetic makeup of the plants and animals used in the product has not been altered for the purposes of food production. GMO-free is the same as non-GMO.

Pesticide - Pesticides are a substance used to kill pests. More specifically, *insecticides* kill insects, *Herbicides* kill weeds, *Fungicides* kill diseases.

Pesticide-free - Generally refers to produce that is not treated with any synthetic (human-made) pesticides. Pesticides are substances used to control insects, weeds, or disease-causing organisms. Additionally, pesticide-free produce is produce that has not been tested against the strict regulations to be certified as organic.

Synthetic Pesticide vs Organic Pesticide - Synthetic pesticides are made through chemistry (in a laboratory) whilst organic pesticides are derived from natural sources. However, whether they are made in a lab or naturally, if they

Food Supply Chain - The series of processes, operations and entities that help to take food from its raw material state to a consumption ready state.

Food Supply Chain Management and Operations - Food Supply Chain Management includes the operations that are undertaken to keep the safety and quality of various food under efficient and effective modes. These operations include production, distribution, and consumption.

Food Supply Chain Actors - Participants in a Food Supply Chain, including producers(farmers), transportation agents, processing agents, retailers and consumers.

Provenance - Source. Origin. History of ownership of a valued object or work of art or literature.

Transparency - Making the information relevant to each Supply Chain operation visible to interested parties. Examples of this information includes who has been involved in the production and handling of the produce.

Traceability - The ability to follow the movement of a feed or food through specified stage(s) of production, processing and distribution.

Food Democracy - Food democracy emphasizes fulfilment of the human right to safe and nutritious food that has been justly produced, within a local context and championed by local residents as opposed to large corporations.

Food Citizenship - The practice of engaging in food-related behaviours that support, rather than threaten, the development of a democratic, socially and economically just, and environmentally sustainable food system.

Food Poverty - The inability to afford, or to have access to, food, to make up a healthy diet. It is about the quality of food as well as quantity. It is not just about hunger, but also about being appropriately nourished to attain and maintain health.

Figure D.6: A screenshot of the Food Facts 101 section on FoodPrint website. This page contains some relevant food related definitions and facts.

FAQS & DEFINITIONS

Technology 101

Distributed Ledger Technology (DLT) - Umbrella term to designate multi-party systems that operate in an environment with no central operator or authority, despite parties who may be unreliable.

Blockchain - A digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamper-proof records. The name blockchain stems from its technical structure — a chain of blocks, each block is linked to the previous block with a secure mathemtical property.

Blockchain vs Distributed Ledger Technology - Blockchain falls under the Distributed Ledger Technology umbrella. However, not all distributed ledgers necessarily employ blockchain.

Bitcoin vs Blockchain - Bitcoin is a cryptocurrency, which simply out, is a financial application of blockchain technology. Blockchain itself is more of a foundational/enabling technology, with alternative uses outside of financial transactions.

Applications of Blockchain - Since blockchain reduces the need for a trusted authority (given its decentralised and tamper-proof nature), it can be used not only for capturing transactions but for general-purpose record keeping well. Blockchain can optimize processes and improve efficiencies. In particular, the tamper-proof nature gives rise to auditable traceability, which in turn makes blockchain especially useful in supply chain traceability.

Blockchain for food traceability - The complexity of global food systems makes food supply chains more opaque and less robust. The ability to instantaneously trace the entire lifecycle of food products from origin through every point of contact on its journey to the consumer combats food fraud and bolsters credibility, efficiency and safety.

What technology is required to use FoodPrint - An internet connection and an internet-enabled mobile device.

Is FoodPrint open-source? - Transparency is at the heart of what we do at FoodPrint. As such, the core of our core work is open.

Reporting - The process of organizing data into informational summaries in order to monitor how different areas of a business are performing.

Analytics - The process of exploring data and reports in order to extract meaningful insights, which can be used to better understand and improve business performance.

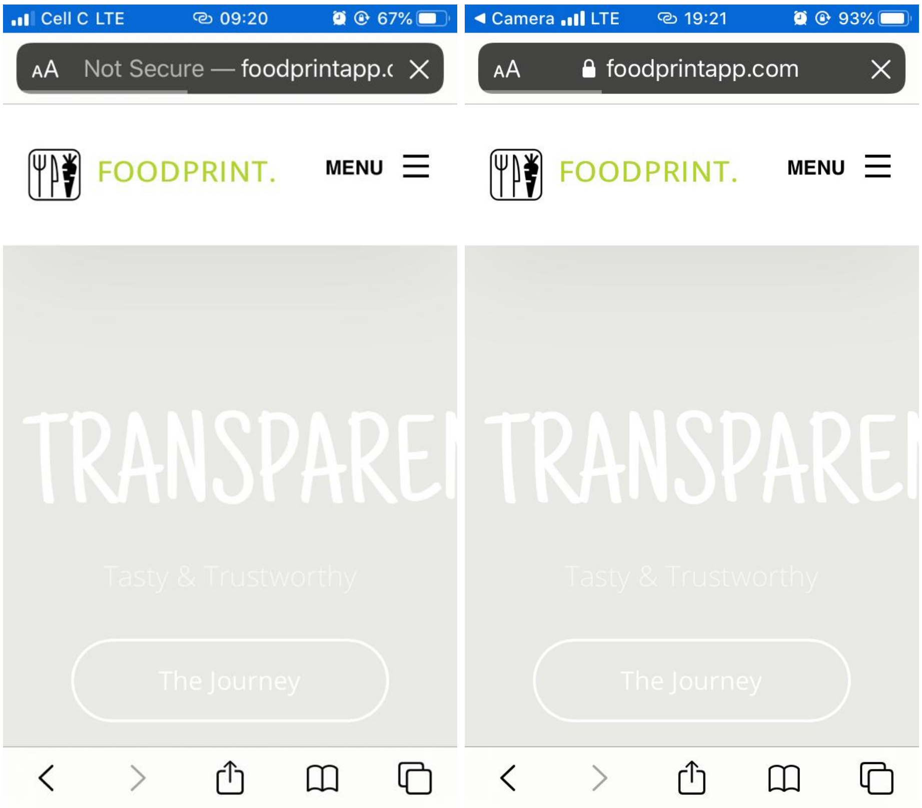
Internet of Things (IoT) - IoT describes the network of physical objects —"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

