NGI ONTO CHAIN

Blockchain for the Next Generation Internet

ONTOCHAIN STATE OF THE ART (YEAR 2)

30/12/2022

NGI ONTO CHAIN

Grant Agreement No.: 957338
Call: H2020-ICT-2020-1

Topic: ICT-54-2020
Type of action: RIA

D3.2 ONTOCHAIN STATE OF THE ART (YEAR 2)

BLOCKCHAIN APPLICATIONS AND TECHNOLOGIES

WORK PACKAGE	WP3
TASK	T3.1
DUE DATE	31/08/2022
SUBMISSION DATE	19/01/2023
DELIVERABLE LEAD	IS
VERSION	1.2
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ABSTRACT	This deliverable updates the State of the Art Report released in the year 1, with a more specific focus on applications. Applications are categorized in 15 domains, each of which distinguished in different use cases. Moreover, this report updates as well the technology related State of the Art for technologies addressed in the year 2, as NFTs and IoTs.
KEYWORDS	blockchain applications, blockchain technologies, blockchain usecases

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957338

Document Revision History

Version	Date	Description of change	List of contributor(s)
0.1	09.01.2022	Section 3 (Applications and Usecases) first draft	A. Ciaramella
0.2	26.01.2022	Section 3 (Applications and Usecases) updated	A. Ciaramella
0.3	27.05.2022	Section 3 (Applications and Usecases) updated	A. Ciaramella
0.4	18.07.2022	Section 3 (Applications and Usecases) updated	M. Ciaramella
0.5	27.07.2022	Section 3 (AppIlcatIons and Usecases) updated	A. Ciaramella
0.6	01.08.2022	Section 3 (Applications and Usecases) updated	M. Ciaramella
0.7	08.08.2022	Section 3 (Applications and Usecases) updated	A. Ciaramella
0.8	21.09.2022	Section 3 (Applications and Usecases, final, Section 2 (Technologies, first version)	M. Ciaramella, A. Ciaramella
0.9	29.09.2022	Released for internal review	M. Ciaramella, A. Ciaramella
1.0	18.10.2022	Released including comments of internal reviewers Thanasis Papaioannou and Petar Kochovski	M. Ciaramella, A. Ciaramella
1.1	28.12.2022	Released including other comments of internal reviewers Thanasis Papaioannou and Petar Kochovski	M. Ciaramella, A. Ciaramella
1.2	19.01.2023	Released including further comments of internal reviewers Thanasis Papaioannou and Petar Kochovski	M. Ciaramella, A. Ciaramella

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Dissemination Level

Nature of the deliverable:	PU

PU	Public, fully open, e.g., web
CL	Classified, information as referred to in Commission Decision 2001/844/EC
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EXECUTIVE SUMMARY

This report is the deliverable "D3.2 ONTOCHAIN State of the Art report (Year 2)" of the European project "ONTOCHAIN Trusted, traceable and transparent ontological knowledge on blockchain".

This report complements the deliverable D3.1 ONTOCHAIN State of the Art report (Year 1) of the European project "ONTOCHAIN Trusted, traceable and transparent ontological knowledge on blockchain", hence both reports D3.1 and D3.2 have to be read in order to get the complete state of the art produced by the ONTOCHAIN project.

Section 2 updates the state of the art of technologies, already well covered in the first year deliverable D3.1, for technologies specifically developed by Open Call 2 projects.

This section 2 of course mentions the state of the art at the beginning of Open Call 2 projects, not including specific evolutions developed in Open Call 2 projects, which are detailed in other specific reports of the WP4.

Section 3 includes the state of the art of applications enabled by blockchain and semantics, as identified from the overview of the literature. Applications in this report are categorised into 15 domains (or verticals), such as agrifood, art and creativity, constructions, education and science, energy, fashion and luxury, finance and banks, healthcare, industry and manufacturing, information and media, insurances, logistics, mobility, smart cities, tourism. For each domain, up to 10 subdomains have been analysed, identifying reasons why to adopt blockchain.

Each use case is associated with motivations to use blockchain architectures. In evolutionary cases the use of blockchain adds security and privacy or increase the efficiency and reduces operational costs in comparison to centralised data base architectures. In more advanced and even disruptive cases the use of blockchain architectures enables new applications and/or business models.

This state of the art of applications supported the decision about key topics to select in Open Call 3, which is more focused to applications.

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TABLE OF CONTENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957338

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957338

LIST OF FIGURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957338

LIST OF TABLES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957338

ABBREVIATIONS

ABI	Application Binary Interface
AEC	Architecture, Engineering and Constructions
AECO	Architecture, Engineering, Construction and Operation
AI	Artificial Intelligence
AML	Anti-money laundering
BIM	Building Information Model
BITA	Blockchain in Transport Alliance
CBME	Competency Based Medical Education
CDISC	Clinical Data Interchange Standards Consortium
DAO	Decentralised Autonomous Organisation
DeFi	Decentralised Finance
DER	Distributed Energy Resource
DeSci	Decentralised Science
DEX	Decentralised Exchange
DID	Decentralized Identifier
DLTs	Distributed Ledger Technologies
DSCSA	Drug Supply Chain Security Act
EBA	European Banking Authority
EBSI	European Blockchain Services Infrastructure
EEA	European Economic Area (EU + Iceland, Liechtenstein, and Norway)
EIOPA	European Insurance and Occupational Pensions Authority
EHR	Electronic Health Record

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EMR	Electronic Medical Record
EPA	Entrustable Professional Activity
EPCIS	Electronic Product Code Information Services
ESAs	European Supervisory Authority (EBA, ESMA, EIOPA)
ESMA	European Securities and Markets Authority
EVM	Ethereum Virtual Machine
FAO	Food and Agriculture Organisation (United Nations)
FATF	Financial Action Task Force
GDPR	General Data Protection Regulation
GPS	Global Positioning System
HIPAA	Health Insurance Portability and Accountability
HL7	Health Level Standard
ICD	International Classification of Diseases
ICTSD	International Centre for Trade and Sustainable Development
IDD	Insurance Distribution Directive
IoT	Internet of Things
IoHT	Internet of Healthcare Things
ISIC	International Standard Industrial Classification of AllEconomic Activities[1]
KYC	Know your Customer
LBS	Local Based Services
M2M	Machine to Machine
M2X	Machine to EveryThing
MiCAR	Markets in Crypto Assets Regulation
MIFID	Markets in Financial Instruments Directive
MOBI	Mobility Open Blockchain Initiative

[1] defined and maintained by the United Nations

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ML	Machine Learning
NACE	Statistical Classification of Economic Activities in the European Community[2]
NCA	National Competent Authority
NFT	Non Fungible Token
OC1	ONTOCHAIN Open Call 1
OC2	ONTOCHAIN Open Call 2
OC3	ONTOCHAIN Open Call 3
OECD	Organisation for economic cooperation and development
OPSI	Observatory of Public Sector Innovation
OWL	Web Ontology Language
RDF	Resource Description Framework
PHC	Precision Healthcare
PoL	Proof of Location
PoO	Proof of Offset
SAE	Society of Automotive Engineers
SGX	Software Guard Extensions
SoA	State of the Art
SSI	Self sovereign identity
TLS	Transport Layer Security
TSO	Transmission System Operator
TVL	Total Value Locked
U4SSC	United for Smart Sustainable Cities
UDI	Unique Device Identifier
W3C	World Wide Web Consortium
WHO	World Health Organisation

[2] From the French acronym "Nomenclature statistique des Activités économiques dans la Communauté Européenne"

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1 INTRODUCTION

The ONTOCHAIN project[3] is a NGI cascade founding project to develop a new software ecosystem for trusted, traceable & transparent ontological knowledge on blockchain including new technologies and applications. A recent overview of the ONTOCHAIN architecture is provided in the paper by Papaioannou et al. [1].

More details about the architecture are presented in the ONTOCHAIN Deliverable D3.4 Framework Specification (Simonet-Boulogne et al. [2]) from which the following block diagram is extracted.

This block diagram identifies the main components of the architecture as applications, ontologies, distributed ledger, core protocols, application protocols

This block diagram summarizes also the specific Open Call in which a technology or an application is intended to be developed.

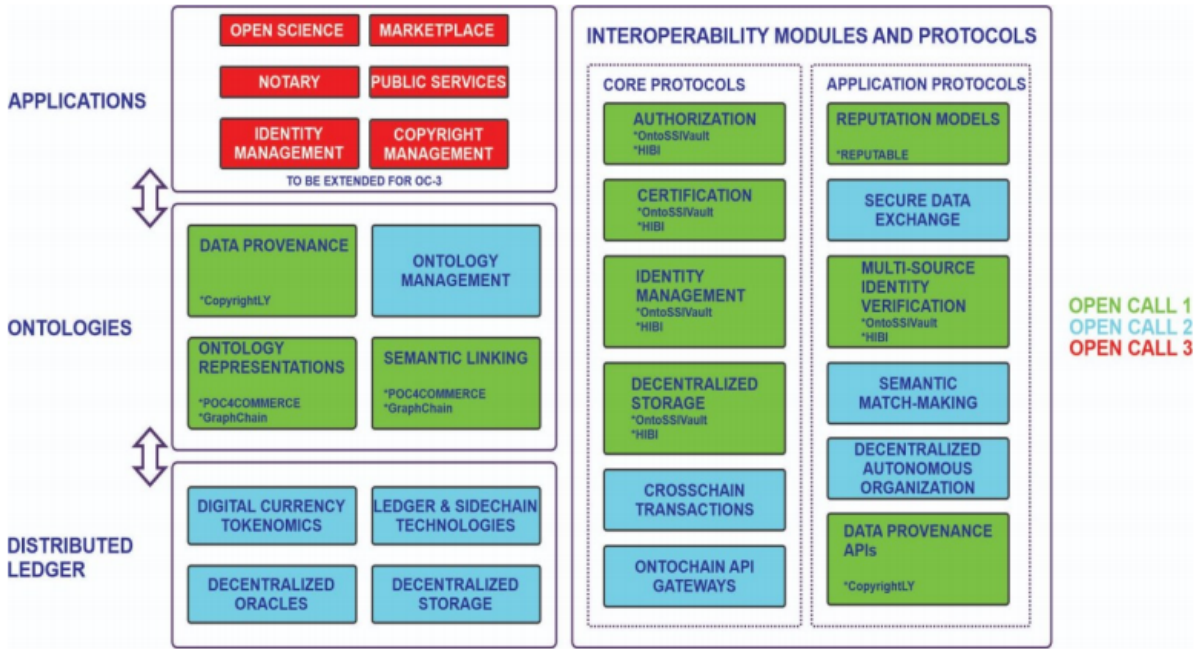

FIGURE 1: Diagram of Ontochain functional architecture

In fact, the ONTOCHAIN project is structured in three Open Calls (an open call per year), in which the first two Open Calls (OC1 and OC2) were about new technologies to inte-

[3] https://ontochain.ngi.eu/

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grate in the ONTOCHAIN platform, whilst the last Open Call (OC3) is mostly about new applications to deliver on the ONTOCHAIN platform, but will include also calls for some new technologies which have been identified useful to include or to improve.

Two state of the art deliverables are produced in ONTOCHAIN, the first at the end of the year 1 (D3.1) and the second (this one) at the end of the year 2 (D3.2).

This second year state of the art report (D3.2) integrates information provided in the first year state of the art report (D3.1, Papaioannou et al. [3]), and includes new information not covered before, as:

- **the state of the art about technologies** developed in OC2 (section 2), whilst the first year report was about technologies developed in OC1.
- **the state of the art about applications** (section 3), presented in the first report only at very high level, and in this second report definitely in more detail.

Hence, for a complete overview of the state of the art produced by the project ONTOCHAIN, both D3.1 and D3.2 have to be read, as they do not overlap.

In this state of the art, the following criteria have been used for the selection and use of the bibliographic sources:

- sources published under Open access (OA) policies have been preferred;
- sources published in the last four years (2018 - 2022) have been preferred, since blockchain technologies and application panorama are rapidly evolving. However, older sources are also included if considered still valid or of a particular relevance;
- review papers for illustrating specific application domains, as healthcare, are preferably from academia. In any case, when relevant, also business information sources are used;
- specific application examples are more typically extracted from the business news, with a special attention to what happens in Europe, but also including examples from all over the world when needed. These examples have not to be considered exhaustive in any way. Where possible, projects within ONTOCHAIN ecosystem are also mentioned.

An objective of this deliverable has been to prepare the ONTOCHAIN OC3, by identifying the most interesting application topics also taking into account the state of the art of applications.

But more in general, we tried to elaborate a general framework for applications and technologies, which of course could be eventually updated with new information, since the topics addressed by the project ONTOCHAIN are evolving quickly (Casino et al. [4]).

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2 TECHNOLOGIES

2.1 INTRODUCTION

The state of the art of technologies was the main topic of last year's deliverable D3.1, which had a specific focus on the state of the art of technologies contributed by OC1 projects.

This section integrates the state of the art of technologies, with a specific focus on technologies contributed by OC2 projects.

This section does not include the state of the art of technologies already adequately covered in the deliverable D3.1, and which do not require updates i.e. reputation systems.

The following table summarises technologies detailed in this section, for each of which it is associated with the OC2 projects which contributed to these technologies, also to acknowledge their contributions to the state of the art.

TABLE 1: OC2 technologies and projects.

Technology	**Project**
Semantics	ONTOSPACE, OriginTrail DKG, PS-SDA, BOWLER
NFT	PRINGO, PiSwap, NFTWatch
IoT	ADOS, DESMO-LD, CARECHAIN
Interoperability	PERUN-X
Authentication	MFSSIA
Geolocation	GEONTOLOGY
Software development kits	BOWLER

The following paragraphs will summarise or update the state of the art of the technologies mentioned as most relevant for OC2, in particular **semantics**, **NFT** and **IoT**.

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2.2 SEMANTICS AND BLOCKCHAIN

Semantics means to add meanings to data. In order to represent meanings, suitable standards were defined by W3C, such as the Resource Description Framework (RDF) and thew Web Ontology Language (OWL).

More specifically, the high-level knowledge in a specific domain (as, for example, e-commerce) can be identified and represented as an ontology, and this ontology can be reused in different e-commerce applications.

Many useful ontologies are now available for facilitating applications development.

But now these advances on semantics can benefit also blockchain, and, even better, **semantics and blockchain can benefit from each other** as anticipated by English et al. [5] and analyzed in more detail in the paper by Cano-Benito et al. [6].

Main benefits of the **use of semantics in blockchain** of those identified in the previously mentioned paper are the possibility of:

- Linking of data of different knowledge sources
- Searching over the blockchain
- Validating the blockchain consistency

Main benefits of the **use of blockchain in semantics** are:

- Data decentralisation
- Data immutability
- Data transparency and privacy
- Crowdsourcing data

To summarize, whilst semantics adds to blockchain the possibility of reusing all the formalized knowledge already developed, blockchain solutions, and especially public blockchain, add the possibility to extend the scale of semantic solutions, which so far are essentially adopted in "walled garden" applications.

Moreover, the use of blockchain can allow now the fair remuneration of knowledge and semantics, e.g. by the proper use of NFTs.

Hence, semantics and blockchain is an evolving research area, in which the ONTOCHAIN project provides active contributions.

Three ONTOCHAIN OC2 projects provided their contribution in the domain of **semantics for blockchain**, i.e. BOWLER, DESMO-LD and PS-SDA.

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BOWLER[4] used semantics for facilitating the development of smart contracts. **DESMO-LD** [5] used semantics for describing decentralized oracles. **PS-SDA** [6] used semantics in provenance and Smart Data Agreement (e.g. in order to exchange data, also personal data according to Eu regulation, between more organizations[7]) to develop their solution.

Two ONTOCHAIN OC2 projects provided their contribution in the domain of **blockchain for semantics**, i.e. ONTOSPACE and OriginTrail DKG. **ONTOSPACE** [8] developed on-chain semantic data base (Tomaszuk et al., [7]), whilst **OriginTrail DKG**[9] developed off-chain semantic data bases. ONTOSPACE and DKG followed two different approaches.

ONTOSPACE followed a top-down approach that combines blockchain nodes with an off-the-shelf semantic database: a node of the ONTOSPACE network runs both a modified Hyperledger Besu Ethereum client and an instance of a Triple-Store database. Modifications to the EVM allow smart contracts to directly read and write records in the database. DKG followed a bottom-up approach in the sense that they built a knowledge graph that is decentralized by design.

To avoid modifying blockchain clients and the EVM, DKG decided to rely on cryptographic primitives to implement trusted data links between smart contracts and the databases

Last, but not least, **different kind of ontologies were developed or extended** in ONTOCHAIN. As an example, it must be cited the ONTOCHAIN OC1 project **POC4COMMERCE** [10] (Bella et al. [8]), which extended e-commerce ontologies.

2.3 NFTS

Non-fungible tokens (NFTs) represent a unique item - physical or intangible - like a picture or other kinds of intellectual property asset[11]. The recent paper by Wang et al. [9] provides an overview of components and protocols of NFTs, and identifies opportunities and challenges.

