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SMART CONTRACT AND WEB DAPP FOR TRACING SUSTAINABILITY INDICATORS IN THE TEXTILE AND CLOTHING VALUE CHAIN

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INSTITUTO POLITÉCNICO
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Resumo

Na sociedade atual, o têxtil e vestuário é um dos maiores setores de mercado do mundo. O rápido crescimento desta indústria está a ter impactos sem precedentes na sustentabilidade do planeta, respondendo por consequências negativas ambientais, sociais e de saúde. As tendências da *fast-fashion*, juntamente com a falta de transparência na cadeia de valor têxtil global, somam-se a cenários desfavoráveis para o mundo, à medida que os níveis crescentes de poluição e consumo de recursos dentro da cadeia de valor atingem máximos históricos a cada ano que passa. O ciclo de vida de uma peça de roupa precisa de se adaptar a um modelo económico regenerativo em vez de linear, que acaba no equivalente a um caminhão de lixo de produtos têxteis sendo descartado num aterro sanitário a cada segundo [1]. Não só as indústrias precisam de reformular os seus processos para circularizar as suas cadeias de valor e promover ações sustentáveis, mas também os consumidores precisam de participar dn processo de manter os produtos no círculo da cadeia de valor, pois cabe a eles decidir o destino final de um produto vestuário aquando o seu fim da vida útil. Com estas questões em mente, esta dissertação visa desenvolver duas soluções que possam mitigar os problemas acima mencionados e promover ações sustentáveis rumo a uma economia circular na cadeia de valor do têxtil e vestuário. Uma solução *business-to-business* baseada em *smart contracts* do Hyperledger Fabric para gerir a cadeia de valor do têxtil e vestuário com funcionalidade de rastreabilidade foi desenvolvida como prova de conceito para apoiar as reivindicações de sustentabilidade dos participantes na cadeia de valor, da fibra à peça final de vestuário. A actual funcionabilidade de rastreabilidade desenvolvida no smart contract fornece aos operadores da cadeia de valor a capacidade de rastrear um lote até à sua origem, contudo, também limita a escalabilidade devido ao aumento exponencial do tamanho do bloco, especialmente se considerarmos uma cadeia de valor circular. Para os consumidores, foi proposta uma aplicação descentralizada *business-to-consumer-to-consumer* com elementos de eco-gamificação para promover o envolvimento e motivação do utilizador para a realização de tarefas que contribuam para a adoção de uma economia circular na cadeia de valor do têxtil e vestuário. Após testar a usabilidade da aplicação com o questionário *AttrakDiff*, concluiu-se que o sistema precisa de focar a sua usabilidade em prol de um produto orientado à tarefa em vez da orientação pessoal atual da aplicação a fim de promover ações que contribuam para a economia circular da cadeia de valor do têxtil e vestuário.

Abstract

In today's society, Textile and Clothing (T&C) is one of the biggest market sectors world wide. The sheer size and fast growth of this industry is having unprecedented impacts on sustainability, accounting for negative environmental, social and health consequences. The *fast-fashion* trends alongside the lack of transparency in the global T&C value chain add up to unfavorable scenarios for the world as the increasing levels of pollution and resource consumption within the value chain reach historic highs with every year that passes. The lifecycle of a clothing item needs to adapt to a regenerative economic model instead of a linear one that ends up in the equivalent of a garbage truck full of textiles being disposed into a landfill every second [1]. Not only do the industries need to revamp their processes to circularize their value chains and promote sustainable actions, but the consumers also need to partake in the process of keeping the products in the value chain loop as it is up to them to make the final decision upon the end-of-life of an item of clothing. With these issues in mind, this dissertation aims to develop two solutions that can mitigate the aforementioned problems and promote sustainable actions towards a circular economy in the T&C value chain. A Proof-of-Concept (PoC) Business-to-Business (B2B) T&C value chain management smart contract solution built on Hyperledger Fabric with traceability features was developed to support the sustainability claims of participants in the value chain, from fiber to garment. The current traceability feature developed into the smart contract provides value chain operators the capabilities to trace a batch back to its origin, however, it also constraints scalability due to the exponential increase in block size specially if considering a circular value chain. For the consumers, a Business-to-Consumer-to-Consumer (B2C2C) Decentralized Application (DApp) was proposed with eco-gamification elements for promoting the user's engagement and motivation to complete tasks that contribute for the adoption of a circular economy in the T&C value chain. After testing the consumer DApp's usability with the *AttrakDiff* survey, it was concluded that the system needs to focus its usability towards a task-oriented product instead of the current self-oriented results in order to promote actions that contribute to the circular economy of the T&C value chain.

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"We have not inherited this earth from our parents to do with it what we will. We have borrowed it from our children and we must be careful to use it in their interests as well as our own."

Moses Henry Cass

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Acronyms

ACL	Access Control Layer
AI	Artificial Intelligence
API	Application Programming Interface
B2B	Business-to-Business
B2C	Business-to-Consumer
B2B2C	Business-to-Business-to-Consumer
B2C2C	Business-to-Consumer-to-Consumer
B2B2C2C	Business-to-Business-to-Consumer-to-Consumer
BCT	BlockChain Technology
BDD	Behaviour-Driven Development
BFT	Byzantine Fault Tolerant
BLE	Bluetooth Low Energy
BLL	Business Logic Layer
BPMN	Business Process Model and Notation
C2B	Consumer-to-Business
C2C	Consumer-to-Consumer
CA	Certificate Authority
CDH	Context-Dependent Heuristic
CE	Circular Economy
CFT	Crash Fault Tolerant
CLI	Command Line Interface
CRUD	Create, Read, Update and Delete
CS	Circularity Score
CSR	Corporate Social Responsibility
DAG	Directed Acyclic Graph
DApp	Decentralized Application
DB	DataBase
DBMS	DataBase Management System
DLT	Distributed Ledger Technology
DOI	Depth-Of-Interest
DSL	Domain Specific Language
DSR	Design Science Research
ECDSA	Elliptic Curve Digital Signature Algorithm

ECS	Environmental & Circular Score
EEA	European Economic Area
EMH	Extrinsic Motivation Heuristic
ERP	Enterprise Resource Planning
ESG	Environmental, Social, and Governance
EU	European Union
GDH	Gameful Design Heuristics
GHG	GreenHouse Gas
GNSS	Global Navigation Satellite Systems
GOTS	Global Organic Textile Standard
GPDR	General Data Protection Regulation
GPS	Global Positioning System
Gt	gigatonnes
HCI	Human-Computer Interaction
HQ	Hedonic Qualities
ID	IDentifier
IMH	Intrinsic Motivation Heuristic
IoT	Internet of Things
IPFS	InterPlanetary File System
KEG	Kaleidoscope of Effective Gamification
KYC	Know Your Customer
OCS	Organic Cotton Standard
LCA	Life-Cycle Assessment
LDAP	Lightweight Directory Access Protocol
LoISA	Lens of Intrinsic Skill Atoms
MSP	Membership Service Provider
NFC	Near Field Communication
OOP	Object Oriented Programming
P2P	Peer-to-Peer
pBFT	practical Byzantine Fault Tolerance
PK	Public Key
PKI	Public Key Infrastructure
PoA	Proof-of-Authority
PoET	Proof-of-Elapsed Time
PoC	Proof-of-Concept
PoS	Proof-of-Stake
PoW	Proof-of-Work
PQ	Pragmatic Qualities
QR	Quick Response
REST	REpresentational State Transfer
RFID	Radio Frequency IDentification
RSA	Rivest–Shamir–Adleman
SDK	Software Development Kit
SDT	Self-Determination Theory
SES	Social Economic Score
SHA	Secure Hashing Algorithm
SK	Secret Key

SME	Small Medium Enterprise
T&C	Textile and Clothing
TDD	Test-Driven Development
TLS	Transport Layer Security
UI	User Interface
UNECE	United Nations Economic Commission for Europe
USA	United States of America
UUID	Universal Unique IDentifier
UX/UI	User Experience/User Interface
VM	Virtual Machine
XP	eXperience Points

Chapter 1

Introduction

Textiles are materials used in manufactured products that are a necessity by humans nowadays. Whether it's in fashion, household, industrial or in other areas of application, textiles are quintessential need of today's society. In the case of the clothing sector, they provide us with options to wear according to our surrounding environment and for many are an important expression of individuality.

Clothing is one of the biggest industry sectors in the world, representing more than 60% of the total textiles used (excluding footwear) and is expected to remain the largest application in the industry [15]. Even after nearly two years of disruption and a 20% decline in revenues due to the COVID-19 pandemic [2], the $1.7 trillion global fashion industry employed approximately 430 million people along its value chains. With a global workforce of 3.4 billion people [252], this means that about 12.6% of people working around the globe are involved in the fashion & textiles industry (roughly 1 in every 8 workers) [50].

High, low, and middle-income countries, as well as those with economies in transition, are deeply involved in the global garment and footwear trade. Simultaneously, their jobs will quite often be separated. Design, branding, and retailing, as well as other consumer-related activities like consumption and post-consumption, are common in high-income nations' operations in the downstream part of the value chain. The upstream portion of the value chain, where more labor-intensive activities like farming, harvesting, ginning, spinning, dyeing, weaving, stitching, tanning, cutting, and finishing take place, is where countries with low, middle, and transitioning economies typically intervene the most [238].

Over the last twenty years, not only did the textile industry doubled its production but also the average global annual consumption of textiles has doubled from 7 to 13 kg per person [211, 1]. In fact, the dramatic growth in textile production and fashion consumption is reflected in the emergence of *fast fashion*, a business model that provides consumers with frequent freshness in the form of cheap, trend-setting clothing products. This business model is based on recurring impulsive purchases of garments and is being successful at it, proven by its steady and sustained growth, outperforming the traditional fashion market. *Fast fashion* can frequently provide more flexibility and faster delivery of products [16, 166]. Characterised by its low cost, *fast fashion* means buying more and wearing less [16, 1, 167] as seen in the United States of America (USA) where the average consumer now buys a clothing item every 5.5 days [167, 80]. With the rise of fast-fashion, the average number of times clothes are worn before being discarded has decreased by 36% [1].

This rate of production and consumption is one of many problems within the sector as the sheer size of the textile industry negatively impacts our environment, society and health because the processes behind it heavily rely on activities and materials that contribute to global pollution on several areas and a larger carbon footprint.

1.1 Motivation

As previously mentioned, the T&C industry has been growing vastly over the last decades with clear trends of over-production and over-consumption led by the rise of *fast fashion*. This takes a toll on the planet's environment as there are no current limits for growth in the industry. Social implications as well as health issues for factory workers and consumers are also related to the use of agrochemicals, leading to nausea, diarrhea, cancer and respiratory diseases [192, 205]. Acute pesticide poisoning alone is accountable for almost 1000 deaths a day, afflicting neurological and reproductive problems [235].

The following subsections 1.1.1 and 1.1.2 further describe the problems regarding the environmental impact and social impact of the T&C value chain respectively.

1.1.1 Environmental impact

The current flow model in most textile industries' value chain is the "take-make-dispose" model where the materials for production and its successors flow in a linear fashion as shown in Fig. 1.1. The main flow (in yellow) is linear despite the many complex relationships to other entities that can be required to partake for other purposes such as certifications, contracts and associations.

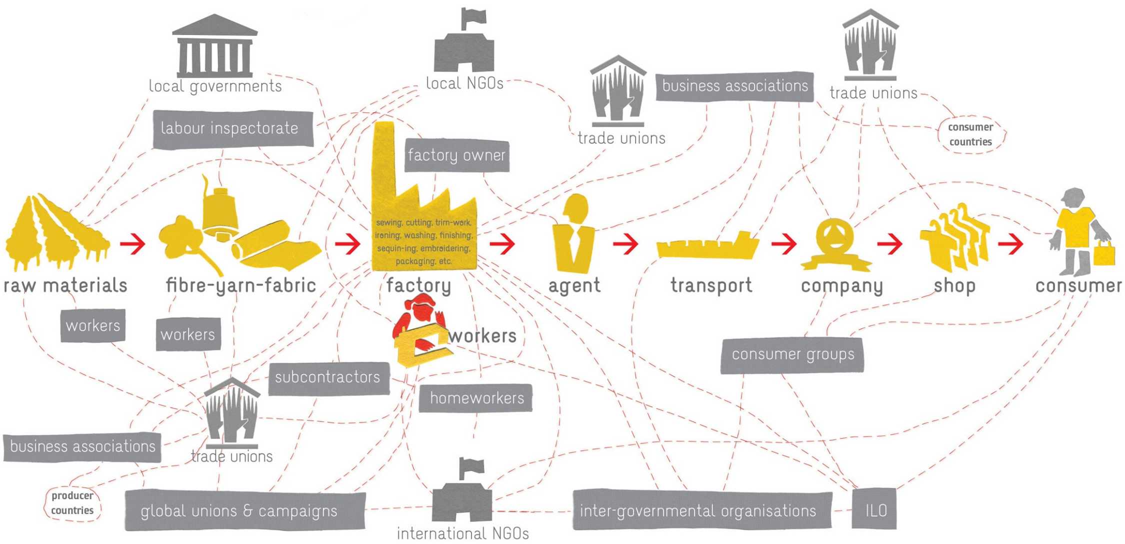

Figure 1.1: Abstract representation of the garment supply chain its relationships (taken from [108])

As described in [84], to produce a textile product there are several production activities that this item will usually go through in its value chain:

- **Fiber production** - harvest and/or production of necessary materials by agricultural firms to create fibers, a material necessary to create any type of clothing product. These can be categorized into 2 types: natural and manmade/synthetic. Natural fibers can come from diverse sources such as plant fibers (e.g., cotton and hemp) [208, 224] and animal fibers (e.g., silk, wool and leather) [25, 207, 251]. Synthetic fibers (e.g., polyester and nylon) are generally made from non-renewable materials such as coal, petroleum and castor oil [224, 251, 207]. Manmade fabrics include cellulose based fibers (e.g., viscose and acetate) [73]. Some fibers can be a mixture of both natural and synthetic fibers [224];

  Table 1.1 lists the global fiber production volumes, market share and recycled share per fiber in 2021 as reported by [73]. Global fiber production reached a record 113 million tonnes in 2021, almost doubling in the last 20 years from 58 million tonnes in 2000 and at this rate, it is expected to grow to 149 million tonnes by 2030. That's about 14.3 kg of fibers being produced per capita in the year of 2021 alone. It is also worth mentioning that ∼56% of these fibers are made from fossil-based sources, ∼38% from renewable sources, ∼8% from recycled bottles but less than 1% are recycled from pre-consumer or post-consumer textiles and other non-bottle feedstock. Polyester clearly dominates fiber production due to its performance characteristics and cost-efficiency [73].

- **Yarning / Spinning** - converting the fibers into yarns through spinning mills [251];

- **Fabric production** - usually the biggest stage regarding production within the value chain. This is where we have the weaving, knitting and non-woven processes to produce the fabric. After those, there is dyeing, printing and finishing the fabric [21];

- **Garment production** - consists of various stages from creating the design to cutting, joining and stitching the fabric pieces. Lastly, the garment goes through the finishing, cleaning, pressing, packing and labeling processes to be ready for distribution [63, 207, 21];

- **Retailing** - final phase of the B2B operations. Here the textile companies can sell their products to local and/or global retailers who can then sell to customers.

It is worth mentioning that between these stages, the product can be present in transportation activities that ship the product between the different suppliers, operators and entities in the value chain. After every aforementioned stage, the product is in the consumer's hands and it is used/worn through its life-cycle until the consumer disposes it and thus the linear "take-make-dispose" model reaches the end.

The T&C value chain is globally distributed, with most of the initial fiber production and garment manufacturing occurring in developing countries, while consumption typically occurs in developed countries [168]. The majority of sustainability

Table 1.1: Global fiber production volumes, market share and recycled share per fiber in 2021 (adapted from [73]).

Type	Fiber	Production volume (in million tonnes)	Market share	Recycled share (per fiber)
Synthetic	Polyester	∼60.5	∼54%	∼15%
	Polyamide	∼5.9	∼5%	∼2%
	Polypropylene	-3.0	∼2.7%	∼0.2%
	Acrylics	∼1.7	∼1.5%	-
	Elastane	∼1.2	∼1.0%	∼3%
Plant	Cotton	∼24.7	∼22%	∼1%
	Other	∼6.7	∼5.9%	-
Manmade cellulosic	Viscose	∼5.8	∼5.11%	∼0.5%
	Acetate	∼0.9	∼0.84%	
	Lyocell	∼0.3	∼0.28%	
	Modal	∼0.2	∼0.17%	
	Cupro	∼0.02	∼0.01%	
Animal	Wool (sheep)	∼1.0	∼0.92%	∼6%
	Down	∼0.69	∼0.51%	∼1%
	Silk	∼0.17	∼0.15%	-
	Other	∼0.05	∼0.05%	-
Total		**∼113**	**100%**	**∼8.9%**

hotspots are concentrated in these upstream manufacturing activities due to their nature and socioeconomic context, and industry actors face the greatest difficulties in identifying, preventing, and mitigating them [238]. The shift of textile and apparel production to countries with lower labor costs has led to significant declines in, and in some cases near extinction of output in many developed countries while increasing the complexity and transparency of supply chains [117].

Every stage of the T&C value chain has a significant negative impact to the planet's environment in different areas as described in [168] and listed in table 1.2 per stage.

Considering the entirety of the T&C value chain, it can be generalized into 4 stages:

1. **Raw material** - harvest and production of the feedstock created by agricultural farms (natural fibers) and chemical manufacturers (synthetics).

   Throughout a synthetic-based garment life-cycle, energy usage and CO_2 emissions are the highest during its initial fiber production due to the raw materials originating from non-renewable sources like fossil fuels [246] (e.g., polyamide

Table 1.2: Areas of environmental impact per garment life-cycle phase.

Stages		Areas of environmental impact			
		Energy consumption	Water use	Chemical use	Waste production
Raw material		✓	✓	✓	
Transformation		✓	✓	✓	✓
Logistics		✓			✓
Consumer	Life-cycle	✓	✓		
	End of life	✓			✓

uses 160 kWh/kg of fiber during its production [160]). In the case of a cotton-based garment, this energy use can derive by production method as well like the different modes of cotton production where conventional cotton cultivation can emit 3.5 times more CO_2 than organic cotton [160]. It is worth noting that organic cotton production can offset the impact by requiring more water than the conventional variety [16].

Cotton cultivation is also a large contributor to the total water usage in the T&C value chain. 44 trillion liters of water are used annually for irrigation in textile production [180, 229] (about 3% of global irrigation) with 95% of that associated with cotton production [185].

Even though cotton itself isn't as energy intensive as synthetic fibers, it still negatively impacts the environment regarding chemical usage. The numbers suggest that 6% of global pesticide production is applied to cotton fields [178] as well as including 16% of insecticide use, 4% of herbicides, growth regulators, desiccants and defoliants, and 1% of fungicides;

2. **Transformation** - production processes of yarns, fabrics, garments and trims from fiber to finalized product.

   The bleaching, dyeing, printing and finishing phases - wet processes - of production largely contribute to the water use of the T&C value chain [168]. Not only it affects the amount of water usage but some of the toxic chemicals being used in these transformation steps are also being discharged into local groundwater that can pollute biospheres and ecosystems such as in Cambodia, as of 2008, where the fashion industry was the cause of about 60% of water pollution and 34% of chemical pollution [16].

   Regarding the latter, chemical usage is present in fabric and garment production activities like spinning and weaving activities by using lubricants, accelerators and solvents. The wet processes that use bleaches, surfactants, softeners, dyestuffs, antifoaming agents and water repellents also present in this stage can use about 500 gr of chemicals per kg of textiles to process [206]. The global impact of this extensive usage of chemicals in the transformation stage can also be seen in wildlife where fluoropolymers, a type of chemical used to waterproof textiles, was found in the bodies of polar bears and seals in remote Arctic locations [76].

It is estimated that 15-30% of fabric used in the manufacturing process is wasted [51, 197] due to the cutting phase of creating a piece of clothing as well as human mistakes in assembly [197];

3. **Logistics & retail** - transportation, distribution, storage, and retail operators to handle logistics between the participants in the value chain.

   Deadstock, a somewhat recent trend in textiles, is the greatest area of waste in the logistics & retail stage. Deadstock refers to new clothing that is unsold or returned by consumers designed as waste. In the European Union (EU) retailers, a third of all imported clothing items is not sold to customers [150]. More specifically, in the Netherlands, 21 million garments were not sold in 2015 [186]. Furthermore, H&M, a fashion brand based in Sweden, reportedly held $4.3 billion worth of deadstock garments [179] and incinerated it in a waste-to-energy plant in Denmark [221, 100], leading to more emissions and atmosphere pollution whereas a recycling approach would've had a lesser environmental impact [49]. This means that the resources the T&C value chain has put into these garments to later be unsold and/or disposed end up being wasted [166].

4. **Consumer** - garment life-cycle and end of life throughout its use by consumers;

   (a) **Life-cycle**

   During the garment's life-cycle in the consumer use phase, washing activities tend to have the most impact on the environment. Considering that up to 64% of new fabrics in clothing are made of some synthetic material [35], it is relevant to note that washing clothes releases half a million tonnes of microfibers into the ocean every year. This is the equivalent to more than 50 billion plastic bottles [237, 1]. Overall, textiles account for nearly 9% of annual microplastic losses to the ocean [237]. This has various negative economic, environmental, and societal impacts [121] and by 2050 it is estimated that there could be more plastics than fish in the ocean by weight [142].

   (b) **End of life**

   Just like in the logistics & retail stage, waste production ends up being the biggest segment in the product's end-of-life of consumer stage with nearly 60% [194] of 150 billion garments produced worldwide in 2012 [125] being disposed by consumers. The decrease in garment lifespan alongside the increase in consumption has led to an increase of landfill textile waste with more than a fifth (22%) of mixed global waste being from textiles [171]. This equates to a garbage truck of textile waste entering a landfill every second [237].

> These values of waste do not positively correspond with the low levels of textile recycling rates with only 15% of disposed textiles by consumers being recycled in 2015 and less than 1% being recycled in closed loop [1] (the rest is being recycled into lower-value applications).

Interpreting the T&C value chain as a whole, in 2015 the fashion industry used about 79 billion cubic meters of water [4] and averaged 200 tonnes of water per one tonne of produced textile product [16]. Textile dyeing is also the second largest polluter of water globally and it takes around 7500 liters of water to make a typical pair of jeans [237].

This industry uses a variety of over 15000 chemicals during its processes [196], leaching into the soil and decreasing its diversity, fertility and killing microorganisms, plants and insects in the case of agrochemicals [235].

Globally and excluding the consumer use phase, the fashion industry produces an estimated 2.9 gigatonnes (Gt) of CO_2 equivalent emissions (1.93 Gt relative to the production of synthetic fibers, textile and garment manufacturing) [168]. Overall, the T&C industry is accountable for 10% of global GreenHouse Gas (GHG) emissions [236]. These carbon footprint statistics heavily rely on the energy source (e.g., China greatly depends on coal-based energy which leads to a 40% larger carbon footprint than Europe) [203, 246]. Even if producers decide to choose natural fibers for garment production, that does not guarantee a lower carbon footprint due to the higher energy requirements for use phase activities like washing, drying and ironing in comparison with synthetic fibers [160].

Among all consumption domains in the EU, consumption of clothing, footwear and household textiles is the fourth highest pressure category for primary raw materials use and for water use, after food, housing and transport, and the fifth highest for GHG emissions. The land area used to produce the textiles consumed in Europe, mainly cotton, is exceeded only by that for food production [147].

All of these impacts increase public concern for the environment. An European Comission survey reveals that the majority of Europeans (94%) have interest in protecting the environment and promoting sustainability [48]. In this setting, actors further down the chain need to learn more about the origins of their fibers, materials, and all product parts and components, as well as how they are sourced, processed, and traded [238]. The demand growth for transparency and accountability has led to the establishment of Corporate Social Responsibility (CSR) programs and Environmental, Social, and Governance (ESG) criteria worldwide [32]. Growing awareness of the fashion industry's negative impact on people and the environment has led to considerable growth of the sustainable fashion market, but fashion brands use several mechanisms to exploit the perks of environmental branding using exaggerated, deceptive, or unsubstantiated claims of environmental benefits in order to improve their corporate image [151]. This marketing practice, known as *greenwashing*, has become an increasing issue.

1.1.1.1 *Greenwashing*

The term *greenwashing* was coined by environmentalist Jay Westerveld in 1986 and refers to the practice of making misleading claims about the environmental benefits of a brand or product. While it is not a new phenomenon, the rate of *greenwashing* has escalated in the new millennium as the demand for sustainable products increases [59].

In 2009, TerraChoice developed "the Seven Sins of *Greenwashing*", a set of practices done by brands to mislead customers with claims of promoting sustainability and positive impact on the environment [148]:

1. **Sin of Hidden Trade-off** - making environmental claims based on a very "narrow set of attributes" while disregarding other relevant aspects;
2. **Sin of No Proof** - providing no reliable evidence for their environmental claims;
3. **Sin of Vagueness** - using "poorly defined or broad" terminology to imply environmental compatibility (e.g., unregulated buzzwords);
4. **Sin of Irrelevance** - making claims that are not relevant for consumers seeking to make green purchase decisions (e.g., highlighting the absence of a harmful substance that is banned by law);
5. **Sin of Lesser of Two Evils** - making environmental claims about a product that may be true in comparison to a competing product but disregard the negative environmental impact of the product category as a whole;
6. **Sin of Fibbing** - claiming environmental benefits that are factually untrue or misleading;
7. **Sin of Worshipping False Labels** - using "fake labels" (e.g., to imply third-party certification).

These practices of *greenwashing* can be seen in the T&C sector as well. Table 1.3 exemplifies, based in [200], *greenwashing* claims done by brands to mislead customers.

There is clearly a lack of transparency that dominates the T&C industry, making brands providing consumers with claims that are not factually backed. Suppliers and industry operators can hold brands accountable for their sustainability claims as they possess key information to verify said information.

1.1.2 Social impact

Not only does the T&C value chain negatively affect the environment, as previously mentioned in subsection 1.1.1, but also impacts the social status quo, especially its workers. As *fast fashion* keeps pushing the industry to be up to speed and competitive with the rest of the market, poor employment conditions have also been increasing throughout the value chain. The textile sector often employs whole families who depend on their work as their sole source of income, making them highly vulnerable to exploitation. Workers often have no choice but to accept precarious working conditions, unfair pay and informal arrangements with little or no social protection [147]. It is estimated that almost 7% of all labor in developing countries is dedicated just to cotton and its production activities alone [253].

Table 1.3: "Seven Sins of *greenwashing*" [148] in the T&C industry (adapted from [200]).

Sin	Example
Sin of the Hidden Trade-off	A few sustainable production activities can make brands claim their product is sustainable while the remaining processes are not;
Sin of No Proof & Sin of Vagueness	No standard definition on "sustainable cotton" means that it can't be defined as a standardized material like recycled or organic cotton which is certified by the Organic Cotton Standard (OCS) and Global Organic Textile Standard (GOTS); Using buzzwords like "conscious", "ecologically grown", "ethical", "green", etc;
Sin of Irrelevance	Using credible content creators to advertise a brand to increase credibility of sustainability claims;
Sin of the Lesser of Two Evils	Promoting sales of sustainable fashion while condemning *fast fashion* brands for offering discounts;
Sin of Fibbing	Claiming that consumers save resources when purchasing sustainable products;
Sin of Worshipping False Labels	Claiming a product has 100% recycled polyamide while the item contains more than just polyamide; Product "eco-labels" identifying the garment as sustainable while in fact only the tag itself is sustainable;

Various studies indicate that a substantial portion of the labor force in the T&C value chain work informally, being paid less than the legal minimum wage and have no contracts [36, 101]. Only about 4% of what a consumer spends on clothing goes to the garment workers [220]. Consequently, these workers need to work over-long hours to grow their earnings with no guarantee of a welfare state. Child labor is also a prominent trend, especially in Asia where estimates say that, in 2018, nearly 108 million children were working in the agricultural sector, which includes cotton production [104].

Something that defines the T&C industry is the high share of female employees throughout the value chain, covering about 75% of the total workforce in textiles [69]. Most of these women hold positions at the lowest echelons of the value chain with little opportunity for advancement, in stark contrast to the highly skilled, often managerial and formal roles typically filled by men. Underperformance in gender equality and women's economic empowerment in textile supply chains has been documented both in Asia and Europe with verbal, physical, and sexual harassment cases existing in garment factories [34].

Another common aspect of the social impact in the sector is the dangerous working conditions in unsafe infrastructures, a topic that was highly exposed on April 24$^{\text{th}}$ of 2013 with the tragedy of the Rana Plaza textiles factory's collapse in Dhaka, Bangladesh, resulting in the death of 1132 employees and injuring more than 2500. Five months earlier, at least 112 workers had lost their lives in another tragic accident in the burning Tazreen Fashions factory on the outskirts of Dhaka [105]. Unfortunately, these work accidents caused by critical facility infrastructure are not uncommon in the European Economic Area (EEA) either [36].

Despite the clear ethical issues of low payment rate, lack of basic facilities, forced and child labour in the fashion industry [211], brands also conceal their poor enforcement of human rights and labor standards with *bluewashing* practices. Unlike *greenwashing*, *bluewashing* is used to refer to any misleading appeals about the social efforts or impact of a brand, product, or process [24]. A recurring use of these social appeals is in cause-related marketing, a practice of donating a portion of proceeds from sales to charitable causes [195, 45]. Brands can substitute garment discounts with other offers such as promotional gifts or donations (e.g., charity). However, this strategy ends up being beneficial if brands hold long-term commitments to charitable organizations and most of the times it is being used just to enhance corporate social image [155].

1.2 Objectives

Based on the previous section 1.1 regarding the motivation behind this dissertation, it is clear that the T&C needs a holistic approach to tackle the various problems that it currently has in regards to global environmental, social and health impacts.

Consumers, governments and many organizations are calling for change. Be that as it may, as of not long ago, it has been extremely challenging for T&C retailers to vouch with expert for the practical and moral creation upsides of their products. As a result, the industry has made increasing **transparency** a top priority. By tracing and tracking products with **traceability** through the value chain, makers and brands have the data they need to make obvious sustainability claims that consumers, governments and regulators can trust [238]. Companies are better equipped to deal with such impacts and financial, operational, and reputational risks by increasing visibility in value chains. Additionally, traceability in value chains enables businesses to combat counterfeits, safeguard cultural and industrial heritage, ensure product quality and safety, and better respond to unanticipated disruptions [238]. On the other hand, increased transparency enables consumers to make better-informed consumption decisions because they have access to more reliable information regarding product and process sustainability claims. **Eco-gamification** can be used to promote ecological behaviours to consumers for a sustainable environment within the T&C value chain. As a result, transparency and traceability have a great potential to cultivate trust among all stakeholders in the industry [238].

Traceability and transparency, which go beyond marketing and production activities, are enablers that can support **circularity** claims. As a result, they are able to support the transition away from linear economic models (take-make-dispose models) that take resources, make products, and then throw away the waste to circular economic models (the 3Rs model), which reduce the use of new resources, reuse products and parts, and recycle waste. Utilizing zero-waste design, product life extension, resource efficiency, and services for repairing and re-manufacturing are all ways to maximize the value of resources. To achieve the objectives of the circular economy, it is particularly difficult to complete the circle after the sale to the customer. This is because there isn't enough infrastructure in place to collect and process textiles that have been used up; inaccurate or missing information regarding the product's composition; inadequate life-cycle analysis data; and technical obstacles that prevent post-consumer traceability from being implemented for sufficient quantities of products to be useful [238].