Artificial Intelligence (AI) - AI makes it possible for machines to learn from experience, adjust to new inputs and perform human-like tasks e.g. Siri, self-driving cars.

Figure D.7: A screenshot of the Blockchain and Technology 101 section on FoodPrint website. This page contains some relevant technology related definitions and facts.

D.2 Other Design Considerations

Below is a screenshot displaying the observable difference in a mobile device's web address bar before-SSL (Not Secure) and after-SSL (locked padlock icon). SSL technology is a trust-enhancing mechanism (similar to BCT), hence the inclusion in the FoodPrint design considerations.



(a) Before SSL (b) After SSL

Figure D.8: Comparison of the FoodPrint URL bar appearance before and after activating SSL on the FoodPrint website. SSL technology is a trust-enhancing mechanism for online platforms.

E. Usage Statistics

This appendix contains the summary usage statistics from the FoodPrint pilot.

E.1 Summary Statistics

For the FoodPrint pilot at OZCFM, 8 unique FoodPrint QR codes were generated to match the 8 different types of produce (Radish, Fennel, Baby Marrow, Lebanese Cucumber, Green Beans, Basil, Beetroot and Cayenne Pepper) from 2 participating smallholder farms (White Mountain Produce Farm and Quick Crop Growers Farm).

Table E.1 on the next page shows an aggregation of the QR code scans per produce type and date.

Table E.1: Statistics from the FoodPrint pilot at Oranjezicht City Farm Market. These statistics show the number of QR code scans per produce type and the corresponding date. The statistics can be summarised as 8 different types of produce (each with a unique FoodPrint supplier-produce specific QR code) and 2 participating smallholder farms.

Produce Type	Produce Source	Number of QR Code Scans	Date
Radish	White Mountain Produce Farm	3	21 December 2019
Fennel	White Mountain Produce Farm	10	21 December 2019
Basil	Quick Crop Growers Farm	1	21 December 2019
Cayenne Pepper	Quick Crop Growers Farm	6	21 December 2019
Baby Marrow	White Mountain Produce Farm	8	21 December 2019
Green Beans	White Mountain Produce Farm	7	21 December 2019
Radish	White Mountain Produce Farm	1	22 December 2019
Fennel	White Mountain Produce Farm	4	22 December 2019
Cayenne Pepper	Quick Crop Growers Farm	3	22 December 2019
Green Beans	White Mountain Produce Farm	1	22 December 2019
Radish	White Mountain Produce Farm	0	28 December 2019
Fennel	White Mountain Produce Farm	3	28 December 2019
Baby Marrow	White Mountain Produce Farm	2	28 December 2019
Green Beans	White Mountain Produce Farm	3	28 December 2019
Radish	White Mountain Produce Farm	4	18 January 2020
Fennel	White Mountain Produce Farm	11	18 January 2020
Baby Marrow	White Mountain Produce Farm	9	18 January 2020
Lebanese Cucumber	White Mountain Produce Farm	2	18 January 2020
Green Beans	White Mountain Produce Farm	7	18 January 2020
Basil	Quick Crop Growers Farm	4	18 January 2020
Beetroot	Quick Crop Growers Farm	15	18 January 2020

In addition, Table E.2 below shows an aggregation of the QR code scans per source mobile device operating system (OS) and date.

Table E.2: Aggregated QR code scan statistics from the FoodPrint pilot at Oranjezicht City Farm Market. The scans are per source mobile device operating system (OS) and date.

Number of QR Code Scans	Source	Date
30	iOS	21 December 2019
4	Android	21 December 2019
9	iOS	22 December 2019
1	Android	22 December 2019
8	iOS	28 December 2019
0	Android	28 December 2019
42	iOS	18 January 2020
10	Android	18 January 2020

F. FoodPrint Source Code, Deployment and Technology Glossary

This appendix contains the FoodPrint source code, smart contract class diagram, details of the deployed FoodPrint version and a summary of the technology used.