The history of NFTs so far can be distinguished in three phases: 1) early uses, 2) first

[4] https://ontochain.ngi.eu/content/bowler
[5] https://ontochain.ngi.eu/content/desmo-ld
[6] https://ontochain.ngi.eu/content/ps-sda
[7] https://da.igrant.io/
[8] https://ontochain.ngi.eu/content/ontospace
[9] https://ontochain.ngi.eu/content/dkg
[10] https://ontochain.ngi.eu/content/poc4commerce-practical-ontochain-commerce
[11] https://cointelegraph.com/nonfungible-tokens-for-beginners/fungible-vs-nonfungible-tokens-what-is-the-differen

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market awareness 3) more general adoption[12]. The first time an NFT was used was in 2014, in which an NFT named Quantum was minted. After that other applications were developed, although with limited market impact.

The game CryptoKitties, in the year 2017, sparkled the first significant market awareness for NFTs. The game CryptoKitties, to purchase, collect, breed and sell virtual cats, become suddenly so successful to congest the Ethereum network in December 2017, reducing as a side effect the interest for this game.

But many other NFTs applications were developed. Hence, starting from the year 2018, the whole NFTs market had grown significantly. This increase was especially relevant during the year 2021, when the trading volume of NFTs increased more than 210 times in comparison to the previous year 2020.

In this year 2022, NFT trading is becoming more conservative. However, this could be also positive fact. This can be also the sign that this market is becoming less speculative and more mature.

In conclusion, the NFTs opportunities seems promising in some application domains. Whilst NTFs become popular first with collectibles, use cases are definitely broader than those initially proposed. A recent PwC report authored by Arslanian and Fitzgerald [10] summarizes many domains in which NFTs can be applied, as:

- collectibles;
- gaming [11];
- digital; [12] and physical art;
- sports [13];
- cultural artifacts and history;
- real estate (real word asset representation);
- music and digital arts;
- tickets [14];
- education and research [15].

Besides those mentioned, other verticals are now emerging. As the use of NFTs for common goods, an example of which is the application PRINGO developed in the ONTOCHAIN OC2.

In spite of the increasing visibility and even adoption of NFTs, this is still a very evolu-

[12] https://blog.portion.io/the-history-of-nfts-how-they-got-started/

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tionary research topic, including the analysis of:

- primary and secondary markets sale prices (Tunc et el. [16]);
- influence of social media on NFT valuation (Kapoor et al. [17]);
- suspicious behaviour identification (Pelechrinis et al. [18], v. Wachter [19]);
- security issues (Das et al. [20]).

In any case, there are still **technology and business challenges**. The overview paper already mentioned authored by Wang et al.[9] mentions these 4 challenges:

- **usability** challenges as slow confirmation time and high gas prices;
- **security and privacy** as NFT data inaccessibility and anonymity/privacy;
- **governance** as legal issues (cross border, Know Your Customer) and taxation;
- **extensibility** as cross-chain interoperability and updatable NFTs in case of soft forks.

Three NFTs projects participated to the OC2 Open Call:

- PRINGO (Private incentives for common goods)[13];
- PiSwap (Price Building Mechanism for asymmetric NFT-markets)[14];
- NFTwatch (ontology and tools for NFT data) [15].

PRINGO implemented an application example whose objective is to improve the financing of resources for common/public goods. To improve funding, common goods organisations will be able to create a digital representation of their common goods in the form of NFTs. In this way, they make a profit from their sale.

PiSwap implemented a NFT-DEX with autonomous Price Building Mechanism. Users can use NFTSwap to create markets for any owned or not-owned NFT by minting a derivative NFT. This derivative market will be provided with liquidity and will create a Bull-Bear-Token allowing users to participate in the price building of this particular NFT.

NFTwatch provided an ontology dedicated to NFTs and tools to manipulate usually unstructured NFT-related data. The final service enables a multi-facet search and visual discovery of the NFT world.

[13] /https://ontochain.ngi.eu/content/pringo
[14] /https://ontochain.ngi.eu/content/piswap
[15] /https://ontochain.ngi.eu/content/nftwatch

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2.4 BLOCKCHAIN INTEROPERABILITY

Blockchain Interoperability (also abbreviated as BI) is becoming more and more relevant for the whole blockchain ecosystem (Lafourcade and Lombard-Platet [21], Lohachab et al. [22]).

In fact, more and more blockchain projects (private and public) are now available. Any blockchain project was developed independently from others, with different rules and concepts. Hence, native communication mechanism between different blockchains are not available.

As a result, the problem of interoperability between different blockchains, predicted to be relevant since the beginning of blockchain development (Mohanty et al. [23]), is now perceived as more and more relevant and is becoming an active area of research. with different possible approaches.

A taxonomy of BI approaches is provided by Belchior et al. [24], which distinguishes three main categories: **Public Connectors**, **Blockchain of Blockchains**, and **Hybrid Connectors**.

Public Connectors aim to provide interoperability between cryptocurrency systems only, hence they were proposed first. Public Connectors include **sidechains** (Loom network[16], Polygon[17]), **Hashed Timelock contracts** (Connext[18]) and **notary schemes** which include centralized (Coinbase[19], Kraken[20]) and decentralized exchanges (Belchior et al., [24]).

Blockchain of Blockchains aim to solve a more general problem. In fact, they are frameworks that provide reusable data, network, consensus, incentive, and contract layers for the creation of application-specific that interoperate between each other. Blocchain of Blockchaind include **parachains** such as Polkadot[21], Cosmos[22] or ARK[23], and **bridges** between different mainnets with specific smart contracts.

Hybrid Connectors go even further. They attempt at delivering a blockchain abstraction layer capable of exposing a set of uniform operations allowing a dApp to interact with blockchains without the need of using different APIs. Hybrid Connectors include trusted relays and agnostic protocols. **Trusted relays** operate as gateways (i.e. pNet-

[16] https://loomx.io/
[17] https://polygon.technology
[18] https://connectblockchain.com/
[19] https://www.coinbase.com/
[20] https://www.kraken.com/
[21] https://polkadot.network/
[22] https://cosmos.network/
[23] https://ark.io/

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work[24]) where interoperability is implemented by a trusted component (either hardware module, single entity or consortium) that locks a token on one blockchain (1 BTC locked) and mints either a wrapped token on the receiving blockchain (i.e. 1 wBTC minted) or the equivalent of the value in another token. **Gateways** are especially useful for connecting blockchains not able to execute smart contracts.

An example of Hybrid Connector that is part of the ONTOCHAIN ecosystem is **Perun-X**[25]. Perun-X has amongst his point of strengths the performance of communications, in particular the speed, between its nodes. Hence, the name Perun means that this solution implements "run of peers", in addition to be the name of an antique deity.

Hybrid approaches, whilst being more effective are also more complex, since sub-chains to be interconnected have be reached with the use of suitable **decentralized oracles** that act as bridge between on and off chain elements [22].

In order to overcome these limits of hybrid approaches, the OC2 project Perun-X adopts a protocol-agnostic approach with trustless interoperability. This is implemented by using trusted brokers in the architecture. Moreover, the inclusion of privacy-preserving encryption protocols between the components makes possibile to secure the communication between different ecosystems.

2.5 DATA TRUSTWORTHINESS AND INTEGRITY THROUGH ORACLES

Oracles are entities that connect Blockchain to external systems, thereby enabling smart contracts to execute functions based upon inputs from the real world[26]. Therefore, different technologies for such oracles are feasible and available, with different trade-offs and typical uses (Ezzat et al. [25]).

Hence, it is essential to guarantee the trustworthiness of Oracles by themselves and of the data acquired through Oracles. This is the so-called **blockchain oracle problem**, also a research topic. Moreover, two challenges have to be considered: a) data availability and b) data reliability.

Solutions using a **single oracle** provide a single point of failure. They contradict the decentralised assumption for blockchain architectures. In any case, they do not assure the data availability, since an input can not be transferred to the blockchain in case of failure.

In spite of the drawbacks mentioned, **centralised oracles**, i.e oracles running on a single server are still the commercial current state of the art. Examples of this kind are

[24] https://p.network/
[25] https://ontochain.ngi.eu/content/perun-x
[26] https://chain.link/education/blockchain-oracles

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provided by the commercial solutions **Oraclize**[27] and **Town-crier**[28].

Hence, **multiple distributed oracles** is the new architectural paradigm which solves the single point of failure challenge. The figure below, from Al-Breiki et al. [26], compares the single oracle configuration and the multiple oracle configuration.

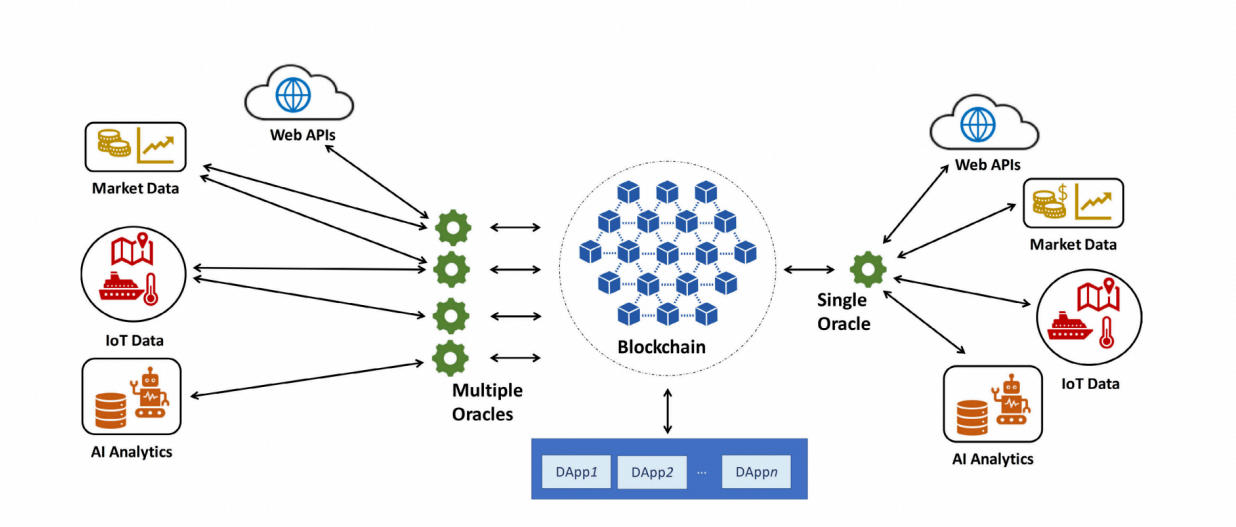

FIGURE 2: Single vs. multiple oracles configurations. (from: Al-Breiki et. al)

In a network of distributed oracles multiple nodes form a peer-to-peer network to inject external data to the blockchain. Distributed oracles can have different instantiations, as in the research demos **ASTRAEA** (Berryhill and Veneris [27]), **Shintaku** (Kamiya [28]), and **Chainlink** (Chainlink 2.0 White paper [29] and Breidenbach et al. [30]) and in the paper by Woo et al. [31].

Moreover, it has to mentioned also the commercial solution **iExec Oracle factory**[29], launched in Beta on October 2021[30] by the ONTOCHAIN partner iExec and available for ONTOCHAIN OC2 projects, which allows to create decentralised oracles (e.g. Norta et al. [32]).

To enter in some technical details of the different approaches of distributed oracles, two problems have to be solved:

- the consensus between eventually different values of the same input
- the data integrity.

[27] Oraclize (now renamed Provable) https://provable.xyz/. Link available: 16/02/2022
[28] "Town Crier Oracle", https://www.town-crier.org/. Link available: 16/02/2022
[29] https://oracle-factory.iex.ec/
[30] "iExec Launches The iExec Oracle Factory: Create Your Own Custom Oracle in Minutes!", 12/10/2021, https://medium.com/iex-ec/iexec-launches-the-iexec-oracle-factory-create-your-own-custom-oracle-in-minutes-14

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However, ASTRAEA, Shintaku and Chainlink solve only the consensus problem, without considering the integrity problem. **ASTRAEA** assumes that voters will only act sincerely without a special reward or penalty. **Shintaku** encourages voters to vote legitimately by rewarding or penalising depending on the answers given to the oracle questions. In **Chainlink**, the external data imported by each oracle server is agreed through the Byzantine Fault Tolerance (BFT) consensus algorithm.

The solution described by Woo solves the data integrity issues (Woo et al. [31]) by using Intel SGX and Transport Layer Security (TLS) communication. Intel SGX[31] in fact allows user-level code to allocate private regions of memory, called enclaves, to protect their access.

The **iExec decentralized Oracles**[32] seems amongst the most advanced solution available in this category, and by the way available for the project ONTOCHAIN ecosystem [32]. Such decentralized oracles are aimed to connect different blockchains (cross-chain technology), in order to comply the project objective of interoperability. IExec Oracles technology is based on sidechain technology[33]. However, it includes the **TEE** (i.e. Trusted Execution Environment) to increase the privacy-preserving and the SSI security of tasks execution [33].

Using iExec Oracle Factory to build oracles implies to make an application-dependent software development, declared however not too complex nor really time-consuming, following the iExec documented guide lines[34].

After having analysed problems and solutions associated with Oracles, we now have to analyse problems and solutions associated with the acquisition stage through IoT, which can be further distinguished into two topics:

- how to verify that the IoT data are correct;
- how to integrate Blockchain and IoT.

The problem of verifying the correctness of data acquired through IoTs is solved by properly using AI, including a training phase to tune expected models. In fact data acquired from a sensor should be related together, typically based on temporal regularities, which can be produced by the sensor itself. Moreover, also the data acquired from nearby sensors could be correlated. This general suggestion has to be, of course, be instantiated for specific cases. By the way, this is the approach used for the OC2 project ADOS[35].

[31] Intel Software Guard Extension", https://www.intel.com/content/www/us/en/developer/tools/software-guard-extensions/overview.html
[32] https://docs.iex.ec/use-cases/iexec-doracle
[33] https://medium.com/iex-ec/iexec-oracle-factory-migration-how-to-migrate-your-oracles-to-the-new-production-cha
[34] https://medium.com/iex-ec/tutorial-integrate-an-oracle-from-the-oracle-factory-into-your-dapp-54dca917e705
[35] https://ontochain.ngi.eu/content/ados

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As far as it is concerned the **integration of blockchain and IoT**, the figure below shows the most commonly used architectures (Reyna et al. [34], Nartey et al. [35]).

As shown in the figure, the most common integration architectures are:

- **IoT-IoT**, which could be the fastest one in terms of latency,
- **IoT-Blockchain**, which requires more bandwidth and data, but allows also to get blockchain benefits, as the availability of all transactions
- **Hybrid approach**, where only part of the interactions and data take place in the blockchain and the rest are directly shared between the IoT devices, with a suitable compromise.

No one of these solutions is superior to others, but the decision to adopt a specific solution depends on the specific use case (number and kind of sensors, real time and throughput required.

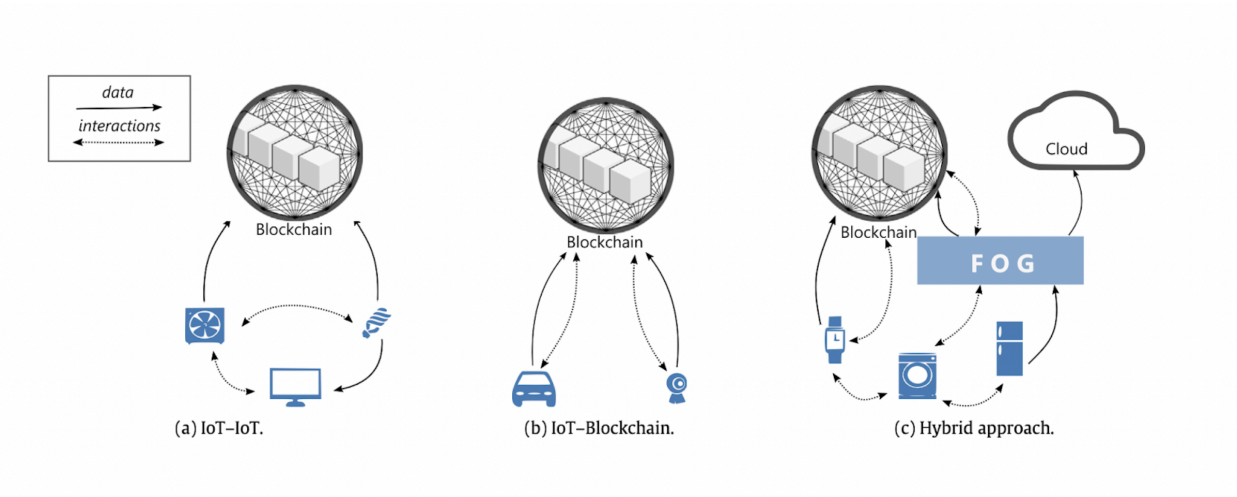

FIGURE 3: Blockchain / IoT most common integration architectures [34]

2.6 MULTIFACTOR AUTHENTICATION AND BLOCKCHAIN

Multi-factor authentication (MFA) is an authentication method which requires the user to provide more factors of evidence before being authenticated (Ometov et al. [36]). Hence, it enables a more robust protection than a password, which is however the most common solution.