At the same time, there is abundant evidence to suggest that their current capacity to carry out and direct activities in support of enhanced traceability and transparency is constrained, and that their digital skills and abilities to gather and analyze data require further development. Actions to improve traceability and transparency in the garment and footwear value chains must encompass globally dispersed actors in order to be effective, maximize scale, and increase efficiency [238]. Systems and technologies for data entry, product labeling, and performing various levels of verification of processes, products, parts, and components at all stages of the value chain are necessary for the implementation of traceability and transparency. Barriers imposed by technology raise concerns in this regard. **Distributed ledgers and Internet of Things (IoT) technologies** all present an opportunity. However, mastering these technologies may be challenging due to scalability, costs, the availability of infrastructure, and the effects on the environment. Additionally, cooperation among various players in the value chain necessitates patience and openness on the part of all parties. Numerous actors pursuing traceability, particularly non-vertically integrated businesses, brands, and Small Medium Enterprise (SME)s, are concerned about these costs [238].

Considering the aforementioned information, the main objective of this dissertation consists in developing a PoC solution that can enable transparency and circularity in the T&C value chain supported by a traceability system built with technologies that can provide it in a multi-organizational level like blockchain and IoT as well as design frameworks for promoting the circular economy to consumers such as eco-gamification.

1.3 Methodology

The methodology that was followed for the elaboration of this dissertation is Design Science Research (DSR). This research methodoly approaches the development of a solution to a previously identified problem through a building/evaluation loop [54]. It is a methodology in which design is used progressively as it is tested, through the creation of an artifact. Thus, it is possible to assess which components of the artifact are suitable for solving the problem and which are not, being able to improve the artifact until reaching an adequate solution to the problem [22].

The DSR research process involves, by definition, six activities [54, 3, 181]:

- **Problem identification and motivation** - defining the research problem. This definition will be used for the development of artifacts that help to achieve the solution. At this stage it is necessary to justify the value of the solution and its relevance to the area in question. This requires a good understanding of the state-of-the-art in the area of the problem and the importance or relevance of the solution;

- **Objectives definition** - once the problem is known and the state-of-the-art survey has been completed, the objectives for the solution should be defined. The objectives may be quantitative or qualitative. If they're quantitative, the proposed solution should be better than the existing ones. If the objectives are qualitative, the solution should describe how the new artifact supports the solution of the problem;

- **Design and development** - at this stage, the artifact(s) are designed and constructed. Conceptually, an artifact can be any designed object for whose development research contributes. They can be models, methods or new technical properties. This activity includes the artifact construction from the definition of its features and architecture, to its design and development;

- **Demonstration** - this phase demonstrates the use of the artifact to solve one or more instances of the problem. Demonstration may involve experiments, simulations, applications in case studies, etc. A valuable demonstration demands an appropriate and well-defined environment. The demonstration can serve as proof that the idea works;

- **Evaluation** - this stage verifies, by observing or measuring, whether the artifact really supports the solution to the problem. This activity involves comparing the objectives set with the results produced by the artifact in the demonstration.;

- **Communication** - finally, it is necessary to communicate and disclose the problem and its relevance, the artifacts and its usefulness and the results obtained to other researchers and professionals in the field. The papers should preferably be published in journals or conferences of the research area. The communication must take into account the intended audience.

In Fig. 1.2, the six activities are listed 3 times (top row, middle row and bottom row).

The top row of activities is relevant to the previous work done by the author, a literature review in [13] with a state-of-the-art and related work relevant to the set of technologies to be used in a B2B system for managing the T&C value chain with traceable assets and its underlying capabilities, as well as a proposed solution for it in [12]. The first two activities, *Problem identification and motivation* and *Objectives Definition*, have been previously developed, and are the focus of the "Sustainable and Circular Textile ID 4.0" PPS1 subproject of the *STVgoDigital* research project (www.stvgodigital.pt). The main objective in the PPS1 subproject is the development of a solution for traceability of environmental and social indicators of T&C products throughout all of their value chain. This should include a blockchain-based traceability platform, integrated with the business applications. And, applications for the final consumers, enabling them to consult sustainability information about product lots throughout the entire T&C value chain. The 3rd DSR activity, *Design and development*, in the current iteration, involves the design of the platform architecture and development of the smart contract for the traceability core of the system. The *Demonstration* phase (4th activity), discusses and analyses the use of the artifacts to solve one or more instances of the problem, and the *Evaluation* phase (5th activity) assesses

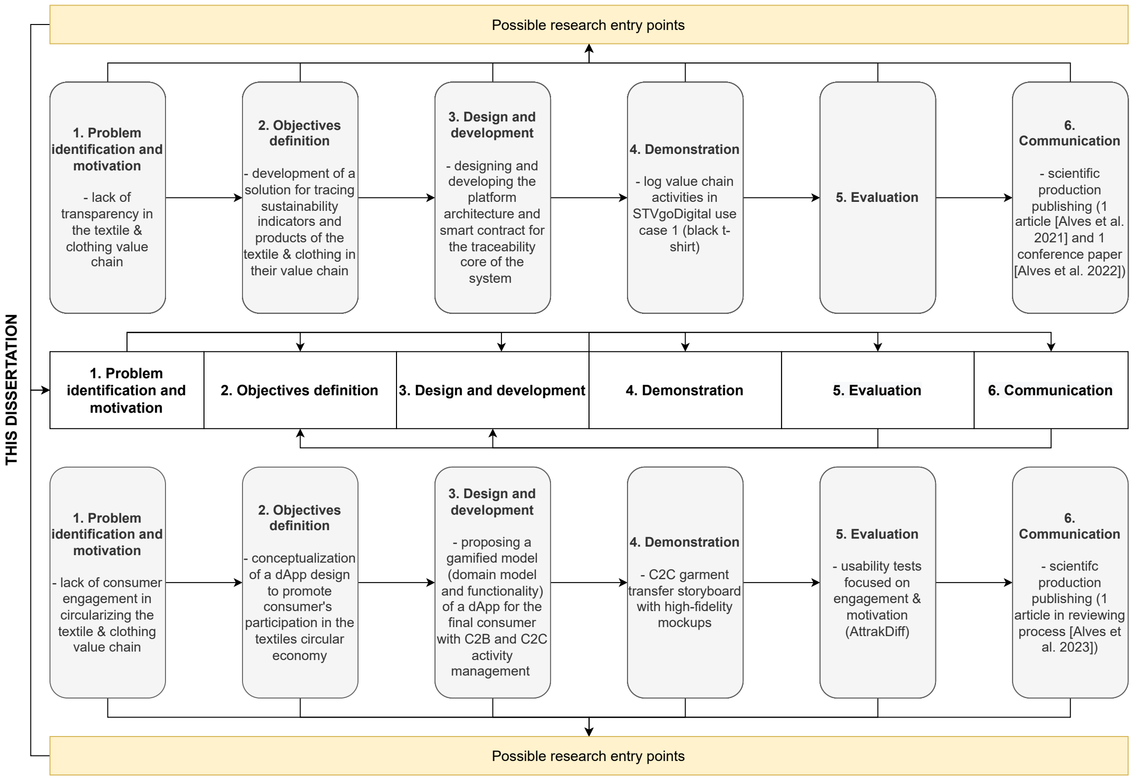

Figure 1.2: DSR methodology model of this dissertation (adapted from [181])

how well the artifacts support the solution to the problem. In the 6th and last DSR activity, the *Communication* activity, communication to management-oriented public is made, in order to trigger strategic organizational responses from the disruptions of using the created artifacts [54]. Besides the feedback from the scientific community after publishing the previous work to improve the discussion in order to enhance the artifacts in future iterations, this activity is made by communicating results to the industry members of the research project consortium, and obtaining their opinions and further artifacts' improving ideas.

The bottom row of activities is relevant to the previous work done by the author, an article in reviewing process in [13] with a literature review and related work relevant to the use of eco-gamification techniques to be used in a Business-to-Consumer (B2C) system for promoting the circular economy in the T&C value chain. Unlike the top row, the paper in [11] outlines itself by presenting all the activities in the DSR methodology schema even though it was not used at the time for developing the mentioned scientific production. As results, the paper presents a Business-to-Business-to-Consumer-to-Consumer (B2B2C2C) circular business process model for the T&C value chain, and proposes the gamified model (domain model and functionality) of a DApp for the final consumer that allows them to register the Consumer-to-Business (C2B) and Consumer-to-Consumer (C2C) activities, from the circular value chain's business process model, and benefit from a game-like experience.

The middle row represents the current document's research methodology DSR structure. It is possible to take various research entry points from both artifacts (top row and bottom row) to complement the dissertation throughout its development.

1.4 Dissertation outline

To outline the structure of this dissertation, the following bulleted list details the dissertation's 7 chapters:

- **Chapter 1** - is the current chapter, outlining the **motivation** behind the development of the document and its artifacts. It also contains information regarding the **objectives and research methodology (DSR)** used for this dissertation;
- **Chapter 2** - provides the needed key concepts to understand the work, as well as explanations about the existing tools and projects regarding multiple topics addressed like the **T&C value chain, circular economy, value chain traceability, blockchain, IoT and gamification**;
- **Chapter 3** - provides a study of the state-of-the-art and literature review on what has been done in the scientific community to tackle the issues stated in the current Introduction chapter related to the technologies and methods mentioned in chapter 2;
- **Chapter 4** - proposes a **PoC B2B T&C value chain management smart contract with traceability** capabilities as 1 out of 2 artifacts developed for this dissertation to create a solution for the lack of transparency in the T&C value chain;
- **Chapter 5** - proposes a **circular B2C2C eco-gamified consumer DApp for the T&C value chain** as the 2nd artifact developed for this dissertation, providing a gamified data model to promote circularity to consumer and its engagement in closing the loop in the T&C value chain;
- **Chapter 6** - features a system demonstration, unitary tests and usability tests for the aforementioned artifacts in respective order to evaluate both systems and verify the validity of both based on the gathered requirements;
- **Chapter 7** - sums up this document, consisting of an overview of the work done in the dissertation, providing an answer to the previously defined problems, and following it up with possibilities of future work in this area.

After the bibliographic references, the document presents an appendix list, consisting of a single Appendix A to provide mockup simulation links for the eco-gamified consumer DApp defined in chapter 5.

Chapter 2

Theoretical background

The current chapter provides key background concepts for a better understanding of the subject at matter. It is worth noting that the research presented below is the result of published scientific production by the author in [13] and an article in reviewing process in [11]. The work done in [13, 12] provides literature review regarding the T&C value chain in section 2.1, circular economy in section 2.2, value chain traceability in section 2.3, adequate technologies for circularizing the T&C value chain like blockchain in section 2.4 and IoT in section 2.5. The article in reviewing process [11] contains the literature review regarding gamification and its frameworks in section 2.6 and subsection 2.6.2 respectively.

2.1 The textile and clothing value chain

The value chain of the T&C industry has gone global (global value chain) and, nowadays, from the production stages to the final consumer, it involves a lot of different companies, from different countries. This value chain, or different value chains, may involve the participation of industries in the areas of fibers and filaments, textiles (which includes processes of spinning, weaving, knitting, fabrics, processing), clothing (clothing, home line and technicians) and other suppliers (e.g., chemical inputs, machinery and equipment). Each of these industries can operate in different countries and continents, so it also involves distribution, transportation and storage companies.

The T&C sector includes the manufacturing of shirts, underwear, dresses, suits and other fashion and clothing items, curtains, towels, bed linen, and other home and furnishing items, and ropes and nettings, parachutes, medical textiles, and other industrial and technical textiles. These manufacturing processes involve many companies in different locations, with some of them producing final products to the end consumer, but with most of these companies producing some kind of intermediate product, such as fibers, yarns, woven or knitted fabrics, dyed or printed fabrics, etc.

The manufacturing of these products, and of the fibers (e.g., cotton, wool) that they are made of, consume great amounts of land, water, energy, chemicals and fossil fuels. The environmental impact of the industry appears throughout the life cycle of a textile product [112]. This sector is a major contributor to climate change, given its energy use and waste production and management. A sustainable approach is necessary for a textile system that would minimize the environmental and social impacts brought upon the planet while respecting its carrying capacity.

It is important to know the environmental impact of the value chains and find a way to measure it [159]. Therefore, it is necessary to know and store information about each one of the steps in the value chain, allowing traceability, enabling the final consumer to be informed and assess whether or not to buy the garment.

2.2 Circular economy in the T&C value chain

Circular economy (or circularity) is a business model that heavily contributes to the transformation of industry for a more climate-neutral and planet-sustainable approach, delivering substantial material savings throughout the value chains and production processes, generating extra value and unlocking economic opportunities [129, 126]. It is a restorative and regenerative industrial system designed to minimize waste production and maximize resource efficiency and ecological sustainability where the value of products, materials and resources is maintained in the economy for as long as possible [82]

The circular mindset's focus is on decoupling economic growth from resource consumption operating at a micro and macro level. To accomplish this, alternatives to the take-make-dispose model must be found to replace the different aforementioned levels: products, companies, and consumers at a micro level; cities, regions, nations and beyond at a macro level [126].

Unlike the linear economy model (model of production and consumption) that has been used during the 20th century, a circular economy represents its opposite. While industries in the linear model harvest and extract materials for manufacturing products for consumers to buy, use and discard, the circular approach switches the "end-of-life" idea with restoration and recycling, together with the use of renewable energy and other actions to promote a self-sustainable functioning [143].

The T&C industry's current linear economy / take-make-dispose model is the root cause of the industry's environmental problems and economic value loss, making it one of the most polluting and resource-intensive production and consumption systems, especially in the production and use phase [147]. It has substantial limits and does not appear to be able to attain the sustainable development goals that now dominate the agenda of policy-makers at a global level. Increasing attention is therefore placed on the development of policies that allow a transition to a circular economy model [112]. A more circular and sustainable textile system could contribute to the achievement of both EU and global goals. In the EU, it would contribute to economic growth and job creation, as well as to meeting the aims of the circular economy and a number of climate, environmental and waste targets [147].

2.3 Supply/Value chain traceability and transparency

Traceability, as per ISO9001:2015 [106], is understood as "the ability to trace the history, application or location of an object" in a value chain. In the textile context, it can be defined as the ability to "identify and trace the history, application, location and distribution of products, parts and materials to ensure the reliability of sustainability claims in the areas of human rights, labour (including health and safety), the environment and anti-corruption" [170] and "the process by which enterprises track materials and products and the conditions in which they were produced through the supply chain" [172].

Traceability is an essential requirement for creating transparency. It makes it possible to determine the locations of assets as they move through a value chain. Consequently, all of the assets that were used to create a final product can be identified, along with their origin, characteristics, and processing and transformation methods [238].

Regarding transparency, companies must be aware of what is occurring upstream in the value chain and communicate this information to internal and external stakeholders in order to be transparent. This knowledge includes the place, who made the product, how, with what materials, and when it was made. In fact, a growing number of consumers are demanding transparency in the value chain of the products they purchase and are willing to pay more for brands that provide this information [23]. The surrounding ecosystem includes supporting policies, norms and standards, incentives, promotion, capacity building, and collaborative initiatives. A traceability system, together with its surrounding ecosystem, forms a traceability framework [238].

Traceability systems can support claims about the characteristics of a product, a process, or an organization by collecting data to validate these claims (e.g., sustainability indicators and/or scores) based upon defined verification criteria. To do this, a system needs to [238]:

- Identify the claim(s) and the related verification criteria which will define the traceability information to be collected, exchanged and verified;
- Identify the traceable assets for supporting the claim – which could range from raw materials to final products;
- Select the most appropriate traceability models for organizing the value chain's processes;
- Track/identify traceable assets when they are transported in logistics units;
- Consider the needs of post-consumption processes when identifying verification criteria;
- Mark/tag each traceable asset and logistics unit with a unique Identifier (ID);
- Record and link these IDs to information that will support the verification criteria;
- Identify the events where data must be collected as the traceable assets move between the entry and exit points for traceability in the value chain;
- Have a verification process, preferably carried out by third parties, which verifies that the data collected are accurate, aligned with the verification criteria and support the claims.

Sustainability claims are high-level statements about the characteristics and specifications of a product, process or organization associated with that product that cover multiple sustainability dimensions (environmental, social, economical, etc.) [238]. These claims can be condensed to take form as a sustainability indicator or score that can summarize how sustainable the product is compared to others in its class (e.g., A to F as shown in Fig. 2.1). This is only possible through Life-Cycle Assessment (LCA) processes that track the indicators and resources used to manage the traceable assets - individually, in batches, or in trade units - that need to be tracked along the value chain. Calculating the impact can involve many different data and criteria. On one hand, factors that influence the environment throughout a product's life-cycle, and on the other hand any additional pluses and minuses, for example, sustainability labels that have been awarded. Traceable assets frequently undergo transformations in the T&C value chains (for instance, from cotton to yarn to fabric). Along their route, they can also be aggregated and/or disaggregated into trade or logistical units. Through a "chain" of unique IDs, traceability is maintained from the farm to the finished product. For instance, each transformation process's output ought to be given a unique ID that is linked to the IDs of its inputs. Therefore, unique IDs are essential for tracing an asset's progress through the value chain [238].

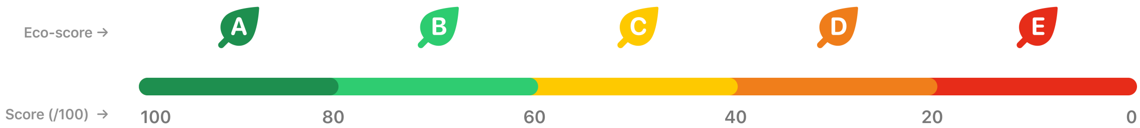

Figure 2.1: Eco-score rating explained (from [175])

When visualizing the traceability of a traceable asset, a common practice is using tree layout visualization as the product intended to trace is represented by the root of the tree. Tree visualization of traceability data of the T&C value chain can be quite extensive as the value chain is long and complex as previously mentioned. Hence, one of the tree-based visualization diagrams that fits these requirements of complexity is the Depth-Of-Interest (DOI) tree layout. As shown in Fig. 2.2, DOI tree layouts are a type of space-constrained, multi-focal tree layout. With a similar structure to a operating system folder, it sorts out "uninteresting" nodes block by block until all of the blocks on a level fit within the bounds, making an effort to position child blocks underneath parents [38]. This type of visualization is useful due to scale constraints by the tree breadth growing exponentially, running out of space even with a tidier layout.

Traceability mechanisms allow insights upon product items or lots through connecting data that was previously siloed. When we allocate a digital identity to materials at various levels of granularity (batch, single item, etc.), and follow it through a value chain, we are able to capture information from primary production all the way through to its ultimate use and to its disposal or re-use in the future. As described in [19, 131, 55], this brings advantages in:

- **Sustainability** - by gathering sustainability credentials and allowing primary stakeholders the opportunity to assess and report on their appointed suppliers' approach to social and environmental sustainability factors.

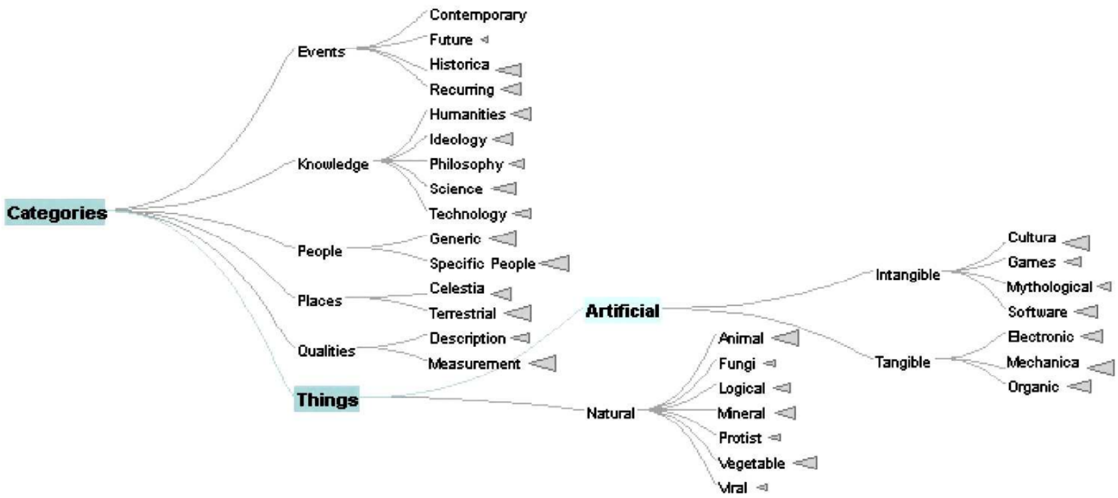

Figure 2.2: DOI tree visualization layout example

- **Efficiency** - by having a decentralized trusted platform, such as a blockchain, that can use smart contracts to track and automate transactions without the need for a centralized authority (more in section 2.4).
- **Engagement** - environmental-social responsibility is a big factor nowadays, regarding consumer etiquette, and having a transparent product-consumer connection between the company and its clients allows the consumers to have a more favorable opinion towards the product and brand itself.
- **Safety** - in case there is a threat to public health (e.g., the use of toxic paint), it allows a quick and effective recall of all the products involved, because the products involved are easily located.

In [83], the authors analyzed different supply chain risks, including the T&C value chain, and mentioned the importance of traceability to identify and eliminate potential sustainability-related risks. Product authentication emerged as the second most influential factor towards traceability, owing to the issue of counterfeit products that make brands suffer huge economic losses. The authors also mentioned that the current solutions of Radio Frequency IDentification (RFID) tags are difficult to apply in a production system for traceability purposes because they're very hard to produce in a large quantity due to high costs and advanced programming. On the other hand, we have barcode and 2D codes that are easy to reproduce but are also very easy to counterfeit or copy. A summary of a traceability implementation solution for the T&C supply chain is presented in [5].

2.3.1 Digital twin

The idea behind the digital twin (or digital passport) is to create a virtual replica, completely faithful to a physical object, so that this digital model can provide all important data and in all perspectives on the use of the product.

As shown in Fig. 2.3, while the physical product is going through the T&C supply chain in its life cycle, the different phases and processes on which it goes through should be recorded accordingly on a data system. Therefore, a digital twin profile of the physical product is created to efficiently track and trace the desired asset alongside its basic information such as product identification, product name, sustainability scores, etc. [102].

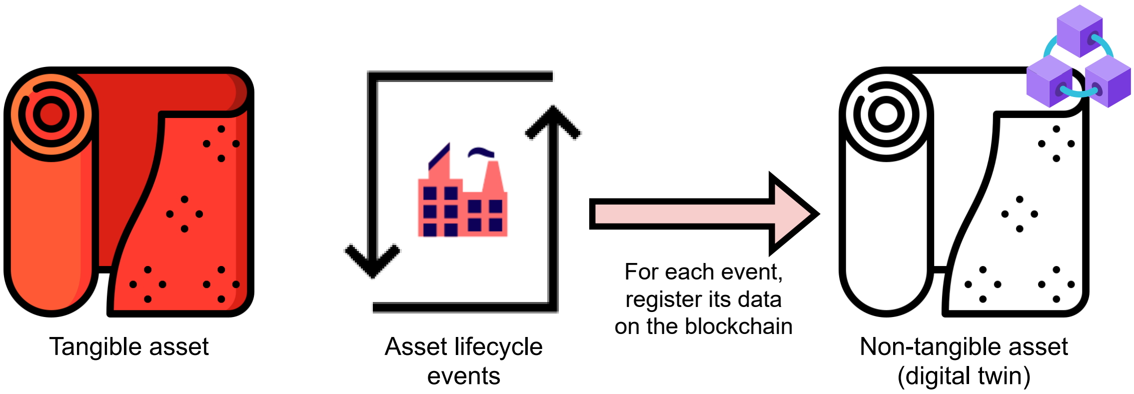

Figure 2.3: Digital twin representation with T&C value chain assets

To accurately link the tangible and digital realm, according to [225], IoT technology can help collect data at any product stage with devices that can ensure seamless tracking and reveal an asset's full story. When paired with blockchain technology, this information becomes immutable, private, and transparent, when it comes to data sharing as well as asset-token digitization, by providing token ownership that would act as a digital watermark, correspondent to physical ownership [124, 111]. So, every time an event (transaction) happens to a specific product, its life cycle data can be captured by the use IoT devices and properly managed with the use of blockchain technology. The digital twin plays an important role in the implementation of the circular economy and in the traceability of a product.

2.3.2 Closing the loop: circularizing the T&C value chain

In this section, a new generic integrated business process model is proposed to represent the circular economy of the T&C industry. The business process model, represented in Fig. 2.4, is using Business Process Model and Notation (BPMN) language mostly because it is a standard and a language easy to understand by everyone involved in the project. The presented business process model abstracts all activities and companies involved in the value chain.

As stated earlier, the fashion and textile supply chain from production to the final consumer can involve a lot of different companies and, in most cases, based in different countries. Each country has its own culture, traditions and laws. As a consequence, what is legally and socially well accepted in one country may not be in another. That is why the final consumer, and each participant in the value chain, must have access to all the information about what goes on at each stage of the process, in order to be able to evaluate according to their own standards.

In the T&C supply chain there are, typically, four main types of participants involved, which are: Producers, Industry, Logistic companies and Retailers. Each one

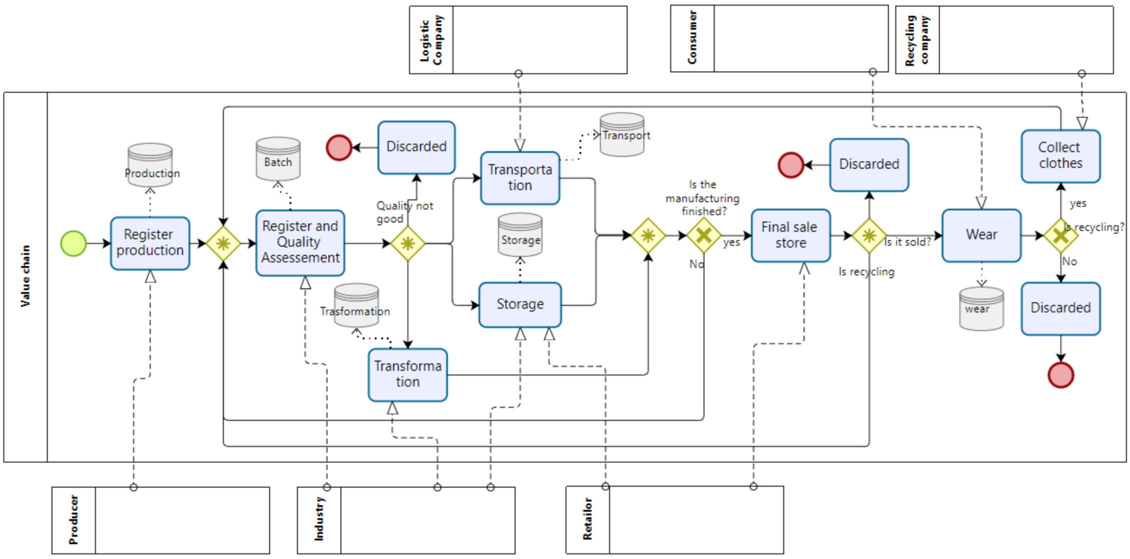

Figure 2.4: Generic integrated circular business model for the T&C value chain

of these participants is represented as external participant in the business process model in Fig. 2.4.

- The **"Producer"** external participant, represents the producer/farmer of any type of fiber. There are several types of fibers from various sources. Natural fibers of agricultural origin such as cotton, wool, silk, linen, etc. Fibers of mineral origin as asbestos. Synthetic fibers of petrochemical origin such as polyester, nylon, etc.
- The **"Industry"** external participant, represents any type of transformation industry, like industries for spinning, weaving, knitting, warping, sewing, dyeing, etc.
- The **"Logistic company"** external participant, represents any type of storage and/or transportation company (it may involve boats, trains, trucks, airplanes or others).
- The **"Retailer"** external participant, represents any type of retailer, such as a seller of a final piece (for example a t-shirt) or it can represent the seller of an intermediate item, such as fabric.

Each participant must provide information about their participation in the value chain and must provide all the detailed information of all necessary indicators about the performed activities (production, transformation, transportation, storage, etc.).

As mentioned before, for the T&C value chain to become more environmentally friendly, avoiding waste, reducing water consumption, etc., its business model needs to be circularized, by closing the loop of the currently linear model. For this to happen, the final consumer has a crucial role, by adhering to the circular economy. In order to portray the circular economy of T&C, it becomes necessary to represent, in the business model, the final consumer and also a new player that is the recycling company. Both are represented as external participants in Fig. 2.4.

- The **"Consumer"** external participant represents the final consumer, which becomes part of the value chain when recycling the clothes instead of discarding them.
- The **"Recycling company"** external participant represents a company responsible for collecting T&C items for recycling, making them reenter in the value chain and closing the loop.

New types of industries may emerge in the value chain, for example companies that actually recycle items, but they are already represented by the **"Industry"** external participant.

The business process model in Fig. 2.4 represents the main value chain activities at a high abstraction level. Each of these activities may represent a sub-process, meaning that the activity may be further decomposed in other activities (tasks) being executed internally to the company responsible for executing the sub-process activity.

Usually, the value chain starts with the production of fiber, represented in the first activity of the process (activity "Register production" in Fig. 2.4). The production information must be stored. These fibers will undergo various transformations (spinning, weaving, warping, sewing, etc.) and can be transported and stored several times throughout the value chain process, as represented in Fig. 2.4. Each transformation can be done in a specific company, requiring transportation and probably storing between each activity. However, some companies can perform several transformations in the same facilities. As represented in Fig. 2.4, usually, after executing one of these activities, the product quality is checked and if it is not acceptable, the product is discarded (or re-entering in the cycle contributing to the circular economy).

Some of these activities give rise to new products (for example, yarn gives rise to fabric) and a new product batch is registered. After the internal manufacturing cycle is finished, the final piece will be sold to the final consumer to wear. According to [168], about 30% of the clothes are never sold. These clothes are usually burned, but instead, these clothes can be recycled, re-entering in the cycle, contributing this way to close the loop.

After wearing a garment, preferably many times, the end consumer is responsible for making the garment re-enter the cycle, by choosing to recycle (decision represented by the last gateway in Fig. 2.4). The item to be recycled will then be collected and selected to be transformed to new raw material for new items of clothing. This way, among other advantages, waste is avoided and water consumption in the cultivation of new fibers is reduced, and the environment is preserved.

2.4 Blockchain and distributed ledgers

When it comes to the implementation of traceability systems, especially in a circular economy model, blockchain is one of the best technologies that can tackle the various challenges that are posed in the T&C value chain in a B2B domain [6]. This Distributed Ledger Technology (DLT) is getting increasing attention as a secure data management solution. Ever since the introduction of Bitcoin in 2008 [162], the science behind blockchain has been applied to different commercial scenarios, including value & supply-chain cases [193, 40, 230].

The same way a typical ledger records transactions in a double-entry book, in a blockchain the ledger, which is shared between the authorized nodes, records transactions between the nodes. This ledger is permanently shared among the nodes, making it a distributed ledger [88].

A ledger is just a book where transactions between two entities are recorded. We can consider it as a "database" of transactions. Therefore, distributed ledgers are ledgers that are shared and synchronized in a consensual way by the nodes of a network. These nodes can represent people, entities, organizations, and so on. A node that is part of the network can access the ledger records and has an exact same copy of the ledger in its node. Any changes made to the ledger are copied to all nodes in a matter of minutes or seconds [88].

The blockchain itself is just one of several ways to implement distributed ledgers, where in this case records are stored in blocks and are structured in a sequentially encrypted linked list. There are various models of distributed ledgers besides blockchains such the Hashgraph and the Tangle which use Directed Acyclic Graph (DAG)s to store their data, as well as Sidechains which similarly to blockchains store data in a list of linked lists [68].