F.1 Source Code Repository

The FoodPrint source code can be found in this GitHub repository - https://github.com/jajukajulz/foodprint (release v0.2-alpha, commit 7fb319c3854f8261e3cc66fe0c4c64ea44b958f6)

The key components in this repository include:

- **Web Server** (Express.js web application framework running on top of Node.js) - https://github.com/jajukajulz/foodprint/blob/master/server.js
- **SQL Database schema** - https://github.com/jajukajulz/foodprint/tree/master/dbxml
- **User Interface** (views made using Embedded JavaScript Templating - EJS) - https://github.com/jajukajulz/foodprint/tree/master/views
- **Application Overview and Instructions** (i.e. README) - https://github.com/jajukajulz/foodprint/blob/master/README.md
- **Solidity Smart Contracts** (source code) - https://github.com/jajukajulz/foodprint/tree/master/contracts
- **Compiled Smart Contracts** - https://github.com/jajukajulz/foodprint/tree/master/build/contracts

F.2 Smart Contract Details

The FoodPrint smart contract for tracking produce harvest and storage operations is called *TheProductV2*. This smart contract is written using Solidity. The core data structures of the contract are *produceHarvestSubmission, produceHarvestSubmissionDetail* and *produceStorageSubmission* as seen in Figure F.1 on the next page. The first two are used for tracking harvest data whilst the last is used for tracking storage data.

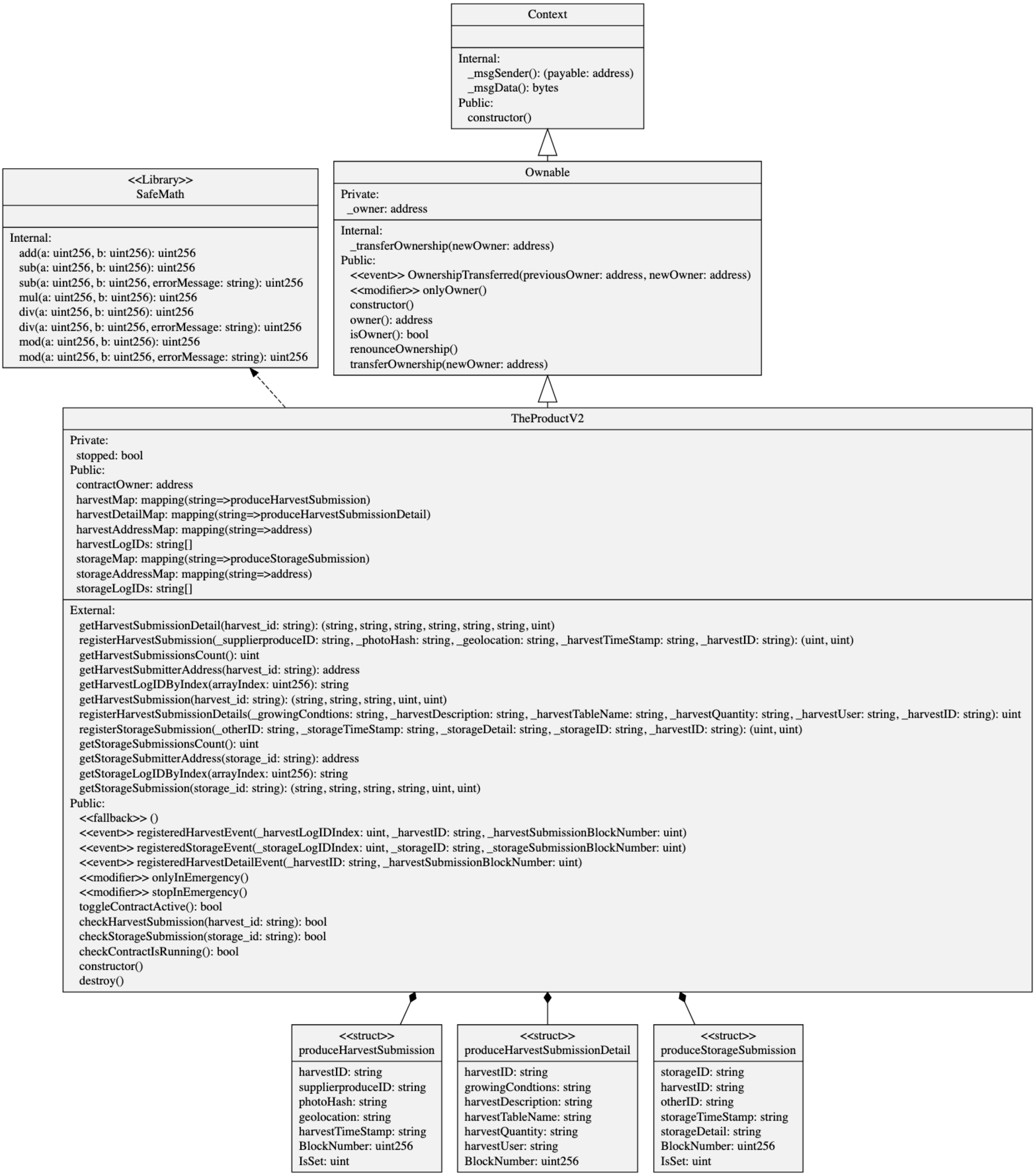


Figure F.1: A class diagram of the FoodPrint smart contract for tracking produce harvest and storage operations. The smart contract is used to permanently persist the core elements of the produce harvest and storage data (that is captured in the respective logbooks during the FSC operations) onto an Ethereum blockchain network.