Factors to be used for MFA by an user can belong typycally to **knowledge** (i.e. something only the user knows), such as a password, to **possession** (i.e. something only the

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user has, such as a cell phone), and to **inherence** (i.e. something only the user is), which can extracted by biometrics, as his/her face or voice. Specific features to use in a specific application can be selected on the basis of the uniqueness, performance, collectability and user acceptability.

The market of MFA is increasing and addresses applications requiring higher security levels in verticals like banking, financial services and insurances (collectively named BFSI), healthcare, government services and many others.

Different companies are active in this market, as Safran (France), Gemalto NV (the Netherlands), NEC Corporation (Japan), 3M (U.S.), CA Technologies (U.S.), Fujitsu (Japan), VASCO Data Security International Inc. (U.S), HID Global Corporation/ASSA ABLOY AB (Sweden), RSA Security LLC (U.S.), Suprema HQ Inc. (South Korea), Cross-match (U.S.), IBM Corporation (U.S.), Microsoft Corporation (U.S.), Securenvoy Ltd (U.K) and Watchdata Technologies (China).

A further evolution of MFA research and implementation is to rely on decentralised platforms, instead of centralised solutions, for increasing the security. Some recent research papers presents different kinds of proposals in this framework, for specific use cases, by Aydar at e. [37] and Cardoso et al. [38].

A more general solution for decentralized architectures relies on the **Authcoin** authentication protocol (Leiding et al. [39] and Norta et el. [40]). The first paper of those just mentioned describes the formal model of Authcoin, whilst the second paper verifies this model in more detail against security and privacy risks. The Authcoin protocol has been proposed by the team of the OC2 Project MFSSIA: Multi-Factor Self-Sovereign Identity Authentication and is the background of their contribution to the ONTOCHAIN project.

2.7 GEOLOCATION

Different kind of services, named **LBS** (Location Based Services), require that the user properly identify his/her location before accessing the service. Reasons for requiring this are different, as **differentiating features** provided to user based on his/her position, or even **denying the access**. Examples of LBS can be **local services**, which could be tuned for the specific location or **national services**, which can be accessed or not depending on the nationality of the users.

Geolocation is the enabling technology for LBS, since it uses data acquired from an individuals computer or mobile device to identify or describe the users actual physical location [41].

In geolocation it has to be distinguished two very different subcases: the **client dependent location** and the **client independent location**.

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Client-dependent methods rely on specific features of the devices located, such as GPS, accelerometers, and triangulation in WiFi or cellular mobile networks. Typically, the location accuracy is high, within meters.

Client-independent methods are used to locate any Internet device without requiring any additional features in the devices located. Accuracy of client-independent geolocation is lower, typically at city level.

Another distinction that can be done is between **centralised solutions** or **decentralised solutions**. Whilst centralised solutions are very common and appreciated, decentralised solutions add the possibility to assure security and privacy, and are suitable for blockchain architectures.

In the following, we will detail only client-independent methods, as data mapping and measurement methods.

Data mapping approaches, whilst commonly used, suffer from some limitations, as the possibility that the real IP address of a specific server is different from the identified IP address, e.g. because a floating IP address is used. Examples of databases used for geolocation are IP2Location[36],[37], Telize[38], with typical relative accuracy 99% at the country level and 75% at the city level.

As far as **RTT measurement methods**, the first paper (Ries et al. [42]) proposing such a kind of solution relies on measurements between different locations in the Internet with known coordinates and the location of the nodes.

Further evolutions of this initial proposal were the research proposals named **Vivaldi** (Dabek et al. [43]), **Pharos** (Chen et al. [44]) and **Phoenix** (Chen et al. [45]). However, it has been found that these methods for geolocating using general latency delays can have, in some cases, an absolute identification error of more than 1000km. The reason for these anomalous cases is that these methods fully trust the cloud data operator.

A someway different approach in this family of measurement methods is named **GEOtrust** and has been proposed in the year 2019 (Jara et al. [46]). This new proposal addresses the case of errors, due for example to VPN. This proposal relies on a specific protocol **PoO (proof of offset)**, which has been further developed by the OC2 project **GEONTOLOGY**[39], by implementing a two steps algorithm. The first step is similar to others just mentioned (Vivaldi, Pharos, Phoenix) , the second step, which is the novelty of the solution GEONTOLOGY, verifies the robustness of the preliminary assumption made by the first step. The second step guarantees the accuracy against possible misrepresentations, as for example in the case of VPN

[36] https://www.ip2location.com/
[37] https://geotargetly.com/
[38] https://www.telize.com/
[39] https://ontochain.ngi.eu/content/geontology

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Whilst measurement approaches can be adapted to blockchain, blockchain native solutions have been recently proposed, and rely on **PoL (Proof of Location)** protocol. References for the proof of offset are (Cheng et al. [47]). The proof of location is a digital certificate that attests someones presence at a certain geographical location at a certain time.

An high-level overview of PoL is provided by Kalogirou [48], which can be complemented by the EU webinar (O Donnell et al. [49]). A scientific reference paper is Amoretti et al. [50]. Examples of specific implementations so far are **FOAM**[40] [51], XYO[41], which in any case are still at the experimental level.

2.8 IDES AND SEMANTIC SMART CONTRACTS

Integrated development environment (IDE) are software applications that facilitate the development of programs. IDEs can be differentiated by the features provided, including text editors, libraries and debugging tools, by the specific language and/or software environment.

IDEs for blockchain are still in their early stage. They can be analyzed from the **implementation point of view**, since first tools have been available, and from the **research point of view**, since interesting evolutions are under way. We will detail both aspects in the following.

From the **implementation point of view** the blockchain ecosystem requires its specific IDEs to be considered a sufficiently mature technology. In any technology in fact IDEs improve the **development efficiency** and improve the **quality** of resulting software.

A secondary objective which can be achieved by the use of IDEs, specifically for new technologies, is to facilitate the entry and training of new developers. This motivation also applies to blockchain, since the number of developers is still rather limited in comparison to the potential request. This is also a reason mentioned by CIOs as a challenge to solve in order to have a faster adoption of blockchain architectures.

To be more specific, blockchain IDEs can be further differentiated into different categories. Hence, so far it seems that no any single IDE alone covers all requirements of a developer (Awosika [52], Goyal [53]). The most relevant categories are **smart contract IDEs**, for developing smart contracts (as for example **Astracode/BOWLER IDE**[42], Van den Heuvel et el. [54])), and **Web3 IDEs**. Web IDEs are oriented to all stacks of the Web 3 application, including the User Interface, as for example **Moralis**[43]. Hence, smart con-

[40] https://foam.space/company
[41] https://xyo.network/
[42] https://ontochain.ngi.eu/content/bowler
[43] https://moralis.io/

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tract IDEs and Web3 IDEs provide **complementary features** and are typically used in synergy as smart contracts are developed first and full Web3 applications are developed by integrating these smart contracts. Smart contract IDEs, which we will analyze here in more detail, can be categorised according to three main dimensions:

- variety and kind of blockchain technologies supported (as for example Ethereum, Hyperledger, Corda etc.
- testing features available, including the possibility to develop unit tests
- business model (Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS).

Examples of smart contract IDEs are **Aurachain**[44], **SIMBAChain**[45], **BlockApps**[46] , **Joget**[47], **Settlemint**[48], **FabDep**, **KompiTech**[49] and **BOWLER**[50].

We will not provide more detailed comparisons, even at a qualitative level, since commercial solutions are evolving and comparisons will become quickly obsolete.

In any case it should be mentioned than the testing features available seem the most significant limitation of today low-level code IDE.

In ONTOCHAIN OC2 the project BOWLER (Blockchain-Oriented Warehouse & Low-Code Engine and Reasoner) developed a low level IDE Astracode/Bowler. The Bowler team builds up from their background Astracode and adapted to the ONTOCHAIN network through the new extension BOWLER. AstraKode/Bowler supports Ethereum platform and is provided as PaaS.

But low-code IDEs imply not only software engineering activities, but also **new research**, especially on **semantic contracts**. An example is the semantic implementation of smart contracts, which are emerging as an active research field. In fact Semantic Web technologies, and notably ontologies, have been recently studied in order to allow the users to treat formal specification of smart contracts, as detailed in the following.

Ontologies are defined as formalisations of concepts and relations within a domain encompassing a representation (Allemang and Hendler [55]). This definition includes the formal naming and the notion of the categories, properties and relations between concepts, data, and entities.

As a result, ontologies do not only introduce a shareable and reusable knowledge rep-

[44] https://aurachain.ch/about-us/
[45] https://simbachain.com/
[46] https://blockapps.net/
[47] https://www.joget.org/
[48] https://www.settlemint.com/
[49] https://blockchain.kompitech.com/
[50] https://ontochain.ngi.eu/content/bowler

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resentation but can also add new knowledge about the domain. The standard approach to implement ontologies through semantic web languages including OWL[51] and RDF[52].

Many ONTOCHAIN OC1 and OC2 projects used, extended or developed ontologies. A noteworthy example is the OC1 project POC4Commerce[53], which extended ontologies in the domain of e-commerce.

Semantic technologies should facilitate the development of smart contracts. This is viable if semantic contracts are implemented by joining a ontology which describes the contract and a blueprint of smart contract. This approach means to adopt **declarative** instead than procedural programming.

Smart contracts developed this way should be **more robust against coding errors and malevolent behaviours**. Last, but not least, semantic contracts should be **easier to test**, by implementing the reasoning, as detailed in the following.

Hence, the research in low code smart contracts could further be distinguished in two related directions:

- generating smart contracts from ontologies
- testing semantic smart contracts

As far as the generation of smart contracts is concerned, it has to be mentioned first that Ethereum itself is based on an ontology, named EthOn (the Ethereum Ontology, see also English [5]).

EthOn formally stipulates concepts and terms of the Ethereum ecosystem in OWL. EthOn describes all the Ethereum objects as classes in the ontology. Also, it structures all interactions and attributes of objects as properties from the ontology perspective of view.

At a much more abstract level, Norta et al. [56] propose an ontology that includes the principal smart contract concepts and properties with the objective of managing decentralised autonomous organisations. In fact such decentralized organizations can be technically enabled by the use of the blockchain technology.

Choudhury et al. [57] introduced and explored a method to automatically generate smart contracts in the Go language within the Hyperledger environment and relying on the OWL language. For this purpose, they exploit the Semantic Web Rule Language (SWRL[54]) to expand the expressiveness of OWL and abstract syntax trees. In this way they can systematcally generate the code of the needed smart contract given a prede-

[51] https://www.w3.org/OWL/
[52] https://www.w3.org/RDF/
[53] https://ontochain.ngi.eu/content/poc4commerce-practical-ontochain-commerce
[54] https://www.w3.org/Submission/SWRL/

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fined template.

It has to be mentioned that the OC2 project BOWLER[55] uses blueprints, with an approach someway similar to the approach followed by the just mentioned paper by Choudhury et al. [54].

The SANSA [58] constitutes an open-source framework that allows RDFs processing at scale. It provides a set of libraries aimed for semantically-enriched features as distributed reading, executing SPARQL queries, performing inference as well as analytics over large-scale knowledge graphs.

In the contribution by Petrovic et al. [59], a smart contract source code ontology has been suggested that allows to issue queries as semantic triple stores to check various types of vulnerabilities. This researchs contribution also introduces a transaction runtime ontology to verify smart contracts, before and after thd execution.

3 APPLICATIONS

3.1 INTRODUCTION

Blockchain enables a new wave of Internet applications and technologies and is becoming more and more popular: for example, the report[56] begins by mentioning that *"the global blockchain market is projected to grow from $7.18 billion in 2022 to $163.83 billion by 2029, at a CAGR of 56.3% in forecast period, 2022-2029"*.

Blockchain's architectures are based on distributed databases, in which new transaction results are appended in sequence of blocks after the reach of consensus of different validator nodes, whilst past transactions cannot be changed anymore.

The first complete idea of Blockchain was proposed in 2008 by the paper [60] authored by Nakamoto, a fictitious name of a person. This proposal unifies already existing research fields as:

(a) how to register immutable and time stamped transactions, with a landmark paper written in the 90 by the Bell Labs researchers Haber and Stornetta [61], also registered as patents [62] [63];

(b) how to validate distributed databases through distributed consensus methods, as for example in Thomas [64];

[55] https://ontochain.ngi.eu/content/bowler

[56] "Blockchain market in Fortune Business Insights reports", https://www.fortunebusinessinsights.com/industry-reports/blockchain-market-100072

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and, moreover, suggests how to remunerate those participating in the infrastructure: the first applications were in fact specific for cryptos.

Further evolutions of blockchain architectures introduced the concept of smart contracts, as in the Ethereum white paper by Vitalik Buterin [65]), allowed to generalise the potential applications.

In summary, blockchain solutions, given their decentralised and immutable database, can support more secure, transparent and private applications than more traditional applications characterised by centralised databases.

In any case, besides opportunities, there are also challenges, in evolving from more traditional centralised solutions, to new blockchain solutions, as summarised in the paragraph 3.2.

The following paragraph 3.3 provides an overview of 15 domains (or verticals), whilst the following paragraphs detail for any of these vertical the most interesting use cases.

To write this section about applications, we used the following information sources:

(a) scientific papers and business literature identified, which can be further distinguished into 3 levels:

- documents which provide a higher level overview;
- documents which provide an overview of a specific domain, as for example healthcare;
- documents which provide an overview of a specific use case in a domain, as for example clinical trials in healthcare documents which provide an overview of a specific domain (or vertical), as for example healthcare.

(b) reports from EU bodies and initiatives, as the EU blockchain Observatory and Forum and the Joint Research Center[57][58];

(c) specific reports from other international bodies, as OECD (Organisation for Economic Co-operation and Development)[59] and the United Nations;

(d) OC2 internal meetings between ONTOCHAIN partners and OC2 participants, from which we also extracted the topics proposed for OC3[60] and we extracted the framework for the ONTOCHAIN Software ecosystem[61];

[57] https://ec.europa.eu/info/departments/joint-research-centre_en
[58] https://publications.jrc.ec.europa.eu/repository/
[59] https://www.oecd-ilibrary.org/
[60] https://ontochain.ngi.eu/apply
[61] https://ontochain.ngi.eu/projects-map

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(e) presentations provided in the ONTOCHAIN summit in Berlin (1-2 June 2022)[62] in the session Open Call #3: Technologies & Applications, in which 11 possible applications have been presented.

[62] https://ontochain.ngi.eu/ontochain-summit

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3.2 WHEN AND WHY TO USE BLOCKCHAIN

3.2.1 The Technical Point of View

In spite of the increasing use of blockchain solutions, not all applications are suitable for a blockchain implementation or also for a specific blockchain architecture (e.g. public, private): this topic is analysed or detailed in some recent research papers (Wüst et al. [66], Lo et al. [67], Hunhevicz et al. [68]).

The following figure (from Wüst et al.) [66] exemplifies the process for deciding the most suitable architecture to adopt.

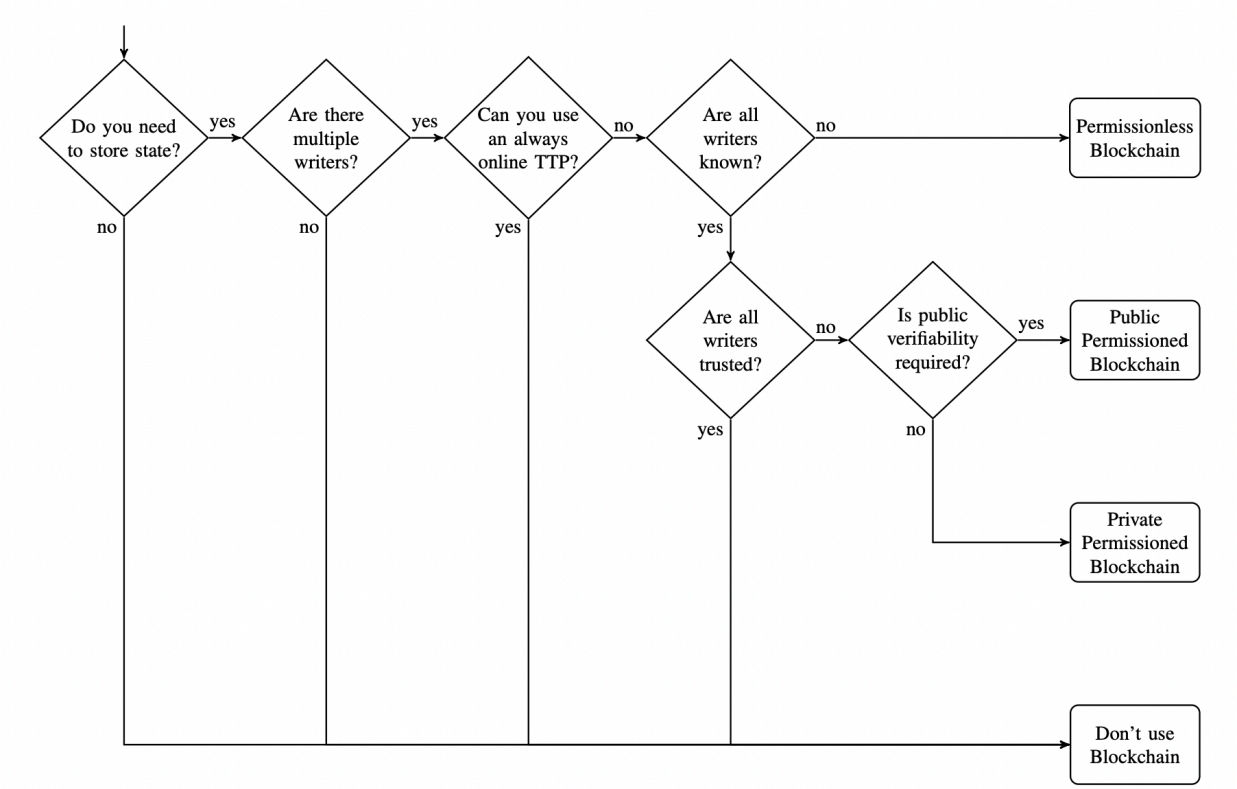

FIGURE 4: How to select the most suitable blockchain architecture

The suggested architecure has to be considered in the assessment of ONTOCHAIN OC3 applications, as the potential market of the application, the achievable market and the business model.