Blockchain technology is a subset of DLT and thus, by definition, a blockchain is considered to be a distributed database that allows its participants (blockchain nodes) to store and share information in the form of blocks in real time and in a secure manner [133, 78, 247]. Each of these blocks has a link to the previous block, hence the “chain”. In other words, blockchain is an open ledger that captures the transactions between two or more parties in a permanent and verifiable way [137].

The following subsections provide detailed information about blockchain technology regarding its operation in subsection 2.4.1, consensus mechanisms in subsection 2.4.3, membership type 2.4.2, smart contracts in subsection 2.4.4 and lastly a review on Hyperledger Fabric distributed ledger in subsection 2.4.5

2.4.1 Blockchain operation

2.4.1.1 Transaction

The basic operation of a blockchain can be summarized to the concept of transaction. A transaction is typically just the exchange of goods or services, whether monetary or not. In the case of the pioneer Bitcoin blockchain, it is a monetary transaction where a value is sent from one address to another by "digitally signing a hash of the previous transaction and the public key of the next owner and adding these to the end of the coin", coin meaning transaction (Tx) data in this context [162]. But, there are many cases of applicability where the transactions do not involve anything financial such as contract records, sensor data records, and others [137]. Within database systems, including most blockchains, a transaction corresponds to a persisted modification of data as the result of an operation. In a traceability system, a transaction may be seen as a standard template to record product life cycle data of digital twins. In a blockchain, these types of transaction are handled through smart contracts (more in subsection 2.4.4).

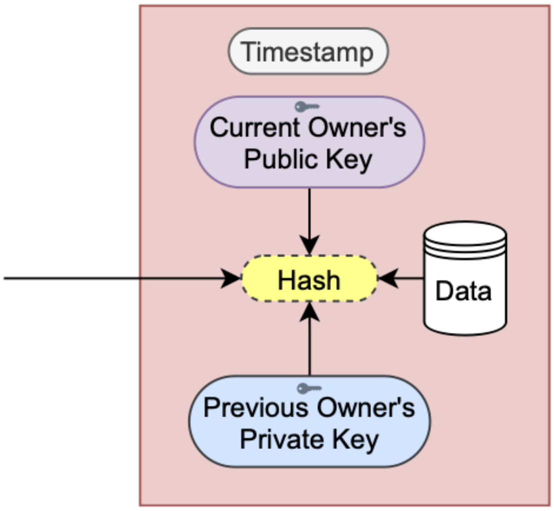

Figure 2.5: Transaction structure (adapted from [102])

As shown in Fig. 2.5, a blockchain transaction typically involves an asset's data and it is the basic component of data management, comprising [102]:

1. The asset's data;
2. The Public Key (PK) of the asset's current owner;
3. The private/Secret Key (SK) of the asset's previous owner;
4. The transaction timestamp, marking its date & time of creation.

2.4.1.2 Digital signatures and hashes

One way to ensure authenticity in the identification of participants when they make transactions is to use hashing functions and digital signatures. Unlike physical signatures on paper, in which the signature is the same for all documents and easily copied, a digital signature changes depending on the document we want to sign, thus guaranteeing the authenticity of the person signing it. A digital signature is a method of authentication that allows the sender of a message to attach a unique code that acts as a signature. These signatures use Public Key Infrastructure (PKI)s: each participant has 2 keys, 1 PK to identify that participant and verify signatures and 1 SK that should not be shared and is used to sign transactions [118]. Fig 2.6 presents a simplified flow diagram of the functioning behind a digital signature and its verification.

Typically, the signature is created by encrypting the message with the sender's SK and taking the message's hash. Using the recipient's PK, the plain message, the message signature, and the sender's PK are combined to create an encrypted and signed message. After the signed and encrypted message has been unpacked by the recipient, the same hashing function is used to compute the message digest, which is then compared to the decrypted signature. The message's authenticity and origin are

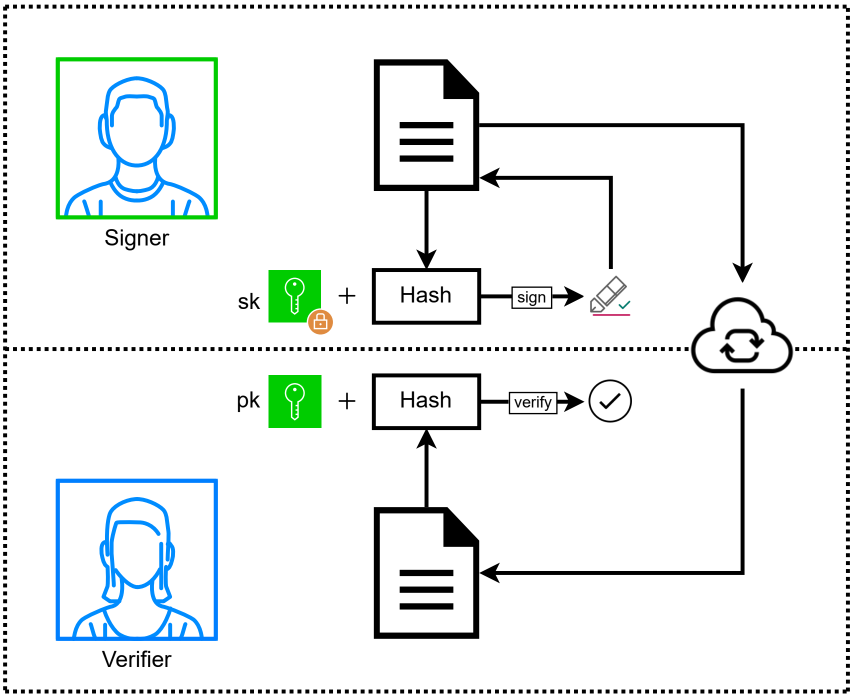

Figure 2.6: Functioning of a digital signature (adapted from [118])

guaranteed by the signature [118]. Applying this to transactions, to change an asset's ownership, the current owner creates a digital signature by signing the latest transaction hash with their SK as well as the new owner's PK. If there are needed changes to the asset's information while maintaining its ownership, the resulting transaction will have the same public and secret key but a different asset data and timestamp.

Today, digital signatures are created through algorithms like the Rivest–Shamir–Adleman (RSA) algorithm [115] or elliptic curve algorithms, like Elliptic Curve Digital Signature Algorithm (ECDSA) [114][33]. Digital signatures alone can justify authenticity claims due to the inclusion of hashing functions.

The data to be traded between addresses/participants is encrypted with hashing functions that are mathematical algorithms that transcribe variable data into a binary block with a fixed size, also called the "hash" or "digest" [154]. This makes these types of algorithms practically a one-sided function that is not feasible to invert, as the slightest change to the function's input is enough to change the resulting output through an avalanche effect on the bits as shown in Fig. 2.7, where we have several very similar inputs with small changes of 1 or 2 characters resulting in completely unrelated digests.

In the case of the Bitcoin blockchain, the hashing function is the Secure Hashing Algorithm (SHA)-256 algorithm where the output that results from this function is a 256 bit hash. This value amounts to:

- **1157920892373161954235709850086879078532699846656...**
  ...40564039457584007913129639936 combinations in a 2^{256} value.

Taking this into account, it is safe to conclude that it is unlikely to reverse these types of algorithms. Relatively to the signatures of the aforementioned transactions,

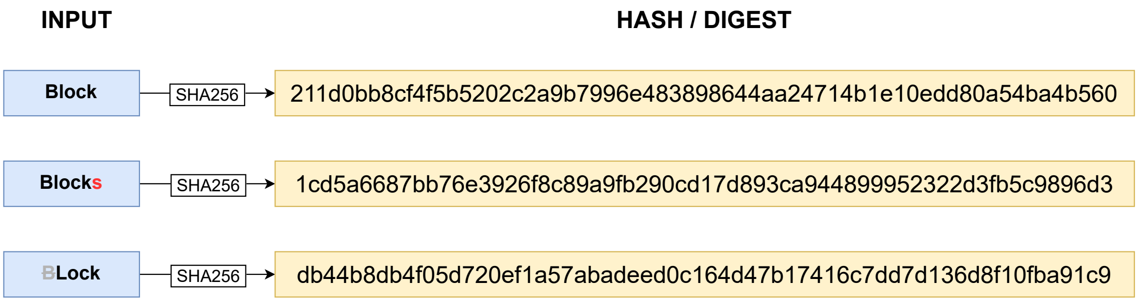

Figure 2.7: SHA256 input-digest examples

it means that the participants of the network can be sure, that the verification of the transaction, using its content together with the signature and the public key of the person who issued it, is legitimate and trustworthy [17].

2.4.1.3 Block and blockchain structure

A block consists in a set of transactions, as shown in Fig. 2.9. A block is composed of a block header and a block body. The header data consists of the following attributes [245, 102]:

1. **Block version**, indicates the set of validation rules to follow for that specific block;

2. **Root Hash**, represents the 256-bit hash value of the Merkle Tree root of transactions;

3. **Prev Hash**, is the Root Hash of the previous block in the chain;

4. A **Timestamp** value, corresponding to the date and time of the block creation;

5. The **nBits** field, which is a difficulty parameter / hashing target in a compact format;

6. **Nonce**, stands for "number only used once," which is a random number associated with the "Prev Hash", "Timestamp" and "Root Hash", used to solve a mathematical puzzle for creating blocks.

The block body contains information regarding the transactions, specifically a transaction counter and the remaining Merkle Tree components. A Merkle Tree is usually a binary tree where its nodes are acyclically connected, directly or indirectly. As can be seen in Fig. 2.8, the tree's structure can be hierarchically classified into "Root", "Internal Nodes" and "Leaves". Since the "Root" hash is located in the block header the rest of the nodes, which contain the hash pointer data to their children, are present in the block body [245, 33, 18].

The leaf nodes have data regarding the valid transactions within the network and do not have predecessor nodes, since their creation is inherently based on whether there are new transactions or not. The internal nodes, however, are the result of a hash function concatenating its two parent nodes and its single child node is used

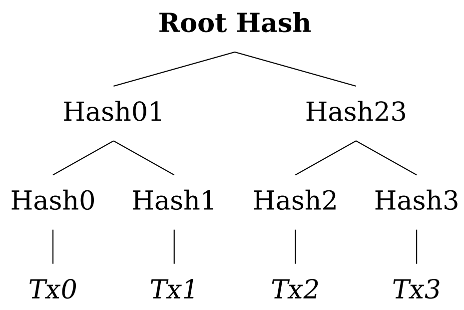

Figure 2.8: Merkle (binary) hash tree topology

in the following hashing, iterating through the internal nodes successively until the root hash/node that has two predecessors and no children [33]. This method allows for data storage efficiency because there's no need to store the entire block's data to maintain data integrity and blockchain validation so, when the transactions are buried under enough blocks, the interior branches do not need to be stored [162]. The maximum number of transactions that a block can store is dependent on the block size and the transaction size as well [245].

By including the "Root Hash" of the previous block in the header of a block, the blockchain is implemented in a linked list structure which provides the chain architecture formed between the blocks. The first block of a blockchain is called the "Genesis Block" and it doesn't have the "Prev Hash" attribute since there's no previous block to the first one.

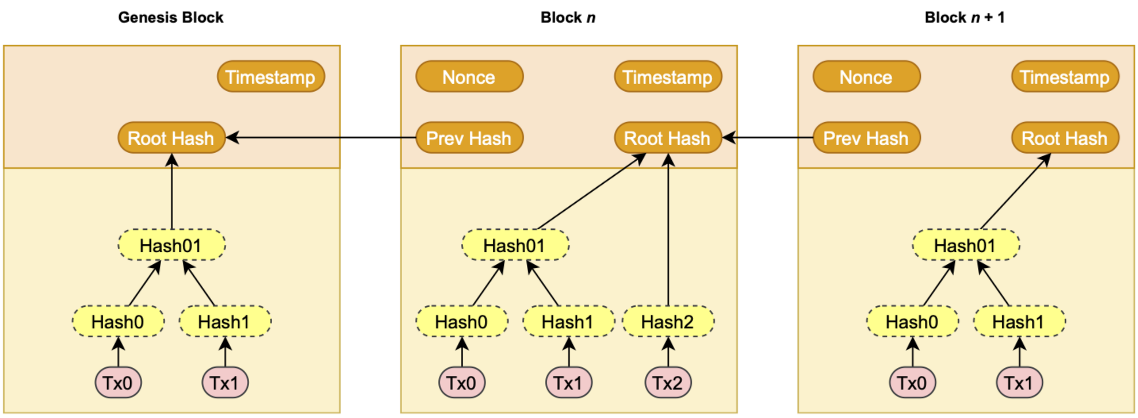

Figure 2.9: Blockchain structure (adapted from [162])

2.4.1.4 Peer-to-Peer (P2P) network

In P2P networks, a group of nodes communicate directly with one another. Each node has similar capacities and responsibilities, unlike the conventional client-server model, in which the clients and servers are separated. In a P2P topology, each node/peer acts as both a server and a client [113]. Both client-server and P2P network models can be depicted in Fig. 2.10

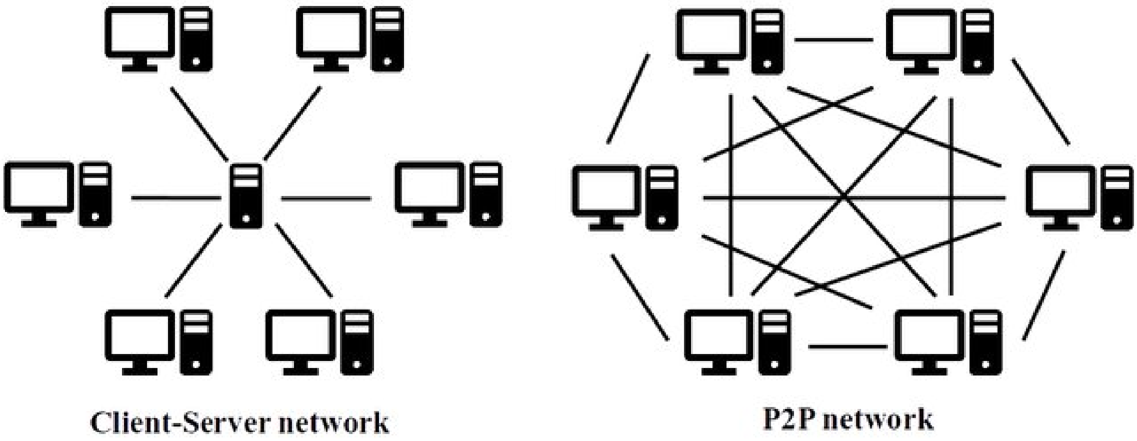

Figure 2.10: Client-server & P2P network topologies (from [113])

There is no centralized server in Bitcoin's architecture. To support the system, a distributed strategy has been taken instead. Many aspects of the system make use of the distributed approach, the most important of which are: data transmission, data confirmation, and data storage [64]. The nodes first validate a transaction before it is entered into the P2P network. The decision is written down in a block if the nodes agree that the transaction is legitimate. This new block is locked because it joins the previous block chain. The most recent block thus maintains a consensus-based view of the blockchain's current state [173].

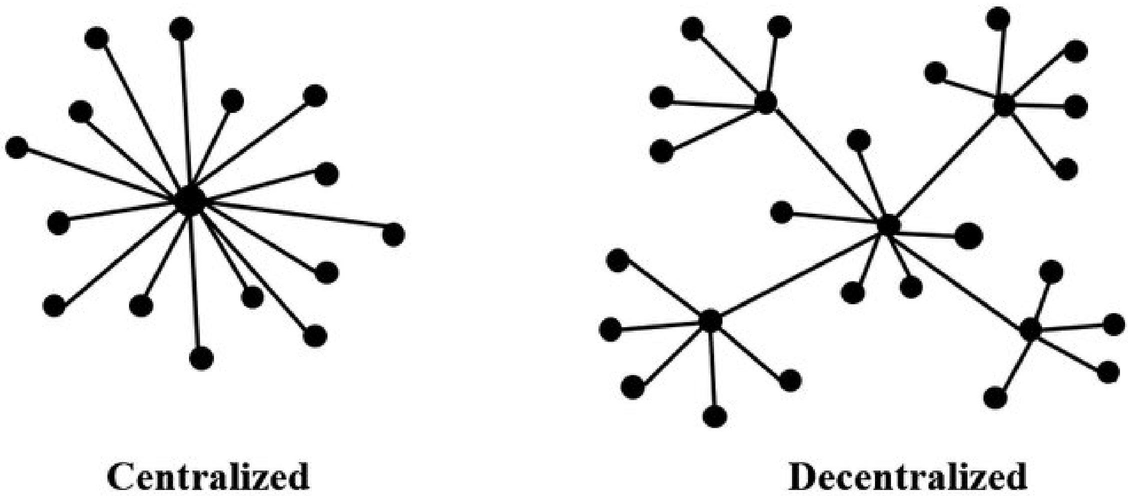

Figure 2.11: Differences in centralized and decentralized networks (from [113])

In a blockchain distributed ledger there is no central authority to effectively make sure that the nodes' ledgers are equal throughout the network, making the network decentralized as shown in Fig. 2.11. To tackle this issue, transactions can be verified and committed to the ledger through a consensus protocol, ensuring ledger consistency throughout all nodes in a blockchain [245, 90].

2.4.2 Membership

Blockchains can have different properties, depending on the defined membership properties of how the nodes access it [90, 6]:

- **Public blockchains** are open, where anyone can join and participate in it. These types of blockchain are truly decentralized in the sense that no particular node controls the whole or part of a network [33];
- **Consortium blockchains**' nodes have permissioned authority and are usually seen in partially decentralized B2B scenarios, where data can be public or restricted [137];
- **Private blockchains**, put in place restrictions on participants' roles, and the nodes require adequate permission to join and perform transactions.

The more nodes a network has, the more decentralized it is, and the higher is its guarantee of immutability. However, a high number of nodes will decrease the network's efficiency for consensus [245]. Blockchains are also categorized by their consensus process type which can be permissionless or permissioned. Public blockchains are open for anyone to join so they are permissionless. Any blockchain that has any node participation restriction falls under the permissioned type [137, 133].

A different aspect of blockchain criteria is its availability for reading purposes, where blockchains can be categorized as open or closed. When combined with the consensus process type, a blockchain can have a more flexible access control - [public, consortium, private] and [open, closed] [33]. Considering the necessities of the system, a closed consortium blockchain is the ideal format for the B2B smart contract solution.

2.4.3 Consensus mechanisms

Consensus mechanisms guarantee that all blockchain nodes have to agree in the same transactions' block, and can make sure that the latest block was correctly added to the chain, ensuring that the data stored by a node is the same for every node [137].

For public blockchains, like Bitcoin, the Proof-of-Work (PoW) consensus mechanism is used and it makes the Bitcoin blockchain highly secured from attacks. PoW allows the miners (pool of processing nodes) to compete with each other to find the correct hash of the new block and earn a reward, in the form of bitcoins, by calculating the "Nonce". As the difficulty of the block ("nBits") increases, the harder it is to solve the "Nonce" problem [6].

There are several other consensus algorithms/ mechanisms optimized for different blockchain types, for energy saving, and to tackle future concerns, like quantum computing. Some of the most popular ones used in several blockchain projects include the Proof-of-Stake (PoS), Proof-of-Elapsed Time (PoET), Proof-of-Authority (PoA) and Byzantine Fault Tolerant (BFT) [245].

2.4.4 Smart Contracts

Assuming that the consensus protocol is secure, a blockchain can be thought of as a decentralized conceptual party that can be trusted for correctness and availability, but not for privacy [130]. Smart contracts, as firstly defined by Nick Szabo [222], are computerized transaction protocols that execute the terms of a contract "that control users' digital assets, formulating the participants' rights and obligations" [137]. It can be seen as a complex if-then statement that is executed if and only if a set of conditions is met [88]. They are programmable logic and/or rules with strict implementation conditions that define a data structure and its operations, just like classes in an object-oriented context [6, 250], and are stored in the blockchain, where they're automatically executed alongside transactions without human intervention, bringing convenience among participant corporations [90, 124, 245]. When a smart contract is deployed on a blockchain network, it cannot be changed unless a future majority approval of changes and it will always execute by the defined rules [247].

In sum, blockchain improves data tracing and reconciliation, reliable up-to-date data in real time, access to the same data by multiple stakeholders, thereby providing everyone with the same "truth" and increased faith in the data's reliability [238]. With the use of blockchain it is possible to guarantee the same "truth" for every participant, but the information the consortium of operators decide to believe as true needs to be trustworthy when entering the system and that's where IoT technologies can contribute to the solution. Blockchain provides the technological foundation needed to both transparently track ecological data and incentivize shifts in land use toward more regenerative practices. It is also an apt technology for encouraging collaboration amongst diverse stakeholders, who ultimately have shared aims but may not otherwise be so inclined to cooperate [28].

The adoption of blockchain would be useful, as it provides compliance, transparency, tracking, tracing, error reduction, payment processing, and many others advantages [226]. A blockchain-based system is capable of safely recording important data about operations along the entire value chain inter-organizational process. Blockchain technology provides transparency, traceability and security to transactions, real-time data and smart contracts to suit the needs of its users [163] and may integrate with other areas, such as Big Data, Artificial Intelligence (AI), IoT, cloud computing, and more.

However, for enterprise use, we need to consider the following requirements:

1. Participants must be identified/identifiable;
2. Networks need to be permissioned;
3. High transaction throughput performance;
4. Low latency of transaction confirmation;
5. Privacy and confidentiality of transactions and data pertaining to business transactions;

2.4.5 Hyperledger Fabric

Based on the necessities of the system above and the meetings had in the *STVgoDigital* project, the technical consortium of the PPS1 subproject had decided to develop the intended solution in Hyperledger Fabric. To further explain Fabric and its intricacies on how it differs from the usual permissionless blockchain, the following text is mostly based in Hyperledger Fabric's documentation [103].

While many early blockchain platforms are currently being adapted for enterprise use, Hyperledger Fabric has been designed for enterprise use from the outset as an enterprise grade permissioned distributed ledger platform that offers modularity and versatility for a broad set of industry use cases. Fabric is an open source enterprise-grade permissioned DLT platform, designed for use in enterprise contexts, that delivers some key differentiating capabilities over other popular distributed ledger or blockchain platforms.

Fabric can leverage consensus protocols that do not require a native cryptocurrency to incent costly mining or to fuel smart contract execution. Avoidance of a cryptocurrency reduces some significant risk/attack vectors, and absence of cryptographic mining operations means that the platform can be deployed with roughly the same operational cost as any other distributed system. The combination of these differentiating design features makes Fabric one of the best performing platforms available today both in terms of transaction processing and transaction confirmation latency, and it enables privacy and confidentiality of transactions and the smart contracts (what Fabric calls "chaincode") that implement them.

2.4.5.1 High-level architecture

Hyperledger Fabric has been specifically architected to have a modular architecture. Whether it is pluggable consensus, pluggable identity management protocols such as Lightweight Directory Access Protocol (LDAP) or OpenID Connect, key management protocols or cryptographic libraries, the platform has been designed at its core to be configured to meet the diversity of enterprise use case requirements. At a high level, Fabric is comprised of the following modular components:

- A pluggable ordering service establishes consensus on the order of transactions and then broadcasts blocks to peers;
- A pluggable Membership Service Provider (MSP) is responsible for associating entities in the network with cryptographic identities;
- An optional P2P gossip service disseminates the blocks output by ordering service to other peers;
- Smart contracts ("chaincode") run within a container environment (e.g., Docker) for isolation. They can be written in standard programming languages (Go, Javascript, Java) but do not have direct access to the ledger state;
- The ledger can be configured to support a variety of DataBase Management System (DBMS)s;
- A pluggable endorsement and validation policy enforcement that can be independently configured per application.

2.4.5.2 Transactions

Fabric introduces a new architecture for transactions that is called **execute-order-validate**. It addresses the resiliency, flexibility, scalability, performance and confidentiality challenges faced by the order-execute model by separating the transaction flow into three steps, as shown in Fig. 2.12:

- Execute a transaction and check its correctness, thereby endorsing it;
- Order transactions via a (pluggable) consensus protocol;
- Validate transactions against an application-specific endorsement policy before committing them to the ledger.

This design departs radically from the order-execute paradigm in that Fabric executes transactions before reaching final agreement on their order.

2.4.5.3 Privacy

Hyperledger Fabric, being a permissioned platform, enables confidentiality through its channel architecture and private data feature. In channels, participants on a Fabric network establish a sub-network where every member has visibility to a particular set of transactions. Thus, only those nodes that participate in a channel have access to the smart contract (chaincode) and data transacted, preserving the privacy and confidentiality of both. Private data allows collections between members on a channel, allowing much of the same protection as channels without the maintenance overhead of creating and maintaining a separate channel. Where Hyperledger Fabric breaks from some other blockchain systems is that it is private and permissioned. Rather than an open permissionless system that allows unknown identities to participate in the network (requiring protocols like “PoW” to validate transactions and secure the network), the members of a Hyperledger Fabric network enroll through a trusted MSP.

Hyperledger Fabric also offers the ability to create channels, allowing a group of participants to create a separate ledger of transactions. This is an especially important option for networks where some participants might be competitors and not want every transaction they make — a special price they’re offering to some participants and not others, for example — known to every participant. If two participants form a channel, then those participants — and no others — have copies of the ledger for that channel.

Depending on the needs of a network, participants in a B2B network might be extremely sensitive about how much information they share. For other networks, privacy will not be a top concern. Hyperledger Fabric supports networks where privacy (using channels) is a key operational requirement as well as networks that are comparatively open.

2.4.5.4 Shared ledger

Hyperledger Fabric has a ledger subsystem comprising two components: the world state and the transaction log. Each participant has a copy of the ledger to every

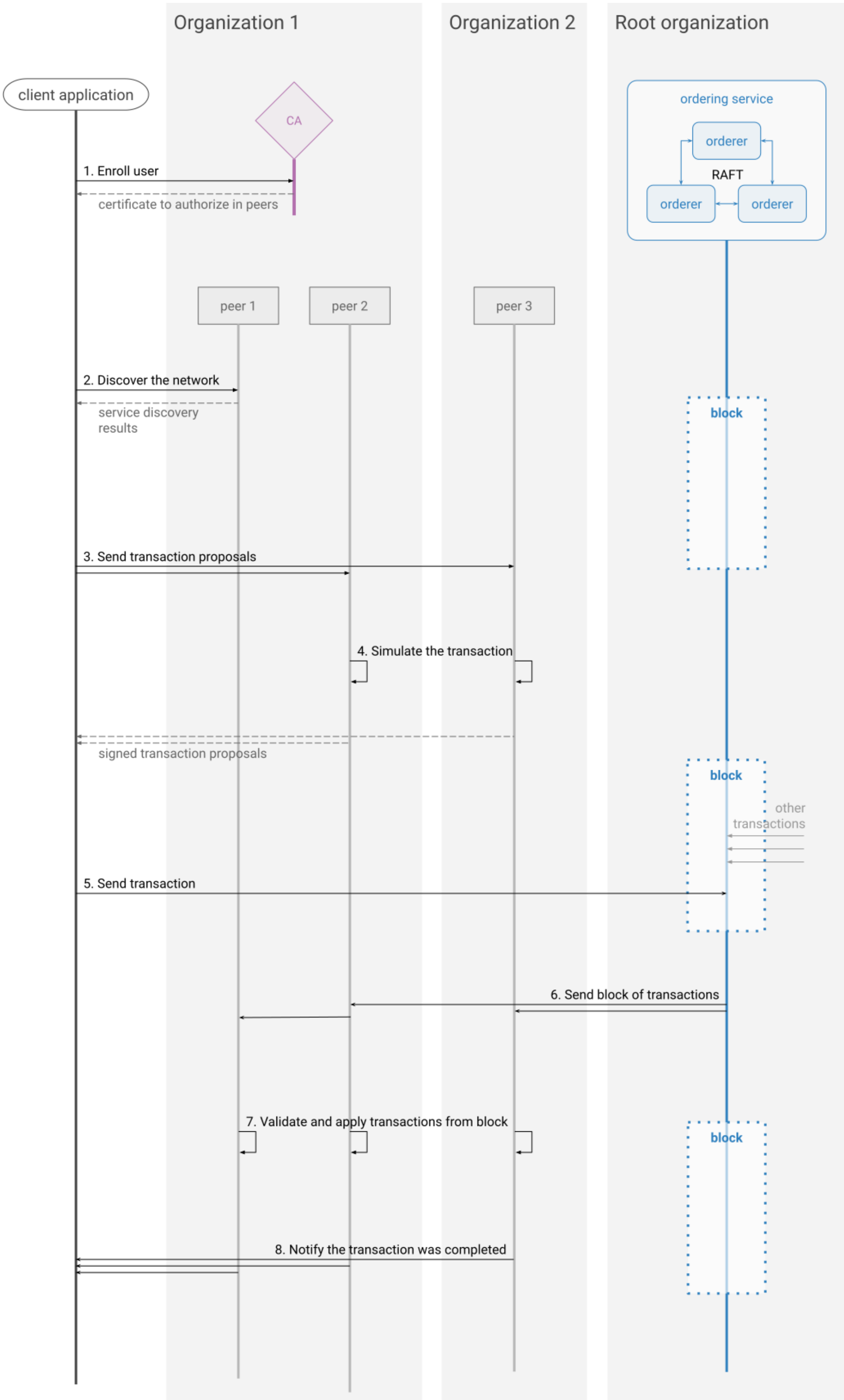

Figure 2.12: Fabric transaction sequence diagram

Hyperledger Fabric network they belong to. The world state component describes the state of the ledger at a given point in time. It's the database of the ledger. The transaction log component records all transactions which have resulted in the current value of the world state; it's the update history for the world state. The ledger, then, is a combination of the world state database and the transaction log history as seen in Fig. 2.13. The ledger has a replaceable data store for the world state. The transaction log does not need to be pluggable. It simply records the before and after values of the ledger database being used by the blockchain network.

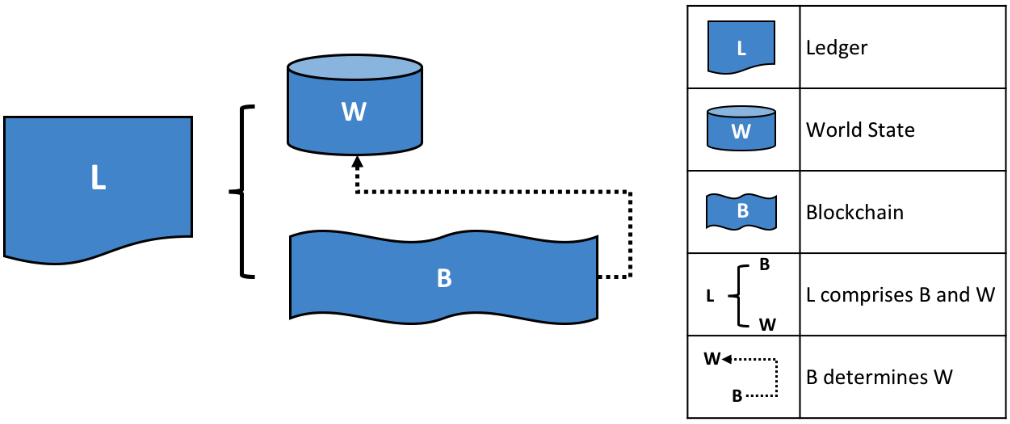

Figure 2.13: Fabric ledger diagram (from [103]

2.4.5.5 Chaincode

Hyperledger Fabric smart contracts are written in chaincode and are invoked by an application external to the blockchain when that application needs to interact with the ledger. In most cases, chaincode interacts only with the database component of the ledger, the world state (querying it, for example), and not the transaction log.

Fabric supports smart contracts authored in general-purpose programming languages such as *Java*, *Go* and *Node.js*, rather than constrained Domain Specific Language (DSL)s. Fabric is also permissioned, meaning that, unlike with a public permissionless network, the participants are known to each other, rather than anonymous and therefore fully untrusted. This means that while the participants may not fully trust one another, a network can be operated under a governance model that is built off of what trust does exist between participants, such as a legal agreement or framework for handling disputes.