F.3 Deployment Details

Below are the links relevant to the deployed FoodPrint application:

- **FoodPrint application** - https://www.foodprintapp.com
- **FoodPrint smart contract** (TheProductV2) (latest deployed version on the Rinkeby testnet at the time of this write up) - https://rinkeby.etherscan.io/address/0xfC4d26073650887069dFa7Da686A491535ab8Fd4
- **Harvest Logbook** - https://www.foodprintapp.com/app/harvest
- **Storage Logbook** - https://www.foodprintapp.com/app/storage
- **Produce Search** - https://www.foodprintapp.com/app/trace_produce
- **Blockchain Explorer** - https://www.foodprintapp.com/app/blockchain_explorer
- **Blockchain and Technology Education** - https://www.foodprintapp.com/tech101
- **Food Production Systems Education** - https://www.foodprintapp.com/food101

NB: Local development environment URL will be http://localhost:<PORT>

F.4 Technology Glossary

Below is a glossary of technology used in the development of the FoodPrint platform:

- **Express.js** - A Node.js web application framework. https://expressjs.com
- **Infura** - A hosted Ethereum node cluster. Enables users to run Ethereum blockchain applications without setting up their own nodes. https://infura.io
- **Ganache** - A personal blockchain for rapid Ethereum and Corda distributed application development. https://www.trufflesuite.com/ganache
- **HTML5** - HTML5 is the latest version of Hypertext Markup Language that is used for structuring and presenting content on the World Wide Web.
- **JavaScript** - JavaScript is a high-level programming language that conforms to the ECMAScript specification and enables interactive web pages.
- **MetaMask** - A web browser extension which makes it easy for web applications to communicate with the Ethereum blockchain. MetaMask is available as a plugin for Google Chrome, Vivaldi, Opera and Firefox. https://metamask.io
- **MySQL** - An open-source relational database management system. https://www.mysql.com
- **Node.js** - An open-source, cross-platform, JavaScript runtime environment that executes JavaScript code outside a web browser. https://nodejs.org/en
- **GitHub** - A Git repository hosting service. https://github.com
- **Heroku** - A cloud platform for hosting applications. https://www.heroku.com
- **Rinkeby** - An Ethereum testnet that uses proof-of-authority consensus (as opposed to proof-of-work on the Ethereum mainnet). https://www.rinkeby.io
- **Solidity** - Object-oriented programming language for writing smart contracts. https://solidity.readthedocs.io
- **Truffle** - An Ethereum development framework. https://www.trufflesuite.com/truffle
- **Web3.js** - An Ethereum JavaScript API. https://web3js.readthedocs.io

G. Surveys

This appendix contains the user surveys used in this research.

G.1 Consumer Survey

G.1.1 Consumer Survey Questions

FoodPrint Consumer Survey

Do you know the source of the food you eat? Imagine if you could trace your food. Which farm it is from, when it was harvested, when it was transported, right through to when you purchase it. That's where we come in. We're FoodPrint and we're tracking food, from farm to fork. Check us out at www.foodprintapp.com.

Any personal identifiable information you provide will be anonymously analysed in conjunction with your survey responses.

Expected survey completion time - 3 minutes.

I consent to participate in this Food Traceability and Blockchain study. I am aware that participation is voluntary and I may withdraw at any time should I wish to do so.

- ◯ Yes
- ◯ No

Are you a local or a tourist?

- ◯ Local
- ◯ Tourist
- ◯ Other:

If you are a tourist, would knowing about the traceability count as part of your tourist experience?

- ◯ Yes
- ◯ No
- ◯ Undecided

What is your age?

- ◯ 18-24 years old
- ◯ 25-34 years old
- ◯ 35-44 years old
- ◯ 45-54 years old
- ◯ 55-64 years old
- ◯ 65-74 years old
- ◯ 75 years or older
- ◯ Prefer not to say

Which of the following best describes your race or ethnicity?

- ◯ White
- ◯ Black
- ◯ Asian
- ◯ Mixed
- ◯ Prefer not to say

Are you interested in knowing the origin of your food (where the product is really coming from, who made it, where it was transported, by who and how)?

- ◯ Yes
- ◯ No
- ◯ Sometimes

Are you more likely to buy if you can see traceability? Would that boost your confidence in the farmers and markets? Would that increase your loyalty to the farmers and markets?

◯ Strongly Agree
◯ Agree
◯ Undecided
◯ Disagree
◯ Strongly Disagree

Would you be happy to pay more for your food if you can trace it?
◯ Strongly Agree
◯ Agree
◯ Undecided
◯ Disagree
◯ Strongly Disagree

Do you care if the food you purchase is locally sourced?
◯ Extremely
◯ Moderately
◯ Not at all

Do you care if the food you purchase is organic?
◯ Extremely
◯ Moderately
◯ Not at all

Do you care if the food you purchase is pesticide free?
◯ Extremely
◯ Moderately
◯ Not at all

Do you care if the food you purchase is antibiotic free?
◯ Extremely
◯ Moderately
◯ Not at all

Are you concerned with compliance and ethics in the production of your food?
◯ Extremely
◯ Very
◯ Moderately
◯ Slightly
◯ Not at all

Do you trust your local retailer e.g Woolworths?
◯ Yes
◯ No

Do you trust the local market?
◯ Yes
◯ No
◯ Undecided

If yes to the above, why?