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3.2.2 The Business Point of View

As in any new technology wave, blockchain based solutions can be introduced for three general reasons:

1. to replace legacy solutions in order to solve well known challenges, related to privacy and security;
2. to replace legacy solutions to provide more cost-effective and efficient solutions;
3. to provide brand new applications which are not possible with legacy technology, to be further distinguished between:
    a) new application pulled by other technology evolutions, as in the P2P energy distribution;
    b) new applications suggested by the availability of blockchain technologies, such as Decentralised Finance (DeFi).

The following table summarises these general reasons for introducing a new technology and blockchain specific subreasons. It can be also used as a framework for assessing the business motivation (or even a combination of business motivations) to introduce blockchain in a specific application.

TABLE 2: Business motivations to introduce blockchain solutions

General reason for introducing a new technology	**Blockchain-specific subreason**
To solve well known challenges of legacy technology	To cope with lack of privacy and of adequate rewards, for contributors
	To cope with: lack of privacy and lack of quality assessment about provenance and contributions, for readers
To replace legacy solutions with better solutions	To provide a more secure solution
	To provide a more efficient solution from the operation point of view

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General reason for introducing a new technology	Blockchain-specific subreason
To provide brand new applications not possible with legacy technology	To properly remunerate different actors (e.g through NFTs)
	To simplify the value network, by reducing the need of intermediaries
	To simplify the governance, including the possibility of distributed autonomous organisations

But there are also challenges associated to the typologies just mentioned.

In the first typology, in which the blockchain solves today challenges (e.g. privacy and security), the provider of a new blockchain based solution has to properly motivate its users to **switch from a centralized solution** they already use. In fact users have to cope with costs of adapting themselves to a new user experience, moving their data to a new platform and very likely to incur new users costs, which should be typically higher in blockchain-based solutions. By the way, some **regulations**, such as **GDPR** (General Data Protection Regulation)[63], can also motivate users to switch to blockchain.

In the second typology, more common in **B2B**, blockchain-based solutions are typically motivated by the **reduction of times and costs of day by day operations**, as for example in **logistics**, **banks** and **insurances**. Whilst these use cases are really promising, even in these cases customers have to consider the switching costs **from the centralized legacy** to the new solution: this could delay the decision to move to blockchain.

The use cases belonging to the third typology are more open to new applications and new entrants, whilst also in this case some challenges have to be considered, as:

(a) blockchain regulations in the specific vertical domain have to be sufficient mature;

(b) the business models enabled has to be sustainable and win-win for all participants;

(c) the problem solved has to be really interesting for specific user groups.

[63] https://eur-lex.europa.eu/eli/reg/2016/679/oj

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3.2.3 Regulations, directives and standards

Some specific verticals, such as Finance, Insurance, Health Energy, Logistics are regulated at the international level. This has to be taken into account for blockchain application providers, to comply with the present state of regulations. These regulations are also evolving, not to miss the opportunities provided by blockchain technologies also in these verticals. Hence these evolutions have to be **constantly monitored** by application providers.

Directives and policies of the **EU Commission** as the **Digital Services Act**[64], the **Digital Markets Act**[65] and the **Data Act**[66] promote evolutions in applications and business models which can benefit from the adoption of blockchain technologies.

In fact blockchain technologies allow to **protect users of data and services** through better security and privacy, whilst enable to **establish more agile and disintermediated markets of data and services** and enable to lower the barrier of entry for new players also by facilitating the establishment of new consortia of providers, integrated vertically and horizontally. In addition, blockchain technologies can suitably support a fair remuneration of service prosumers.

Last, but not least, an enabling factor for the acceptance of blockchain solutions is related to the evolution of the related **technology standards**. In fact, whilst significant results in this area have already been consolidated, other activities are under way and should be suitably monitored. A useful resource for this is the European Commission page about blockchain standards[67].

This page mentions as particularly relevant today for standardisation the following topics:

- **interoperability**: to ensure the different blockchain and DLT protocols and platforms can exchange data and seamlessly communicate with each other;
- **governance**: to identify best practice and standards in governing blockchain projects as well as blockchain consortia working on decentralised platforms;
- **identity**: to promoting a common identity framework and/or interoperable identity among different blockchain protocols and platforms;
- **security**: to ensure a secure operation of the different nodes, networks and services;

[64] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/digital-services-act-ensuring-safe-and-accountable-online-environment_en
[65] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/digital-markets-act-ensuring-fair-and-open-digital-markets
[66] https://digital-strategy.ec.europa.eu/en/policies/data-act
[67] https://digital-strategy.ec.europa.eu/en/policies/blockchain-standards

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- **smart contracts**: to support best practice and standards to ensure smart contract technology is safe and secure.

3.3 VERTICALS AND USE CASES OVERVIEW

Many use cases and applications have already been identified as relevant for the blockchain in different reports (Casino et al. [4], [69]) and even their categorization depends on the report.

This report D3.2 uses a two level categorization:

1. a first level categorization by economic activity, similar to the level 1 NACE (Statistical Classification of Economic Activities in the European Community)[68], in which 15 verticals have been identified as specifically relevant for blockchain applications, i.e. Agrifood, Arts, Constructions, Education and science, Energy, Fashion and Luxury, Finance and Banks, Healthcare, Industry, Information and Media, Insurances, Logistics-including e-commerce-, Mobility, Public sector and Smart-cities, Tourism;
2. a second level categorization of most relevant use cases by any economic activity, including typically from 6 to 10 use cases for each vertical.

The first level categorization has been selected in such a way that verticals are the most independent as possible, to allow as possible to associate a use case to a specific vertical. In any case it is unavoidable that some specific use cases belong to two verticals at the same time, as for example insurances for agriculture.

Moreover, the first level categorization is similar to the categorization used in most business reports to provide aggregate revenues by domain.[69]

However, the first level categorization does not include technology or business related categorizations, as for example IoT, NFT and like. These categories have to be eventually considered as attributes of specific use cases and not categories.

The table in the following summarizes for any domain the most relevant overview papers. Papers and contributions detailing specific use cases and examples are presented in the paragraph which details the domain.

[68] "NACE Codes: What Are They and Why Do They Always Matter", April 7, 2022, at https://connects.world/nace-codes/

[69] https://www.grandviewresearch.com/industry-analysis/blockchain-technology-market

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TABLE 3: Verticals in Blockchain.

Number	Vertical	Main references
1	Agrifood	[70], [71], [72], [73] .
2	Arts	[74], [75] .
3	Constructions	[76], [68] .
4	Education and science	[77], [78], [79], [80] .
5	Energy	[81], [82], [83] .
6	Fashion and Luxury	[84], [85] .
7	Finance and Banks	[86], [87], [88], [89], [90] .
8	Healthcare	[91], [91], [92], [93], [94], [95], [96] .
9	Industry	[97], [98], [99], [100], [101] .
10	Information and media	[102], [103], [104].
11	Insurances	[105], [106], [107], [108], [109] .
12	Logistics, including e-commerce	[110], [111] .
13	Mobility	[112], [113], [114] .
14	Public sector and Smart cities	[115], [116] .
15	Tourism	[117], [118], [119] .

3.4 AGRIFOOD

The agribusiness is very differentiated, by kind of goods (livestock, plants) and activities. Also general requirements are different between developed and developing nations, as summarised in a **FAO report** [120] authored by Tripoli and Schmidhuber. In any case, the application of blockchain technologies to different needs in agrifood is considered promising and can generate many emerging opportunities [121]. The analysis of background and overview papers (Rocha et al. [70], Xiong et al. [71], Wassenaer et al. [72] and Feng et al. [73]) shows that most agrifood applications are in **supply chain** management, with different kinds of motivations. Other applications are in **financial** and insurance farmer-specific services, in land **notarization**, in **production** optimization and in **green** optimization and reconversion.

Blockchain solutions in Supply Chain have been introduced first to certificate the **ori-**

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gin of products and to guarantee as well the quality of the distribution chain. On the other side (i.e. from consumer to producer), blockchain solutions have been proposed to enable a better alignment of the producer's supply to consumer **requests**, also with the objective of reducing waste.

Other blockchain applications in the supply chain aim to improve the efficiency of the whole business process, e.g. by reducing intermediaries and related costs or, more in general, to facilitate suppliers in the access of this market, by facilitating the qualification and also the aggregation of minor suppliers.

Parametric insurances are those in which the customer is paid in the case that some specific events happen, without any additional investigation on effects. This simplifies internal processes, hence reducing internal costs of the insurance. Parametric insurances have different applications. In the case of farmers, parametric microinsurances are typically paid automatically in the case that an extreme weather condition arises, e.g. a storm, without having to verify in detail the consequences. These extreme conditions are verified through a suitable network of IoT sensors connected to the blockchain architecture through distributed oracles.

Parametric micro insurances for farmers have been originally proposed for tropical countries, but are now proposed also more generally, since climate change can make extreme weather conditions more common. Micro insurance solutions can be further distinguished between platforms ("Etherisc White Paper", November 2017, [122]) and services.

As a micronsurance example it has also to be cited the project **CareChain**[70], one of ONTOCHAIN OC2 projects, which has developed a micro insurance demo for farmers whose Smart contract identifies the exceptional weather conditions under which the insured farmer is paid, e.g. a wind over 120 Km/h in the municipality of the farmer. This kind of application requires that specific meteo conditions are measured by devices connected to the blockchain infrastructure through distributed oracles in connection with an IoT network of suitable sensors. In such a cases, the application has to filter eventual spurious inputs from sensors and this has to be assured by suitable AI technologies. An example is the Carechain application, are provided by the project outcome provided by the OC2 project **ADOS**[71].

Farmer-specific finance solutions are proposed or under experiment, and this could become an interesting opportunity especially for developing countries. In fact farmers have to face a yearly cycle for new funding needs for seeds. Less wealthy farmers can be challenged, since their activities are typically not effectively collateralized. Hence blockchain solutions have been proposed to deliver seasonal investment products to farmers on the basis of their operation's and business credibility. In fact such credibility is supported by the history and characteristics of each farmer, and they are perma-

[70] https://ontochain.ngi.eu/content/carechain
[71] https://ontochain.ngi.eu/content/ados

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nently stored and updated in a blockchain solution.

Another way of getting business credibility is by being certificated for the land used. **Land registries** are a good opportunity for applying blockchain solutions, especially in developing countries (Kshetri and Voas [123]), where paper documentation of the land ownership is not always available of complete, and this provides a further incentive to adopt new technologies. An example of this kind of service is BitLand in Ghana[72].

Last, but not least, blockchain architectures can be useful in **smart and precision agriculture**. Smart agriculture solutions consolidate and share best practices, which are stored in DLT. Precision agriculture solutions allow to optimise operations, e.g. irrigation, by suitably interacting with distributed sensors and actuators. A related application domain is the green agriculture (Wassenaer et al. [124]), which faces the specific challenge of **reducing waste in agriculture** (also referred as "food losses and wastes", or FLW), as in the paper authored by Azri Amran et al. [125].

The optimization of production, especially for smart and precision agriculture, is another topic where blockchain can bring advantages. Smart architecture consolidates and shares best practices, which are stored in DLT, when precision architecture optimise operations, e.g. irrigation, by suitably interacting with distributed sensors and actuators. A specific sector of product optimization faces with the specific challenge of reducing waste in agriculture, as in the paper by Azri Amran et al..

The following table provides an overview of most relevant agrifood specific use cases, not mentioning in any case other use cases which can help SMEs, e.g. in the international trade, whilst in any case not agrifood-specific.

TABLE 4: Use cases for the use of Blockchain in Agrifood.

Use Cases	Motivations	Examples
Supply chain management for quality control	To support the provenance and tracing of goods	Ripe[73], Ambrosius[74], Provenance[75], AgriOpenData[76]

[72] https://borgenproject.org/property-rights-for-the-worlds-poor/
[73] https://www.ripe.io/
[74] https://ambrosus.io/
[75] https://www.provenance.io/
[76] https://www.ezlab.it/our-project/agriopendata-project/

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Use Cases	Motivations	Examples
Supply chain management, to forecast the demand	To support the provenance and tracing of goods To connect more efficiently consumers and farmers	INS[77]
Supply chain management, for business optimization	To reducing distribution costs through shorter supply chain	IBM[78]
Supply chain management and e-commerce	To support small farmers, even in developing countries, through better visibility and aggregation of the offer	SAP Cloud Platform Blockchain[79]
Specific insurance services for farmers	To save damage evaluation costs for the insurance company by parametric micro insurances: insurances are automatic paid in case of extreme weather conditions in the area measured through IoT and distributed oracles	Etherisc[80]
Specific financial services for farmers	To rely on the business reputation more than on collaterals to provide seasonal credits (in the seed season, for example)	Tempo [126], AB InBev[81]
Land notarization	To provide an easier certification of land ownership, especially in cases when a paper register does not exist	Bitland[82], HARA[83]
Production process optimization, in Smart and Precision agricolture	To register and share best practices, to measure conditions and act through suitable sensors and actuators	Golden State Foods (GSF)[84]

[77] https://fooddigital.com/food/ins-using-blockchain-grocery-industry
[78] https://www.protocol.com/ibm-blockchain-supply-produce-coffee
[79] https://www.techtarget.com/searcherp/feature/4-key-blockchain-in-supply-chain-use-cases-and-examples
[80] https://etherisc.com/
[81] https://www.forbes.com/sites/alexknapp/2019/04/16/this-buds-for-blockchain/?sh=6f5390fd5966
[82] https://borgenproject.org/property-rights-for-the-worlds-poor/
[83] https://www.hara.ag/
[84] https://www.ibm.com/blogs/industries/golden-state-foods/

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Use Cases	Motivations	Examples
Green optimization	To reduce wastes produced in agrifood or left in the environment	PlasticBank[85]

3.5 ARTS AND CREATIVITY

According to the overview paper by Whitaker [74], this vertical is definitely suitable to exploit **NFT and metaverse**, and can be further distinguished in different subdomains (Mire, [75]) , as:

- cultural heritage management;
- digital fine art and digital contributions marketplaces;
- performing arts (as music) marketplaces and events.

In **cultural heritage management**, it can further distinguished different use-cases:

1. assuring the **provenance** and/or **authenticity** of fine artworks. Strong rules exist for this vetting, whose associated procedures increase the cost of sales. The recording of the provenance and authenticity in immutable blockchain will significantly reduce these costs, whilst a remaining challenge in this area is the association between the physical artwork and the blockchain listing;
2. enabling decentralised **auctions** and **trading**. Decentralised auctions are more secure than traditional centralised actions since they do not suffer from the "single point of failure". By the way, blockchain decentralised auctions can be applied to other sectors, including energy trading (Shi et al. [127]);
3. supporting **fractional ownership** of costly fine art artworks in order to popularise fine art investment.

In **digital fine arts** and digital contributions, it can be further distinguished:

1. introducing the **scarcity** of digital works by using NFTs;
2. exploiting the market of **social contents** (e.g. street art).

It has to be mentioned that a possible application enabled by the OC1 project **CopyrightLY**[86] is the monetization of the copyrighted contents posted on social websites,

[85] https://cointelegraph.com/news/unwrapping-the-ocean-plastic-conundrum-via-blockchain
[86] https://ontochain.ngi.eu/content/copyrightly

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as e.g. Youtube[87] (García et al. [128]).

Finally, **performing arts** have to be mentioned . Main motivation for music marketplaces is to **disintermediate** artists to customers. In fact, since today the intermediated structure of market and platform substantially have penalised the less known artists from the remuneration as well as from the visibility point of view (Daley [129]) Whilst this case is significantly disruptive for well established businesses (Chalmers et al. [130]), some technology initiatives and commercial solutions exist. Among the different technology initiatives it can be mentioned the **Open Music Initiative** (OMI)[88] for creating an open source protocol for the uniform identification of music rights holders and creators, and commercial solutions as summarised in Daley [129].