2.4.5.6 Consensus

The ordering of transactions is delegated to a modular component for consensus that is logically decoupled from the peers that execute transactions and maintain the ledger. Specifically, the ordering service. Since consensus is modular, its implementation can be tailored to the trust assumption of a particular deployment or solution.

This modular architecture allows the platform to rely on well-established toolkits for Crash Fault Tolerant (CFT) or BFT ordering.

Fabric currently offers a CFT ordering service implementation based on the */etcd* library of the Raft protocol. In Fabric, Raft is used as the consensus mechanism for ordering service, which is responsible for ordering transactions into blocks before they are committed to the blockchain.

Raft operates by selecting a single node, called the leader, to coordinate the agreement on the state of the ledger. The leader is responsible for receiving client transactions, ordering them, and replicating the ledger to other nodes in the network. The other nodes, called followers, receive the transactions from the leader and ensure that they are committed to the ledger in the same order. If the leader fails, a new leader is elected by the followers through a voting process. This ensures that there is always a leader node to coordinate the agreement and maintain the consistency of the ledger.

In Fabric, Raft provides fault tolerance by replicating the ledger to multiple nodes in the network, so that if a node fails, there is still a copy of the ledger available for the network to continue operating. This helps ensure the durability and reliability of the ledger, even in the case of node failures. Additionally, Raft provides performance benefits, as the leader node can process transactions in parallel and replicate them to followers, allowing for faster processing times compared to other consensus algorithms.

One of Fabric's differentiators is its support for pluggable consensus protocols that enable the platform to be more effectively customized to fit particular use cases and trust models. For instance, when deployed within a single enterprise, or operated by a trusted authority, fully BFT consensus might be considered unnecessary and an excessive drag on performance and throughput. In situations such as that, a CFT consensus protocol might be more than adequate whereas, in a multi-party, decentralized use case, a more traditional BFT consensus protocol might be required.

2.5 Internet of Things

Nowadays, IoT technologies represent not only objects that can communicate, but rather a complete ecosystem that is far beyond connectivity, embracing distinct technologies that run in a higher abstraction layer and can be used to share resources and intelligence, such as IoT platforms available in IBM Cloud, Microsoft Azure, and others. Currently, the use of AI within the IoT ecosystem is also gaining a lot of attention, due to the advent of edge computing, which presents a huge potential to apply, not only machine learning techniques at the edge, but also computer vision, fuzzy logic, and natural language interfacing. This edge computing convergence has been used in IoT ecosystems to efficiently integrate heterogeneous data sources with distributed computing to reduce data dimension and thus help to face the exponential data growth that characterizes the overall IoT ecosystem.

As seen in the previous sections, products' traceability is crucial in many production chains such as food [233, 244, 188], manufacturing [187, 149, 37], farming [20, 46], and pharmaceutical industries [30]. Additionally, the integration of IoT and DLT, cf. [87, 46, 37], increases supply chains' productivity and accountability, due to DLT's known security features mentioned before.

The use of low-cost sensors for monitoring has been a recurring view in several IoT applications, and product traceability is no exception [187]. For example, both food [233, 244, 188, 8] and pharmaceutical [30] value chains need extra attention regarding production traceability, which may include additional sensor data, such as the variations in temperature and humidity that products or goods face during the production, preparation, or distribution stages [8], to avoid damage or contamination at any point of the value chain. In this case, traceability systems provide extra sensor-based information that is collected along the value chain to guarantee the quality and safety of food or drugs, respectively.

This section focus on the survey of IoT solutions for circular economy and traceability in the T&C value chain. Firstly, an IoT traceability model is put forward and then several potential IoT traceability technologies are introduced and compared. Then some real-world implementations are discussed and lastly main challenges and future directions are pointed out.

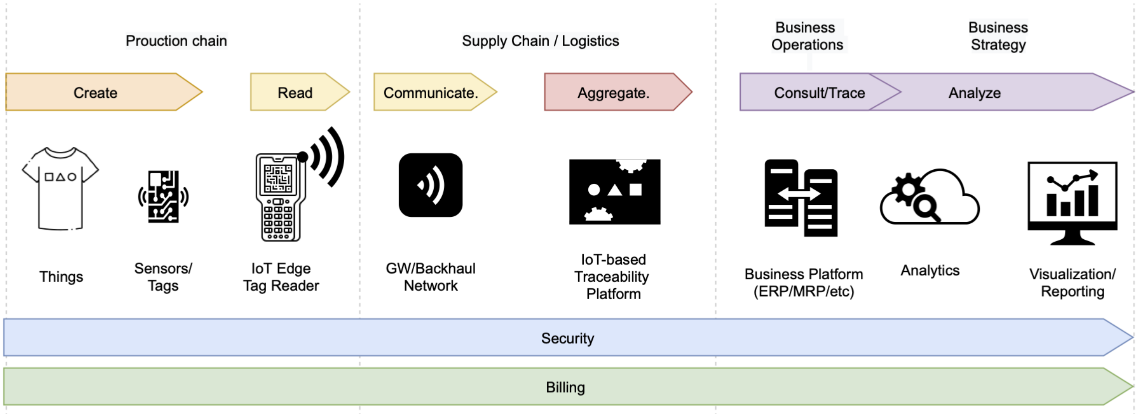

Figure 2.14: Generic IoT traceability model for the T&C value chain

Figure 2.14 presents a general IoT traceability model that includes not only the production and supply chains, but also the business side (operations and strategy). The proposed model will be followed in this document and includes six main stages that have been identified, having in mind the T&C value chain:

1. **Create**: includes the production of the production textile/clothing goods and the integration of Sensors/Tags that will enable IoT traceability along the value chain;

2. **Read**: read sensor/tag information within a specific time-space, i.e. geographical context of the tracer must be also provided. Note that a sensor/tag can be used to store information or sense environmental information using distinct types of implementations.

3. **Communicate**: data communication of the traced information that can be supported with several technologies that must communicate the collected data (at

its geographical context) and guarantee high interoperability (through transparent translation between protocols), which is a critical factor at this stage, because several communication protocols can be used. Therefore, the usage of reference models and standards that create a service-oriented and transparent integration of a multitude of technologies must be considered, e.g. oneM2M IoT Standardized Architecture [174], which particularly addresses the need for a common services Layer that can be easily embedded within hardware and software development.

4. **Aggregate**: reconciles multiple data formats and ensures consistent semantics in data that comes from distinct sources. Moreover, confirms that the data set is complete and consolidates data into one place or multiple places (TSDB, data warehouses, etc);

5. **Consult/Trace**: business operations management that integrates traceability operations, supply chain, reporting, manufacturing, and related human resources activities with a focus on the business operations management (ERP/MRP);

6. **Analyze**: consumes and interprets data using analytics blocks to compute high-level information metrics and indicators that can be used with enriched visual analytics approaches, and used to analyze and evaluate the business processes and create value in the business model with a focus on the business strategy.

2.5.1 IoT traceability technologies

In the model proposed in Fig. 2.14, a sensor, tag, or smart tag (which combines a tag with sensing capabilities) can be seen as a technology artifact that enables parameter reading (sensor) and unique identification, and data transmission.

Legacy traceability technologies include Barcodes or QR-codes that use manual IR or camera-based scanners. The One-Dimensional (1D) Barcodes store up to 30 digits of data horizontally on an identifiable tag using the width and the spacing of the parallel black and white lines [156, 85]. Over the years various types of 1D barcodes emerged with different characteristics than the previous one such as the UPC (Universal Product Code), EAN (European Article Numbering), Code 39, Code 128, and more [79]. Even though it isn't a relatively new technology, barcodes are still being heavily used nowadays by society and in study cases as in [74] where the authors combine barcode tags with RFID technology for the development of a traceable labels identification system. The introduction of a second dimension to these barcodes brought along the QR (Quick Response) Code is an evolution of its predecessor, the one-dimensional Barcode. Its history traces back to the Japanese automotive parts industry in the late 1990s but nowadays it has mass adoption making it way more popular. It's also an ISO international standard approved technology (ISO/IEC18004) [218, 215]. With uses in proposed traceability systems [227, 189], the 2D code provides a significant opportunity for supply chains.

Table 2.1: IoT technologies for traceability and circular economy.

	1D Barcode	QR Code	RFID		NFC	BLE	LPWAN			GNSS
			Passive	Active			SigFox	LoRaWAN	NB-IoT	
Passive / Active	Passive	Passive	Passive	Active	Both	Active	Active	Active	Active	Active
Cost-Effective	✓	✓	✓	✗	Tag Type Dependent	✓	✓(LPWAN-wise)	✓	✗	✗
Real-Time Tracking	✗	✗	✗	✓	✗	✓	✓	✓	✓	✓
Power Consumption	N/A	N/A	N/A	9mW (Low)	60mA (Low)	25µA (Low)	Ultra-low	32mA (Low)	125mA (Low)	22mA (Low)
Storage Capacity	30 digits	3 kBytes	2 kBytes	128 kBytes	Tag Type Dependent (up to 8 kBytes)	N/A	12 Bytes	243 bytes	1600 bytes	36 kBytes
Scanning Range	Code size dependent (Usually contact/short)	Code size dependent (Usually contact/short)	1m (Short)	Frequency dependent (100m @433MHz)	<10cm (Contact)	<30m (Medium)	Up to 10/50kms (City/Rural)	<20kms	<10kms	Global
Continuous Scanning	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓
Communication Flow	Unidirectional	Unidirectional	Unidirectional	Bidirectional	Bidirectional	Bidirectional (Mesh)	Bidirectional	Bidirectional	Bidirectional	Unidirectional
Sensor Compatibility	N/A	N/A	✓	✓	✓	✓	✓	✓	✓	N/A
Battery Autonomy	N/A	N/A	N/A	1 year	N/A	Connection Interval Dependent	1.5-2.5 years (2400mAh)	>10 years	<20 years	3 days (Real-time: 10h)
References	[56, 217] [79, 109, 183]	[218, 135, 215] [110, 156, 217]	[77, 52, 7] [177, 212, 41]	[177, 144, 43] [249, 67, 255]	[138, 212, 66] [134, 93]	[29, 254, 256] [228, 138, 190, 81]	[153, 152, 42] [191, 86]	[182, 216, 153] [152, 139]	[152, 216] [219, 191, 153]	[71, 65] [213, 145, 92]

On the other hand, IoT traceability technologies typically include RFID, Near Field Communication (NFC), and Bluetooth Low Energy (BLE), which are now widely available technologies, integrated by several smartphones' manufacturers as built-in technologies. For example, several smartphones have built-in RFID readers, and the adoption of NFC and BLE technologies is now common among smartphones/tablets' manufacturers.

RFID systems follow a set of standards (ISO, IEC, ASTM International, the DASH7 Alliance, and EPC-global) and consist of a reading device called reader, and a small radio frequency transponder called RF tag [7]. Passive tags use lower frequencies and do not have an internal power source. When in context with traceability platforms, RFID technology has been a subject of study for the authors in [41] where the devices work together with a different set of sensors to provide the wine sector full traceability from vineyard to consumer glass. The same concept is applied in the work [9], also involving sensors with a slight change in the domain into environment-sensitive agricultural food products. Active RFID Tag Systems, however, have an active radio frequency transmitter and their tags use batteries to power the board and to communicate with the reader [249]. It has found uses in suggested platforms like iLocate [257], a highly accurate object location solution using active RFID technology.

NFC is a proximity communication subset of RFID technology based on electromagnetic fields [66]. It operates within the radio frequency of 13.56MHz, has bandwidth speeds up to 424Kbits/s, and is heavily customer-oriented with a variety of mobile devices already supporting it [209, 138]. In [240], the authors used NFC technology for a system to correctly identify and monitor the health patients in hospitals and health-related centers for better tracking and control. Another example of NFC being useful is in [93] where the proximity was explored to provide secure validation on transactions by using NFC-featured mobile phones alongside its ambient sensors (audio and light).

BLE is a short-range, low bandwidth, and low latency protocol for IoT applications. Its power consumption can be 10 times less than the classic Bluetooth while its latency can be 15 times less. It can also support an unlimited number of nodes with its star network topology [202, 7]. BLE has been used in several studies that include domains from smart manufacturing on industrial devices [228] to agri-food product track & trace systems [242].

In early 2013 the term "LPWAN" wasn't even coined so the concept of Low Powered Wide Area Network is relatively recent when considering the spectrum of long-range connectivity and communications [216]. Many of these technologies have gained traction licensed/unlicensed realm of frequency bandwidth. Most notably, Sigfox, LoRa, and NB-IoT are the present leading emergent technologies that are categorized as LPWAN [153]. Sigfox was a pioneer in the LPWAN market, being founded in 2009 with significant growth since then. By employing ultra narrow-band modulation on its physical layer and keeping the network protocols secret [42], Sigfox provides a solid solution for implementing LPWAN technology in the suggested agriculture context in [153] where the inherent need for long-lasting battery sensors is required. Long Range Wide-Area Network is a type of LPWAN standardized by the LoRa Alliance, an open non-profit association that develops LoRaWAN [139].It is optimized for a larger capacity and range while bringing low power consumption and cost [66]. Regarding traceability purposes, this low power WAN has been used in previous work like in [258] where the authors implemented a LoRaWAN architecture for long range communication and cattle tracking, including the design and development of the application and protocol. It has also been suggested in [123] that LoRaWAN is an effective way of capturing an object's traceability when the paper applied it to develop a bicycle location tracking and management system. NB-IoT is a "narrowband LPWAN technology which can coexist in LTE or GSM under licensed frequency bands" [152]. This new cellular technology was introduced in 3GPP Release 13 for wide-area coverage in Internet of Things domains [248]. With its aims in enabling deployment flexibility, better autonomy, effective cost and signal coverage, the narrow-band technology. Petrenko et al. propose in [184] an Industrial Internet of Things (IIoT) / IoT Control Center model with basis on the Russian NB-FI standard for wireless communications, which is NB-IoT based. The technology can also be used in a smart city context as demonstrated in [210] where a smart parking system was built based on NB-IoT with successful deployment in two cities in the Zhejiang province of China. Global Navigation Satellite Systems (GNSS) consist of four satellite technologies [213]:

- **GPS**: United States' Global Positioning System;
- **GLONASS**: Russia's GNSS;
- **BDS**: China's BeiDou Navigation Satellite System;
- **Galileo**: European Union's civilian GNSS.

These consist of three segments that provide point precise positioning and timing that other connectivity-based technologies lack [70]. The utility of these systems is present in services and activities like sailing, aviating, car driving, hiking, and emergency rescue [146]. Research in [92] shows that Global Positioning System (GPS) trackers used in combination with LoRa technology can be effectively used for a dementia patient traceability & tracking system with a one-minute location update cycle. Through the work in [98], the authors proposed a solution architecture for an integrated supply chain track and trace platform with the use of a synergistic hybrid of RFID and GPS technologies.

The wide availability of these technologies, notably RFID, NFC, and BLE, has been pushing the increase of smart tags along with sensory data like ambient temperature/humidity, vehicle speed, geolocation, that can be processed and aggregated to effectively enhance the supply chain traceability. Moreover, the usage of conventional smartphones/tablets as readers, increases the cost-benefit of this approach, since, most of the effort will be on the business side, i.e. in the development of a software application that directly interacts with the IoT platform using SoA or microservices software architectures. Table 2.1, compares some relevant IoT traceability technologies that have higher potential for the T&C value chain.

Comparing the IoT traceability technologies in Table 2.1, it is worth noticing that these devices can be applied to different phases and processes in the textile circular economy model proposed in section 2.3.2 of this article. The aspects of IoT adoption in the garment industry as presented in [157] are the following:

Table 2.2: IoT implementations in textile manufacturing processes.

Phase / Area	IoT Technology	Implementation(s)
E-garments	1D Barcode; QR Code; RFID (Passive)	A secured tag for implementation of traceability in T&C supply chain [5]; QR Code Fabric Tag System for Textile Companies in Turkey [176]; Passive UHF RFID textile tags as wearable moisture sensors [214]
Automated monitoring of Factory operations	LoRaWAN	Integrating IoT into operational workflows for real-time and automated decision-making [140];
Equipment Maintenance	RFID (Passive); RFID (Active)	Framework of an IoT-based Industrial Data Management for Smart Manufacturing [204].
Weaving and Embroidery Machines Efficiency and Exiting loading of products	RFID (Active)	Big Data Analytics for Processing Time Analysis in an IoT-enabled manufacturing Shop Floor [122].
Product Development	NFC	Contact range identification in manufacturing process.
Digital printing	QR Code	A Survey on Interactive Clothing Based on IoT using QR code and Mobile Application [161].
Guided Sales Process / E-commerce / Virtual Reality	GNSS	Display in-store stock.
Streamline operations	BLE	Machinery proximity optimal for BLE mesh topology.
Increase uptime	RFID (Active)	Continuous monitoring for machine performance.

1. **E-garments**: clothing with embedded purposeful sensors for business model compliance;
2. **Automated monitoring of Factory operations**: monitoring and controlling the major parameters of the physical environment of a factory;
3. **Equipment Maintenance**: important machine operating data like can be accumulated and synced in real time and then analyzed;
4. **Weaving and Embroidery Machines Efficiency and Exiting loading of products**: the machinery used in garment manufacturing can preserve data related to output per hour, thread counts, maximum hours worked, etc for later analysis;
5. **Product Development**: "Virtual Sampling Tools" are used to convert designs as digital samples for future applications;
6. **Digital printing**: IoT has lowered the cost of production and increased operational efficiency in digital textile printing;
7. **Guided Sales Process/E commerce/Virtual Reality**: virtual product samples and product images have been replacing the traditional mode of displaying products or physical display.;
8. **Streamline operations**: Sensors attached to the machines and related software can provide real-time data regarding the performance of the machines;
9. **Increase uptime**: ensure equipment uptime through automated conditional monitoring systems.

With that said, the following table 2.2 lists related work implementations as well as author suggestions for each aforementioned area of IoT adoption with its own assigned IoT technology used/suggested in the implementations.

The use of IoT technologies in the T&C value chain could increase data collection automation. In addition, as low-energy and sensor innovations for IoT gadgets advance, they additionally take into account the computerized assortment of new information (like the temperature within holders and other operations units or the utilization of water/synthetic compounds by manufacturing machinery). Lastly, it can allow the automated collection of higher-quality track-and-trace information and the attaching of additional data to traceable assets. When combined with other technologies like blockchain and AI, these labeling technologies, which include both digital and physical markers, can also offer higher speed and automation in addition to lower costs for tracking data that are attached to products, and improved accuracy in physical raw material tracing through multiple product transformations [238].

2.6 Gamification

Firstly introduced in the early 2000s, but only getting wider adoption in the second half of 2010 [89], the term *gamification*, as described by [44, 62], consists on applying certain fun and engaging elements, that are usually found in games, to a non-game context. Often interpreted as "Human-Focused Design" due to its focus on optimizing human motivation [44], the gamification concept derives from the gaming industry because of its mastery in bringing entertainment and positive experiences to humans. Usually, people play games with the purpose of getting fun. And, when the players aren't enjoying it, they leave the game and find other things to do. In this document, the term "gamified" will be used to indicate the presence or use of "gamification".

For gamification to effectively work on a specific domain, it should follow a set of motivational perspectives, that are not context-dependent. Different motivational outcomes can be triggered by different game design elements [201]. Within the self-determination aspect of motivation, Self-Determination Theory (SDT) seems to be an accepted approach to this field [201]. SDT uses "traditional empirical methods while employing an organismic metatheory that highlights the importance of humans' evolved inner resources for personality development and behavioral self-regulation" [199]. These methods investigate one's tendencies and a total of three needs that make up their own motivation and own personality [199]:

1. Relatedness: The universal need to interact and be connected with others;
2. Competence: The universal need to be effective and master a problem in a given environment; and
3. Autonomy: The universal need to control one's own life [89].

These three intrinsic psychological needs are resources that can be shaped with a change in the person's environment, hence the belief that behavior patterns for motivation can be promoted by addressing the human needs for competence, autonomy, and social relatedness [239]. None of these works focus or even mentions the use of gamification techniques.

2.6.1 Eco-gamification / Green Gamification

Regarding the gamification domain, these design techniques for behavior change are applied to several contexts, from self-management to productivity, education, finance, health, news, entertainment, and others [61, 89] including one conveniently related to this article's implicit domain, which is sustainability.

"Eco-gamification" or "green gamification" is a concept specifically aimed towards a sustainable environment focused on ecological behaviours. Its foundation is the same as standard gamification, but applying the game elements to sustainability, to make it fun, rewarding and fulfilling [169]. This results in the so-called "green games", which promote environmentally sustainable behaviors, challenging the player through the proposal of real-life tasks, that are beneficial in one or more issues, aimed to reduce the overall impact on the planet's health. Through the development of these games we can link technological evolution with eco-friendly activities [96].

2.6.2 Gamification Frameworks

There are several gamification frameworks and methods that evaluate a system's design based on how gamified it is [158]. Some of these, however, can have a set of classifiable dimensions that can be identified and graded, making it possible to have a better perspective on motivational heuristics and metrics for ease of comparison. The authors in [231] analysed the following measurable frameworks described below.

The developer of the Octalysis Framework for gamification design, Yu-Kai Chou, structures the tool in [44] as having eight Core Drives, which correspond to motivation dimensions that appeal to each person when showing interest to play a game. These Core Drives are categorized by feelings (White-Hat, Black-Hat) and by type of motivation / side (Extrinsic - Left Brain, Intrinsic - Right Brain), and are measured and analysed in a octagonal shape, hence the name Octalysis, outputting a final score regarding the gamification rating.

In the six sided HEXAD Model [232], each side is assigned to a user type, which are "personifications of people's intrinsic and extrinsic motivations", supported by SDT that suggests a binary interpretation to an individual's motivation, whether with intrinsic or extrinsic value.

The Kaleidoscope of Effective Gamification (KEG) Framework applies a circular layered model, like the layers of an onion, to the motivation dimensions [116]. The layers in the model converge inwards, having an initial outer *Perceived Layer of Fun*, with excitable attributes and elements of surprise for a memorable first impression. As getting inward through the model, several other layers appear, such as the Game Design Process Layer, Game Experience Layer, Motivated Behaviour Layer and finally the Effective Gamification Core. This central core of the model sets the nucleus of player experience which is coherent with all the other layers, representing the main objectives of creating an effective gamification state.

The Lens of Intrinsic Skill Atoms framework [61], which the author describes as a way of articulating the main structural components of a gamified system, is a design method based on the concept of lenses and skill atoms. The lenses are a way of interpreting one's design, by bundling a principle with a set of questions to take a mental note, to act design-wise, with that principle in mind. The skill atoms are described as a set of skill components associated with the purpose of the previously described lenses.

Table 2.3: Gamification framework comparison and their dimensions (adapted from [231]).

	Gameful Design Heuristics	**Octalysis**	**HEXAD**	**KEG**	**LoISA**	**RECIPE**
Purpose & Meaning	Meaning, Information & Reflection	Epic Meaning & Calling	Philanthropist	N/A	N/A	Information, Reflection
Challenge & Competence	Increasing Challenge, Onboarding, Self-challenge	Development & Accomplishment	Achiever	Motivated Behaviour Layer, Game Experience Layer	Challenge Lenses, Intrinsic Rewards	Engagement
Completeness & Mastery	Progressive Goals, Achievement	Development & Accomplishment	Achiever	Motivated Behaviour Layer, Game Experience Layer	Goal & Action Lenses, Intrinsic Rewards	N/A
Autonomy & Creativity	Choice, Self-expression Freedom	Creativity & Feedback	Free Spirit	Motivated Behaviour Layer	Object Lenses, Intrinsic Rewards	Play, Choice
Relatedness	Social Interaction, Social Cooperation, Social Competition, Fairness	Social Influence & Relatedness	Socialiser	Motivated Behaviour Layer	Intrinsic Rewards	Engagement
Immersion	Narrative, Perceived Fun	N/A	N/A	Perceived Layer of Fun	N/A	Exposition
Ownership & Rewards	Ownership, Rewards, Virtual Economy	Ownership & Rewards	Player	Motivated Behaviour Layer	Intrinsic Rewards	N/A
Unpredictability	Varied Challenges, Varied Rewards	Unpredictability & Curiosity	Free Spirit	N/A	Varied Challenge, Varied Feedback, Secrets	Play
Scarcity	Scarcity	Scarcity & Impatience	N/A	N/A	N/A	N/A
Loss Avoidance	Loss Avoidance	Loss & Avoidance	N/A	N/A	N/A	N/A
Feedback	Clear & Immediate Feedback, Actionable Feedback, Graspable Progress	Creativity & Feedback	N/A	N/A	Feedback Lenses	N/A
Change & Disruption	Innovation, Disruption Control	N/A	Disruptor	N/A	N/A	N/A
References	[231, 232]	[44]	[198] [60] [232]	[116] [198] [99] [94]	[61]	[165] [231]

On the RECIPE for Meaningful Gamification [165], the author explains the given name, through the first letter of its main concepts inspired by Gameful Design:

- **R**eflection;
- **E**ngagement;
- **C**hoice;
- **I**nformation;
- **P**lay;
- **E**xposition;

These elements represent the different metrics that can be applied to gamification for a meaningful (intrinsic) purpose.

Tondello *et al.* developed Gameful Design Heuristics (Gameful Design Heuristics (GDH)), in [231], based on the comparative study between the previous five frameworks, gathering the different measurable motivational dimensions. The resulting heuristics are heavily based on SDT's theory of intrinsic & extrinsic motivation [199, 198] and behavioural economics [95] and are classified in a total of 28 heuristics organized within the 12 identified dimensions from the study's analysis.

Based on the aforementioned comparison study, the Gameful Design Heuristics methodology demonstrates to be a more inclusive tool as a multidimensional approach to evaluate gameful design, and thus it will be used not to evaluate but to define the gamification structure needed to implement it on a B2C2C context of a circular economy, in this case in the T&C area.

Chapter 3

Literature review and state of the art

3.1 Approaches to Traceability in the T&C value chain

With the globalization of supply chains, traceability, meaning the capability of tracking a product, is getting special attention, especially in food supply chains, because of public health reasons. In the T&C supply chain, it is also necessary to be able to track products, namely knowing the origin and location of each product, to ensure the authenticity of a product's origin avoiding forgeries. Traceability is currently seen as synonymous of transparency in the value chains [57].

Table 3.1: Solutions for traceability and circular economy in the T&C value chain.

	Blockchain-based framework for supply chain traceability	**A secured tag for implementation of traceability in textile and clothing supply chain**	**Developing a Framework for Traceability Implementation in the Textile Supply Chain**	**Blockchain Enhanced Emission Trading Framework in Fashion Apparel Manufacturing Industry**	**Traceability of ready-to-wear clothing through blockchain technology**
Technology	Blockchain	QR Code & Data Server	RDBMS & XML	Blockchain	Permissioned Blockchain (N/A)
Circular Economy Optimization	✗	✓	✗	✓	✓
Traceability	✓	✓	✓	✗	✓
IoT Integration	✓	✓	✓	✗	✓
B2B / B2C Apps	B2B	B2C	B2B + B2C	B2B2C	B2B2C
Features	N/A	QR Secure Counterfeit Code	N/A	Multi-operator carbon emission coverage & Industry 4.0 compliant	N/A
References	[6]	[5]	[132]	[78]	[33]

Some platforms have been proposed for traceability in T&C value chain, some of them are presented next and summarized in Table 3.1.

Agrawal *et al.* proposed a blockchain-based traceability framework for the textile industry. Through a simulation-based demonstration of the used distributed ledger configuration and its operator's interaction, the authors provided a structural solution for its use case and applicability while maintaining data safety and trust among the value chain operators [6].

The authors in [5] proposed a traceability solution for the T&C industry. The proposed system is based on QR Code tags mapped with a secure code to provide an extra layer of authenticity and verification to fight the vulnerability of the sector to counterfeit products. These tags should be lasting enough until the user decides to recycle, making it optimal for a circular economy model.

Kumar *et al.* propose a system based on RDBMS (Relational DataBase Management Systems) and XML (eXtensible Markup Language) to capture data for the purpose of tracing a textile product's traceability within an operator of the supply chain or a full inter-actor traceability [132].

Fu *et al.* propose a blockchain-based emissions trading system, with the use of an emission link to evaluate carbon emission standards for a specific product in the fashion and apparel manufacturing industry [78]. Although not built for traceability purposes, the system is a sustainability forward project integrated into the Industry 4.0 paradigm that measures how much of an environmental impact a certain clothing asset has had and suggests solutions to the operators for compensating carbon emissions of that same product.

In [33], Pérez *et al.* analyze how the use of blockchain technology can help authenticate actors and products of the T&C supply chain and trace products back to their origin. Using a case study of a woman's shirt, they concluded that the use of a permissioned and open distributed ledger to store important data from the manufacturing processes' transactions would be beneficial for the end goal of textile traceability.

3.2 Blockchain-based approached to Traceability in the T&C value chain

Nowadays, blockchain is being seen as one of the technologies that better fits the needs of traceability in the supply chains [57]. This technology is being used to implement traceability in many areas including agriculture and food supply chains, as is the case of [230, 26, 223, 40, 53, 10], in wood supply chains as is the case of [75], in textile supply chains as is the case of [6], and many other areas.

The proof-of-concept system proposed in [88] promotes interactivity between edge IoT devices and an Ethereum blockchain in a food-chain traceability scenario. The specific use case of a fish products' cold supply chain is suitable for IoT integration by capturing temperature sensor data for quality assessment needs.

In [58], the authors present a distributed Ethereum-based solution for a carbon footprint traceability decentralized application.

As mentioned before, Mueen Uddin proposes a track and trace blockchain-based solution - Medlegder - for transactions' registration for traceability in the pharmaceutical drugs supply chain [234]. Enabled by the Hyperledger Fabric blockchain platform, the Medledger minimizes the need of a central entity/authority and also integrates other decentralized systems like distributed data storage (IPFS, Swarm & Filecoin).

In [75], the authors are using Blockchain Technology (BCT) to implement traceability in wood supply chain. The system is based on RFID sensors and open source technology. The system is able to trace wood from the forest (marking and cutting trees) until the final consumer, passing through activities such as stacking, transport, sawmill processing, production and selling.

Table 3.2: Blockchain-based solutions for traceability.

		Blockchain and IoT: Food-Chain Traceability	Blockchain-based Traceability of Carbon Footprint	Blockchain Medledger	Electronic Open Source Traceability of Wood	Harvest Network
Blockchain	Platform	Quadrans (Ethereum-based)	Ethereum	Hyperledger Fabric	Azure Blockchain Workbench (Ethereum)	Ethereum
	Consensus Process	Permissioned	Permissionless	Permissioned	Permissionless	Permissionless
Circular Economy Optimization		✗	✗	✗	✗	✗
IoT Integration		✓	✗	✗	✓	✓
Application Areas (Use Cases)		Food & Cold Chain	Food Carbon Footprint	Drug traceability system for counterfeit drugs in pharmaceutical industry	Wood Supply Chain	Food Supply Chain
B2B / B2C Apps		B2B + B2C	B2B + B2C	B2B + B2C	B2B2C	B2B + B2C
Features		On-device signing, IoT RPC Server	React DApp, NodeJS API & B2B2C Solidity Smart Contracts	Decentralized Data Storage (IPFS, Swarm & Filecoin)	Cloud deployment, REST API, Off-chain SQL Server Storage, Azure IoT Hub Integration	ERC-721 NFT standard, Asset tokenization, GS1 integration, Analytic dashboard
References		[88]	[58]	[234]	[75]	[124]

Table 3.3: Blockchain-based solutions for circular economy.