____

Do you trust that the market acts in the best interest of the farmers and the consumers?
◯ Yes
◯ No
◯ Undecided

Do you trust the farmers that produce the food you buy?
◯ Yes
◯ No
◯ Undecided

If yes to the above, why?

____

Would a mechanism to communicate directly with a farmer be of value to you?
◯ Yes
◯ No
◯ Undecided

Are you interested in knowing about the labour practises at the farms that produce the food?
◯ Yes
◯ No
◯ Undecided

What comes to mind when you hear Blockchain and Food Traceability?
☐ Trust
☐ Transparency
☐ Complex Technology
☐ Unnecessary Hype
☐ Never heard of Blockchain before
☐ No comment

Do you believe blockchain enabled-supply chain processes would be transparent?
◯ Strongly Agree
◯ Agree
◯ Undecided
◯ Disagree
◯ Strongly Disagree

Would you prefer to know in advance which produce will be at the market every week?
◯ Strongly Agree
◯ Agree
◯ Undecided
◯ Disagree
◯ Strongly Disagree

Have you had to deal with fraud or tampering of produce purchased at the market?

◯ Yes
◯ No

How do you find the quality of produce at the market?

◯ Excellent
◯ Above Average
◯ Average
◯ Below Average
◯ Very Poor

Do you have a channel you can use to comment on the quality produce you purchase from the market?

◯ Yes
◯ No

Do you want to know expiry date of produce you buy?

◯ Yes
◯ No
◯ Maybe

Do you want to know the price paid to the farmer by the market?

◯ Yes
◯ No
◯ Maybe

Do you want to know the amount of water used to grow the produce?

◯ Yes
◯ No
◯ Maybe

How much would you be comfortable to pay on a monthly basis for an online system to keep track of your produce preferences, shopping list, recipe suggestions, pre-ordering of produce?

◯ R50 per month
◯ R100 per month
◯ R150 per month
◯ R200
◯ Other: ______________________________

Any comments about the market? ______________________________

G.1.2 Consumer Survey Response Summary

Table G.1 below shows a summary of the responses to the Farmer Survey.

Table G.1: Summary of the responses to the consumer survey carried out at the Oranjezicht City Farm Market for the FoodPrint pilot (n=12).

Question	Summarised Responses	Researcher Comment
I consent to participate in this Food Traceability and Blockchain study. I am aware that participation is voluntary and I may withdraw at any time should I wish to do so.	100% Yes	Required consent to participate in the survey.
Are you a local or a tourist?	66.7% Local, 8.3% Tourist, 25% Other	Respondents who chose other include long stay tourists and respondents who have lived in Cape Town for more than 5 years but less than 10 years.
If you are a tourist, would knowing about the traceability count as part of your tourist experience?	72.7% Yes, 9.1% No, 18.2% Undecided	At least 50% of the respondents indicate that knowing about produce traceability counts as part of their tourist experience.
What is your age?	58.3% 25-34 years old, 25% 35-44 years old, 8.3% 45-54 years old, 8.3% 18-24 years old	More than 80% of the survey respondents are between the ages of 18 and 34.
Which of the following best describes your race or ethnicity?	58.3% White, 25% Black, 8.4% Asian, 8.3% Mixed	-
Are you interested in knowing the origin of your food (where the product is really coming from, who made it, where it was transported, by who and how)?	83.3% Yes, 16.7% Sometimes	At least 80% of the respondents indicate interest in knowing about the provenance of the produce they buy. The rest of the respondents are sometimes interested. None of the respondents indicate that they are not interested in knowing about the provenance of the produce.
Are you more likely to buy if you can see traceability? Would that boost your confidence in the farmers and markets? Would that increase your loyalty to the farmers and markets?	58.3% Strongly Agree, 16.7% Undecided, 25% Strongly Agree	At least 80% of the respondents are inclined to buy and be more loyal to the market and its farmers because of traceability information.
Would you be happy to pay more for your food if you can trace it?	33.3% Agree, 41.7% Undecided, 8.3% Disagree, 16.7% Strongly Disagree	There does not appear to be a strong conviction to pay more for produce that is traceable. One potential reason for this is the existing trust in the local food supply chain.
Do you care if the food you purchase is locally sourced?	58.3% Extremely, 41.7% Moderately	Locally sourced produce is important to the consumers.
Do you care if the food you purchase is organic?	75% Moderately, 25% Extremely	The consumers care about the nature and quality of the produce they eat.