Main motivations for using blockchain solutions for **festival organisations** are to manage in a more efficient and agile way the **logistics** of the event itself and of **different kinds of players involved** and to provide a **fair compensation** to the different players involved, from artists to organisers, by using a more advanced rewards and payment system, as possible by the use of NFTs. In fact festivals today are rather challenged from the economic point of view and have to rely heavily on volunteers' unpaid work, whilst these events provide direct or indirect benefits to the community in which they are organised, by increasing visitors.

Hence the use of blockchain in festival organisation seems an interesting possibility to consider in this use case, which also partially overlaps with tourism and smart cities (Whitaker et al. [131]).

It has to be mentioned that one of the exploitation demos of OC2 project **BOWLER**[89] is the NFT-based ticketing for festival management.

The following table summarises the use cases mentioned in this paragraph.

TABLE 5: Use cases for the use of Blockchain in Art.

Use Cases	Motivations	Examples
To guarantee the provenance and authenticity	To support fine art traceability	Verisart[90], Artory[91]

[87] https://www.youtube.com/
[88] https://open-music.org/
[89] https://ontochain.ngi.eu/content/bowler
[90] https://verisart.com/
[91] https://www.artory.com/

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Use Cases	Motivations	Examples
To support the activity of auction houses	To enable more efficiency	Christie's[132]
To facilitate the co-ownership of fine arts	To democratise investments	Mecenas[92]
To decentralise art exchanges	To reduce intermediaries	Mecenas[93]
To keep digital art scarce, through NFTs	To exploit a new market	CryptoPunks[94]
To found street art	To exploit a new market	Scarab[95]
To provide marketplaces to disintermediate artists and their public	To support a more agile and efficient marketplace, with more opportunities for less known artists	Open Music Initiative[96], others mentioned by Daley [129]
To support more efficiently the organisation of music festivals	To have more efficient logistic, with less costs and at the same time more revenues with differentiated and agile payments, as NFT [131]	D-Visor[97]

3.6 CONSTRUCTIONS (AECO)

IT applications in constructions (or more properly AECO, i.e. Architecture, Engineering Construction and Operation) can be distinguished according to the different phases, such as procurement, design, operation and maintenance, commercialisation (Scott et al. [133], Perera et al. [134] and Shojaei [135]).

[92] https://www.maecenas.co/
[93] https://www.maecenas.co/
[94] https://www.larvalabs.com/cryptopunks
[95] https://www.thescarabexperiment.org/
[96] https://open-music.org/
[97] https://www.d-visor.nl/en/d-event/

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In the **procurement phase**, different kinds of suppliers have to be engaged (masons, electricians, plumbers, carpenters): a blockchain architecture supporting smart contracts improves the efficiency of this phase.

But even a more strategic reason to use blockchain in the procurement phase is to **reduce planned wastes** and to properly plan the recycling of unavoidable waste. In fact it has to be mentioned that the construction industry typically is the main producer of industrial waste (36% of all industrial waste are produced by the construction industry), as shown in the diagram from Pellegrini et al. [76].

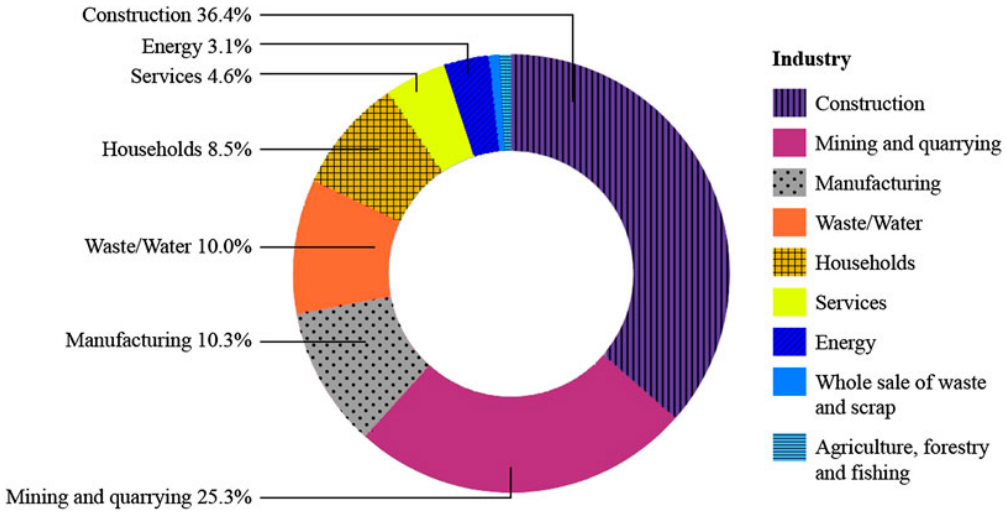

FIGURE 5: Waste generated by different industry verticals (source: Pellegrini et al.

The **design phase** of AEC is provided by BIM solutions (Building Information Modelling), but some new tools are now appearing which include blockchain and Metaverse, to provide more agile and user friendly solutions and, even more important, to support the marketing of new buildings [136].

One of the main uses of blockchain in constructions (or more properly AECO, i.e. Architecture, Engineering Construction and Operation) is to facilitate the **cooperation** of different kinds of suppliers (masons, electricians, plumbers, carpenters) which are required in a typical construction activity. Hence the objective of these applications is to improve the time efficiency: in this framework a permissioned blockchain architecture is well appropriate (Hunhevicz and Hall [68]).

In the end, it has to be cited the blockchain supported solutions to **record contracts** in the real estate industry, which are one of the applications for blockchain supported notarization (e.g. Propy[98]).

[98] https://propy.com/browse/propy-nft/

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As a more advanced possibility, it has to be mention the proposal to **automatize the maintenance of buildings** by suitably integrating smart contracts, distributed Oracles and IoT in a DAO solution, as proposed in Li et al. [137].

The following table summarises the most cited use cases.

TABLE 6: Use cases for the use of Blockchain in Construction.

Use Cases	Motivations	Examples
To support procurement, including Green procurement	To have more efficiency in the whole process of construction logistics, also to reduce waste and control recycle of the materials	VeChain[99], OrionOne[100]
To support the design, including Metaverse	To provide more user friendly and agile BIM solutions	VT platform[101]
To support and coordinate the activity of different kind of suppliers	To increase time efficiency and to reduce miscoordination costs	Excess Materials Exchange[102]
To register contracts through blockchain notarization	To provide safer recording of contracts	Propy[103]
To support the maintenance	To reduce maintenance costs and improve quality by relying on DAO and IoTs	Consensys[104]

3.7 EDUCATION AND SCIENCE

Blockchain solutions in education (Guustaaf et al. [77], Daley [80]) are used primarily for providing a **safe registry of certificates**. Another use is towards providing a new

[99] https://www.veworld.com/
[100] https://orionone.co/
[101] https://www.vt-lab.com/en/home/
[102] https://excessmaterialsexchange.com/
[103] https://propy.com/
[104] https://consensys.net/blockchain-use-cases/real-estate/

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generation of e-learning platforms, whilst in science, as stated by Kosmarski [79]), those solutions can enable new business models in publishing research results and even in research marketplace and founding.

Safe **registry of certificates** can be provided at different levels, typically at the university level. A blockchain solution is more efficient for the university and alumni. A registry platform is more interesting when it aggregates more data. This is the promise of the EBSI[105] initiative in Europe, which includes the "Diploma"[106] as one of the first use cases.

Moreover, based on certificates, other solutions can provide **suggestions to potential employers** about most promising candidates or even **suggest next courses to students** to become more proficient in a specific domain.

Moreover, **e-learning platforms** are now evolving to blockchain architectures to establish more agile applications and marketplaces. It is not surprising that the coursewares provided by these platforms are in most cases about blockchain topics.

Blockchain solutions in science can provide **more controlled open data to validate research**, or can simplify the peer review and publication process, providing **fairer rewards to authors and reviewers**, or can even better support the crowdfunding of research, including the possibility of establishing DAOs for research.

In general, blockchain solutions in science have to **face business challenges**, due to today's most common practices in peer reviewing and publishing, which can be disrupted by blockchain technologies. Notwithstanding blockchain solutions in science can also have a good potential, if sustained by proper investments.

Finally, blockchain solutions in science can support **crowdfunding for research**. From this background sparkled the **Decentralised Science (DeSci)** (Hamburg, [138]) initiative, which has many facets, such as the use of NFT research tokens to remunerate the research and the establishment of new research projects as DAOs (Sprague, [139]) : first DAO research projects are now established, most of which in biotech (Golato, [140])

The following table summarises the most cited use cases and examples, according to background and overview papers it has to be identified for education and science:

[105] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home
[106] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSIDOC/Diploma+Functional+Scope

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TABLE 7: Use cases for the use of Blockchain in Education and Science.

Use Cases	Motivations	Examples
Certifications registry	To provide a safe registry of certifications	EBSI diploma[107], Blockcert[108], Sony Global Education[109]
Suggestions for employers and students	To identify the most suitable candidates for employers or to suggest best courses for students	Parchment[110], APPII[111]
e-learning portals and marketplaces	To support the courseware market and to reward teachers and students	ODEM[112], BlockChainE-ducational-Network[113], BitDegree[114]
Open data for research	To validate research data by timestamp and immutability	Bloxberg[115], Arctifacts[116]
Publishing and peer reviews support	To speed up publishing and to facilitate re-viewers	Orvium[117]
Crowd funding the research	To get a new and more agile source of founding	Catalist[118], Deip[119]
DAO for science	To support new and more agile research initiatives	The science DAO[120]

[107] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSIDOC/Diploma+Functional+Scope
[108] https://www.blockcerts.org
[109] https://www.sonyged.com/en
[110] https://www.parchment.com/
[111] https://appii.io/
[112] https://odem.cloud
[113] https://www.blockchainedu.org/
[114] https://www.bitdegree.org
[115] https://bloxberg.org/
[116] https://artifacts.ai/
[117] https://orvium.io
[118] https://www.catalyst.molecule.to/
[119] https://deip.world/
[120] https://thesciencedao.io/

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3.8 ENERGY

The energy sector faces significant challenges today. The State of the Energy Union Report [141] mentions as priorities the **energy efficiency**, to reduce dependence on imports, **renewable energy**, to face with the climate changes, and a **fully integrated internal energy market**, to enable the free flow of energy through the EU.

These objectives are also mentioned in the European Commission initiative REPowerEU[121].

Blockchain applications can support these challenges, as summarised[122] in the overview authored by Andoni et al. [81], in the recent reports of the JRC authored by Fulli et al. [82] and of the EU Blockchain Observatory and Forum [83] and more in general can provide solutions in line to the new evolution of the energy networks towards a more **decentralised P2P architecture** including smarter edges.

The most relevant use cases (see also Li et al. [142]) are detailed in the following.

First of all, **smart metering** in the today networks can support automated billing and allows to reduce administrative costs whilst at the same time allows to provide a better service to users. From the technological point of view, smart metering implies to rely on distributed oracles and IoT. Smart metering can occur as well in **microgrids**, in order to improve the efficiency and to predict the network loads and finally to properly manage the network.

Another relevant application is the decentralised and efficient management of **green certificates**. Green certificates rely on suitable certificates of origin transmitted immutably through the blockchain infrastructure, whilst retaining the initial identity. Hence they enable the users to facilitate the creation of a market of such assets. However, the first generation solution are still not totally efficient, since they do not include minor energy producers. Moreover, they are not immune from fraud issues. At last, this use case provides a more complete measurement of green energies used, it is surely in synergy with the Renewable Energy Directive, which sets rules for the EU to achieve its 32% renewables target by 2030 in EU [143].

[121] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

[122] "the blockchain could help disintermediate the industry by transforming Transmission System Operator (TSO) and Distribution System Operator (DSO) roles of top-down energy providers and possible single points of trust and failure in the energy supply chain into peers operating in a horizontal network where also producers from Distributed Energy Resources (DER) could freely interact with both industry and retail players"

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The following table summarises the most cited use cases, according to background and overview papers:

TABLE 8: Use cases for the use of Blockchain in Energy.

Use Cases	Motivations	Examples
Decentralised energy trading	To democratise investments	PowerLedger[123]
Green certificates and carbon trading	Decarbonization as a long-term objective.	Wien Energie and RIDDLE&CODE[124], GREENCHAIN from Acciona[125]
Grid management	Congestion management.	Microgrids (e.g. PONTON, Slock.it)
IOT, smart devices automation and man.	Smart metering, real-time monitoring, asset tracking and asset management.	PROSUME[126]
Electric e-mobility	EV charging infrastructure, fault tolerance, economic decoupling between actors (between charging stations or transport providers).	Worldline[127]

There are still some technological and legal limitations for the diffusion of BC solutions in energy market (e.g. scalability, consensus criteria, etc.), that can be however solved with some further evolutions. In fact further fine-grained studies based on the actual industrial information will be able to address correctly the technological and legal conditions in order to obtain advantages from the diffusion of Blockchain technologies.

[123] https://www.powerledger.io/
[124] https://www.smart-energy.com/industry-sectors/new-technology/wien-energie-launches-blockchain-jv/
[125] https://www.acciona.com/
[126] https://prosume.io/
[127] https://worldline.com/en/home/knowledgehub/blog/mobility.html

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3.9 FASHION AND LUXURY

Fashion and luxury face the challenges of counterfeiting and more in general allow to have full control of the provenance and of whole distribution channel, including post-sale activities (Filocamo [84], 101 Blockchains [85]).

In fashion and luxury the blockchain technology is well appropriate for controlling transactions, whilst the use of IoT allows a fine grain control of goods. Hence, the main motivations for the use of blockchain in these verticals are the same of Supply Chain Management (SCM); references are Wang et al. [144], Caldarelli et al. [145], de Acetis [146] and Filocamo [147].

Moreover, fashion and luxury applications can be further categorised into pre-sale and post sale applications.

Presale applications can certify goods, rough components and also the distribution channels.

The certification of luxury goods for **anti-counterfeiting** is certainly an important business, since the total trade in fakes is estimated at around $4.5 trillion, and fake luxury merchandise accounts for 60% to 70% of that amount (Fontana et al. [148]). The use of a secure and history immutable database as possible with blockchain can save time and errors in comparison to today's practices.

The control of the distribution channel, including the **certification of fairness of suppliers** (e.g. that no child labour is involved) can be assured more safely than today by suitably registering suppliers information in a blockchain database. In addition, this use case is also in synergy with the UN agenda for sustainable development[128], and more specifically to the goal 8 ("Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all")[129].

Other than this, and especially in fashion, it is useful to control rough materials[130] to assure that they are **environmentally friendly**, and more in general that they are eventually reused, by reducing waste (Caldarelli et al. [145]).

In **post sales applications** it can be mentioned those to **support the secondary market of goods** between, on the base of blockchain secure certificates, and those to **facilitate interactions between customers and sellers**, in any case without affecting the customers privacy.

The following table summarises the use cases just described.

[128] https://www.un.org/sustainabledevelopment/development-agenda/
[129] https://sdgs.un.org/goals/goal8
[130] https://www.voguebusiness.com/sustainability/leading-luxury-players-bet-blockchain-can-advance-circular-fashio

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TABLE 9: Use cases for the use of Blockchain in Fashion and Luxury.

Use Cases	Motivations	Examples
Anti-counterfeiting	To reduce frauds	The Aura Blockchain consortium[131]
Certification of the fairness of suppliers	To more accurate and granular control of suppliers	Everledger[132][133]
Green economy compliance and general sustainability	To control the greenes of rough materials and to support recycling	MIOO[134], Hedera[135]:
For a more efficient secondary market (e.g. jewelry)	To rely on safe certificate of origin on blockchain	Everledger[136]
To support personalized communication channels between the seller and the customer	Blockchain can provide more controlled privacy than today solutions	McLaren[137], NEUNO[138]

3.10 FINANCE, INCLUDING BANKS

This vertical is the first one which took off. It is actually the most developed today[139].

[131] https://auraluxuryblockchain.com/about
[132] https://www.forbes.com/sites/sap/2022/01/26/blockchain-helps-luxury-retailers-prove-provenance-and-sustainabil ?sh=2c68c758139d
[133] https://everledger.io/
[134] https://mioo.tech/
[135] https://hedera.com/
[136] https://everledger.io/making-the-commercial-case-for-blockchain-diamond-tracking/
[137] https://www.motor1.com/news/584104/mclaren-metaverse-nft-mso-lab/
[138] https://neuno.io/
[139] here we do not include insurances, which are considered in a separate paragraph.

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This vertical can be further differentiated into:

1. evolutionary solutions and platforms (**TradFi**, see post from CB Insights, [90]) which can be used by existing players for providing more efficient operations;

2. revolutionary solutions, aiming at supporting a decentralised market (hence the name **DeFi**, see this document of European Commission [88] and Harvey et al. [86], also called Decentralised Finance), which can enable new entrants and/or new kinds of applications.

TradFi and DeFi are differentiated from each other by the functional and from the operational point of view, as detailed in the recent report of the European Blockchain Observatory and Forum [89] .

From the **functional point of view**: a) TradFi relies on the double-entry accounting, which is perfectly fit to the paper processing, whilst DeFi relies on triple-entry accounting, which is more suitable for IT processing; b) DeFi treats the identities as pseudonymous, whilst TradFi relies on validated and trusted individuals. This is also the reason why **DeFi is more inclusive than TradFi**, at least in principle.