		Everledger	Circularise	VeChain	Waltonchain	Ambrosus
Blockchain	Platform	Hyperledger Fabric	Ethereum	VeChainThor	Go Ethereum	Ambrosus
	Consensus Process	Permissioned	Permissionless	Permissionless	Permissionless	Permissioned
Circular Economy Optimization		✓	✓	N/A	N/A	N/A
IoT Integration		✓	N/A	✓	✓	✓
Application Areas (Use Cases)		Diamonds, Electric Vehicle Batteries	Plastics	Anti-counterfeit, Supply Chain Management, Food Safety, Intellectual Property	Food Traceability, Clothing Traceability	Pharmaceutical Industry
B2B / B2C Apps		B2B + B2C	N/A	N/A	N/A	B2C (programming interface)
Features		Analytics, Brand & Mobile Support,	ZKP Smart Questioning, CIRcoin cryptocurrency	Improved Proof-of-Authority consensus, Two token system (VET + VTHO), VTHO Smart Contracts	Fabric & Solidity smart contracts, Custom WPoC (Waltonchain Proof of Contribution) (PoW + PoS + PoL)	IPFS distribution, Sensor Network Optimization, Proof-of-Authority consensus
References		[141, 72, 47]	[136, 27]	[241]	[243]	[14], ambrosus.io

With the food supply chain in mind, the authors in [124] present the Harvest Network which is a blueprint for a food traceability application, providing a distributed ledger accessible to every operator within the value chain. The Harvest Network includes the use of an ERC-721 non-fungible token standard for asset digitization as well as GS1 product standards integration.

In [10], the authors are proposing a blockchain-based platform to implement traceability in PDO (Protected Designation of Origin)/PGI (Protected Geographical Indication) / TSG (Traditional Specialty Guaranteed) products. The platform has two main goals: the first one, is to avoid forgeries. the second one, is to provide information to the consumer about when, by who and where the product (and raw materials) are produced or manufactured.

The table 3.2 summarizes these approaches.

With the growth of blockchain usage for traceability purposes, several platforms emerged from different companies to provide the solutions needed by supply chain entities to apply this technology for their benefits. Table 3.3 gathers several platforms that use blockchain for the traceability and circular economy, and compares them in aspects such as Blockchain platform used, IoT, use cases, among others.

Everledger stands out as one of the main providers of these types of services when it comes to blockchain based traceability. The Everledger Plaftorm uses enterprise-grade blockchain services for Hyperledger Fabric powered by IBM. There are multiple and useful features for supply chain participants included in the Everledger Platform v1.3 [72] such as:

- IoT integration through real-time with sensors, intelligent labeling, and tamper detection. This intelligent labeling is achieved by radio frequency identification (RFID), near-field communication (NFC), synthetic DNA markers, QR codes, and other identifiers within an object's label or packaging to authenticate objects with interaction with a variety of devices;
- User access control via Access Control Layer (ACL) to specify which users or system processes are granted access to objects, as well as what operations are allowed with ISO27001-compliant standards-based mechanisms for authentication services;
- Analytics & reporting by displaying interactive graphs and visualizations of different types of metrics and data;
- Brand and mobile support for white-labeled progressive web applications (PWAs) with the NFC/QR service from Everledger, and integrated WordPress sites, using React with a suite of third-party plug-ins and integration partners;
- A service infrastructure through RESTful API DLs (Representational State Transfer Application Programming Interface Description Languages) to allow uploading data to the Everledger platform;
- Artificial intelligence capabilities, mainly with advanced optical character recognition (OCR);
- On-demand traceability records by showcasing an asset's provenance record, event and transaction history, related certifications, warranty information and more, alongside industry compliance that can be evidenced by organizations;
- Digital twin features of supply chain asset(s). This involves unique identity (UID) association with the physical product.

Circularise is a Circular Economy (CE)-focused company capable of providing transparency to global supply chains and help them move towards a circular economy. With its main focus on the plastics value chain, it works with Ethereum blockchain technology and has Solidity smart contracts at the core of its protocol [136]. The system that they call CIRbase focuses on accelerating the transition of companies into a circular economy, by helping with the exchange of information between parties while maintaining the competitive nature that these may have. By validating the supply chain operator's encrypted material information and applying a smart questioning system powered by zero-knowledge proof (ZKP) technology and ring signatures for anonymity, it is possible to have a fully trusted platform where its members provide the needed data. However, it is also important that these members are willing to accept the norm of this type of information sharing protocols [27].

Some frameworks are solutions under which a developer can create their own traceability solution. These frameworks are also summarized in table 3.3 and are briefly described next.

VeChain is a Singapore-based company that defines its existence to disrupt the conventional supply chain model. Highly integrable with IoT devices like RFID, NFC, and/or QR Code, the VeChainThor blockchain provides its users with two native cryptocurrencies to handle the network. VET is used for economic purposes, and VTHO is used for smart contracts execution [241].

The **Waltonchain** uses RFID chips to track & trace products in the supply chain, just like VeChain. Their focus is on combining blockchain technology with IoT & RFID, specifically a device that can generate its own hash and upload it to the ledger through an RFID reader. The applicability of this ecosystem in a supply chain use case is beneficial, allowing tracking and traceability throughout the entire value chain [243].

Finally, the **Ambrosus** protocol is specialized in specific supply chain projects, such as pharmaceutical industries. With its proprietary blockchain with the same name, the company uses a PoA consensus mechanism to validate its transactions and the ledger is optimized for interconnection with several other devices like sensors and/or Enterprise Resource Planning (ERP) systems [14](ambrosus.io).

3.2.1 Benefits of blockchain implementation on a T&C Value Chain

The aforementioned BCT components provide the following key features and characteristics [137, 245, 90]:

- **Decentralisation** is achieved by running the network in a distributed peer-to-peer (P2P) topology. Any transaction in the blockchain network can be conducted between any two peers without the need of authentication by a central agency. This also reduces central server costs and performance bottlenecks;

- **Immutability** is an intrinsic trait of blockchain technology due to the near impossibility of changing previously registered data, other than a 51% attack or the uncertain future capabilities of quantum computing;

- **Pseudonymity**, although some authors agree on anonymity instead, is an advantage for avoiding identity exposure in the network through encrypted addresses;

- **Auditability** for traceability purposes is a key factor in BCT due to its timestamp server recording the transactions in chronological order, providing greater provenance capabilities;

- **Autonomy** is another blockchain benefit. Every node in the system can safely manage data, so the idea is to trust a system instead of a single person with no one to intervene in it;

- **Transparency** is present in these distributed ledger systems because any node can consult the data records. More so, several blockchains are open-source, allowing for transparency within the platform itself;

In a value chain context, the blockchain operates as a decentralized transaction environment, with participating members that share product lots' traceability data and concurrently agree to authenticate the true state of shared data. In a blockchain environment, data is stored as transactions in blocks, which are chained in a shared immutable ledger as they continue to grow. At all times, the data is transparently accessible to the value chain participants. Such a collaborated effort for information sharing improves traceability in both global and local supply chain scenarios [163].

Through the analysis of DLT potential, the authors in [133] mention several blockchain applications, and their benefits, in the textile and apparel industry. Cases like the prevention of fake product purchase, where the digital asset transactions are immutable from manufacturer to costumer, maintaining the product's authenticity. Track and trace capabilities, through unchangeable transactional data, are also obtained. The incorporation of Health, Safety, and Environmental (HSE) compliance information could be updated by certified auditors, subjecting compliance conditions into the value chain's contracts. Increased trust between operators would be attained based on the fact that no specific organization provides trust, instead the technology itself creates the trust by default.

For T&C value chain implementation purposes, there are some specifications on which properties are best suited for that domain. Since all the value chain operators within a textile or clothing product's lifecycle can create a consortium, the most optimal blockchain type is a consortium blockchain [102] and thus, the consensus protocol should be optimized for a consortium type such as the practical Byzantine Fault Tolerance [245]. When the tangible product is going through it's lifecycle processes, any of these changes can be represented in a transaction with or without the need of ownership transfer [102].

3.3 Gamification Techniques for engaging the Consumer into Circular Economy

The literature available for gamified sustainability and CE, with the purpose of behavioural change, narrows the domain of sustainability into more precise topics like sustainable mobility, recycling or energy consumption. The following research gathers information on gamification techniques for these application topics as well as their results.

In [91], Gustafsson *et al.* report on the positive outcomes obtained from using *Power Agent* game for encouraging teenagers and their families to reduce energy consumption at home. The game elements used in Power Agent provide a storyline, challenge, leveling, feedback and leaderboards that make the participants highly engaged with the game, consequently resulting in reducing energy consumption.

When it comes to gamification on promoting CE, the Circularity Game [128] explores the combination of these two concepts applied to an existing card deck game for businesses, to integrate CE to their models. By using the Octalysis Framework [44], the solution's design ranks core drives quantitatively, based on its importance to the final product, while also providing specifically chosen features like rewards, feedback, customization, and others to hit the targeted core drives.

On the topic of sustainable mobility, the authors in [39] applied several gamification techniques to public transportation of tourists and residents in Madeira, Portugal. With a big pool of gamification methods, the goal was to pick the ones that are best suitable for the creation of engagement for sustainable mobility. They opted by "using awards for the different places that the user visited, progressing on the number of completed adventures and fostering competition for the leaderboard table" as the selected techniques to improve motivation and usage rate.

Within the same realm of sustainable transport, the use of the gamification platform proposed in [119] ends up using several game elements in the public transport application, such as player's state and task progress visualization, quick actions, achievements, challenges and leaderboards. These game elements are the result of implementing the intrinsic, extrinsic and context-dependent GDH framework [231]. The same group of authors also participated in a different study [120], where a similar implementation of this framework resulted in more user engagement with the "Green Game with ViaggiaRovereto" mobile application that it was applied to. Redesigning the platform with motivational characteristics, like points, badges, achievements and usage rewards, led to the increase of effectiveness in voluntary travel behavioural change, as well as gain in incentive to more sustainable transport options.

Previous studies can also be found related to gamification for recycling, like the work done on the Pantarevir mobile game, presented in [96], which is a good example of how gamification can bring environmental purpose, incentive and aim (eco-gamification). The authors explore the competitive aspect of a gamified implementation of an eco-friendly activity such as recycling. With the use of a map of layered territories, for the users to conquer based on how many cans and bottles they recycle, the end product has succeeded in confirming that it is possible to raise environmental awareness and change recycling habits. That is achieved through fun oriented design of usually tedious habits, into something meaningful and entertaining, purposely built in that way. A case study [31] has been implemented in the city of Zaragoza, Spain, with the purpose of evaluating an eco-gamified mobile application prototype, to encourage waste reduction by increasing recycling rates. The result was an increase in citizens' participation and recycled waste (32.2% and 17.2%, respectively). This has been achieved by a reward and achievement system that discounted the rate of waste management services, based on how much they've recycled, albeit with a reachable goal set by the city's council.

Chapter 4

Smart contract and services

In the previous chapter, the literature review was researched to analyze the state-of-the-art within the existing traceability solutions to tackle the sustainability issues of the T&C value chain. In this chapter, a PoC B2B T&C value chain management smart contract with traceability capabilities is presented with its requirements and domain model in section 4.1, architecture and technological stack in section 4.2 and lastly the chaincode transactions with traceability features in section 4.3. This developed artifact is supposed to be a module of a bigger system being developed in the *STVgoDigital PPS1* research sub-project, meant to be used as a point of consensus to store value chain data of the participant organizations, more specifically, the activity logs, batches digital twins and their respective sustainability scores/indicators. Since only a single smart contract was developed, the terms smart contract and chaincode will be used interchangeably given that the used blockchain protocol (Hyperledger Fabric) considers chaincode as a collection of smart contracts and it is the conventional naming in the protocol.

4.1 System modelling

Before developing the solution, we need to gather the requirements for the system so that it can comply with the necessities of the value chain participants. After several meetings with the consortium of the *STVgoDigital PPS1* research sub-project, the system requirements ended up being defined as listed in subsection 4.1.1, resulting in creating use cases for the system. To support the features being mentioned in the use cases, subsection 4.1.2 below details the established domain model that is being used to structure data in the chaincode.

4.1.1 Requirements and use cases

To interpret the following requirements, please consider the requirement template below:

- **As <USER/ACTOR/SYSTEM>, I want <DO ACTIONS IN SYSTEM>, to <OBJECTIVE>.**

- **R1:** As an OPERATOR, I want to CREATE A REGISTRATION ACTIVITY, to LOG THE ACTIVITY AND REGISTER THE OUTSOURCED BATCH IN THE SYSTEM.
- **R2:** As an OPERATOR, I want to CREATE A PRODUCTION ACTIVITY, to LOG THE ACTIVITY AND ADD THE NEW BATCH IN THE SYSTEM.
- **R3:** As an OPERATOR, I want to CREATE A TRANSPORT ACTIVITY, to LOG THE ACTIVITY AND UPDATE THE BATCHES' LOCATION IN THE SYSTEM.
- **R4:** As an OPERATOR, I want to CREATE A RECEPTION ACTIVITY, to LOG THE ACTIVITY AND ACCEPT/REJECT THE BATCH QUALITY AFTER TRANSPORT IN THE SYSTEM.
- **R5:** As an OPERATOR, I want to READ ACTIVITIES, to READ DATA ABOUT ACTIVITIES.
- **R6:** As an OPERATOR, I want to READ BATCHES, to READ DATA ABOUT BATCHES.
- **R7:** As an OPERATOR, I want to READ BATCH TRACEABILITY BY INTERNAL REFERENCE, to CHECK BATCH TRACEABILITY.
- **R8:** As the SYSTEM, I want to STORE SUSTAINABILITY INDICATORS ON ACTIVITIES AND BATCHES, to SUPPORT SUSTAINABILITY CLAIMS BY VALUE CHAIN CONSORTIUM ORGANIZATIONS.

The requirements are only needed by the operator that registers the value chain activities in the production units. Therefore, the requirements only have the operator as the actor of the requirements template. To further demonstrate the defined requirements, Fig. 4.1 displays an use case diagram of the developed chaincode to manage the value chain activities and its assets (batches).

The use cases of the chaincode are not that many due to the simplicity of the system considering what the actor (Operator) can perform to manage its part of the value chain. Nonetheless, here are the use cases in further detail:

1. ***Create activity*** - an operator can create activities in the system to digitally mimic the activities that happen in the value chain. However, this use case is abstract due to the differences in the specified activity types:

   (a) **Create registration** - creates a registration activity in the system. Registration activities are created when a production unit operator wants to issue an outsourced batch in the platform. It's an activity where creating a batch is mandatory;

   (b) **Create production** - creates a production activity in the system. Production activities are created when a production unit operator wants to log an activity in the system that represents the processes to manufacture a batch in the value chain. It's an activity where creating a batch is mandatory;

   (c) **Create transport** - creates a transport activity in the system. Transport activities are created when a production unit operator wants to log an activity in the system that represents the shipping transport of a batch. The

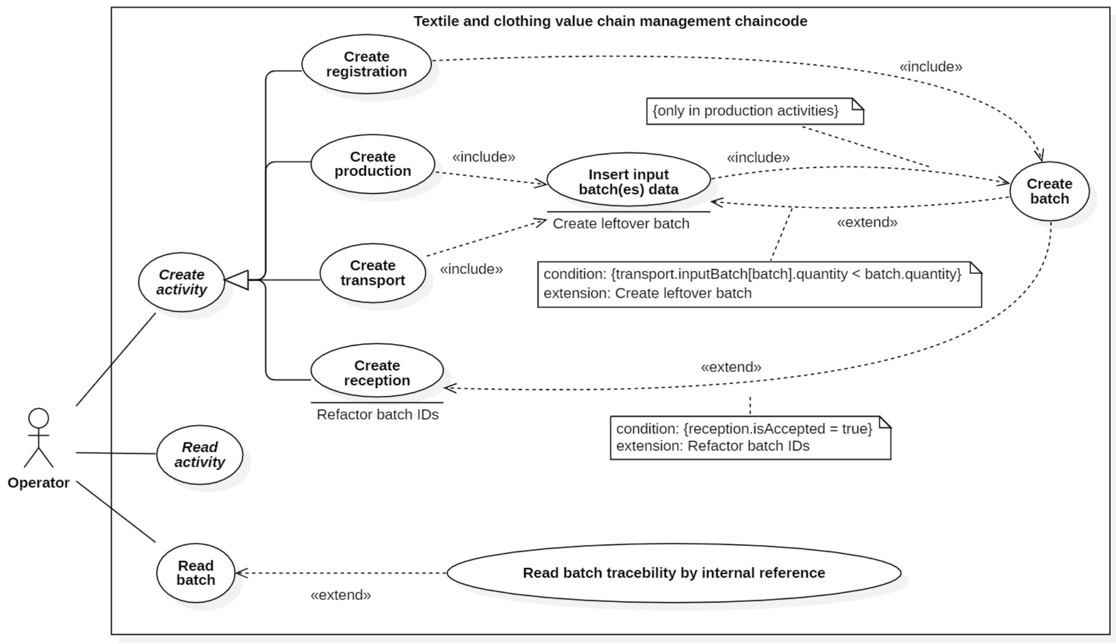

Figure 4.1: Use case diagram of the developed chaincode

next activity for the transported batches must be a reception activity. It's an activity where creating a batch is mandatory only if part of the batch is shipped, to create the leftover batch. The remaining shipping conditions do not require the creation of another batch;

(d) **Create reception** - creates a reception activity in the system. Reception activities are created when a production unit operator wants to log an activity in the system that represents the reception of a batch after a transport activity. It's an activity where creating a batch is mandatory every time the batch is valid and accepted after quality assurance, creating a batch with IDs relevant to the current production unit that owns it. Otherwise, if the batch is not accepted, there's no need to refactor the batch because it will be shipped back to previous production unit (depending on the business process).

2. ***Read activity*** - an operator can read activities to list an activity data given its ID in the system. This abstract use case is similar for every activity type so, unlike *Create activity* above, there is no need to specify it in the diagram.

3. **Read batch** - an operator can read batches to list a batch data given its ID in the system. This abstract use case is similar for every activity type so there is no need to specify it in the diagram.

   (a) **Read batch traceability by its internal reference** - an operator can list just the traceability of a batch given its internal ID / reference in the system. This use case is what operators are expected to use when tracing a batch within their production unit and company, using the internal reference as an identifier for the batch.

The aforementioned use cases were defined taking the requirements above in consideration. To support said use cases, a domain model that can enable and handle the features in those cases needs to be defined, hence the follow subsection 4.1.2.

4.1.2 Domain model

With the system requirements described above, it is now possible to structure the system's data into a domain model. Figure 4.2 shows a class diagram depicting the data model of the chaincode. This figure represents the (on-chain) data to be stored in the blockchain. The programming language used to develop this contract in Fabric is Google's *Go(lang)* which is not a Object Oriented Programming (OOP) language, using structs to model data instead of classes. However, Figure 4.2 reliably represents the data structures and relationships between the defined structs, resulting in a struct diagram instead of a class one.

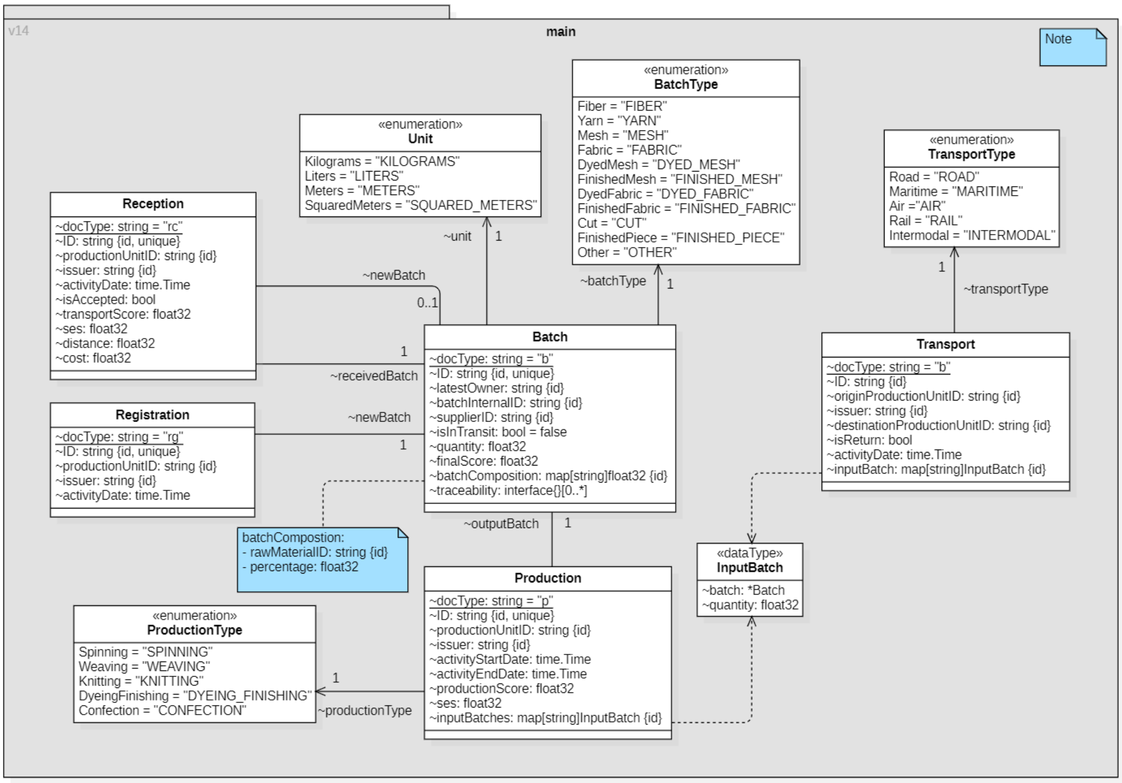

Figure 4.2: Struct diagram of the on-chain data model

The main struct to consider is **Batch**, the digital twin representation of a batch in the value chain. Other structs were defined to digitize the activities within the value chain with activity type granularity, resulting in the definition of **Registration, Production, Transport & Reception**. Other than the enumeration structs to specify default values (**Unit, BatchType, ProductionType, TransportType**), the remaining is a data type definition of **InputBatch**, used in aggregation activities (Production & Transport) where the need of specifying quantities per batch is necessary.

The batch and activities structs have a *docType* attribute to distinguish the object/document definitions in the state database from each other. In this model, single or double character identifiers were used to represent each struct *(b - Batch, rg - Registration, p - Production, t - transport & rc - reception)*. These structs also have an unique composite *ID*, joining the structs' *docType* to a randomized number with a hyphen (-) between both (e.g., *b-001* for batch 001). Some attributes have an {id} tag next to them, to classify them as identifiers from other data structures that are off-chain (e.g., *productionUnitID*), which identifies the production unit that is endorsing the activity transactions that the issuer is invoking. Here are the entities explained in greater detail:

- **Batch** - is the main asset to be tracked on which the value chain operations work on. Besides the aforementioned *docType* & *ID*, the batch definition contains an enumeration struct with default values related to its type *(batchType)*. Regarding off-chain identifiers, batch has attributes to reference the production unit that owns it, supplier and internal batch identifiers for referencing a batch within the scope of a single company - *productionUnitID, supplierID & batchInternalID* respectively. The remaining off-chain identifier is present in *batchComposition*, where a key-value data structure holds the information about what materials and its percentages constitute the batch (e.g., {cotton: 50%, polyester: 50%}). Batch *quantity* and *unit* are self-explanatory, listing the amount and unit of measure of the batch. The attribute *score* is what holds the final score and ranks the batch sustainability claims. The calculations to reach the final score of the batch are made off-chain by other modules of the system, listing just the final value on-chain inside the batch struct. The auxiliary boolean attribute *isInTransit*, with a default value of false upon batch creation, helps to truthfully represent the batch current owner state when it is being shipped between production units. Lastly, the attribute *traceability* being a non-mandatory interface collection data type, can hold any type of data. This attribute will append the activities' "objects" for each activity that a batch goes through, resulting in a recursive collection of activities and its input/output batches throughout the value chain activities until it reaches the current instance of a batch. Visually, this representation results in an inverted tree where the root is the current batch, the straight branches are activities with no aggregation **(Registration, Transport & Reception)** and the branches that split into 2 or more sub-branches are **Production** activities that have 2 or more input batches to merge into an output batch;

- **Registration** - is an activity used when a production unit wants to register a batch that is created outside of the developed system, instead of being created through a production activity, but needs to enter the value chain to be used as an input batch for production activities. It is a simple activity that just has *productionUnitID* to identify the production unit where the batch registration was logged and *activityDate* as a timestamp for the registration, besides the aforementioned *docType* & *ID* attributes. Finally, the newly introduced *batch* needs to be associated with the registration.

- **Production** - is an activity that consumes batch(es) and creates a batch, making it the only activity that can converge the history of one or more batches' with a new batch, by using them as **Input Batches**. These input batches are structured in the *inputBatches* attribute as a key-value pair data type that can hold information regarding a batch pointer reference and the quantity to be used in an activity (e.g., {batchID: b-001, inputBatch: {batch: *b-001, quantity: 100}}). Besides the usual *docType* & *ID* attributes and the aforementioned off-chain identifier of input batches, this struct includes *companyID* & *productionUnitID* to identify the company and its production unit respectively. An enumeration struct with default values related to the production type was also added (*(productionType)*). For timing purposes, *activityStartDate* & *activityEndDate* are timestamps point to the start and finish date and times of the production activity. At last, *productionScore* is a score indicator of the sustainability claims and resources spent in the production activity while *ses* (Social Economic Score (SES)) is related to a rating the company/production unit has relative to its social impact on its workers and operators.

- **Transport** - is an activity used to register a shipment of a batch to another participant in the value chain. To support this functionality, this struct has off-chain IDs for specifying the origin and destination for the transport (*originProductionUnitID* & *destinationProductionUnitID* respectively). The use of **Input Batch** is also present in the attribute *inputBatch* where in this case it only has a cardinality of 1, making it mandatory to include just a single batch in transportation. Even though a shipment may carry more than a single batch, the transaction on-chain to log the transport activity only registers one batch per activity. The reasoning behind this decision is to decouple the batches' traceability in the shipment from each other, maintaining a reliable tracking and tracing of each batch. Other attributes in this struct include predefined data related to its transportation type in *transportType* and *distance* & *cost* for storing the distance of travel and its cost of operation respectively. A boolean *isReturn* attribute with a default value of false is also present to indicate if the shipment is a return transport in case of the destination production unit rejecting the batch upon receiving it (more in **Reception** activity below). Lastly, *activityDate* serves the purpose of logging the timestamp of shipment departure. The date and time of arrival is only registered when receiving the batch, leading up to the activity below.

- **Reception** - is an activity issued upon the arrival of batches to a production unit. This activity is required after a transport activity because the transported batch should be properly received and its quality assessed, to continue through the value chain. Data related to this activity includes the usual *docType* & *ID* attributes and *productionUnitID* as off-chain production unit ID. Receptions must have a *receivedBatch* to reference the batch that was in transport and can have a *newBatch* depending on off-chain quality assurance results. It is necessary to have a boolean attribute as in *isAccepted* for quality assurance purposes, allowing the operators to accept/reject the batch upon reception. If accepted, *newBatch* is created. If rejected, it is not. The reception timestamp in *activityDate* not only does it useful for registering the date and time of the activity but, as previously mentioned, is used to log the arrival date and time of a transport (referencing the last transport activity already happens when appending the transport to the batch's traceability). Last but not least, a *transportScore* & *SES* were added for providing information regarding the environmental and socio-economic sustainability claims of the transport that just arrived to the production unit respectively.

In Fig. 4.2 there are notes in blue in order to explain certain attributes. As an example, for the time-based attributes, Google's Civil Go package was used. It is worth mentioning that registration activities do not have sustainability scores because they're a purely logistic activity that does not affect the areas of impact in those scores. This data model is part of a *main* Go package used to bundle the smart contract to the chaincode.

In order to apply the defined model above to a technological stack, the next section explicitly details the architecture behind the system.

4.2 Architecture / Technological stack

To demonstrate the developed system, Fig. 4.3 illustrates the technological stack architecture proposed for the traceability platform, focusing on the traceability backend and ignoring, here, the client's front-end and integration with other business applications.

Firstly, Fablo is a tool to generate a Hyperledger Fabric blockchain network and run its several components on Docker containers. Fabric is being used as the protocol provider as it is a consortium oriented platform, instead of public or private platforms. Being consortium oriented, it enables the definition of different participant profiles that may respond to the needs of a value chain context. Fablo will also deploy useful containerized tools, like Hyperledger Explorer, to take an in-depth look to on-chain ledger data, and Fablo REpresentational State Transfer (REST), a simple REST Application Programming Interface (API) server, to call Fabric's chaincode methods and provide them to the upper layers. Other components available in a standard Fabric network are the Certificate Authority (CA) containers for registering and enrolling users on the system, as well as tools containers for various auxiliary purposes like the peers' Command Line Interface (CLI).

The Fablo network generation process consists of various stages of file creation and configuration between components, based on a defined configuration file *fablo-config.json*:

1. Reads *fablo-config.json* to detect intended network configuration;
2. Creates crypto material for each defined organization (X.509 certificates, Transport Layer Security (TLS) certificates, SKs in .pem format);
3. Generates genesis block (1st block) for the ordering service;
4. Starts the network containers;
5. Generates configuration for channel and creates it;

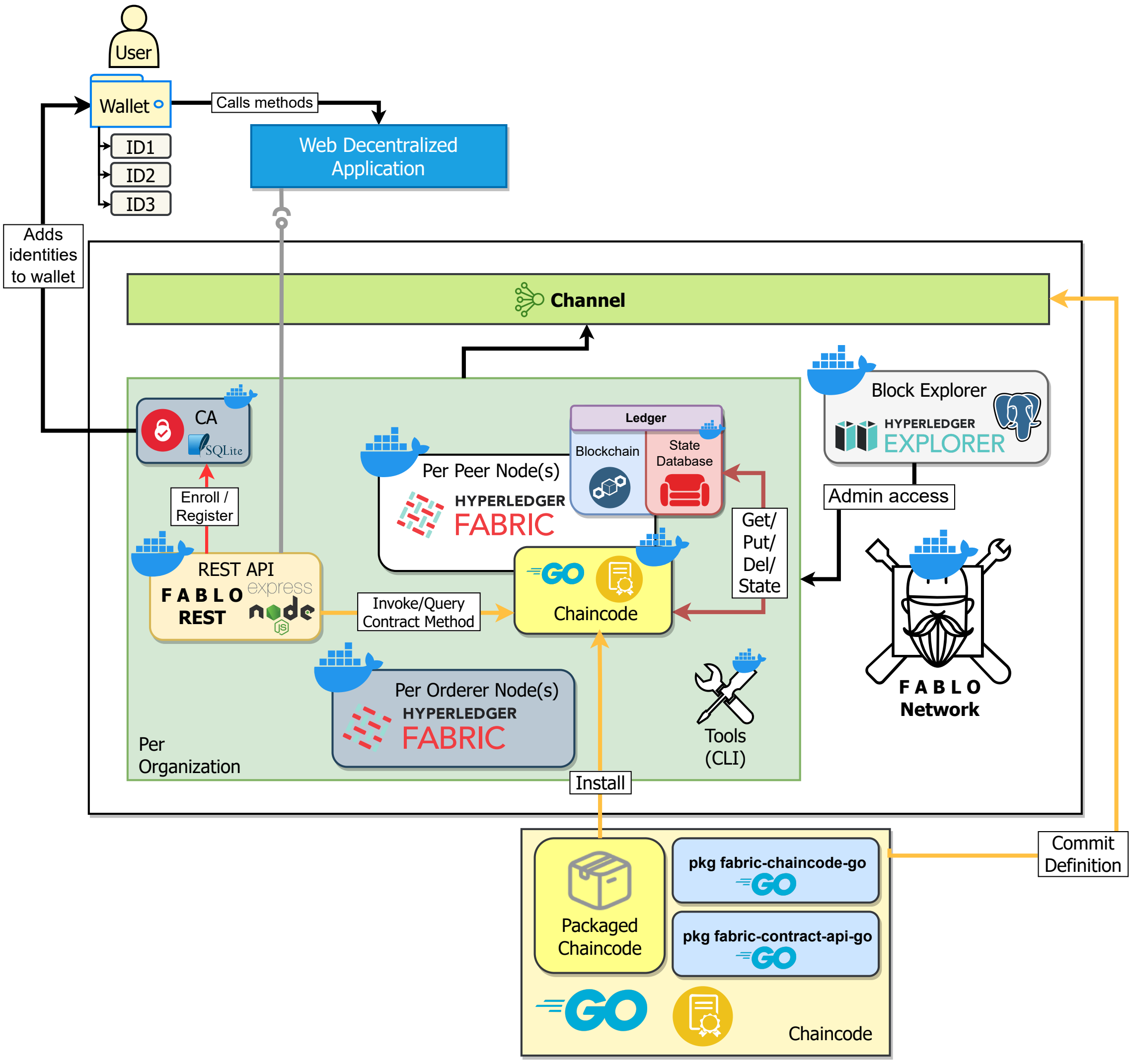

Figure 4.3: Platform architecture

6. Each organization joins intended channel (in this case, just 1 - *stvgd-channel*);
7. Packages chaincode (*stvgd-chaincode*);
8. Installs chaincode in every organization & peer through the organization CLI;

As previously mentioned, the language of choice for developing the smart contract is *Go*, because it is the main supported language in Fabric, and its lightweight low level capabilities make it ideal for smart contract development.