Do you care if the food you purchase is pesticide free?	58.3% Extremely, 41.7% Moderately	The consumers care about the nature and quality of the produce they eat.
Do you care if the food you purchase is antibiotic free?	50% Extremely, 50% Moderately	The consumers care about the nature and quality of the produce they eat.
Are you concerned with compliance and ethics in the production of your food?	50% Moderately, 41.7% Extremely, 8.3% Very	Consumers expect produce grown safely and reported on truthfully.
Do you trust your local retailer e.g Woolworths?	54.5% No, 45.5% Yes	Consumers indicated a few reasons for not outright trusting large retails. Some of these include the fact that the produce purchased from retailers lasts for an unusually long time before perishing and the distance between farmers and the retailer in the supply chain has a number of intermediaries.
Do you trust the local market?	83.3% Yes, 8.3% Undecided, 8.4% No	At least 80% of the respondents indicate that they trust the market.
If yes to the above, why?	Established reputation over the years. Strong sense of community. Human element displayed the market. Ambience at the market. Promotion of locally sourced produce by the market. Better tasting produce at the market as compared to retail supermarkets. Shorter supply chain as compared to retail.	The nature of the market, together with its physical characteristics and direct access to farmers breeds trust.
Do you trust that the market acts in the best interest of the farmers and the consumers?	75% Yes, 8.3% No, 16.7% Undecided	5% of the survey respondents trust that the market acts in the best interest of the farmers supplying them with produce.
Do you trust the farmers that produce the food you buy?	75% Yes, 25% Undecided.	-
If yes to the above, why?	Extension of trust in the market. Interaction with some of the farmers. Shorter supply chain.	Affiliation with the market is a trust-enhancing signal for the farmers.
Would a mechanism to communicate directly with a farmer be of value to you?	58.3% Undecided, 33.3% Yes, 8.4% No	There does not appear to be a strong desire from the consumers for a means to directly communicate with the farmers.
Are you interested in knowing about the labour practises at the farms that produce the food?	50% Undecided, 50% Interested	Half of the consumers are interested in knowing about the labour practises in the growing of the produce they purchase from the market.
What comes to mind when you hear Blockchain and Food Traceability?	66.7% Trust, 50% Transparency, 33.3% Complex Technology, 16.7% Unnecessary Hype, 0% Never heard of Blockchain before, 33.3% No Comment	Mixed response suggests a need to raise awareness on use of blockchain technology in food traceability.
Do you believe blockchain-enabled supply chain processes would be transparent?	66.7% Undecided, 25% Agree, 8.3% Strongly Agree	More than 50% of consumers are undecided, suggesting a need to raise awareness on use of blockchain technology in food traceability.

Would you prefer to know in advance which produce will be at the market every week?	41.7% Undecided, 41.7% Agree, 16.7% Strongly Agree	Mixed response suggests that the consumers may have a reasonable accurate assumption of the fresh produce types available at the market each week.
Have you had to deal with fraud or tampering of produce purchased at the market?	91.7% No, 8.3% Yes	At least 90% of the consumers have found the produce labelling and handling to be as expected.
How do you find the quality of produce at the market?	66.7% Above Average, 33.3% Excellent	The quality of the produce at the market is more than above average.
Do you have a channel you can use to comment on the quality produce you purchase from the market?	83.3% No, 16.7% Yes	At least 80% of the consumers indicate that they do not have an avenue for commenting on the quality of produce. This is unexpected, seeing as the market is very active on social media. One would expect this to be an apparent feedback avenue to consumers.
Do you want to know expiry date of produce you buy?	33.3% No, 33.3% Maybe, 8.3% Undecided, 25% Yes	This mixed response may be explained by the fact that consumers purchase produce on a weekly basis from the market and likely consume it in a couple of days following purchase. In that case, the expiry date, given the produce is purchased fresh is perhaps not relevant then.
Do you want to know the price paid to the farmer by the market?	33.3% No, 33.3% Maybe, 25% Yes, 8.3%	This mixed response may due to the fact that consumers already trust the market and therefore expect that the market pays fair value to the farmers for their produce.
Do you want to know the amount of water used to grow the produce?	50% Maybe, 33.3% Yes, 8.3% Agree, 8.4% No	-
How much would you be comfortable to pay on a monthly basis for an online system to keep track of your produce preferences, shopping list, recipe suggestions, pre-ordering of produce?	58.3% R50 per month, 16.7% R150 per month, 8.3% R200, 8.4% Undecided, 8.3% Not Interested	At least 50% of the surveyed consumers indicate a willingness to pay R50 per month for access to traceability information. Given this minimal monthly amount, it suggests that the consumers do not place a premium on traceability information, which may go back to the existing trust in the market.

Any comments about the market?	Love the market. Great Market. No. Not always keen to pay a premium for produce. Never heard of Blockchain for food safety, only know of Bitcoin. Oranjezicht market is excellent, great for tourists, locals and supporting local economy. Great sense of community. Great to buy produce with less plastic and packaging. Labelling of produce as organic or conventional is good, as consumers would otherwise assume all produce is organic.	Overall positive sentiment towards the market from consumers.

G.2 Farmer Survey

G.2.1 Farmer Survey Questions

FoodPrint Farmer Survey

Do the consumers of the food you produce know where it is coming from? Do they trust you? Imagine if consumers could trace their food back to source. Which farm it is from, when it was harvested, when it was transported, right through to when you purchase it. It could increase trust and sales. That's where we come in. We're FoodPrint and we're tracking food, from farm to fork. And whilst we're at it, we could help you get rid of paper logs and excel sheets! Check us out at www.foodprintapp.com.

Any personal identifiable information you provide will be anonymously analysed in conjunction with your survey responses.

Expected survey completion time - 3 minutes.

I consent to participate in this Food Traceability and Blockchain study. I am aware that participation is voluntary and I may withdraw at any time should I wish to do so.

◯ Yes
◯ No

What type of a farmer are you?