From the **operational point of view**, TradFi services rely on intermediaries, who are also in custody of consumer assets. However, DeFi are (mostly) non-custodial services, as participants can took the control of their own assets. This is the intrinsic reason why DeFi can simplify definitely the kind of actors involved in the operations.

As far as the architecture is concerned, it has to be mentioned that **different DeFi solutions are possible, characterised by different decentralisation levels**. However, in this report we will not further distinguish between the decentralisation levels.

As far as the **applications** are concerned, it has also to be mentioned that some of them are specific to TradFi. Examples are KYC (Know Your Customer) applications . On the other hand, some others are specific to DeFi, such as DEX (Decentralised Exchanges) services.

Customers onboarding (KYC). The process of registering a new customer, including the data related to his/her credit reliability, takes a significant effort for banks. In fact some of the reports mention that this process, named Know Your Customer (KYC), can take up to 10% of the personnel effort (and costs) to collect the information of the new customer and to associate it to the information available over different databases. Moreover, the elapsed time for this project could be significant. In fact it is reported that a percentage of new customers cancel their request if the time incurred in the procedure is too long. A blockchain-based process for customers registration (even for a consortium of banks) is useful for supporting this process.

Moreover, a suitable database consolidated on blockchain is also useful to identify **frauds, including Anti Mney Laundering (AML)**. Such process implies specific rules

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and obligations from banks.

Trade finance includes services that make it possible and easier for importers and exporters to transact business through trade. The traditional way of doing trade finance includes different financial intermediaries (exporters and importers) and the management of different kind of documents, such as letters of credits. The use of blockchain technologies can provide faster and also more reliable trade finance processes. Hence, different kinds of bank consortia rely now on blockchain infrastructure for trade finance.

Settlements between banks is today regulated by the worldwide system SWIFT[140] (Society for Worldwide Interbank Financial Telecommunication), which is the de-facto standard for such kinds of processes. However, the communications within this system are far to be efficient also due to its centralised architecture. Hence , blockchain decentralised solutions can definitely disrupt the present situation, improving the efficiency of today's solution by an order of magnitude, and also reducing the cost of this process. Some blockchain solutions are presently available for this use case, such as **Ripple**[141]. In any case, the challenge that they have to face is to be compared with an infrastructural solution in this vertical for which significant investments have already occurred, and which is still improving on its side.

Payments efficiency can be improved by the use of blockchain infrastructure, of course by relying on coins. This use case becomes more interesting in specific geographical areas or domains. For example, the solution **AZA**[142] is widely used in Africa, in which traditional operations for payments are substantially slow, whilst **BitPay**[143] can be used to support crypto payments on e-commerce payments.

Fundraising for a company by Initial Coin Offereing (ICOs) is a well known opportunity. The other opportunity is to address VCs. However, ICOs imply less formalities and can address a significantly higher number of investors than than VCs. Of course, suitable platforms facilitate contacts between investors and entrepreneurs.

Securities Buying or selling assets, as stock and debts, involves a rather complex interaction of complementary financial entities. The resulting process is paperwork intensive and far from being efficient. For this reasons, it can be also subject to inaccuracies and errors. However, blockchain technology can revolutionise financial markets by creating a decentralised database of digital assets.Polymat[144] is an example of the players in this area. Regulations are the present challenge of this case, since its still unclear if the ownership via blockchain technology is legally binding.

[140] https://www.swift.com/
[141] https://ripple.com/
[142] https://azafinance.com/
[143] https://bitpay.com/
[144] https://polymath.network/

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Lending supported by blockchain collaterals is another use case in which blockchain DeFi can be more efficient and moreover can substantially disintermediate the actors in the market. A significant example is MakerDAO[145], which moreover is decentralised also as a governance, since it is a DAO (Decentralised Autonomous Organisation).

Decentralised Exchange (DEX) support the exchange of tokens. Key players are summarised in the table 10 (see also the already mentioned report of the European Blockchain Observatory and Forum).

Token Derivatives: an obvious evolution of the possibility of exchanging tokens is the possibility of exchanging derivatives based on them, as futures and options. Moreover, in DLT solutions, smart contracts allow defining even more sophisticated derivatives than currently used in financial markets. Key players in this area are summarised at table 12 of the already mentioned report of the European Blockchain Observatory and Forum.

The following table summarises the most cited use cases analysed so far.

TABLE 10: Use cases for the use of Blockchain in Finance.

Use Cases	Motivations	Examples
Customers on boarding (with KYC)	To save internal costs and to service better customers with faster processes by relying on decentralised customers data bases	KYC chain[146]
Fraud prevention, including AML	To improve the reliability of this process, which is mandatory for banks	Exchanges like Shapeshift[147]
Settlements between banks (Interbank Market)	To significantly improve the efficiency of today solution SWIFT and reduce as well costs	Ripple[148], others.
Trade Finance	For improving the efficiency though blockchain consortia platforms	Contour[149], Marco Polo[150], etc.

[145] https://makerdao.com/it/
[146] https://kyc-chain.com/
[147] https://shapeshift.com/
[148] https://ripple.com/
[149] https://contour.network/
[150] https://marcopolonetwork.com/

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Use Cases	Motivations	Examples
Payments	To support more efficient payments	Aza[151], BitPay[152]
Securities	To provide more efficiency in trading securities	Polymat[153]
Fundraising (DeFi)	To support the tokens market	CoinList[154]
Credit/Lending (DeFi)	To support credit and lending in crypto. Significantly more efficient than TradFi services.	MakerDAO[155], Compound[156], Aave[157]
Decentralised Exchange (DeFi)	To support the exchange of crypto assets	Curve[158], Uniswap[159]
Token derivatives (DeFi)	Token derivatives can be used as assets in the emerging cryptofinance	Synthetix[160], dYdX[161]

3.11 HEALTHCARE

The healthcare system is really complex, and includes many actors, as summarised in the following diagram (Hasselgren et al. [149]).

[151] https://azafinance.com/
[152] https://bitpay.com/
[153] https://polymath.network/
[154] https://coinlist.co/
[155] https://makerdao.com
[156] https://compound.finance/
[157] https://aave.com/
[158] https://curve.fi/
[159] https://uniswap.org/
[160] https://synthetix.io
[161] https://dydx.exchange/

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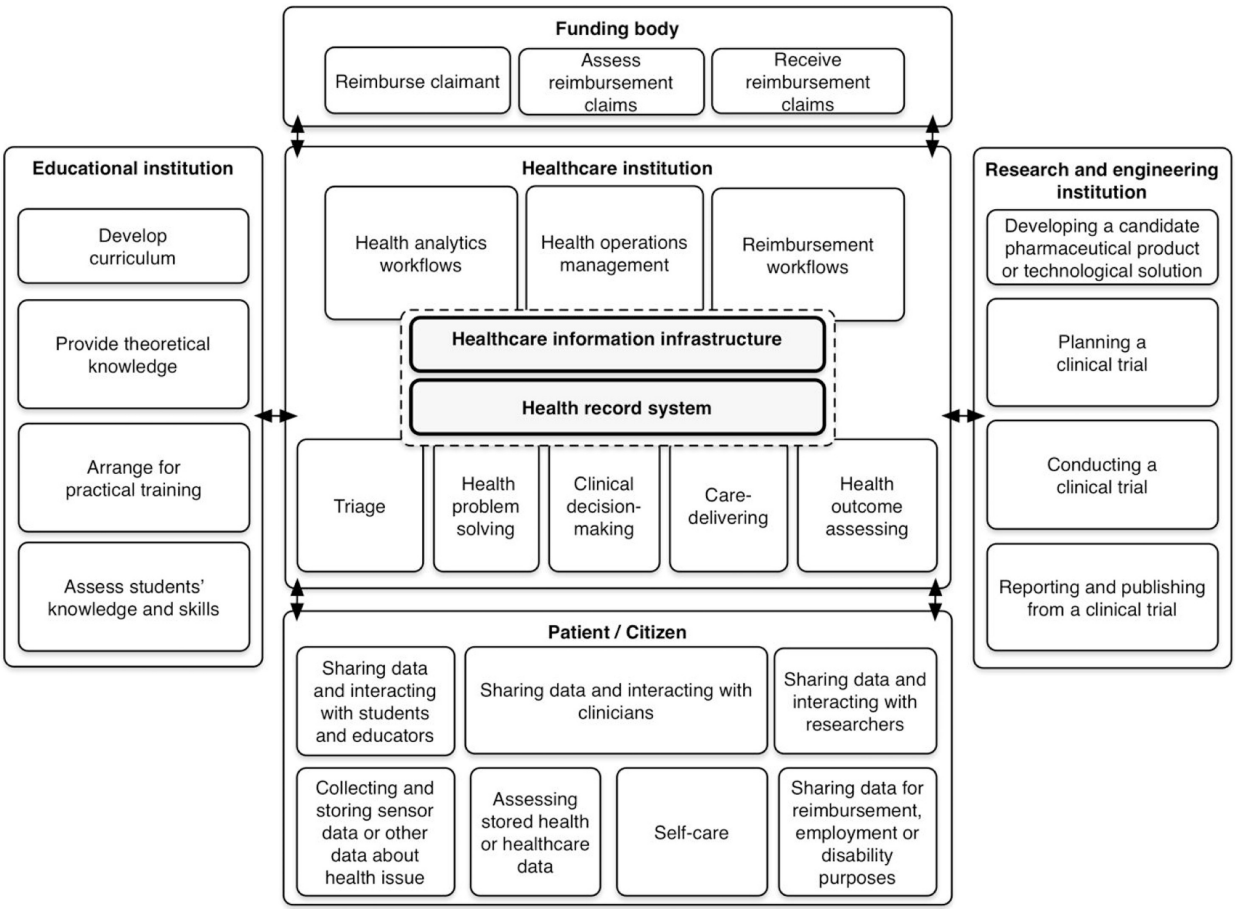

FIGURE 6: A schematization of the healthcare system, from the review paper by Hasselgren et al. [149]

In this vertical the blockchain is typically used for different use cases, as mentioned in different overview papers from Ben et al. [91], Laskowski [92], the European Union Blockchain Observatory [93], Xiao et al. [94], Cooper et al. [95] and Krawiek et al. [96] and more specifically for:

- EHR (Electronic Health Records), to support the safe interchange and controlled access;
- Decentralised telemedicine;
- Pharmaceutical supply chain management, for verifying the quality and quantity;
- Clinical trial support systems;
- Automatic diagnosys support;

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- Public authorities access to aggregate pandemic data;
- Education and certification of professionals;
- Health insurance access.

Other than this, it has to be mentioned that health applications and data are also structured by diseases (e,g. pulmonary diseases, heart diseases), which are categorised according to the ICD (International Classification of Diseases) (by WHO, [150]).

The first use of Blockchain solutions is to **support the privacy of patients**, whilst at the same time facilitating the **EHR data interchange** and **access between authorised parties**, which include doctors, hospitals and also public administrations.

EHRs contain a patients medical history, diagnoses, medications, treatment plans, immunisation dates, allergies, radiology images, and laboratory and test results.

In this framework in Europe it is relevant to mention the **cross border safe exchange of EHR**, which has to be implemented according to the European Commission Recommendation [151].

Another suggested use case of blockchain is in **decentralized telemedicine**, with the objective of solving some challenges faced by centralised telemedicine solutions. Centralised telemedicine solutions in fact incur the risk of single point of failure and of data losses, including patients data. Moreover centralised solution in general are more risky, because they imply a single point of failure (Ahmad [152]). The increase of the efficiency was a real challenge to face during the COVID-19 pandemic.

A third suggested use case of Blockchain solutions is in **Health Supply Chain management**, which, as detailed in Clauson et al. [153], can be applied to validate the origin of medicines, of medical devices and of medical supplies, including Internet of Healthcare Thing (IoHT), or to properly manage the distribution chain of essential medications and vaccines, to avoid shortage.

According to the **World Health Organisation** (WHO) **the worldwide market of illegal medicines is estimated from 75B$ to 200B$ by year**. Moreover, the use of falsified medicines implies further costs to cope with diseases originated by these medicines. Whilst specific government's actions are in place to cope with this challenge, as the Drug Supply Chain Security Act (DSCSA) in US and the Falsified Medicines Directive in the European Union (EU), blockchain based supply chains are well appropriate to **track pharma from the produced to the consumer**. A solution example is Mediledger[162], but other solutions also exist.

Medical devices, including the Internet of Healthcare Things, require a similar care in tracking their origin and distribution. It also required the possibility to claim them in

[162] https://www.mediledger.com/

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the case that eventual defects and vulnerabilities are further identified.

By the way, some solutions proposed for tracking the supply chain of drugs and medical devices can also be used in other supply chains, as food (Castro et al. [154] and Bocek et al. [155]).

A different motivation for the use of supply chain solutions is for **supporting the logistics in public health** including disaster and emergency mitigation, management, protective supplies for healthcare workers during public health emergencies and access to essential medications, vaccines, and immunizations, as exemplified by the challenges faced during the COVID-19 pandemic.

A someway related application is the proactive monitoring by the public authorities of pandemic data to anticipate the evolution patterns (by geographical locations, by patent categories, see Xu et al. [156], Ahmad et al. [157], Zhang and Wu [158], Xiong et al. [159] and to cope properly with these challenges. Also these applications have helped to cope with the COVID-19 pandemic.

Clinical trials support is also suggested as a use case for blockchain solutions. A clinical trial has the objective of testing new drugs and treatments, through various phases. Different phases have the objective of validating the safety and the efficacy of a new drug or treatment on a progressively extending sample of volunteer patients. Due to the immutability and transparency of data stored on DLT, blockchain-based solutions can definitely improve the transparency and trust of clinical trials, which is presently definitely behind expectations (Omar et al. [160], Balfour and Rao [161]. But, besides this strategic objective, the use of blockchain solutions can **optimise patients' related activities** by reducing the time and cost of recruiting and by recording in a safer way their data (personal and clinical), and agreements with them, including payments.

Another suggested use case is in **health insurances**. There, the use of blockchain can reduce frauds and, at the same time, can **reduce insurers costs against possible frauds**. The reason is because blockchain technologies can facilitate data sharing between insurers, also to avoid multiple insurance claims - which is a typical kind of fraud [162]. This can be applied in different kinds of insurances, including healthcare insurances. More specifically in healthcare, automatic insurances can integrate healthcare specific applications, similarly to the mentioned case of clinical trials. The **privacy issue** is also a challenge in healthcare insurances which can be addressed by the proper use of blockchain technologies, as described in Alhasan et al. [163].

Another important category of applications is the support of **smart healthcare** through Artificial Intelligence (AI) and Machine Learning (ML). Such applications had became even more relevant to the market for coping with the challenges of the COVID-19, e.g. in fast screening those affected (Li et al. [164]).

Precision healthcare (PHC) and **personalised medicine** require the use of highly sen-

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sitive data, such as genomic data. This implies significant privacy concerns which limits the widespread of use. However, the use of blockchain architectures can overcome this challenge (Sharma et al. [165]). For example, it is cited the case of a blockchain platform enabling the storage of DNA data[163], whilst other complementary technologies, as AI, are also required to provide a full solution.

Last, but not least, blockchain technologies can be used to support the **Health Professional Education (HPE)**, for different objectives as summarised in Funk et al. [166]:

- to **certificate courses**, by documenting faculty credentials and courses follow up, including impact on learners;
- to support professionals in the **assessment of their background** and in the identification of new useful courses to reach new professional objectives;
- to **certificate credentials** of health professionals towards hospitals and patients.

By the way, this report has already identified these use cases in the vertical Education, whilst they are now detailed for healthcare professionals.

The following table summarises the most cited use cases of blockchain.

TABLE 11: Use cases for the use of Blockchain in Healthcare

Use Cases	Motivations	Examples
Electronic health records (EHR) interchange and controlled accesses, including cross board	To provide controlled access to all interested parties (hospital, doctors) whilst ensuring the patient privacy	Smart4Health[164]
Telemedicine	To support a new generation of decentralised, robust and efficient solutions	Healpoint[165]

[163] https://socialm1.wixsite.com/dnabits
[164] https://smart4health.eu/en/smart4health-and-cross-border-ehr-exchange/
[165] https://healpoint.io

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Use Cases	Motivations	Examples
Supply chain for drugs and medical devices	To cope with illegal distribution, which generate further costs in illness and even casualties	Mediledger[166], Farmatrust[167], KitChain[168] etc.
Public authorities a monitoring of pandemic data	To support an effective pandemic control in the respect of users privacy	MiPasa [167] [168]
Clinical trial support systems	To increase the trust and transparency, to certify rules compliance to the public authority, to safely record clinical and personal data, to improve the efficiency of patients management	Bloqcube [169] and others.
Health insurances[169]	To reduce multiple claim frauds, and at the same time saving anti fraud costs	Anthem[170]
Smart healthcare, for automatic diagnosis and prediction	To support privacy. Use of AI, ML.	GemHealth[171]
Precision and personalised healthcare	To support privacy	LedgertoMe[172]
Health professional education	To certificate courses, to certificate professionals, to support professionals in identifying new training[173]	Beesh[174]

[166] https://www.mediledger.com/
[167] https://www.farmatrust.com/
[168] https://www.kitchain.org/
[169] See also the vertical "Insurance", due potential overlaps
[170] https://www.fiercehealthcare.com/tech/how-anthem-using-blockchain-technology-to-free-up-patients-data
[171] https://www.finyear.com/Gem-Why-We-re-Building-the-Blockchain-for-Healthcare_a36058.html
[172] .
[173] This use case overlaps with some use cases in the vertical "Education and science"
[174] https://www.beesh.fi/

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3.12 INDUSTRY AND MANUFACTURING

The Industry sector is nowadays facing its transition to a completely new phase, the **Industry 4.0**, characterised by the intelligent networking of machines and processes for industry with the help of information and communication technology (Scheer, [97]). This initial definition of Industry 4.0 has been further extended to include the concepts of **smartness** (Zuo, [98]) and **sustainability** (Leng et al. [99]).