The activity flow of the chaincode development lifecycle is as follows:

1. The developer uses the Hyperledger Fabric's *Go* contract API and chaincode packages to build the chaincode;
2. When a chaincode version is finalized, it is then packaged and installed on the organizations' peers, which will endorse a transaction or query. The chaincode definition must be approved by enough organizations, to pass the lifecycle policy;

3. If the defined consensus, usually a majority, passes within the selected organizations, the chaincode is committed to the specified channel through a transaction.

The activity flow for a user to submit or evaluate a transaction on the client Web DApp is as follows:

1. The user interacts with the web DApp, which makes a request to the Fablo REST API to execute a transaction in the chaincode. This request includes the chaincode method to invoke or query the chaincode, when writing or reading data respectively, as well as the method's arguments.

2. The chaincode, which is installed on every non-orderer peer and channel, directly reads, writes or deletes the assets represented as documents on the CouchDB key-value-based database. This database contains the world state, meaning the latest and up to date representation of the items of the blockchain network's ledger;

3. If the transaction consensus passes, the ledger and the world state database update themselves (if this was an invoke/put transaction). Query/get transactions do not need consensus approval.

4.3 Chaincode

To operate on the previously presented data model, a set of chaincode transaction methods has been defined to support the desired traceability functionality for the platform. The code available for the repository of this developed solution is available in *github.com/lcvalves/stvgd-chaincode*. Table 4.1 presents these methods, which mainly support the management of the batch activities that happen on the T&C value chain as well as reading a batch's information and traceability data. Some arguments are automatically filled, especially those with information regarding the production unit calling the transaction method, as well as the score's data. Other methods need data to be manually inserted such as batches' information, quantities and other information regarding the activity. However, there are a couple of business process constraints regarding some of the methods, more specifically the ones that update or delete any type activity, given that these methods should only be used in emergency situation where human error was the issue behind invoking said method. That being said, those methods are created in the chaincode codebase but are not meant to be used by the operators endorsing transactions in the network.

There are also internal methods for managing the batches' information, to transfer batches' ownership, update quantity and others that have not been listed in Table 4.1. These are methods that are not callable from the defined Fablo REST API, depicted in Fig. 4.3, as these batches should be entirely managed through the aforementioned activity methods.

The asterisk symbol (*) in the output batches of Transport and Reception indicate that the batch has an optional cardinality. On transport activities, when the batch to be shipped is not entirely used it creates a "leftover" batch with the remaining quantity kept in the used one. On reception activities, if the production unit rejects

Table 4.1: Contract transaction methods.

TRANSACTION METHOD	DESCRIPTION	AUTOMATIC ARGUMENTS	MANUAL ARGUMENTS	OUTPUT ASSETS
CreateRegistration	Creates a Registration activity	id, productionUnitID, issuer, activityDate	newBatch	registration, batch
ReadRegistration	Reads a Registration activity by id	-	id	registration
CreateProduction	Creates a Production activity	id, productionUnitID, issuer, activityStartDate, activityEndDate, productionScore, ses	inputBatches, outputBatch, productionType	production, batch
ReadProduction	Reads a Production activity by id	-	id	production
CreateTransport	Creates a Transport activity	id, originProductionUnitID, issuer, activityDate, isReturn**	transportType, destinationProductionUnitID, inputBatch, isReturn**	transport, batch*
ReadTransport	Reads a Transport activity by id	-	id	transport
CreateReception	Creates a Reception activity	id, productionUnitID, issuer, isAccepted**, activityDate, transportScore, ses	receivedBatch, newBatch, isAccepted**, distance, cost	reception, batch*
ReadReception	Reads a Reception activity by id	-	id	reception
ReadBatch	Reads a Batch by id	-	id	batch
TraceBatchByInternalID	Lists the batch and its activities, as well as its previous traceable batches' activities	-	batchInternalID	batch.Traceability

* argument dependent
** activity dependent

the batch it does not refactor its IDs, therefore, it doesn't need to create a new batch for that refactoring process. As stated, on both transport and reception activities, the creation of an output batch is entirely dependent on the activity's arguments, hence the optional cardinality. Double asterisk (**) regards the presence of the boolean attributes of *isReturn* and *isAccepted* in both automatic and manual arguments in Transport and Reception activities respectively. This happens due to the arguments having an automatic default value of false which can be manually set to true, hence both attributes being in both columns in Table. 4.1.

To further demonstrate the assets management and Business Logic Layer (BLL) behind the transactions, Fig. 4.4 depicts the validation on each method that issues an activity with an activity diagram. Simple field validation was left apart for this diagram due to sizing concerns. However, it indicates the creation of batches and what arguments and conditions, if met, that define the path of issuing the creation of assets or encountering a validation error.

The algorithm below shows the pseudocode representation of the **CreateProduction** method. This method has a series of verifications and validations that it needs to go through to maintain the data integrity between the batches and their respective activities. These can be data constraints, relative to the used quantities in the production activity, or simply identifier integrity conditions, among others.

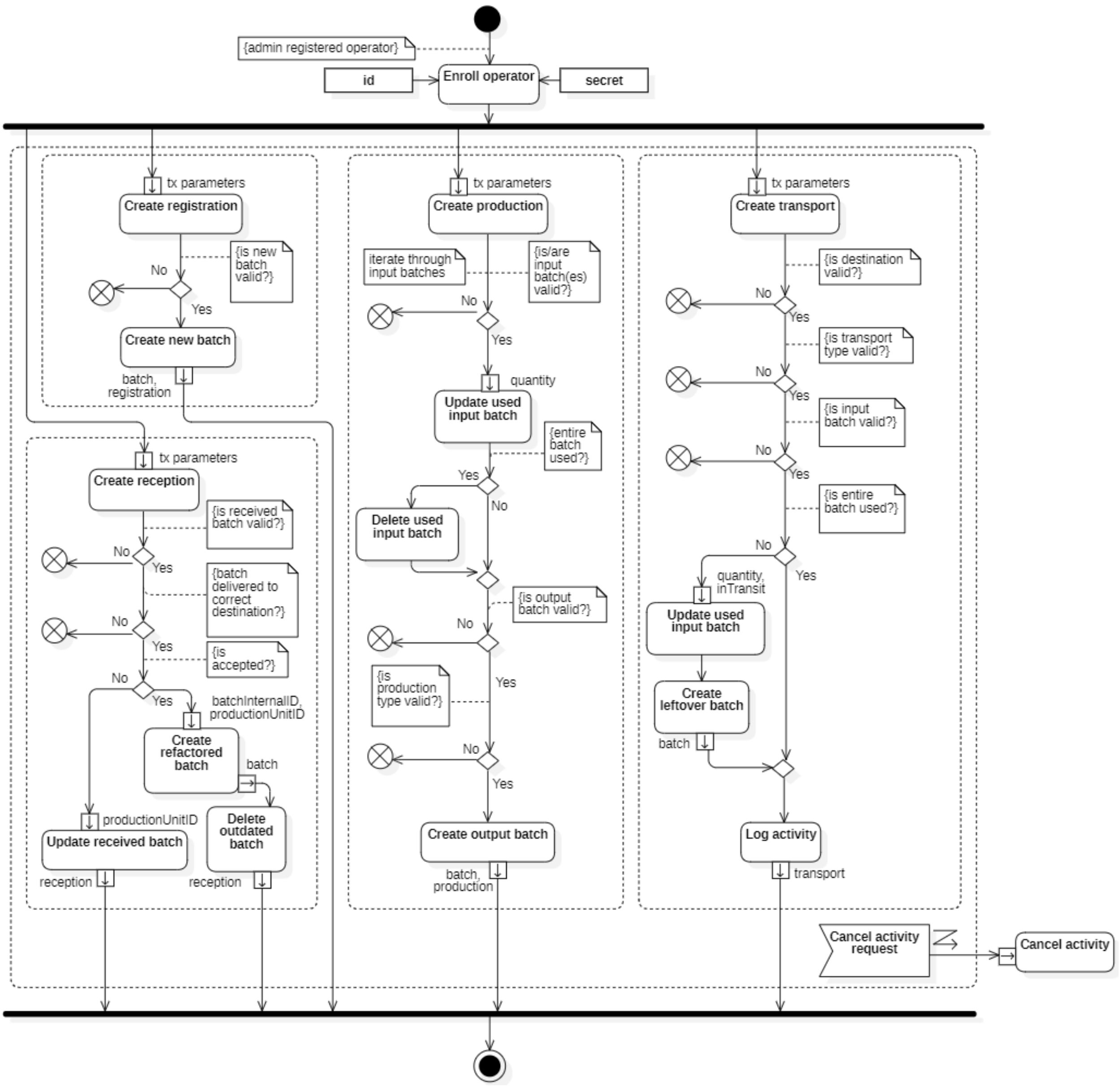

Figure 4.4: Creation (put state) transactions activity diagram

Algorithm 1: CreateProduction pseudocode

```
Input: (automatic and manual arguments of CreateProduction from Table 4.1)
Output: production
if outputBatch exists then
|   throw "batch already exists" error
end
if production exists then
|   throw "production activity already exists" error
end
if production.ID
 ≠ outputBatch.production.ID || productionUnitID ≠ outputBatch.productionUnitID then
|   throw "missing info integrity with the output batch" error
end
// Audit inputBatches data
if 0 inputBatches inserted then
|   throw "must have at least 1 input batch" error
end
foreach batchID, quantity in inputBatches do
|   if batchID does not exist then
|   |   throw "batch does not exist" error
|   end
|   batch = readBatch(batchID);
|   // Validate inserted quantities
|   // (0 ≤ quantity ≤ batch.quantity)
|   switch quantity do
|   |   case ≤ 0 do
|   |   |   throw "input batches’ quantities must be greater than 0"
|   |   end
|   |   case > batch.quantity do
|   |   |   throw "input batches’ qty must not exceed each batch qty"
|   |   end
|   end
|   updateBatchAmount(batchID, batch.quantity-quantity)
end
createBatch(outputBatch);
PutState(production);
return production
```

Chapter 5

Eco-gamified B2C2C consumer dApp

With the previous information in mind, this section conceptualizes a **Circular B2C2C Eco-Gamified Consumer DApp for the T&C value chain**, linking the consumer business model activities in section 2.3.2 with the gamified features developed according to the GDH framework. Then, a use case diagram for the eco-gamified DApp is presented, in subsection 5.2.1, to identify the user operations on the application, and a domain model is proposed, in subsection 5.2.2, defining the entities and their associations, which are able to support the user operations depicted in the use case diagram, that gamify most of the consumer activities present in the business process model. Lastly, in section 5.3, the justification of the proposed eco-gamified model's structure based on the GDH framework implementation is presented, making sure that the DApp and its model hit the selected heuristics, followed by the mockups in section 5.4.

To support the circular business process model previously presented, an application for the final consumers is proposed as a proof-of-concept, in this section. The premise of this application consists on the consumers interacting with the system through a mobile application, unlike the business operators which interact with the system through their own proprietary applications, consuming a service layer linked to the consumer's app. A technological stack isn't here defined, with the intent of allowing this architecture to be used in various systems and technologies. Nevertheless, the use of blockchain technology is proposed to, independently from any business partner, record and trace B2C2C transactions in the eco-gamified consumer DApp [12].

As explained in [13], the data collected for each activity of the value chain is stored on the blockchain, as way to guarantee trustless transparency, immutability and decentralization among the value chain operators. A blockchain wallet system for identification and asset management is proposed for supporting the garment's digital twin transfers between consumers. In this B2C2C scenario, this application will be used in the C2B and C2C activities depicted in the BPMN model in Fig.2.4.

When doing these activities, consumers need to be registered in the DApp, where they can complete challenges, get rewards and achievements, interact with other users and compete with other users for a sustainable future in the T&C value chain.

As an example, let us consider the "Sell/Rent the product" activity from the BPMN process model. When a consumer registers the transfer between users, and identifies the new owner, the latter has to confirm the transfer by identifying the garment's tag. When the transaction is confirmed and the transfer is complete, both users will receive rewards, earn badges, complete achievements and climb the multiplayer leaderboards because they took on an ecological approach instead of buying and discarding clothes.

By maintaining a digital twin replica of the garments in the DApp and registering their lifecycle activities, while in the consumer's use phase, they will be motivated by positively contributing to the T&C value chain by participating in a circular economy model where they get a benefit from it. When the items are sold from consumer to consumer, they are kept in the circular economy, and their life is extended, instead of being discarded.

5.1 GDH implementation

From the main dimensions of the frameworks reviewed in the previous section, Table 2.3 presents a comparison (adapted from [231]) with the aim of specifying the set of dimensions of motivational features that those gamification frameworks have. With that set of 12 dimensions, a new set of 28 heuristics has been defined and categorized to hit those dimensions. These heuristics are split into three categories, namely Intrinsic motivation, Extrinsic motivation, and Context-Dependent Heuristics. Table 5.1 shows how this framework may be used, by providing multiple gamification resources, focusing on the different motivation heuristics. A big part of the solutions provided are suggested from [119], where the same framework, although with less heuristics, has been implemented on an eco-gamified context. Here, it was added another set of solutions to complete the missing ones in the entire list of heuristics. Going through the table with the GDH implementation on B2C applications for textile CE, we have:

Intrinsic motivation relates to the internal needs defined in SDT as well as other factors present in SDT's literature [60, 199, 198]. This category includes the following dimensions: *Purpose & Meaning, Challenge & Competence, Completeness & Mastery, Autonomy & Creativity, Relatedness and Immersion*. The items in the list below represent each Intrinsic Motivation Heuristic (IMH) (refer to the first part of Table 5.1):

- **IMH1.** No resources needed because the gamified context is built to a purposeful sustainable textile future;
- **IMH2.** Like IMH1, the app's domain revolves around a textile circular mindset and provides with information for the users to make a self-made decision to contribute;
- **IMH3.** With a difficulty adjustable challenge mechanism based on how experienced the user is, it's possible to provide new engaging missions/quests;
- **IMH4.** The first steps in the app should be easy for the newcomers so that they don't get "lost" and overwhelmed when first experiencing the system;
- **IMH5.** Creation of harder challenges for self-improvement;

- **IMH6.** A simple leveling system for comparison with other users and motivation;
- **IMH7.** Progress bars and achievement badges are used for completeness purposes;
- **IMH8.** Users are able to choose which unlockables they want to use;
- **IMH9.** With the ability to customize their personable banner and avatar, the users can create new content.;
- **IMH10.** Different garments can be recycled and re-used in the system so users can experiment the circular mindset on various textile products;
- **IMH11.** Multiplayer challenges (cooperative or competitive) provide the needed interaction for relatedness;
- **IMH13.** Competitive challenges bring the more intense competition and extra motivation to achieve circularity;
- **IMH14.** By having different tier rankings, new users can experience winning and thus, have an opportunity of succeeding in the system.

Extrinsic motivation is for heuristics that produce a certain outcome decoupled from what the player is doing [198, 44]. This category includes the following dimensions: *Ownership & Rewards, Scarcity and Loss Avoidance*. The items in the list below represent each Extrinsic Motivation Heuristic (EMH) (refer to the scond part of Table 5.1):

- **EMH1.** Ownable content (custom banners / avatars / badges) brings the ability to possess virtual items;
- **EMH2.** By having points related to user experience and a leveling system and e-cash, the gamified app rewards users actions';
- **EMH3.** These aforementioned e-cash should be used to get other in-game goods;
- **EMH4.** With the use of a kind of in-game lottery system or "wheel of fortune", which rewards users with items of different rarities, the app can bring the feel of scarcity to motivate the players;
- **EMH5.** Setting an expiration date on a challenge creates the FOMO effect (Fear Of Missing Out).

Context-dependent heuristics can be either intrinsic or extrinsic depending on the context like *Feedback* for example. This category includes the following dimensions: *Feedback, Unpredictability and Change & Disruption*. The items in the list below represent each Context-Dependent Heuristic (CDH) (refer to the third, and last, part of Table 5.1):

- **CDH1.** A way to keep users engaged is to provide feedback with push notifications, so that they immediately know information about their current activities;
- **CDH2.** The way CDH1 provides feedback for users current activities, the same should be done for their next and future activities;
- **CDH3.** A progress indicator like a bar is a way of visualizing how much it's needed to get to the next step;

- **CDH4.** The application should provide different challenges on various cyclical and random patterns to avoid monotony;
- **CDH5.** The same concept of heterogeneity present in CDH4 should be applied to the reward and lottery system.
- **CDH7.** Automatic validation systems and anti-cheating features can bring integrity to the data and consequently, to the application.

Table 5.1: GDH implementation on textile CE B2C applications.

Intrinsic Motivation Heuristics		Framework Implementation
Purpose and Meaning		
IMH1. Meaning	Identification of meaningful contribution	Contributing for a greener and sustainable future
IMH2. Information and Reflection	Information and reflection towards self-improvement	Incentivizing for a textile circular mindset
Challenge and Competence		
IMH3. Increased Challenge	Challenges that grow with users' skills	Difficulty adaptability
IMH4. Onboarding	Challenges for newcomers	Easy challenges for newcomers
IMH5. Self-challenge	Discover or create new challenges	Complete achievements & join multiplayer challenges
Completeness and Mastery		
IMH6. Progressive Goals	Next goal achievable is presented	Leveling system
IMH7. Achievement	Monitoring of achievements or advancements	Challenges progress bar and badges
Autonomy and Creativity		
IMH8. Choice	Possibility to make choices, limited by users' abilities	Different usable rewards
IMH9. Self-expression	Create new content	Customizable personal banner and avatar frame
IMH10. Freedom	Possibility of experimenting without serious consequences	Experimenting with different clothing and challenges
Relatedness		
IMH11. Social Interaction	Possibility to connect with others	Multiplayer challenges
IMH12. Social Cooperation	Possibility to work with others to achieve a common goal	-
IMH13. Social Competition	Possibility to challenge or compare with others	Competitive challenges and leaderboards
IMH14. Fairness	Opportunities to success and progression also for newcomers	Partial leaderboards and Tier rankings
Immersion		
IMH15. Narrative	Meaningful story	-
IMH16. Perceived Fun	Possibility to interact and be part of the story	-

Extrinsic Motivation Heuristics		Framework Implementation
Ownership and Rewards		
EMH1. Ownership	Possibility to possess virtual goods or build a profile over time.	Unlockable usable content
EMH2. Rewards	Reward system to incentive interactions and continued use.	Badges, Coins, XP & other metrics
EMH3. Virtual Economy	Results can be exchanged for in-system and outside rewards.	Points translate in higher positions in the leaderboard Association to external real-world rewards like coupons
Scarcity		
EMH4. Scarcity	Presence of rare rewards or items.	Rarity tiers on rewards
Loss Avoidance		
EMH5. Loss Avoidance	Urgency to act immediately to avoid possible losses.	Timed multiplayer challenges and challenge expiration date

Context-Dependent Heuristics		Framework Implementation
Feedback		
EMH1. Clean and Immediate Feedback	Immediate feedback of changes or accomplishments.	Push notifications
EMH2. Actionable Feedback	Information on the next available action.	Push notifications
EMH3. Graspable Progress	Information on the users' path ahead for progression.	Progress bars
Unpredictability		
EMH4. Varied Challenges	Heterogeneity of the task presented	Diverse challenges, both single-player and multiplayer
EMH5. Varied Rewards	Heterogeneity of the rewards offered.	Different usables, badges and rewards in the lottery system
Challenge and Disruption		
EMH6. Innovation	Possibility to contribute with ideas and content for the users.	-
EMH7. Disruption Control	Cheating control.	Automatic validation system.

Thus, from tables 2.3 and 5.1, one may conclude that the most suitable gamification framework to implement in a textile CE traceability is GDH [231], due to its high coverage of gamification dimensions, through categorized motivation heuristics.

5.2 System modelling

5.2.1 Eco-Gamified Use Case Diagram

The use case diagram presented in Fig. 5.1 shows what the actors, mostly consumers, can do on the application. Reading from top to bottom, the diagram contains use cases related to game data interaction, in the top half of the consumer use cases and, in the bottom half, it consists mostly of garments' data and respective transactions.

A consumer/player can use rewards gained from interacting with the gamified DApp. This includes redeeming coupons from retailers participating in the DApp's economy, and using those rewards as virtual wearables to customize their in-game user profile. These rewards can be obtained by completing challenges and achievements that can be completed by interacting with the DApp, by buying them with in-game e-cash or by redeeming them in a lottery system. Regarding a garment's data, a consumer can edit its information, check its traceability and discarding it, even though this would negatively impact the player in the DApp system. When transferring the garment between consumers, the new owner can provide its wallet identifier and the previous consumer can read it. When confirming this transfer, the new owner can also read the garment's identifier tag. Another actor in the system, who can also read the garment's tag, is a business operator, such as a retailer, when a consumer returns a product. It can also read a consumer's identifier to register a transaction when an item is sold or rented.

With this gamification structure theorized, one can now define a model to support these gamified features that reward an active participation in the DApp and, consequently, the T&C circular economy.

5.2.2 Eco-Gamified Domain Model

In Fig. 5.2, an eco-gamified UML domain classes model is depicted. The model is divided into three sections, with distinct color-coded areas, which represent three different subjects regarding the proof-of-concept B2C DApp, with which participants (incl. consumers, retailers and other operators besides the B2B environment) can interact.

There are also some relevant User Game Data & Metrics defined to create a more game-like experience:

- **Levels & eXperience Points (XP)** - Users can gain XP by completing and / or winning Challenges. Users need a minimum XP level to unlock certain Rewards (Aesthetic & Coupons);

- **Coins (in-game e-Cash)** - Users are able to purchase Rewards (Aesthetic & Coupons) with in-game Coins to customize their profile. Users can get Coins by completing and / or winning Challenges;

- **Circularity Score (CS)** - The CS is a metric that measures the total sum of CS of each owned clothing item related to its circularity index + CS of eco-friendly auditable actions on these assets;

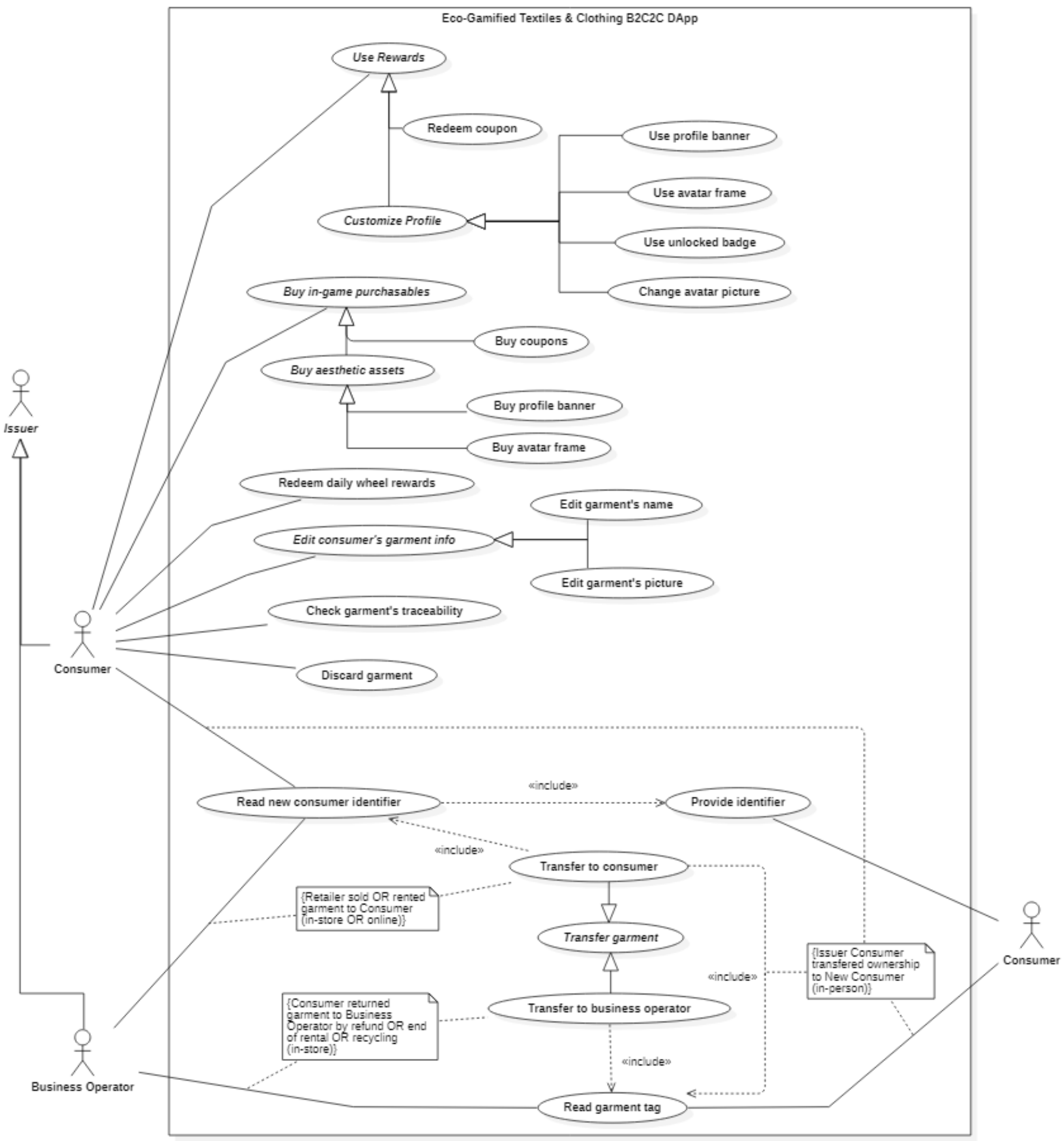

Figure 5.1: Eco-gamified Consumer DApp Use Case Diagram

The three areas specified in the model are Gamification Structure, User Data, and Traceability Data. Some entity classes are related to two of these topics due to some attributes making the connection between different areas of concept. The entity classes are the following:

- **Reward** - A game asset rewarded to the user for completing Challenges. Some of these can also be bought in the in-game store with in-game Coins (Purchasable items);
  - **Purchasable** - A type of reward that can also be purchased with Coins restricted by the user's XP Level and/or CS. These purchasables have a rarity field;

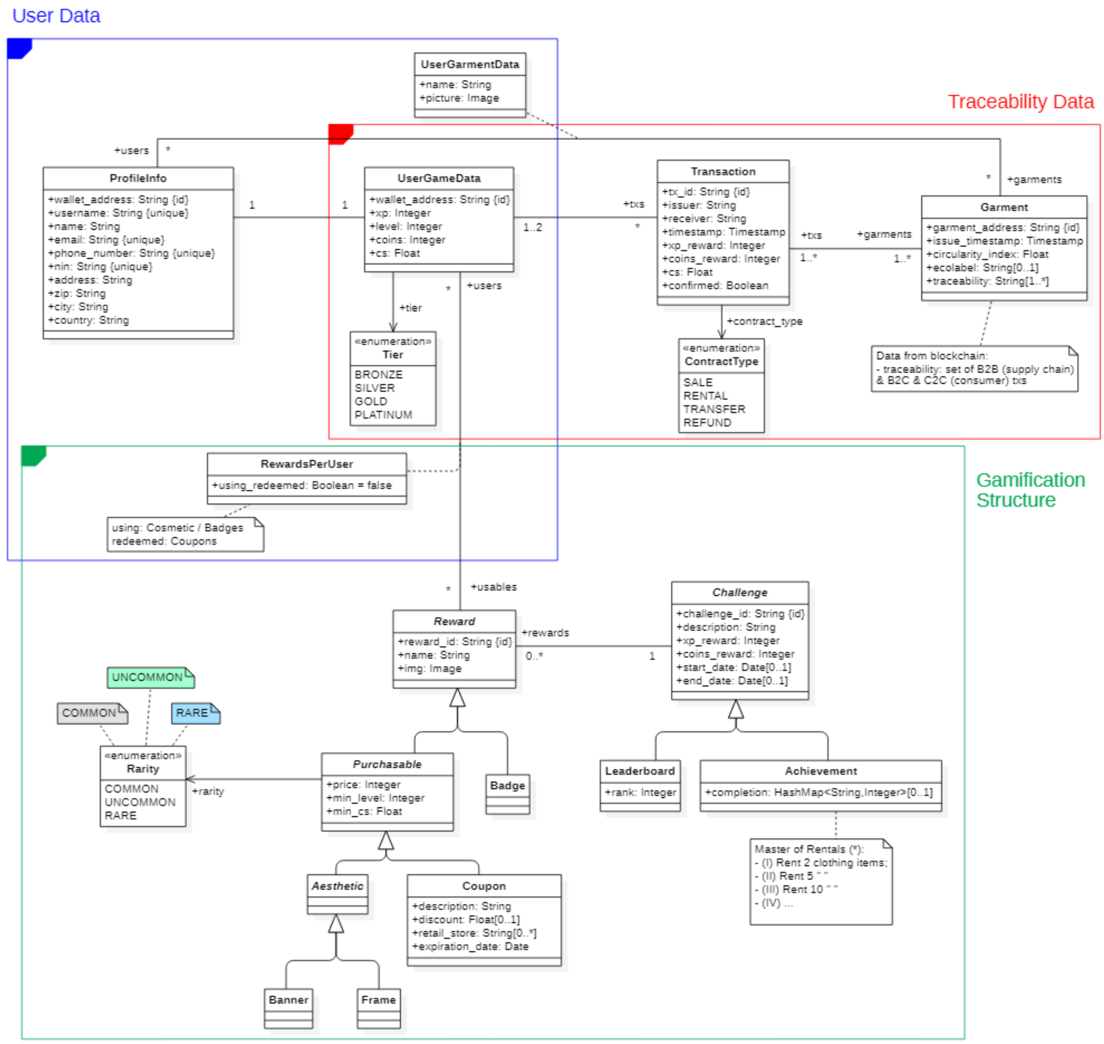

Figure 5.2: Eco-gamified consumer DApp domain model

∗ **Aesthetic** - A type of Purchasable that is merely aesthetic for the users to customize their profile;
  · **Banner** - A type of Aesthetic usable to add to the background of a user profile;
  · **Frame** - A type of Aesthetic usable to frame the user's profile avatar;

∗ **Coupon** - A type of Purchasable that provides a discount coupon at an available / participating retailer;

– **Rarity** - Enumeration field to describe the rarity of a Purchasable, increasing in rarity:
COMMON → UNCOMMON → RARE;

– **Badge** - A type of Reward that can only be given by completing Challenges. Users may use one of these badges to display in their profile page;

• **Challenge** - An activity, on which a user can participate, complete and get rewarded by completing it successfully (either Rewards and/or XP & Coins). There are single-player (Achievements) & multiplayer (Leaderboards) challenges;

  - **Achievement** - These are single-player multi-level challenges that are based on the user activities (i.e. Transactions) that are multi-leveled meaning that you can complete the same challenge in a higher "difficulty";
  - **Leaderboard** - These are time-based multiplayer challenges that compare user's metrics (i.e. CS) and rank them accordingly on a specified time frame;

- **Rewards Per User** - The active Rewards that the user claimed/is using/redeemed. The boolean field *usingOrRedeemed* acts as a validation & verification tool for the Badges & Aesthetic Rewards being used in the user profile as well for indicating which Coupons the user has redeemed due to the latter having an expiration date;
- **Profile Info** - Data related to Know Your Customer (KYC) information (username, email, phone number) identified by a wallet address;
- **User Game Data** - Data related to in-game metrics & scores (XP & Level, Coins and CS) directly associated to Profile Info on a one-to-one relationship;
- **User Garment Data** - User custom info related to an owned garment (custom picture & name) identified by the garment & user address;
- **Transaction** - Data related to a Garment(s) transaction between two participants on the network, either two consumers or between one consumer and one business operator (hence the 1..2 cardinality on User Game Data on the one/two-to-many relationship). This cardinality is restricted regarding the Transaction's Contract Type - PURCHASE or REFUND(1), RENTAL or TRANSFER(1..2);
- **Contract Type** - Enumeration type class to define the contractual type of Transaction;
- **Garment** - A garment model definition equivalent to the identified digital twin of the piece of clothing in the B2B value chain network. This provides data relative to the garment's circularity index as well as an ecolabel & its traceability transactions (either B2B or B2C). Multiple garments can be added to multiple Transactions in the DApp (many-to-many relationship), however it may be a single transaction per garment process in the backend, if we were to use a blockchain-based transaction process.