◯ Subsistence Farmer - self-sufficiency household-farming, farmers produce mainly for household consumption and production is based on the family requirements rather than markets. Production is further reduced by limited technology and access to resources.
◯ Smallholder Farmer - Produce for household consumption and markets, earning ongoing revenue from their farming businesses, which form a source of income for the family. Access to comprehensive support (technical, financial and managerial instruments) required to engage in commercial farming.
◯ Emerging Farmer - "In transition" towards becoming a commercial farmer.
◯ Semi-Commercial Farmer - Produce on medium sized holdings and grow at least one commercial product that may be sold at the farm gate or to the distributors.
◯ Commercial Farmer - established farming venture undertaken by an individual or business entity for the purpose of the production and sale of agricultural products to make a profit.

What produce do you sell?

____

Do you use certified seeds for planting?

◯ Always
◯ Often
◯ Sometimes
◯ Seldom
◯ Never

Is your produce currently certified by any bodies?

◯ Always
◯ Often
◯ Sometimes
◯ Seldom
◯ Never

If yes, then what bodies are they certified by?

____

Is your produce organic?

◯ Yes
◯ No
◯ Sometimes

Is your produce pesticide free?

◯ Yes
◯ No
◯ Sometimes

Do you have access to finance from banks?

◯ Yes
◯ No

If you have access to finance from banks, what collateral do they require? Immovable Asset e.g. Property Guarantor

◯ Movable Asset
◯ Lien on Produce
◯ Other: ______________________________

Transparency is mapping of a food supply chain end to end and making this information visible to interested parties e.g. customers to know who has been involved in the production and handling of produce; regulatory bodies etc. How would you describe the transparency in the food supply chain that you take part in?

◯ Good
◯ Fair
◯ Poor

Traceability is the ability to is the ability to identify, track and trace food produce as it moves along the supply chain from the farm of origin to the consumer. How would you describe the traceability in the food supply chain that you take part in?

◯ Good
◯ Fair
◯ Poor

How do you currently store operational data e.g. what produce you have planted, major dates e.g. application of pesticides, harvest data. Tick all that apply.

☐ Paper Forms
☐ Microsoft Excel
☐ Farm Management System

Do you have any internal/in-house periodic reporting/summaries on your farming activities (e.g. graphs and dashboards) to help you pick up trends and quickly get a snapshot of your farming related data?

◯ Yes
◯ No
◯ Other: ______________________________

Do you forecast demand for produce?

◯ Always
◯ Often
◯ Sometimes
◯ Seldom
◯ Never

If you do forecast, how do you do so?

◯ Use Historic Data
◯ Consult with markets in advance
◯ Use weather data

Do you have reliable internet access at your farm?

◯ Yes
◯ No

Do you have a device that can access the internet? Check all that apply.

☐ Smartphone
☐ iPad
☐ Laptop/Computer
☐ Other: ______________________________

Food fraud occurs when food or drink is sold in a way that deliberately misleads or deceives consumers for financial gain. Are you aware of any fraud that occurs (or may have previously occurred) in the supply chain?

◯ Yes
◯ No
◯ Not Applicable

Select the inefficiencies in the current food supply chain between farmers and markets. Tick all that apply.

☐ High transaction costs (farmers incur labour costs for loading and offloading of agriculture produce and weighing costs)
☐ Flaws in the Information Flow and Lack of Quality Check (farmers are often paid less for their high quality agriculture produce and at the same time, retailers feel that they have paid more for lower quality food)
☐ Sharing produce inventory information with markets is manual
☐ Order placing by markets is over the phone
☐ Receiving payment from market is slow
☐ There are too many middlemen in the food supply chain before produce reaches the consumer
☐ Other: ______________________________

Do you think that the markets that you supply are trustworthy?

◯ Agree
◯ Undecided
◯ Disagree

How is trust established with the market? ______________________________

Are you happy for the market to have access to your harvest data on an online platform?

◯ Agree
◯ Undecided
◯ Disagree

Have you had excess produce that the market could not take on? If so, how did you resolve the situation?

◯ Some of the produce was sold at a lower price and some of it was spoiled/wasted
◯ All of the produce was sold at a lower price and none of it was spoiled/wasted

- ◯ We have not had excess produce
- ◯ Other: ______________________________

What comes to mind when you hear Blockchain and Food Traceability?

- ◯ Trust
- ◯ Transparency
- ◯ Complex Technology
- ◯ Unnecessary Hype
- ◯ Never heard of Blockchain before
- ◯ No comment

How much would you pay on a monthly basis for an easy-to-use online system to keep track of your harvest data, connect you with markets and enable you to communicate with consumers of your produce?

- ◯ R1000 per month
- ◯ R2000 per month
- ◯ R5000 per month
- ◯ Other: ______________________________

G.2.2 Farmer Survey Response Summary

Table G.2 below shows a summary of the responses to the Farmer Survey.

Table G.2: Summary of the responses to the farmer survey carried out at the Oranjezicht City Farm Market for the FoodPrint pilot (n=4).