Industry 4.0 objectives are enabled by new advanced technologies, such as Artificial Intelligence, Internet of Things and blockchain technology, typically combined together in synergy. More specifically, blockchain technologies enables security and confidentiality by the decentralised database and moreover can support **smart automatisation**, by the proper use of Dapps, and **smart interactions**, by the proper use of Doracles.

As summarised in the review paper authored by Javaid et al. [170], this vertical can be further distinguished into these areas:

1. smart factory
2. smart solutions
3. smart products
4. smart logistics

Logistics has some overlap with the specific vertical mentioned in a different paragraph, but it this paragraph has to be more specifically intended "logistic for industry".

Another possible categorization of applications is by specific industry, which can have specific requirements (automotive, aerospace and others).

The following table summarises the most cited use cases, according to background and overview papers:

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TABLE 12: Use cases for the use of Blockchain in Industry and Manufacturing

Use Cases	Motivations	Examples
Manufacturing data protection	Support of role-based access controls (RBAC) to enable multi-party management of complex supply chain, internal and external, including SC development kits[175]	OpenZeppelin[176], AstraKode[177]
Identification of products and assemblies	Inventory of technical components and assemblies, management of BOMs (Bill of Materials)	Prologis[178]
Procurement	Industry production logistics, supply chain control	Blockchain in Transport Alliance (BiTA)[179]

3.13 INFORMATION AND MEDIA

This vertical includes different sub verticals (which can be also considered use cases), such as **social networks** (Guidi, [171]), **journalism** (Serebryantseva, [172]) **data marketplaces** (Rahul, [173]), , **entertainment** (Zeeve et al. [174]) and **gaming** (Attaran and Gunasekaran[175]). The most relevant papers providing overviews are from Liu et al. [102], Dutra et al. [103] and Bilow [104]: these papers identify as well as relevant digital **rights management**, digital **advertising** and **content production**.

Solutions of use cases just mentioned can be already available in more "traditional" architectures, but the use of blockchain can add different advantages, as:

1. rights and royalties management
2. reputation management
3. new content monetization models
4. incentivized crowdsourced content distribution

[175] https://datarella.com/ask-datarella-what-is-a-security-model/
[176] https://www.openzeppelin.com/
[177] https://www.astrakode.tech/
[178] https://www.prologis.com/
[179] https://bitastandardscouncil.org/

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5. content security
6. tracking content through complex workflow
7. verification of authenticity

In all these use cases the use of blockchain technologies allows to cope with today's challenges and to support new interesting applications for users and new business models.

Social networks are very popular today, but their "traditional" implementation gives a bigger role to the provider. Hence blockchain social networks will empower users, protect their data and identity and will also support the possibility of monetizing contents. Blockchain-enabled social media (BSM) and networks are now available (Guidi, [171]), whilst they have to face the challenge of traditional solutions, which are definitely more known by the typical Internet user.

Journalism and news. Today journalism is challenged by the easy dissemination of fake news, which in the long term reduces credibility and business. The use of blockchain solution should support better quality journalism, by suitably identifying and blocking fake news, moreover the use of blockchain will support new remuneration models, to enable new forms of journalism, including citizens journalism.

Data marketplaces represent a significantly increasing opportunity, which moreover is promoted in Europe by a clear background of regulations and specific initiatives (e.g. the European Strategy for data [176]). Data marketplaces solutions can be of course provided without relying on blockchain architectures, but blockchain architectures provide transparency and control, privacy and anonymity. Other than this, a blockchain supported data marketplace enables more advanced and flexible revenue models. Last, but not least, a blockchain data marketplace is well suited to be extended with AI algorithms and professionals know-how.

It must be explicitly mentioned the project **KnowledgeX**, which was one of the winners of the first ONTOCHAIN call[180], which developed a data marketplace to support the selection of the best consultant in a specific domain and the following consultancy.

The **entertainment** industry is challenged today by heavy intermediation costs: hence the performer or author typically receives a rather marginal fee, of the order of 10%. Hence the use of blockchain should have a significant impact on this industry, since the blockchain supports the disintermediation.

Therefore, the main advantages of blockchain based solutions will be:

(a) better % of revenues for authors, through disintermediation;

[180] https://ontochain.ngi.eu/content/kx-knowledgex

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(b) more agile and flexible way of payment, associated to a more precise definition of ownership;

(c) more reliable advertisement measures, if the case.

Digital rights management can also benefit from the blockchain technology, since the immutability of blockchain data, by discovering and storing in a permanent database the copyright of a specific content (text, video).

A solution of the ONTOCHAIN ecosystem to mention is the project **CopyrightLY**, which was one of the winners of the Open Call 1[181].

Digital advertising is substantially challenged today by frauds. Blockchain-based solutions have the objective of facing this challenge by providing solutions in which advertisement data can not be manipulated and at the same time to support more fair business models for any kind of partner involved i.e. advertisers, publishers and users (as in the case of AdEx[182]).

Finally, **digital production** solutions should support the different production phases, from the verification of the right to different contents, to the unification of different contents into the same web page.

The following table summarizes the most relevant usecases in this vertical.

TABLE 13: Use cases for the use of Blockchain in Information and media.

Use Cases	Motivations	Examples
Social networks and platforms	To empower users, to allow them to control their data and identify, to support the monetisation of contents	Forsting, Howdoo and others[183]
Journalism and news	To provide better quality journalism, by identifying and blocking fake news, and to support new form of journalism, including citizens journalism, through new kind of remunerations	Civil, PressCion and others[184]
Data marketplace	To support transparency and control, privacy and anonymity To provide more flexible remuneration to data providers.	KnowledgeX[185]

[181] https://ontochain.ngi.eu/content/copyrightly
[182] https://www.ambire.com/adex/platform
[183] (cf. tab. 6 from Liu et al. [102])
[184] (cf. tab. 2 from Liu et al. [102])
[185] https://www.knowledgex.eu/

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Use Cases	Motivations	Examples
Entertainment	To allow disintermediation, with significantly higher revenues for authors. To support a more agile and flexible way of payment. More reliable advertisement measures,	Publica[186], Sapien[187]
Gaming	To improves the security. To provide new NFT games. To facilitate payments. To facilitate the entry of new developers.	CryptoKitties[188]
Digital rights management	To store and verify Copyrights relying on the blockchain immutability	Custos Media and others[189], CopyrightLY[190]
Digital advertising	To solve advertising fraud and to support more fair business models	AdEx and others[191]
Content creation platforms	To support the different creation phases (verifying the right to use content, assembling different content into the same page)	Steemit, ImmVRse and others[192]

3.14 INSURANCES

The insurance sector is very articulated, since it includes 3 main domains, i.e. **property**, **life** and **casualty (P&C)**. Casualty further includes different subdomains, including home, car, agriculture, health, travel.

Moreover, this sector is characterised by complex interactions between different stakeholders, including **customers** (business or consumers), different kinds of **providers** including insurers, brokers, reinsurers and regulatory and **controlling authorities**.

General overviews are provided by Dror et al. [105], Amponsah et al. [106], by the discussion paper from EIOPA (European Insurance and Occupational Pensions Authority) [107], by CB Insights [108] and by Daley [109],

[186] https://publica.com/
[187] https://www.sapien.network/
[188] https://www.cryptokitties.co/
[189] (cf. tab. 4 from Liu et al. [102])
[190] https://copyrightly.rhizomik.net/
[191] (cf. tab. 3 from Liu et al. [102])
[192] (cf. tab. 5 from Liu et al. [102])

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Moreover the use of blockchain can enable services like P2P insurances and can enable **new kinds of services**, typically belonging to the long tail, through parametric insurances and micro insurances.

P2P insurances are addressed to a small group of people, as family members, friends, or individuals with common interests who combine their premiums to insure against risks. When a loss occurs, money from the pool is used to cover the individual. Because each insured is responsible for the entire groups risk profile and refund, they are motivated to maintain low individual risk to keep costs low for all involved.

Parametric insurances are those in which the customer is paid in the case that some specific events happen, without any additional investigation on effects. This simplifies internal processes, hence reducing internal costs of the insurance company. Parametric insurances have different applications, as to insure travellers against excessive flight delay and farmers against extreme weather conditions. **Parametric micro insurances for farmers** have been originally proposed for tropical countries, but are now proposed also more generally, since the climate change can increase extreme weather conditions everywhere.

As a micronsurance example it can also be cited the project **CareChain**[193], one of ONTOCHAIN OC2 projects, which is developing a micro insurance demo for farmers whose Smart contract identifies the **exceptional weather conditions** under which the insured farmer is paid, e.g. a wind over 120 Km/h in the municipality of the farmer. This kind of application requires that specific meteo conditions are measured by devices connected to the blockchain infrastructure through distributed oracles and an IoT network of suitable sensors. In such a case the application has to filter eventual spurious inputs from sensors and this has to be assured by suitable AI technologies, which in the Carechain application are provided by the solution provided by the OC2 project **ADOS**[194].

An important business challenge for insurance blockchain applications is about regulations, which should be specifically adapted for blockchain technologies. The EIOPA (European Insurance and Occupational Pensions Authority) in the year 2021 has issued a report about opportunities and challenges in the insurance domain [177] and has collected feedbacks from national competent authorities (NCAs). Evolutions of the regulations in the insurance domain of course have to take into account the Insurances Distribution Directive (IDD) issued in 2016[195], to suitably guarantee customers and suppliers.

Moreover, some initiatives have the objective of facing technological challenges. Among those it has to mention some sandbox initiatives to test insurance applications in a controlled environment, such as the initiative LBChain[196] supported by the Bank

[193] https://ontochain.ngi.eu/content/carechain
[194] https://ontochain.ngi.eu/content/ados
[195] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L0097&from=IT
[196] https://www.lb.lt/en/lbchain

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of Lithuania.

Another technical challenge for insurance blockchain applications is the multiplicity of users that the same application has to consider, as the insured person and the insurance company, the platform manager and commercial representatives, and last but not least other business partners, as other reassurance companies and banks. An example of this kind, is the **reinsurance process**, which implies B2B interactions between the cedent insurer, the broker and the reinsurer, as in the case of B3i[197] which is partnered by most significant players in this domain.

The following table summarises the most cited use cases, according to the mentioned background and overview papers. Some of these use cases could also be included in other verticals, such as health, logistics and travel.

TABLE 14: Use cases for the use of Blockchain in Insurances.

Use Cases	Motivations	Examples
Fraud detection and risk prevention of fraudulent claims	To reduce costs for insurers and customers	ClaimShare[198]
Property and casualty	To achieve more efficiency and to reduce costs in paying claims	StateFarm, for car insurances[199]
Health insurance	For sharing data records with the suitable privacy	Anthem[200]
Reinsurance	For increasing the efficiency of this complex process[201] and reducing costs	B3i[202]
Life insurance	For reducing costs and times	LifeChain[203]
Maritime insurance	For improving the efficiency of a multi stakeholder process	Insurwave[204]

[197] https://b3i.tech
[198] https://claimshare.intellecteu.com/
[199] https://newsroom.statefarm.com/blockchain-solution-solves-state-farm-usaa-subrogation-challenge/
[200] https://www.fiercehealthcare.com/tech/how-anthem-using-blockchain-technology-to-free-up-patients-data
[201] The reinsurance process implies B2B interactions between the cedent insurer, the broker and the reinsurer.
[202] https://b3i.tech
[203] https://www.singsaver.com.sg/blog/lifechain-blockchain-insurance-claims
[204] https://guardtime.com/blog/world-s-first-blockchain-platform-for-marine-insurance-now-in-commercial-use

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Use Cases	Motivations	Examples
Insurances for travellers	For improving the efficiency of insurance, e.g. against delayed flights	Etherisk Flight Delay[205]
Microinsurance for farmers	To reach also low income customers	Saldo (a microisurance service in Mexico)[206]
P2P insurance	To share risks between small groups	Lemonade[207]

3.15 LOGISTICS, INCLUDING THE CIRCULAR ECONOMY

According to the background and overview papers from Dujak and Sajter [110] and Khanfar et al. [111], main motivations for using the blockchain in logistics are the traceability of goods and the security of information. Moreover, blockchain could support smarter and more efficient logistic solutions. However, the decision to adopt the blockchain technology in Logistics is viable when the incentives of the different players involved are not conflicting[208].

Logistic application examples are those **controlling the provenance of goods** and those **controlling the conditions of transport** (e.g. temperature) of goods like food and pharma goods. Therefore, some logistic applications can be very expensive in term of information processing. In fact, it is estimated that processing of documents and information for container shipments can cost as much as the physical transport itself[209].

Some logistic applications have the objective to contribute to the **Circular Economy** (Kouhizadeh et al., [178]). In fact, the circular economy can be defined as an *"economic system aimed at reducing resource consumption and eliminating waste with the promise of economic development continuity. Circular economy systems employ recycling, reuse, remanufacturing and reclamation within a closed system"* (De Angelis et al. [179]). Also tracking and reclaiming goods rely on logistics, hence are mentioned here.

Logistics has also to rely on specific **interoperability standards**, which is specifically en-

[205] https://fdd.etherisc.com/
[206] https://borgenproject.org/tag/consuelo/
[207] https://content.naic.org/cipr_topics/topic_peertopeer_p2p_insurance.htm
[208] https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/glo-core-blockchain-trend-report.pdf
[209] https://www.merckgroup.com/en/research/science-space/envisioning-tomorrow/smarter-connected-world/blockchain.html

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gaged by the **BITA** (Blockchain in Transport Alliance) Standards Council[210], which is developing different kind of proposed standards for logistic data. Other standards useful for logistic applications are those related to the products real time traceability. An example of such standard is the Electronic Product Code Information Services (**EPCIS**).

In **E-commerce**, the use of blockchain can allow users to save costs since it can reduce the number of intermediaries (Treiblmaier and Sillaber. [180]).

In e-commerce, it has to be mentioned the OC1 ONTOCHAIN project **POC4Commerce**[211], which developed a semantically enhanced e-commerce prototype.

The following table summarises the most cited use cases.

TABLE 15: Use cases for the use of Blockchain in Logistics.

Use Cases	Motivations	Examples
To assess the provenance	To avoid frauds and counterfeiting, to build consumer confidence, to assure safe foods and safe medicines	Provenance. SFCR framework, Merck.[212]
To verify the conditions of the transport	To assure the health of the distribution channel, through DLT and IOT	DHL[213] FedEx[214]
To coordinate different logistic players	To assure the privacy and the safety of data exchanged in the ecosystem	IBM[215]
To track shipments	To optimise costs	Maersk, ShipChain[216], Freight Trust & Clearing[217]

[210] https://bitastandardscouncil.org/
[211] https://ontochain.ngi.eu/content/poc4commerce-practical-ontochain-commerce
[212] https://www.merckgroup.com/en/research/science-space/envisioning-tomorrow/smarter-connected-world/blockchain.html
[213] https://www.dhl.com/it-en/home/insights-and-innovation/insights/blockchain.html
[214] https://www.fedex.com/content/dam/fedex/us-united-states/Compatible-Solutions/images/2019/Q2/Could_Blockchain_Revolutionize_Parcel_Shipping_V2_50457811.pdf
[215] https://www.ibm.com/thought-leadership/institute-business-value/report/blockchain-expedited-delivery
[216] https://shipchain.io/
[217] https://freighttrust.com/

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Use Cases	Motivations	Examples
To improving demand forecasting	To improve the whole process and optimise inventories	IBM
To optimise the logistic process, and contribute to the Circular Economy	To reduce the inefficiencies of Less-than-truckload (LTL) shipping	TradeLens[218]
To reduce e-commerce costs	To reduce the number of intermediaries, as possible with blockchain	Wine Industry[219]

3.16 MOBILITY

This vertical is perceived as of high priority, since their **use cases are directly or indirectly related to energy saving**.

Blockchain technologies in this vertical can be used:

a) to provide safer and more agile solutions to use cases already serviced by centralised solutions, such as car sharing and car parking;

b) to extend the functionalities of use cases initially serviced by centralised solutions, as platooning;

c) to solve challenges in new use cases which could not be solved with traditional centralised solutions, as e.V charging and autonomous vehicles;

d) to support new business models, such as the self owning car.