5.3 Game elements

To demonstrate which DApp components represent the gamified features implemented in Table 5.1, the mapping between the defined heuristics and their implementation in the aforementioned eco-gamified domain model (in Fig. 5.2) and other system components has been represented in Table 5.2.

As seen in Table 5.2, several components, like the domain model defined in section 5.2.2, the DApp's User Experience/User Interface (UX/UI) scope, and other architectural features, support the conceptual structure of GDH's implementation, previously mentioned in section 5.1.

Since most of the features are supported by the Domain Model, Table 5.2 has a column indicating which classes and attributes have been defined to allow the respective heuristic's feature. So, as an example, we have the intrinsic motivation heuristic **IMH4**, where *Easy challenges for newcomers* would be supported in the Domain Model by defining attributes in an instance of the UserGameData entity, to classify the consumer's ranking by its XP and, therefore, its level. The Challenge entity is also linked to this gamified feature, because users complete challenges that have a defined difficulty based on the consumer's experience with the DApp, making it possible to effortlessly complete a set of challenges in the beginning phases of the DApp's use, increasing difficulty as the consumer progresses through the "game".

5.4 Mockups

To demonstrate the UX/UI context of an use case in action, Figure 5.3 shows the in-DApp screen mockups for two consumers transferring a garment between them. The mockups in the top row show the previous owner's perspective, while the bottom row shows the new owner's screens. The screens' timeline goes from left to right. Firstly, the previous owner selects which garment it intends to transfer, then scans the new owner's identifier (here represented with an QR Code). After the new owner's identification, the previous owner will issue the transfer and the new owner needs to confirm it on their side. To confirm it, the new owner can access a menu with pending transfers and select the one they needs to confirm. This process relies on a garment confirmation as well, so the new owner needs to scan the garment's identifier tag to confirm that it now owns the product. After the confirmation is processed, the new owner receives rewards because an activity that supports the circular economy in the T&C value chain has just been completed. The previous owner will also receive rewards when the garment is identified by the new owner, because his/her participation in this activity was just as important as the participation of the new owner.

The aforementioned use case can cover a lot of the heuristics and means to achieve them, represented in table 5.1, in several realms such as rewards, interaction with other players, competitiveness through challenges, rankings, player progression and others. This is just one representative use case where we can validate that a set of heuristics is supported by the defined eco-gamified domain model in Fig. 5.2.

Table 5.2: GDH implementation class definition.

Heuristic	Implementation	Supporting Component(s)	Defined Classes and [Attributes]
IMH1	Contributing for a greener and sustainable future	Mobile DApp scope / context	N/A
IMH2	Incentivizing for a textile circular mindset	Mobile DApp scope / context	N/A
IMH3	Difficulty adaptability	Domain Model	UserGameData [XP, Level]
IMH4	Easy challenges for newcomers	Domain Model	UserGameData [XP, Level] Challenge
IMH5	Complete achievements and join multiplayer challenges	Domain Model	Challenge (Leaderboard, Achievement)
IMH6	Leveling system	Domain Model	UserGameData [XP, Level]
IMH7	Challenges progress bar and badges	Domain Model	Achievement [Completion]
IMH8	Different usable rewards	Domain Model	UserGameData [Usables], Reward
IMH9	Customizable personal banner and avatar frame	Domain Model	Aesthetic (Banner, Frame)
IMH10	Experimenting with different clothing and challenges	Domain Model	Reward, Challenge
IMH11	Multiplayer challenges	Domain Model	Challenge
IMH12	N/A	N/A	N/A
IMH13	Competitive challenges and leaderboards	Domain Model	Challenge
IMH14	Partial leaderboards and Tier rankings	Domain Model	Challenge
IMH15	N/A	N/A	N/A
IMH16	N/A	N/A	N/A
EMH1	Unlockable usable content	Domain Model	UserGameData [Usables], Reward
EMH2	Badges, Coins, XP and other metrics	Domain Model	UserGameData [XP, Level, Coins, CS], Badge
EMH3	Points translate in higher positions in the leaderboard Association to external real-world rewards like coupons	Domain Model	Leaderboard [Rank], Coupon
EMH4	Rarity tiers on rewards	Domain Model	Rarity
EMH5	Timed multiplayer challenges and challenge expiration date	Domain Model	Challenge
CDH1	Push notifications	Architectural Feature	N/A
CDH2	Push notifications	Architectural Feature	N/A
CDH3	Progress bars	Mobile UX/UI	N/A
CDH4	Diverse challenges, both single-player and multiplayer	Domain Model	Challenge
CDH5	Different usables, badges and rewards in the lottery system	Domain Model and Architectural Feature	Reward
CDH6	N/A	N/A	N/A
CDH7	Automatic validation system	Architectural Feature	N/A

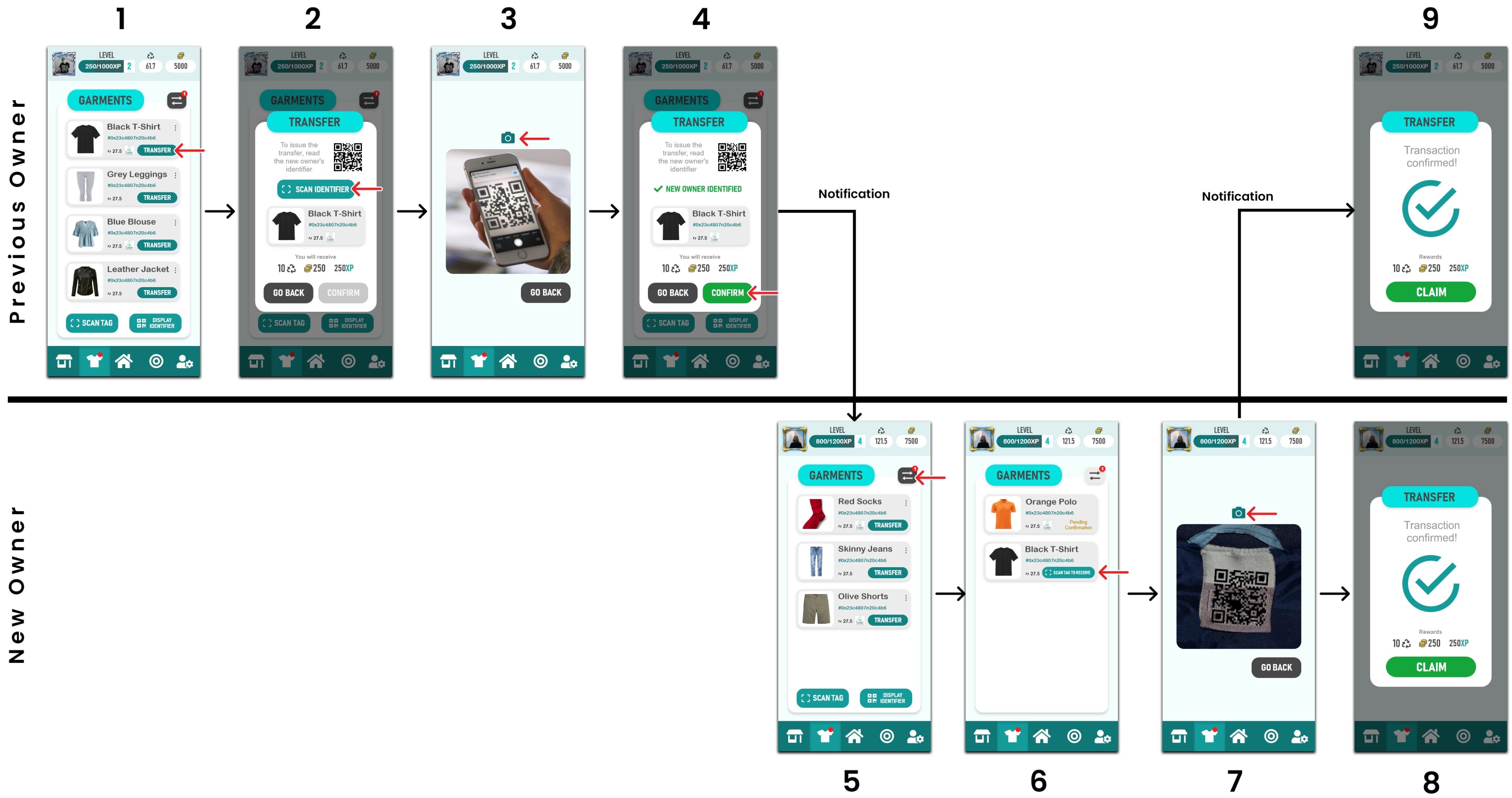

Figure 5.3: C2C garment transfer use case mockup demonstration

Chapter 6

Analysis and discussion

6.1 Demonstration

To better understand how the platform provides features to support the traceability of sustainability indicators of batches and activities, Fig. 6.2 provides a hypothetical use case scneario of a T&C business process with some of STVgoDigital's pilot entities *(Inovafil, A. Sampaio, Tintex and TMG)*. These companies can have 1 or more production units (identified as *<companyMSPID>:PU<number>* in the diagram) and, in this scenario, they collaborate to create a batch of black T-shirts. The diagram reading does not need to follow a linear timeline because many batches and activities may not be sequential.

The use case may be read as follows:

- *Inovafil* receives two batches from a participant outside the platform consortium and issues two **Registration** activities to register both batches (cotton and polyester);
- *Inovafil* then issues a **Production** that uses the newly registered batches to produce a yarn batch. The entire batch of polyester is used in this production as well as the cotton one. The system responds to this by deleting both the polyester batch and cotton batch from the state database caused by the update of the batches' quantity to 0. If a batch were not to be fully used, the remaining batch quantity would be updated;
- Then, *Inovafil* issues a **Transport** activity to ship the half of the newly produced batch of yarn to *A. Sampaio*. As stated above, since the batch is not fully used, a new batch is created to ship the intended yarn and the remaining batch's quantity is updated;
- *A. Sampaio* receives the batch by issuing a **Reception** activity, indicating if the batch passes the quality assessment conditions set by the consortium or production unit for that type of product. A "new" batch is created to represent the shipped batch inside the production unit's system, deleting the latter. If it is not accepted, the aforementioned creation/deletion of batches does not happen. Linking these batches through activities serves the purpose of properly tracing the batch's movement through the value chain;

- After that, the processes similarly repeat themselves until the creation of the final batch of black T-shirts. *A. Sampaio* uses the received yarn to produce a batch of fabric, issuing a **Production** activity to do so;
- Then it ships, with a **Transport** activity, the produced batch to *Tintex*. *Tintex* assesses the batch and accepts it with a **Reception** activity;
- For its next **Production** activity to dye the fabric with black paint, *Tintex* had to input the batch of paint with a **Registration** activity sometime in the past or just before creating a batch of black fabric;
- Finally, it ships the black fabric batch with a **Transport** activity to *TMG* Lastly, *TMG* is in charge of issuing confection (**Production** activities) in this business process to produce the final product, but before it must log the **Reception** of said the black fabric batch that it had just received.

Other value chain operations may be issued, different from the ones in Fig. 6.2, but as long as the batches that are produced inside the system have a **Production** activity related to them or, on the other hand, batches that are produced outside the system firstly pass through a **Registration** activity, and there are **Transport** and **Reception** activities respectively when changing production units, the platform is trustworthy and compliant for traceability purposes.

A production unit may also partially or fully return a batch, due to the criteria defined when issuing the reception activity and this would imply a return to sender transport activity, which would add to the sustainability score of the batch.

Considering the traceability diagram in Fig. 6.2, the top row contains batches that are registered in the system (through registration activities) but are not produced inside the value chain consortium. These batches usually come from suppliers at the early stages (e.g., fiber producers) but can also represent other accessory items. The third row is similar but only containing the batches that are produced from within the value chain operators. A defining characteristic, regarding the attribute differences in these two rows, is that batches in the top row don't have a production activity ID associated with it, while the ones in the third row have. Lastly, the middle row represents the activities logged in the platform that operate with the batches (registration, production, transport and reception) through aggregation/disaggregation and logistical needs. The bottom row simply states the batch's current owner in the diagram.

The traceability (inverted) tree visualisation can be found in Fig. 6.1. The tree is horizontally split in the figure for better visualization, with its root on the left side of the image. In the top left is the traceability of the batch that is queried to track and trace (considering the black t-shirt use case scenario, it is the batch with ID *b-010*) and further down it decomposes into branches by its input/output batches throughout the value chain activities until we get to the leaves, corresponding to the end of the tree in each branch. The utility tool used to visualize this traceability data is JSON Crack, available at jsoncrack.com.

To demonstrate batch aggregation on production activities, Fig. 6.1 has a blue border rectangle to focus on the production activity *p-001*, where it uses 100KG of batch *b-001* and 100KG of batch *b-002* as input batches, resulting in the output batch *b-003*.

TraceBatchByInternalID("b-010-iid")

Response: →

Figure 6.1: Black T-shirt use case scenario traceability tree visualization

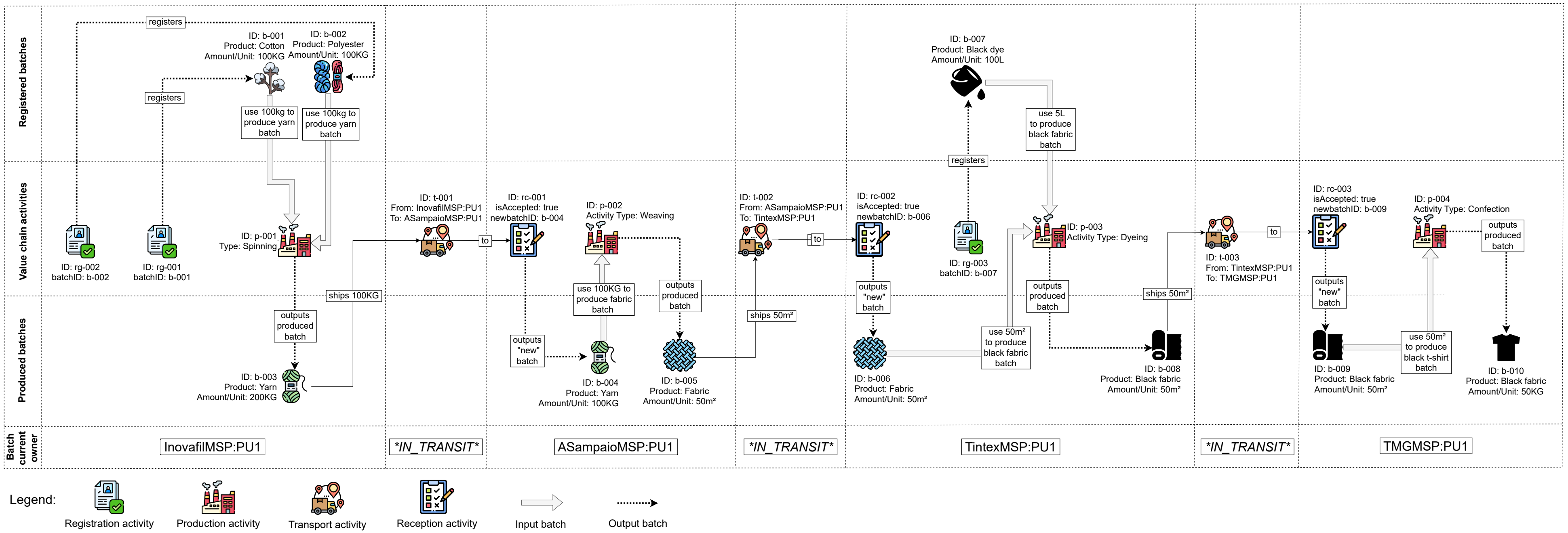

Figure 6.2: Black T-shirt use case scenario traceability diagram

The following figures (Fig. 6.3, Fig. 6.4 and Fig. 6.5) are provided by Hyperledger Explorer, the on-chain block explorer with details regarding the transactions and blocks stored in the ledger's blockchain. This is a useful tool to visualize the low-level functioning of the distributed ledger component of the system.

Fig. 6.3 displays the dashboard for the enrolled organization administrator in Hyperledger Explorer. As we can see, it provides the blockchain data to analyze on charts, graphs and counters.

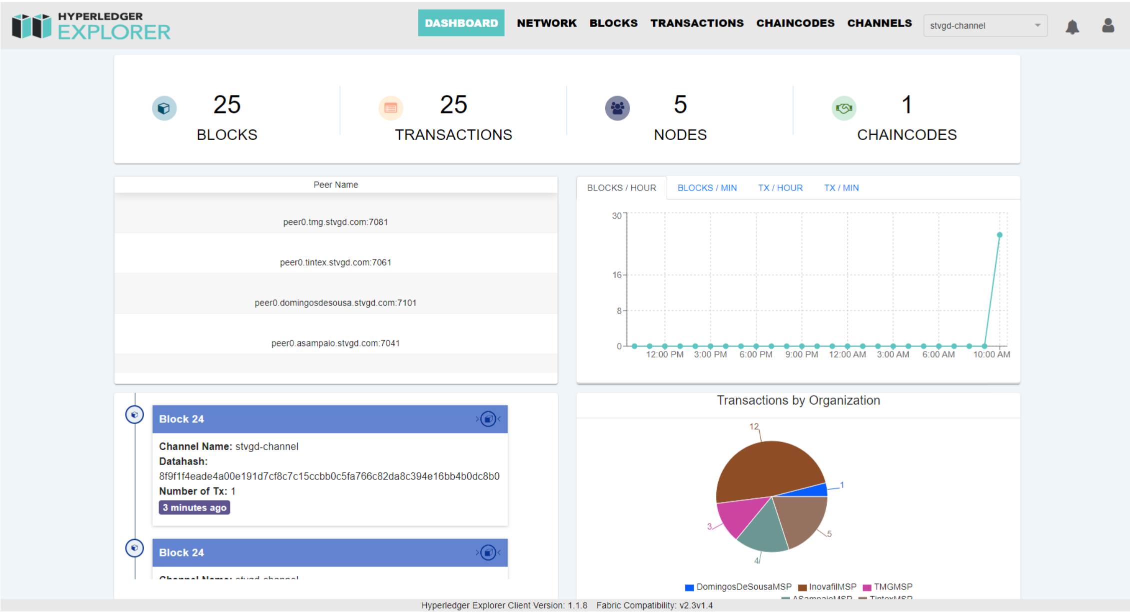

Figure 6.3: Hyperledger Explorer dashboard

In Fig. 6.4, a list of transactions, identified by their hash, is displayed and ordered by the their latest transaction timestamp (descending order by date). Several fields related to those transactions are also listed, including the issuing organization, the channel name, the type of transaction and the chaincode from whence it was issued from.

Let's take a closer look at the latest transaction issued by TMG, hovered by the mouse cursor in Fig. 6.4. This transaction regards the creation of production *p-004* that uses the totality of batch *b-009* to produce batch *b-010*. In Fig. 6.5 it is possible the analyze the details of the transaction, including the organizations who endorsed the transaction (in this case, A. Sampaio, TMG & Inovafil). If we look at the Writes section of the transaction details, we can see that *b-009* was deleted while *b-010* and *p-004* were the assets created in the transaction invoked by TMG, validating what happens in the BLL of the smart contract for that activity type.

One thing to consider in regards to the use case demonstration is increase in size of the blocks for each transaction. Hyperledger Explorer lists the block size per transaction due to the rate of sequential transaction endorsing being slow enough for the use case scenario for the ledger to update its blocks with a single transaction per block. Table 6.1 lists the transactions previously mentioned in Fig. 6.2 alongside their outputs and block/transaction size in the last column. As it is shown, the transactions are increasing in size due to the traceability attribute being appended with a

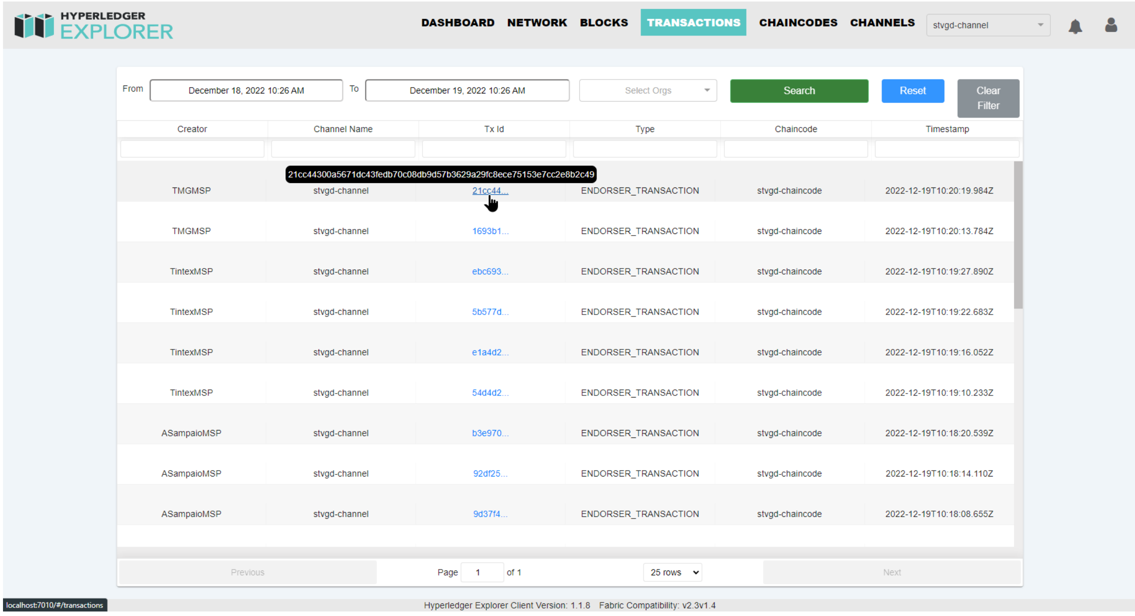

Figure 6.4: Transactions in *stvgd-channel*

new activity every time a batch goes through the value chain process. The current configuration of the network supports, ideally 512KB per block with a absolute maximum size threshold of up to 99MB & 10 total transactions per block. These limits can seem big for this PoC but it is worth considering that the T&C value chain can be extensively complex with lots of activities between operators and the preference for circularity can exponentially increase the size of these transactions.

6.2 Unitary tests on the smart contract API

The validation of the smart contract's BLL requires unitary tests of the business rules implemented to check if the defined conditions and requirements are fulfilled by the developed artifact in chapter 4. Due to the increased complexity of multi-asset generation in each invoking transaction that issues state database objects (e.g., activities and batches), the unit tests were run on the API with request testing scripts inside Postman's Node.js runtime suite. The decision to switch to API testing instead of smart contract testing was potentiated after the occurrence of several development struggles regarding unitary testing directly on the smart contract. Since it is needed to add/put multiple assets of different struct definitions to the state database in a single transaction (e.g., a registration activity and its registered batch), mocking the *PutState()* function available in the ChaincodeStub type definition of Fabric's Chaincode Go package ended up not being possible due to the different restrictions and expected values of each instance of *PutState()* being called for the different assets.

Postman's Node.js runtime suite tool uses Chai, an assertion library for Node that enables unit testing within the Postman client itself (Postman is an API platform for building and using APIs that simplifies each step of the API lifecycle and streamlines collaboration). Chai has several interfaces that allow the developer to choose

Figure 6.5: Create *p-004* production & *b-010* batch transaction details

Table 6.1: Transaction size in black t-shirt use case scenario

ISSUER	**TRANSACTION DESCRIPTION**	**OUTPUT ASSETS**	**SIZE (KB)**
Inovafil	Register cotton fiber batch	batch	7
Inovafil	Register polyester fiber batch	batch	7
Inovafil	Produce cotton-polyester yarn batch	batch, production	11
Inovafil	Ship produced batch to A. Sampaio	batch, transport	14
A. Sampaio	Receive cotton-polyester yarn batch	batch, reception	14
A. Sampaio	Produce cotton-polyester fabric batch	batch, production	15
A. Sampaio	Ship produced batch to Tintex	transport	17
Tintex	Receive cotton-polyester fabric batch	batch, reception	18
Tintex	Register black dye batch	batch	7
Tintex	Produce black cotton-polyester fabric batch	batch, production	22
Tintex	Ship produced batch to TMG	transport	23
TMG	Receive black cotton-polyester fabric batch	batch, reception	24
TMG	Produce black cotton-polyester t-shirts batch	batch, production	26

the chain-capable Behaviour-Driven Development (BDD) styles that provide an expressive language & readable style, or like Test-Driven Development (TDD) assert style which provides a more classical feel. The developed tests for the API requests use BDD syntax through the Expect object inside Chai.js and its code is available in github.com/lcvalves/stvgd-chaincode/tree/dev/test/assertions.

As seen in Fig. 6.6, the left window contains the written unit test code that asserts the expected request and response data from the API and the right windows displays the test results after sending the request. Focusing on the left pane, we can see that the tests expect explicit responses based on values of the inserted arguments in the request's body. As an example, let's take the following assertion:

- *pm.expect(parseFloat(finalScore), "Score out of bounds (should be between -10 & 10)").to.be.within(-10, 10);*

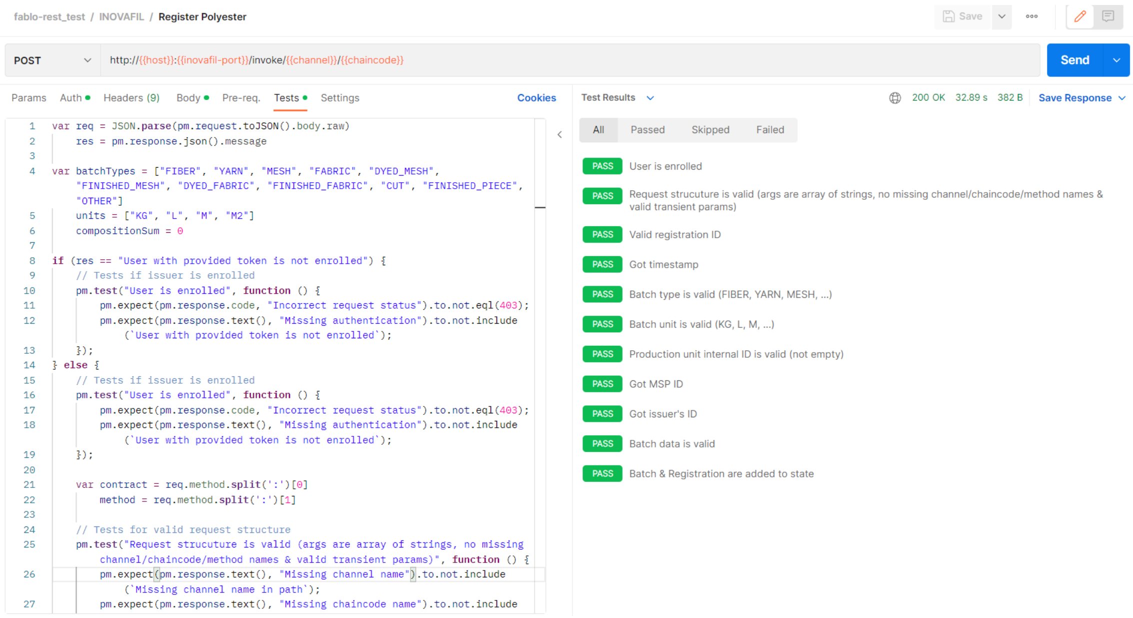

Figure 6.6: Postman's request Chai testing suite

This assertion expects a valid batch final score value between -10 & 10 and based on the value inserted in the final score argument in the request's body, it will either pass or fail the assertion and, consecutively, the test which it belongs to. The intuitive test syntax of Chai makes it easy for the developer to reliably test the business logic behind an API.

As a way to demonstrate the valid tests for each activity type (Registration, Production, Transport & Reception), the following screenshots in Figs. 6.7, 6.8, 6.9, 6.10 display the test results for each corresponding activity type. The left pane shows the arguments passed in the request's body and the right pane displays the test results of the defined tests in the "Tests" tab.