Question	Summarised Responses	Researcher Comment
I consent to participate in this Food Traceability and Blockchain study. I am aware that participation is voluntary and I may withdraw at any time should I wish to do so.	100% Yes	Required consent to participate in the survey.
What type of a farmer are you?	50% Smallholder Farmer, 25% Semi-Commercial Farmer, 25% Commercial Farmer	-
What produce do you sell?	Flowers, dairy and fruit (peaches and plums). Vegetables, eggs and milk. Vegetables and herbs.	Farmers supply not only fresh produce but poultry and dairy products as well.
Do you use certified seeds for planting?	50% Always, 50% Often	Quality seedlings mean quality yields.
Is your produce currently certified by any bodies?	50% Always, 25% Often, 25% Never	-
If yes, then what bodies are they certified by?	Coetzee and Coetzee. Demeter and biodynamic. Participatory Guarantee System (PGS).	PGS is seen as a complimentary alternative to third-party organic certification for smallholder farmers and producers.
Is your produce organic?	100%	Although 100% of the survey participants indicate that their produce is organic, it is worth noting that some of the produce sold at the market is conventionally grown.
Is your produce pesticide free?	100%	-
Do you have access to finance from banks?	75% No, 25% Yes	Access to finance is difficult for smallholder farmers.
If you have access to finance from banks, what collateral do they require?	75% Immovable Asset e.g. Property, 25% Guarantor, 25% Other	The collateral requirements are prohibitive for smallholder farmers.
Transparency is mapping of a food supply chain end to end and making this information visible to interested parties e.g. customers to know who has been involved in the production and handling of produce; regulatory bodies etc. How would you describe the transparency in the food supply chain that you take part in?	50% Poor, 25% Fair, 25% Good	Half of the survey respondents describe the transparency as poor. This may be due to the existing trust which means that supply chain participants do not request for transparency.

Traceability is the ability to is the ability to identify, track and trace food produce as it moves along the supply chain from the farm of origin to the consumer. How would you describe the traceability in the food supply chain that you take part in?	50% Fair, 25% Good, 25% Poor	Traceability in the food supply chain at the time of conducting the survey is a combination of tracing communication and inventory records across different systems and mediums.
How do you currently store operational data e.g. what produce you have planted, major dates e.g. application of pesticides, harvest data. Tick all that apply.	100% Paper Forms, 50% Microsoft Excel, 0% Farm Management System	All the survey respondents indicate that they do not use a dedicated farm management system.
Do you have any internal/in-house periodic reporting/summaries on your farming activities (e.g. graphs and dashboards) to help you pick up trends and quickly get a snapshot of your farming related data?	50% Yes, 25% No, 25% Other	Mixed response suggests that there is no standardised analytics being carried out by the farmers.
Do you forecast demand for produce?	50% Seldom, 25% Never, 25% Sometimes	Farmers do not appear to be actively forecasting demand for produce. This could be due to lack of resources, time or know-how.
If you do forecast, how do you do so?	100% Use Historic Data, 33.3% Consult with markets in advance, 0% Use weather data	-
Do you have reliable internet access at your farm?	100%	Connecting to the internet does not seem to be an issue.
Do you have a device that can access the internet? Check all that apply.	100% Smartphone, 50% iPad, 75% Laptop/Computer	Farmers have access to internet enabled devices that can access cloud applications via a web browser.
Food fraud occurs when food or drink is sold in a way that deliberately misleads or deceives consumers for financial gain. Are you aware of any fraud that occurs (or may have previously occurred) in the supply chain?	75% Yes, 25% No	-
Select the inefficiencies in the current food supply chain between farmers and markets. Tick all that apply.	100% High transaction costs, 100% Sharing produce inventory information with markets is manual, 50% Order placing by markets is over the phone, 50% Receiving payment from market is slow, 25% Other	Main inefficiencies appear to be high transaction costs experienced by the farmers and order placing from the market which is over the phone or email. Since the supply chain is a short one, the farmers do not have to contend with any middlemen and therefore this is not selected as an inefficiency.

Do you think that the markets that you supply are trustworthy?	75% Yes, 25% Undecided	More than half of the survey respondents indicate that the markets they supply are trustworthy. This position is likely established over time.
How is trust established with the market?	Working relationship built over time. Good communication. Transparency. Mission.	Common theme of trust earned over time, coupled with professionalism and good intent displayed by the Oranjezicht Market.
Are you happy for the market to have access to your harvest data on an online platform?	100% Yes	Access to harvest data enables market to place orders online.
Have you had excess produce that the market could not take on? If so, how did you resolve the situation?	25% Some goes unsold, 25% We have not had excess produce, 25% All of the produce was sold at a lower price and none of it was spoiled/wasted, 25% Some of the produce was sold at alower price and some of it was spoiled/wasted	Excess produce is either sold at lower price or else it goes to waste.
What comes to mind when you hear Blockchain and Food Traceability?	100% Trust, 100% Transparency, 75% Complex Technology, 25% Unnecessary Hype, 25% Never head of Blockchain before	Mixed response suggests a need to raise awareness on use of blockchain technology in food traceability.
How much would you pay on a monthly basis for an easy-to-use online system to keep track of your harvest data, connect you with markets and enable you to communicate with consumers of your produce?	50% R1000 per month, 50% Other	Half of the survey respondents express a willingness to pay R1000 per month to access a farm management system whilst the other half indicate a preference of less than R1000. This suggests hat there is some value to a farm management system although the pricing would need not be prohibitive for smallholder farmers.