These and other use cases will be analysed in some more detail in the following, also on the basis of some overview papers from Karger et al. [112], Gösele and Sandner [113], Fridgen et al. [114].

Car sharing. This application field is very valuable for cities, since it can reduce the total amount of waste. Some solutions exist relying on "traditional" centralised solutions. However, these "traditional" solutions can be criticised, as they provide a single point

[218] https://www.tradelens.com/
[219] https://www.ezlab.it/case-studies/wine-blockchain/

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of failure and a not so secure digital identity. On the other hand, the new blockchain based solutions should be the most appropriate to solve these challenges, by providing a new generation of car sharing platforms.

In addition to car sharing, **car parking** is another case already serviced by the "traditional" centralised solutions, whose challenges can be solved by evolving to blockchain solutions. Those blockchain solutions should provide a more efficient platform and at the same time more support to privacy and more efficiency in payment. Many references provide more details, as in this post authored by Lashuk [181].

In **platooning** (Gazran, [182] and Ghosal [183]), several vehicles (typically, trucks) drive behind each other in very close distance. This behaviour leads to typically significant savings in terms of energy consumption due to the reduced wind resistance of vehicles following the platooning head. Therefore, fuel savings are bigger for those following the platooning head (even 20%), than the platooning head (even 10% indeed). Another platooning advantage is the reduction of the drivers cost, since the drivers of the vehicles following the head could also have a rest or being absent, depending on the specific technology used. This use case also requires real-time exchange of sensor data to guarantee the proper management of distances between vehicles. Moreover, the dynamic platoon management includes also the authorization of trucks joining or leaving the platoon and the suitable remuneration of the leading truck from followers.

Blockchain is one of the enabling technologies for the most advanced solutions, since it supports a decentralised solution with higher level of security and it can support payment systems.

EV charging implies to satisfy the needs of the electric vehicles charge without congesting the grid. This is achieved by **smart charging** (Daina, [184]), which can be implemented through centralised solutions or, better, **trough decentralised** solutions. Decentralized solutions are enabled by blockchain. As exemplified in this reference (Okwuibe, [185]), these solutions allow to reduce the number of intermediaries, to increase the **efficiency of the use of the grid** and to properly incentivize all players involved.

Other blockchain based solutions for e-V charging are instead specifically focused on the **establishment of an efficient marketplace** between different players, as in this reference (Lasla et al. [186]).

An **autonomous (self driving) vehicle** incorporates vehicular automation, i.e. is capable of sensing its environment and of moving safely with little or no human input. More specifically, different automatization levels have been standardised, from the level 0 (no automatization at all) to level 5 (full automatization). By the way, some automatisation levels can be required also in platooning applications just mentioned.

The motivation towards the autonomous vehicle is **to reduce car accidents**; whilst a challenge to consider is the liability of the car in case of accident. Autonomous vehi-

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cles are enabled by a suitable communication infrastructure and by appropriate sensor technologies, but have to rely also on a safe network infrastructure, hence they require to rely on blockchain networks. An example is Level 5, acquired by Toyota in 2021 (Korosec, [187]).

Temporary functions management. In the automotive industry it is common that extra equipment in cars have to be bought in the initial order, as a later upgrade is mostly unavailable or involves a great deal of expenses. The use of the blockchain technology could enable the temporary activation of extra equipment in a safe way. Users then can unlock various extra features for a limited period of time via a smart contract. This use case relies on blockchain enabled smart contracts and payments.

Blockchain in **car insurance** can support different use cases : a) to support operations to reduce frauds and to facilitate the onboarding of new customers b) to have a faster and more accurate registration of the conditions of an accident c) to support through smart contracts new kinds of insurance contracts for minor damages.

Car history. Applications in this use case have the objective of maintaining a complete and reliable history of the car, including mileage and maintenance, to support repairs and also to facilitate the resale of the car. The immutability of the history in a blockchain is well suited to support this use case.

Digital twin (of the car). The recording of data of components in a decentralised database offers the possibility to ensure congruence between data of assets in the real world and those in the database and therefore creating a digital twin. Recorded data could include manufacturer, seller but also the mechanic's name or real-time data about the components state. Digital twin is more general than the automotive industry and is typically in synergy with AI, IoT and blockchain. Blockchain in fact is an enabling technology to rely on secure and decentralised data for digital twins (Suhail et al. [188]).

Leasing and vehicle financing: Smart contracts could optimise and automate various processes in the vehicle leasing and financing section. For instance, it is possible to prevent cars, whose leasing rates havent been paid yet, from being used by deactivating the unlocking system. Hence, this function is more related to smart contracts.

Self-owning car: a self-owning car represents an independent financial entity which can also close deals, as natural persons, or corporate entities, and should be liable for these deals. These deals have to be finalised through smart contracts, hence the blockchain is the enabler of this business model. Moreover, with this business model, persons or companies could become investors into such self-owning cars by acquiring shares via a Decentralised Autonomous Organisation (DAO). Whilst this use is very embryonic, so far, it is useful to monitor its evolutions.

The following table summarises the most cited use cases, according to background

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and overview papers (Karger et al. [112], Gösele and Sandner [113]).

TABLE 16: Use cases for the use of Blockchain in Mobility.

Use Cases	Motivations	Examples
EV charging	For providing a better grid utilisation, for reducing intermediaries, for incentivising providers, for establishing an efficient marketplace between providers and users	JuiceNet[220], Energy Web[221], Werenode[222]
Car sharing	To get better privacy and safer recording	Share 'n Go[223], Volvero[224]
Car parking	To get better privacy, safer recording and payment support	Mobix[225]
Platooning of commercial vehicles	Blockchain assures a safer infrastructure. Moreover, blockchain solutions support payments	PolyCrypt[226]
Autonomous vehicle	A blockchain network can assure safe data as required in this application	Level 5[227]
Smart insurance	To get more details about accidents and about other conditions, through the safe recoding of IOT/oracles data	CarPass[228]
Car history	The safe recording on blockchain provides evidences to support maintenance and reselling	Carvertical[229]
Car digital twins	To rely on a safe blockchain to facilitate the maintenance prediction on the digital twin	EY[230]

[220] https://evcharging.enelx.com/news/releases/329-emotorwerks-and-share-charge-deliver-north-americas-first-peer-
[221] https://www.energyweb.org/renewable-ev-charging/
[222] https://werenode.com/
[223] https://site.sharengo.si/en/
[224] https://volvero.com/
[225] https://mobix.ai/
[226] https://medium.com/perunnetwork/platooning-and-blockchain-perun-as-a-digital-car-tow-69581df7a162
[227] https://level-5.global/
[228] https://www.bigchaindb.com/
[229] https://www.carvertical.com/
[230] https://www.ey.com/en_gl/advanced-manufacturing/how-digital-twins-give-automotive-companies-a-real-world-advan

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Use Cases	Motivations	Examples
Leasing and vehicle financing	Smart contracts enable cars to follow specific rules, as to accept (or not) a new driver according to the payment conditions	Volkswagen Financial Services[231], Auto1[232]
Temporarily functions	Enabled by smart contracts and payments	Carnomaly[233]
Self-owning car	Smart contracts and tokens enable cars to behave as autonomous financial entities, whilst following predefined business models (e.g. data sharing)	Mercedes-Benz[234], DAV[235]

3.17 SMART CITIES, PUBLIC ADMINISTRATION AND COMMON GOODS

This vertical includes a) public administration, including cross-border (Cagigas et al. [115]), b) smart cities (Shen and Pena-Mora [116]) and c) common goods.

Lesson learnt so far and suggestions about **public administration** applications are summarised by OPSI, the OECD's Observatory of Public Sector Innovation[236], in a report whose appendices summarise specific use cases and trials [189]. This report expresses the criticism about some public administration applications, which could have also been implemented by using traditional web architectures, since they didn't identify stringent reasons to use blockchain.

The report cites also positive examples, as the applications promoted by the Estonian government, mostly motivated by **security** reasons, although the architecture used relies only partially on blockchain[237].

Other activities to mention are those promoted by European Blockchain Service Initiative (EBSI)[238], whose objective is to provide a public European blockchain infrastruc-

[231] https://www.vwfs.it/news-hub/blockchain-automotive.html
[232] https://mobyfin.net/
[233] https://carnomaly.io/benefits-of-storing-vehicle-history-reports-on-the-blockchain/
[234] https://www.ledgerinsights.com/mercedes-benz-launches-blockchain-based-data-sharing-platform/
[235] https://dav.network/
[236] https://oecd-opsi.org
[237] https://e-estonia.com/solutions/cyber-security/ksi-blockchain
[238] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home

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ture for supporting the safe and **GDPR-compliant cross-border reuse of data**[239], as European digital identity, trusted data sharing, diplomas and notarisation.

Smart cities applications are analysed in the report [190] by the UN-promoted initiative United for Smart Sustainable Cities (U4SSC)[240], which emphasizes the impact of this specific sector since it *"estimates show that two-thirds of the worlds population will live in cities by the year 2050, up from 55% today"*.

The report further distinguishes different motivations for **Blockchain for Cities (B4C) applications**, such as **smart governance**, **smart people**, **smart community**, **smart living**, **smart environment**, **smart mobility**, **smart energy** and **smart environment**.

The report summarises the most successful applications and trials in different cities, a significant percentage of which resulting from EC-funded projects, and mainly *"the cases of the debt relief in the city of The Hague, the Decode and decide projects in Barcelona and Amsterdam; the energy system management in South Holland; Moscow weekend fairs; the Moscow Active Citizen project; the land registry in Georgia and the cell tower voting system in South Tyrol"*.

Finally we will touch **common goods** related applications. Common goods are those accessible by everybody, which are at risk of being subject to overexploitation and diminished availability if people act to serve their own self-interests. An example of common good are fishes in a river: they can be captured by everybody, but an aggressive fishing activity exhausts them (this kind of behaviour is called "free riding").

Blockchain technologies, and mainly NFT in this case, can be used for establishing fairer markets for **common goods**. An example is the ONTOCHAIN project **PRINGO** (Private Incentives for Common Good)[241].

The following table summarises the most cited use cases. Some use cases, as healthcare, smart mobility, and smart energies, can be categorised also by other verticals. In any case we will consider them in this vertical if explicitly oriented to citizens.

[239] https://digital-strategy.ec.europa.eu/en/policies/european-blockchain-services-infrastructure
[240] https://u4ssc.itu.int/
[241] https://ontochain.ngi.eu/content/pringo

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TABLE 17: Use cases for the use of Blockchain in Smart Cities, public administration and common goods.

Use Cases	Motivations	Examples
Certificates management, including cross border	For SSI and and blockchain security	EBSI[242]
Land or real estate registry	For better security	OpenLedger[243]
e-Voting	For better security than "traditional" solutions	Voatz[244]
Citizens polls	For better security	I-Voting in Estonia[245], My Vote[246], VoteWatcher[247]
Tax system	For better transparency	KSI[248]
Public procurement	For a better transparency and more effective accounting. For more efficiency in managing public tenders. For more effective control towards frauds (e.g. in cascading subcontracting)	Modtex[249]
Social care	For better privacy and security and a more effective accounting in long-terms care relationship	SimplyVital Health, Chronicled[250]
Smart healthcare for citizens	For better interoperability between healthcare operators, in the respect of privacy and security	MedRec[251], GuardTime[252]

[242] https://ebsi4be.eu/
[243] https://openledger.info/insights/blockchain-smart-cities/
[244] https://www.voatz.com
[245] https://e-estonia.com/solutions/e-governance/e-democracy/
[246] https://myvote.wi.gov/en-us/
[247] https://votewatcher.com/
[248] https://e-estonia.com/solutions/cyber-security/ksi-blockchain/
[249] https://modex.tech/blockchain-the-solution-for-public-procurement-corruption/
[250] https://www.chronicled.com/
[251] https://medrec-m.com/
[252] https://guardtime.com/health

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Use Cases	Motivations	Examples
Smart mobility for citizens	For more granular control, as possible with blockchain and IoT	Mobility Open Blockchain Initiative (MOBI)[253]
Smart energy for citizens	For more granular control, as possible with blockchain and IoT	Energy Web[254]
Smart environment for citizens	For more granular control, as possible with blockchain and IoT	Libelium[255]

3.18 TOURISM (TRAVEL AND HOSPITALITY)

This vertical [117] includes travel [118] and hospitality [119].

The use of blockchain in this vertical is to assure more **security** and **trust** in comparison to today solutions. Moreover, depending on the use case, it can **increase the efficiency of processes** and the security of data, as in **traveller identification**, and to **reduce errors**, as in the case of **duplicate booking and luggage lost**, to have **reliable users ratings** and to provide safe **loyalty programs**, as possible with blockchain [119].

Moreover, by relying on blockchain infrastructures, it is possible to support more effectively the new business models in the tourism sector. An example is the case of **C2C disintermediated tourism**, which aims to support trusted and disintermediated business opportunities between travellers and hosts. This can enable also the **smart tourism**, which is intended to provide a more personalised services and suggestions to travellers and incentivize (e.g with suitable remuneration mechanisms) more sustainable behaviours, as those saving waste and energy. Hence, the smart tourism partially overlaps with smart cities (Tyan et al., [191]).

The following table summarises the most cited use cases, according to background and overview papers.

[253] https://dlt.mobi/
[254] https://www.energyweb.org/
[255] https://www.libelium.com/iot-solutions/smart-environment/

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TABLE 18: Use cases for the use of Blockchain in Tourism.

Use Cases	Motivations	Examples
Traveller identification	To simplify check-in	Known Traveller Digital Identity (KTDI)[256]
Booking services, also prevent duplicate booking	To reduce overbooking errors and for a more precise evaluation of empty sits costs. To support more customer specific discount and offer policies	Rezchain[257], BTU Protocol[258], Blocktix[259], Trippki[260]
Luggage tracking	To reduce errors and improve the travellers satisfaction	Winding Tree[261]
Authentic and verified user rating of services	To reduce the possibility to manipulate scores provided by tourists in social portals	Travala[262]
Loyalty programs	To provide more user friendly and personalized services	Sandblock[263]
C2C disintermediated tourism	To proper qualify and to facilitate the retrieval of small hospitality providers. To facilitate the aggregation of multiple offers.	Lockchain[264] Winding Tree[265]
Smart tourism	To provide more personalised services and suggestions on the basis of the traveller profile and on the destination opportunities. This is also called Tourism Destination Rating System (TDRS)	Chain4Travel[266], Vue.ei[267]

[256] https://ktdi.org/
[257] https://rezchain.com/
[258] https://btu-protocol.com/
[259] https://blocktix.io/
[260] https://medium.com/@sapan_123/trippki-blockchain-project-14130f4b3f08
[261] https://windingtree.com/
[262] https://www.travala.com/
[263] https://sandblock.io/
[264] https://locktrip.com/
[265] https://windingtree.com/
[266] https://chain4travel.com/
[267] https://vue.ai/glossary/journey/

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4 CONCLUSIONS

In this deliverable D3.2, we updated first the state of the art of technologies, which in any case is already well covered in the first year deliverable D3.1. In this deliverable D3.2 we focused more specifically on technologies developed by Open Call 2 projects, as semantics, NFTs and IOTs. However, it must be taken into account that blockchain is in a phase of rapid and constant evolution. The general conclusions from the state of the art of technologies are:

- blockchain technologies have reached a first level of maturity to support an increasing number of applications,
- some research challenges have still to be faced, as scalability, power consumption and interoperability,
- the most important research challenge today to face is the interoperability, to avoid the silos syndrome,
- an interesting software engineering challenge today is to rely on more mature IDEs to increase the development efficiency.

As applications become more and more relevant, in this deliverable D3.2, we included the state of the art of applications enabled by blockchain.

This report categorizes applications into 15 domains (or verticals), such as agrifood, art and creativity, constructions, education and science, energy, fashion and luxury, finance and banks, healthcare, industry and manufacturing, information and media, insurances, logistics, mobility, smart cities, tourism. Each of these domains has been further distinguished into subdomains (up to 10). Any subdomain has been analysed in detail, identifying reasons why to adopt blockchain. The general conclusions for applications are:

- there are many interesting application opportunities for blockchain solutions
- reasons why to use a blockchain architecture instead than centralized architectures are:
    - to replace legacy solutions, with the objective to solve well identified challenges, related to privacy and security, as in social networking sites,
    - to replace legacy solutions to provide more cost-effective and efficient solutions, as in logistics,
    - to provide brand new applications pulled by technology evolutions in some domains, as in the P2P energy distribution

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- to provide brand new applications suggested by the availability of blockchain, such as Decentralised Finance (DeFi)

- there are also challenges associated to the opportunities just mentioned:
  - blockchain solutions replacing legacy solutions to provide better privacy and security, have to take into account the higher costs to face in blockchain-based solutions
  - blockchain solutions replacing legacy solutions to provide better operational efficiency, have to take into account investments already incurred for the legacy solution
  - brand new blockchain solutions have to verify that the regulations are sufficiently mature and that the new business models enabled are easy to understand and fair to all stakeholders

Finally, this report is also intended to provide some guidance in identifying new opportunities in blockchain applications, by providing a taxonomy of use cases with examples.

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