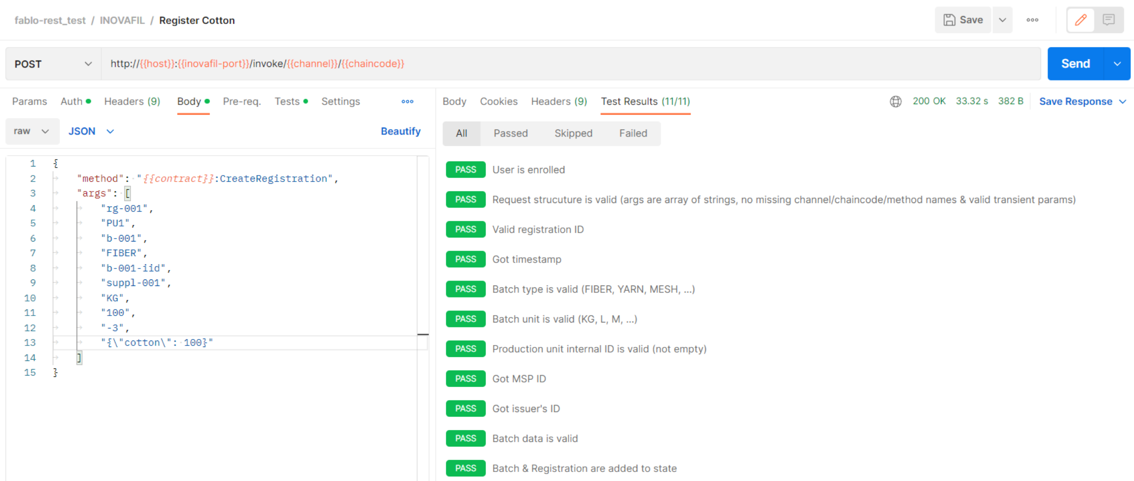

Figure 6.7: Test results for creating registration activities

In each request of activity creation, the tests check for valid body arguments to

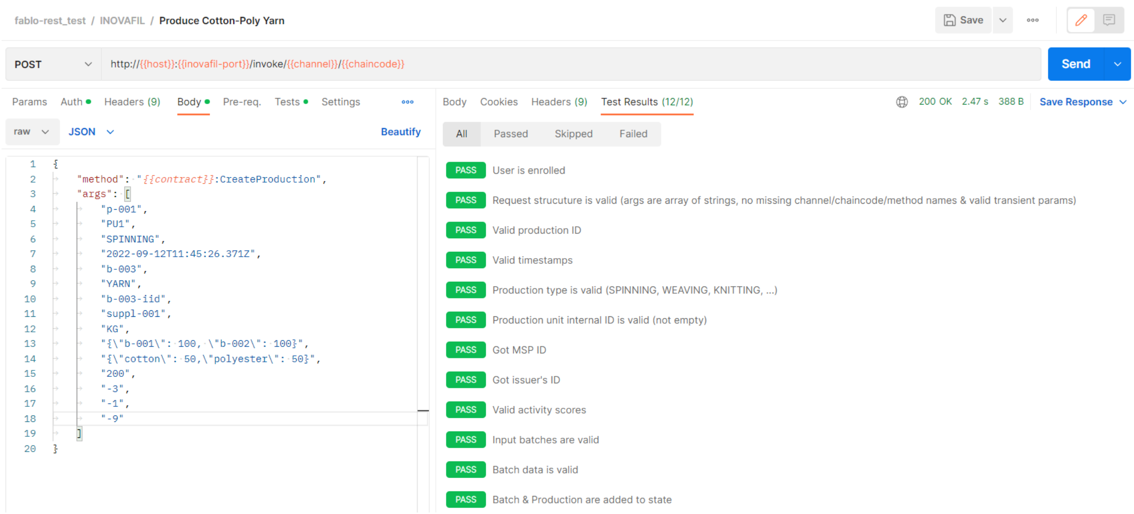

Figure 6.8: Test results for creating production activities

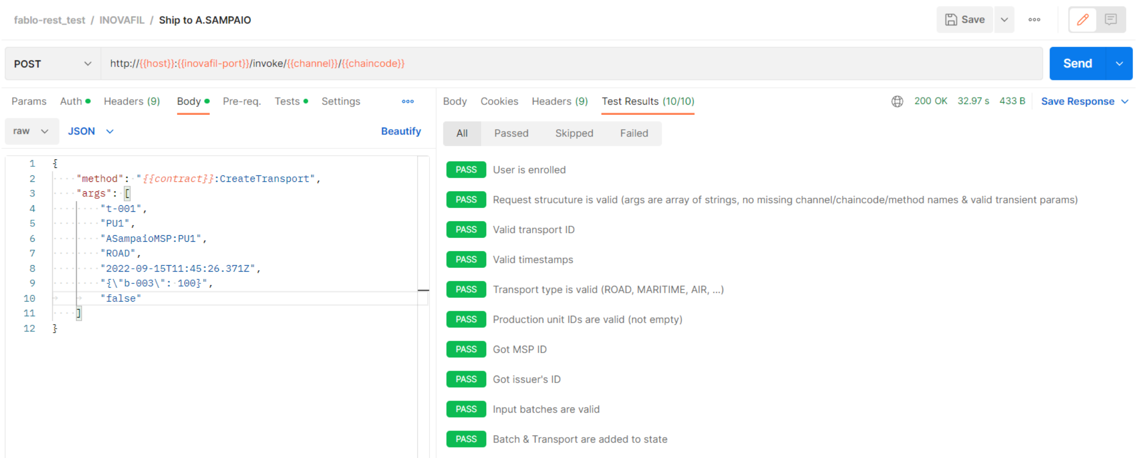

Figure 6.9: Test results for creating transport activities

invoke the transaction as well as the output from the smart contract that is routed as response to the API. Based on the response output of the request, we can test business logic inside the smart contract without testing the contract itself. Besides the business logic of the contract, these tests also verify valid inputs on authentication & authorization requests as well for the request's body structure.

6.3 Usability tests on the Eco-gamified consumer dApp

To further validate the implementation of the used GDH, usability tests have been applied to the developed DApp prototype. According to the ISO-9241-11 norm, usability is the *"extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"*. Usability is an important aspect in the evaluation of interactive systems [107].

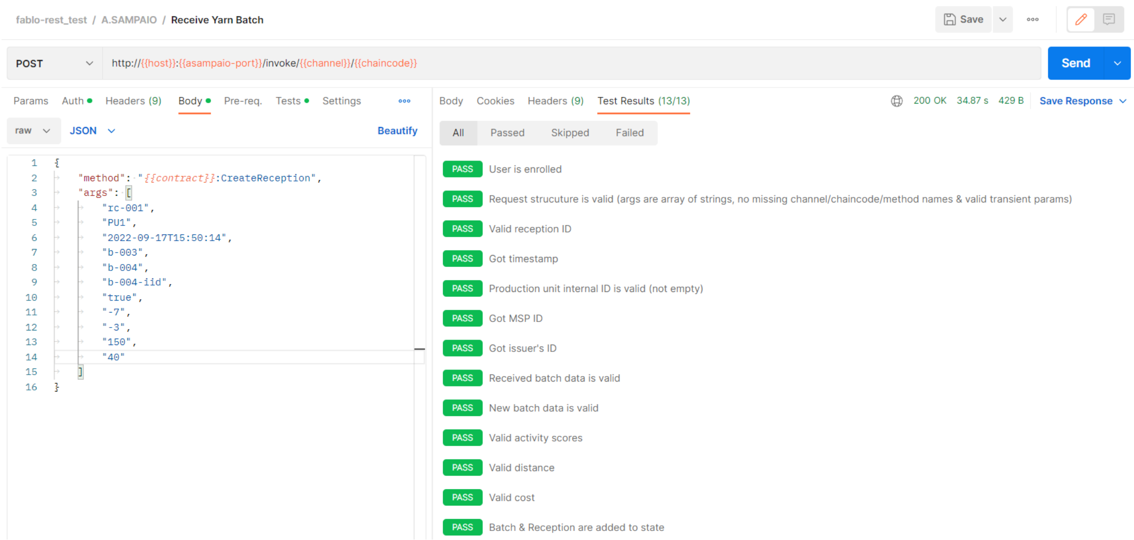

Figure 6.10: Test results for creating reception activities

There are several methods to evaluate usability, including questionnaires that are modeled to focus on different UX/UI dimensions. In [127], the authors compared 6 different surveys typically used in usability evaluations and assessed the dimensions of focus of the questionnaires. The results had the following set of defined dimensions:

- Generic UX;
- Affect / Emotion;
- Enjoyment / Fun;
- Aesthetics / Appeal;
- Hedonic Quality;
- Engagement / Flow;
- Motivation;
- Enchantment;
- Frustration;
- Pragmatic Quality.

Considering the main objective of the defined DApp (chapter 5), which is to motivate and promote consumer participation in circular economy, through the implementation of the GDH framework, the chosen questionnaire to be used in these usability tests has been AttrakDiff, since it has the most impact in the **Engagement / Flow** & **Motivation** dimensions according to [127].

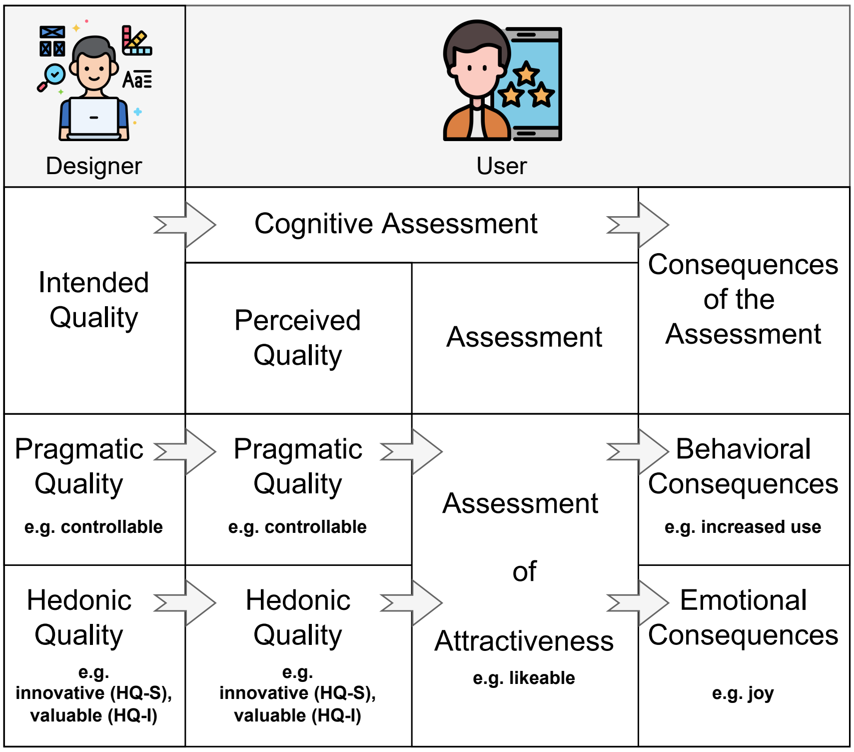

Figure 6.11: AttrakDiff work model (adapted from www.attrakdiff.de)

6.3.1 AttrakDiff

AttrakDiff is one of the most frequently used standardised questionnaires in the Human-Computer Interaction (HCI) field for usability purposes. The theoretical principle on which AttrakDiff is based on, is that a product can have two main qualities: pragmatic and hedonic. Pragmatic Qualities (PQ) are more objective and support instrumental and task-related features of a product, ensuring effective and efficient means to perform a task. On the other hand, Hedonic Qualities (HQ) are more subjective and support stimulation (HQ-S), communicate identity (HQ-I) and provoke memory [97]. The separation of the stimulation and identification sub-qualities became preferable upon the development of the AttrakDiff survey, as it provides more result optimization. Hedonic and pragmatic qualities are perceived consistently and independent of one another. Both contribute equally to the rating of attractiveness (ATT).

The theoretical work model in Fig.6.11 illustrates how the pragmatic and hedonic qualities influence the subjective perception of attractiveness giving rise to consequent behaviour and emotions.

This model separates four essential aspects:

- The product quality intended by the designer;
- The subjective perception of quality and subjective evaluation of quality;
- The independent pragmatic and hedonic qualities;
- Behavioural and emotional consequences.

The designer builds the product with intended qualities (pragmatic (PQ) & hedonic (HQ)). The user then evaluates said qualities with a cognitive assessment from those perceived qualities that results in an idea of overall product attractiveness (ATT), which has consequences on a behavioral and emotional levels, provided by the pragmatic and hedonic qualities, respectively.

6.3.2 Assessment Data

AttrakDiff assesses the user's feelings about the system in a questionnaire with 28 seven-step items, whose poles are opposite adjectives (e.g. "confusing - clear", "unusual - ordinary", "good - bad"). Each set of adjective items is ordered into a scale of intensity. It produces quantitative comparative data which is optimal for analysis purposes.

In the scope of this study it was decided to create a survey with 20 people with different backgrounds, ages and gender to test our DApp, in order to evaluate its usability. As previously mentioned in section 6.3, the most adequate method of usability evaluation is the AttrakDiff survey available in www.attrakdiff.de. The survey results can be seen in Table 6.2.

6.3.3 Assessment Analysis

AttrakDiff's official platform (www.attrakdiff.de) also provided us with some analytics and diagrams that can help us notice key information about the usability of the developed DApp that was named "Green Closet".

In Fig. 6.12, we can see the different adjective pairs that are used to describe the system in the questionnaire, going from left-to-right in order of overall preference. The pairs are grouped by their respective association with the aforementioned pragmatic qualities, hedonic-identification qualities, hedonic-stimulation qualities and attractiveness. The mean values of the word pairs are presented on the blue line. Of particular interest are the extreme values, because these show which characteristics are particularly critical or particularly well-resolved. It is also intended that the values should be positive as a confirmation of well implemented design for the overall appeal of the DApp. Based on these results, we can see that the "technical-human" and "cheap-premium" pair values stand out negatively, as it is likely to be an an area of improvement.

In Fig.6.13, we can see a more abstract interpretation of the results previously detailed. Every quality category is close to a positive score of 1. Pragmatic qualities have the lowest score, with 0.84, and overall attractiveness has the highest score, with 1.39. It is worth mentioning that both identification HQs and stimulation HQs had similar averages, with 1.06 and 1.03 respectively.

Lastly, in Fig.6.14, a XY diagram (called portfolio) is presented. The horizontal axis (X) shows the pragmatic quality while vertical axis (Y) of the portfolio view displays the hedonic quality. Depending on the dimensions' values, the inner blue square, representing the product, will lie in or near one of the defined nine "character-regions". Around the square's placement there's a lighter blue rectangle that represents the result confidence. The bigger the confidence rectangle the less sure one can be to which region it belongs. A small confidence rectangle is an advantage because it

Table 6.2: AttrakDiff's results - questionnaire inputs.

Evaluation								
Human	0	1	5	5	6	3	0	Technical
Isolating	0	0	0	5	6	7	2	Connective
Pleasant	4	6	7	3	0	0	0	Unpleasant
Inventive	2	4	6	6	1	1	0	Conventional
Simple	2	6	3	7	2	0	0	Complicated
Professional	1	10	7	1	1	0	0	Unprofessional
Ugly	0	1	0	4	8	4	3	Attractive
Practical	2	9	6	0	2	1	0	Impractical
Likeable	4	9	5	2	0	0	0	Disagreeable
Cumbersome	0	0	3	7	3	6	1	Straightforward
Stylish	1	9	6	3	1	0	0	Tacky
Predictable	1	3	7	6	1	1	1	Unpredictable
Cheap	1	2	3	7	4	0	2	Premium
Alienating	0	0	1	7	5	6	1	Integrating
Brings me closer to people	0	2	3	5	4	2	4	Separates me from people
Unpresentable	0	0	0	2	3	10	5	Presentable
Rejecting	0	0	0	5	10	3	2	Inviting
Unimaginative	0	0	0	3	4	10	3	Creative
Good	5	11	3	1	0	0	0	Bad
Confusing	0	0	1	6	6	4	3	Clearly structured
Repelling	0	0	0	8	8	3	1	Appealing
Bold	0	2	7	8	2	1	0	Cautious
Innovative	3	8	7	2	0	0	0	Conservative
Dull	0	1	1	3	4	9	2	Captivating
Undemanding	1	1	2	3	8	3	2	Challenging
Motivating	3	6	7	2	2	0	0	Discouraging
Novel	0	7	4	8	1	0	0	Ordinary
Unruly	0	0	0	4	3	12	1	Manageable

means that the investigation results are more reliable and less coincidental. The confidence rectangle shows if the users are somewhat agreeing in their evaluation of the product.

The prototyped "Green Closet" DApp rates between **self-oriented** and **neutral**, but the uncertainty of the results can bring the system to **task-oriented** or even **desired**.

The results presented in Fig. 6.14 clearly indicate the lack of pragmatic qualities in the DApp, as the score from PQ deviates from the average score of HQ (0.84 to 1.045 respectively). This leads to a greater area coverage of the product's usability within the **self-oriented** and **neutral** sections. These results are not fully what was expected, because the intended evaluation of the DApp's usability should be closer to

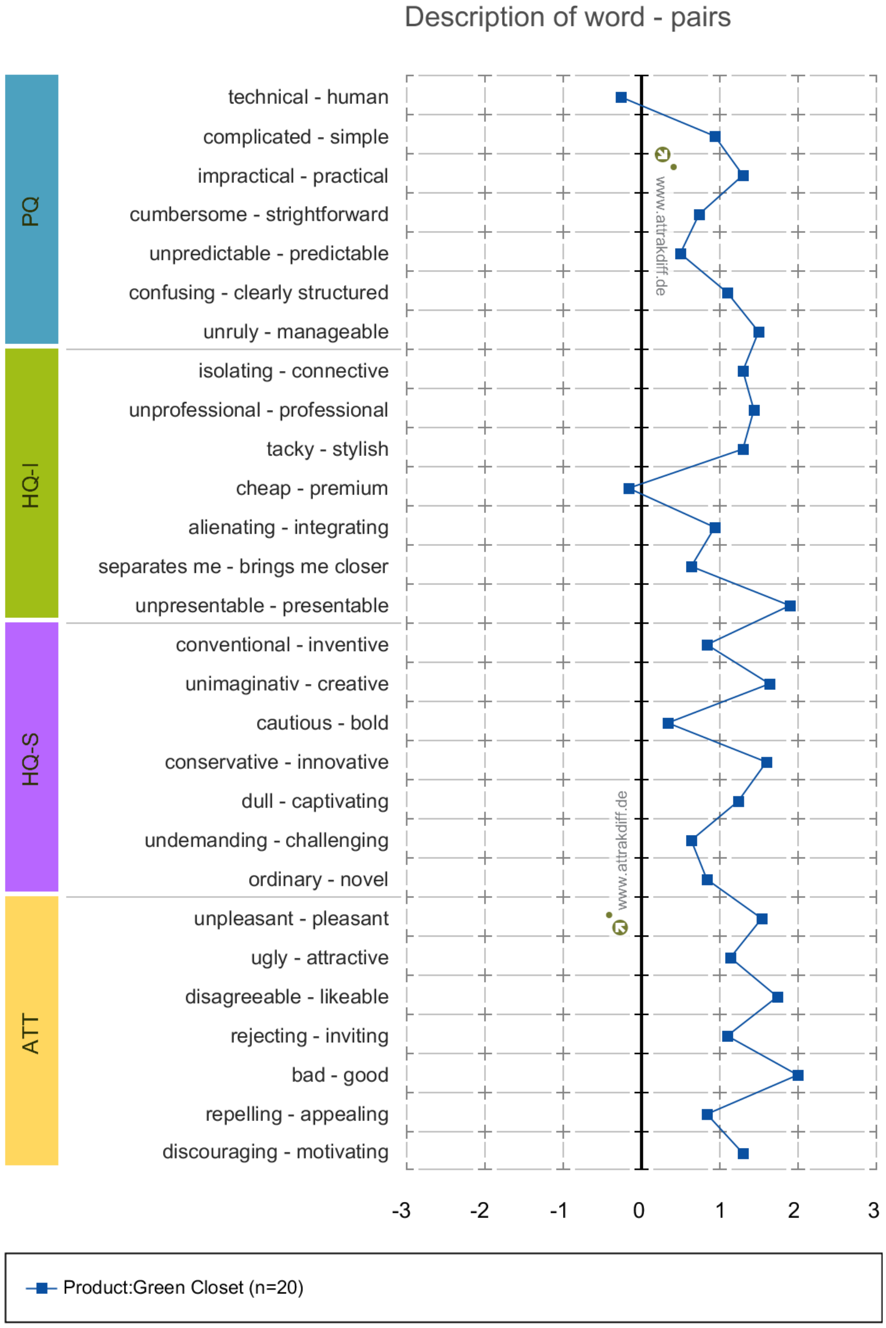

Figure 6.12: AttrakDiff's results - word pairs' average values

a **task-oriented** product. Unlike a self-oriented product, a task-oriented product is what will lead to users contributing by performing the tasks on the DApp, that positively contribute to the sustainability of the T&C value chain, by promoting the circular economy model between users and business operators, as depicted in Fig. 6.15.

On a task-oriented DApp the engagement and motivation to use it do not come from a user-centric design choice, but rather from the tasks inside the DApp. A shift in orientation from self to task would have consumers participating to benefit, not only

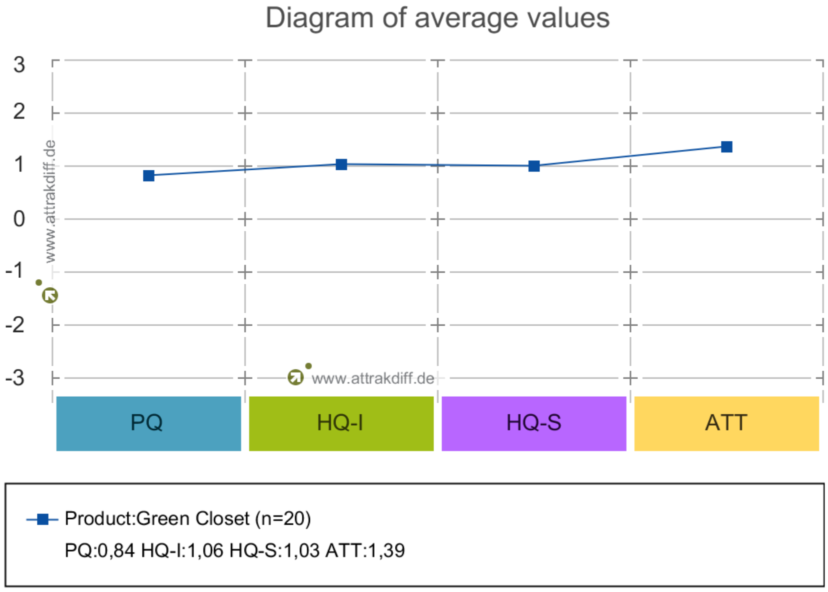

Figure 6.13: AttrakDiff's results - average value per quality category

themselves, but something with a greater meaning, rather than only self enjoyment.

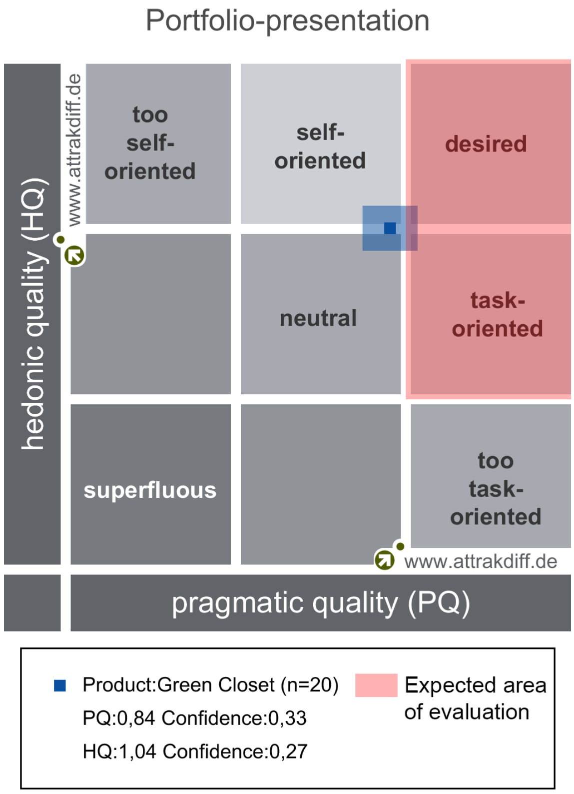

Figure 6.14: AttrakDiff's results - portfolio

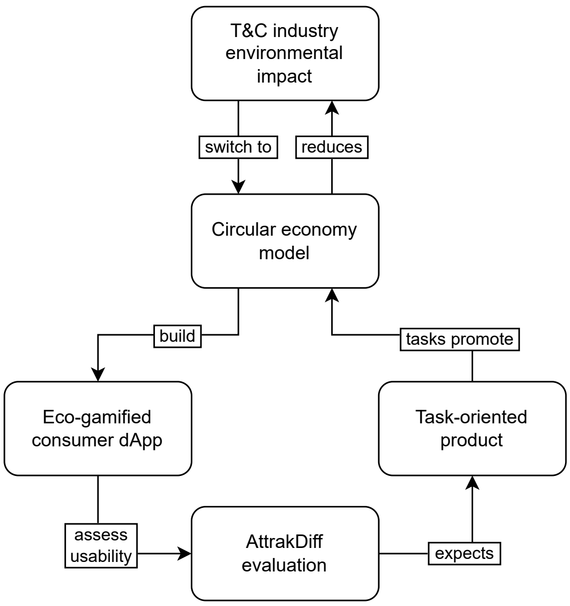

Figure 6.15: Task-oriented product expectation flowchart

Chapter 7

Conclusions

The T&C industry sector is currently of great importance due to the need of clothing for the well-being of people, but also due to the weight of the sector in the economy, both in terms of the large number of jobs created and in terms of the sector's turnover. However, the T&C sector has a significant environmental and social impact due to its growing rate of over-consumption and over-production, making this impact felt throughout its entire value chain, especially with regard to water consumption, chemical pollution, CO_2 emissions and waste production [168, 147].

The circular economy is one of the most promising business models for sustainable development. This model is based on the continuous reuse of materials and resources, allowing the reduction of waste and the preservation of natural resources. To adopt a circular economy business model, this has to be supported by applications that allow data collection to measure circularity. As seen in this dissertation, blockchain is a very promising distributed ledger technology that fits the needs of traceability and circular economy together with IoT.

Nevertheless, some challenges arise, when integrating IoT and blockchain. One challenge, relates with the use of IoT edge devices to gather and communicate readings (e.g., temperature, geographic coordinates) about a traceable item (e.g., product item, product batch). Typically, these readings generate a large volume of data that increases at a fixed time interval pace. However, in the T&C value chain, this may not be as critical, as any eventual sensor reading must be associated with a business partner activity, such as the production, transport, selling, etc., of a product batch (e.g., yarn, fabric) or raw material's batch.

Another challenge is related with the use of digital twins, that is the information about a traceable item (typically a product batch). Through IoT identification labels (e.g. RFID, Quick Response (QR) code), the information about a traceable item is registered in the traceability system. A traceable item may be a garment piece or, more probably, a product batch. When it is a product batch, a value chain activity may not involve the entire batch, as when only part of a yarn's batch is sold, transported and used as input for producing a fabric's batch. Also, when the final consumer delivers a shirt for recycling, there is no way of identifying one shirt. The shirt has the code of the batch produced years earlier. So, each value chain activity on a product batch must also identify the quantity (e.g. number of shirts, weight of cotton, length of yarn) that the activity affects.

The use of blockchain technology for traceability and enforcement of a circular economy in the T&C value chain has, has many advantages over other solutions, the fact of being decentralized, as it runs on a P2P network where each transaction can be confirmed without the need of authentication by a central authority. The data history recorded in the blockchain ledger is immutable, as it is nearly impossible to change previously registered data modifications, because the majority of the consensus nodes would need to agree. And, the transparency of transactions, as anyone is able to consult the recorded data. This transparency also enables easy auditability for traceability purposes as each data record has a timestamp reinforcing its chronological order.

When integrating blockchain with IoT in a T&C value chain circular economy, one may also benefit from increased operational efficiency, as IoT devices are not only more efficient than humans but also make fewer errors, in inventory management and in providing track and trace conditions within transport containers, warehouses or other environments, in real-time, which can help to prevent product damage during transportation.

In a CE business process, the loop in the process is closed by the final consumer, as this is the responsible for delivering the end-of-life T&C items for recycling and circularizing the value chain.

In this dissertation, a lack of transparency problem in the T&C value chain has been described, and for that a B2B value chain management smart contract solution with traceability capabilities has been proposed. The full stack architecture of the solution has also been defined alongside the required transaction methods in the chaincode.

Alongside this, a lack of consumer engagement in closing the loop of the T&C value chain has also been described, and for that a circular B2C2C eco-gamified consumer DApp has also been proposed. The modeling of an eco-gamified DApp has been developed, and its model features have been mapped to GDH framework heuristics, validating that it is possible to support a set of defined heuristics of applied gamification for promoting CE in the T&C value chain. Based on the DApp modeling, in section 5.2, it is possible to create, as future work, an eco-gamified consumer DApp to support the premise of this work - promote consumer's engagement in the circular T&C value chain. This engagement is measurable by analyzing our DApp design through usability testing like AttrakDiff surveys, as mentioned in chapter 6. According to the results obtained, people who tried the prototype and responded to the AttrakDiff survey had an overall positive experience with the prototype, leading us to conclude that motivation and engagement to use DApp are taken into account by design, sometimes without even considering its gamification aspect.

By registering lifecycle activities of a garment, inside the DApp, the consumers are rewarded within the game's environment, which can lead to real-life tangible benefits. Since the prototyped DApp is meant to be a digital representation of the T&C on a B2C2C context, rewarding the consumer's through circular adoption and game-like features is a way of motivating users to actively and positively contribute to a greener supply chain. In this context, today's relevance to consider the use of gamification on a system for increasing consumer participation in a CE value chain if verified, due to the consumer's importance in helping to contribute to a more sustainable society.

7.1 Future work

On the smart contract solution, future work can involve the implementation of the front-end web application, where the API linking to the smart contract will be consumed. Regarding the off-chain data integration, an oracle service can be used to input data from external sources, such as the specific IoT sensor data on which the sustainability score is based on, as well as linking on-chain data to more detailed information that does not need to be on-chain for scalability purposes, such as the value chain participants detailed information. An oracle service acts as a link between on-chain and off-chain data ("real world" data), being able to input information that the blockchain doesn't have access to [164]. This would increase the reliability of the inserted sensor data into the system that ends up being part of the calculations of the sustainability scores. Another way of decentralizing the platform can also be implementing by adding InterPlanetary File System (IPFS), a decentralized storage solution for bigger files that need to be appended to the blockchain. Such an implementation has advantages regarding the scalability of the platform since it does not need to store the bigger files in the same network as it does the batches and activities. This is one way to mitigate the increasing size of transactions as the traceability attribute increases every time a batch and its successors go through value chain activities. Another way, and the most ideal way, to tackle these storage problems is to query the ledger itself to trace the batch instead of the current solution of appending activities sequentially. As an improvement for consistency and data integrity, the addition of Universal Unique IDentifier (UUID) standards to the composite key IDs in the assets being logged in the smart contract is something to note for future development. This feature couldn't be currently implemented in the smart contract as the UUIDs are probabilistic values that randomly generate data on every instance, making it impossible to implement on strictly deterministic logic that the smart contracts are required to have. However, the values of these UUIDs can be declared and validated in an external component which then writes to the ledger through the Fablo REST API. Regarding the network topology, the definition of a proprietary ordering service organization associated with an external certifying entity instead of an ordering node per company organization could settle transactions faster, but at the cost of decreased decentralization between operators

Regarding future improvements of the eco-gamified consumer DApp, there is the possibility to improve the GDH's implementation in Table 5.1 by creating more game data assets that strengthen the motivation towards the DApp's objective. Some of these may include:

- **In IMH2.** Cooperative challenges - Cooperative challenges can bring users together for increased group motivation;
- **In IMH15.** Meaningful sustainable awareness narrative supported by the game - By constantly reminding the user of the inherent narrative motive behind the application, users can be immersed into a new reality within the game space;
- **In IMH16.** System feedback on sustainable contribution (percentages, etc.) - The system should be able to provide feedback on how much they contributed to the CE within their supply chains;

- **In CDH6.** In-game surveys - With the use of in-game surveys and game feedback forms the players have an opportunity to give new ideas.

Based on the results had on chapter 6, the design of the DApp can be improved so that the under-performing aspects (especially pragmatic qualities) that came to light in the AttrakDiff survey would be better, as well as a higher sample size for a more reliable result.

As a way to comply with certain T&C value chain workflow requirements, a garment's identification could be swapped from a single unit ID tag to the garment's batch ID tag. That would imply some changes in the DApp's domain model. This brings us to the final suggestion for future work: interoperability between both systems. The end goal would be a all-in-one multi-network system capable of handling both the B2B value chain smart contract capabilities alongside the consumer DApp for a seamless integration.

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Appendix A

Appendix A

Mockup simulation links for the eco-gamified consumer DApp defined in chapter 5:

- xd.adobe.com/view/e99f7212-c9b2-4a29-87e8-12832c398e2a-bccc (Previous owner simulation);
- xd.adobe.com/view/2658ca25-a80c-4410-8761-3f8fd167cf01-730b (New owner simulation);