Tokenization of physical assets and the impact of IoT and AI

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1 Introduction

The world has changed fundamentally in the last 20 years. With the advent of computers in everyday life many job profiles have changed and completely new jobs have been created. In recent years, this has been summarized under the ambiguous term of Digital Transformation. A parallel digital world, which is becoming more and more similar to our physical world, has been created. The term "Digital Twin", the virtual representation of physical objects from the real, physical world, has now become established in industry.

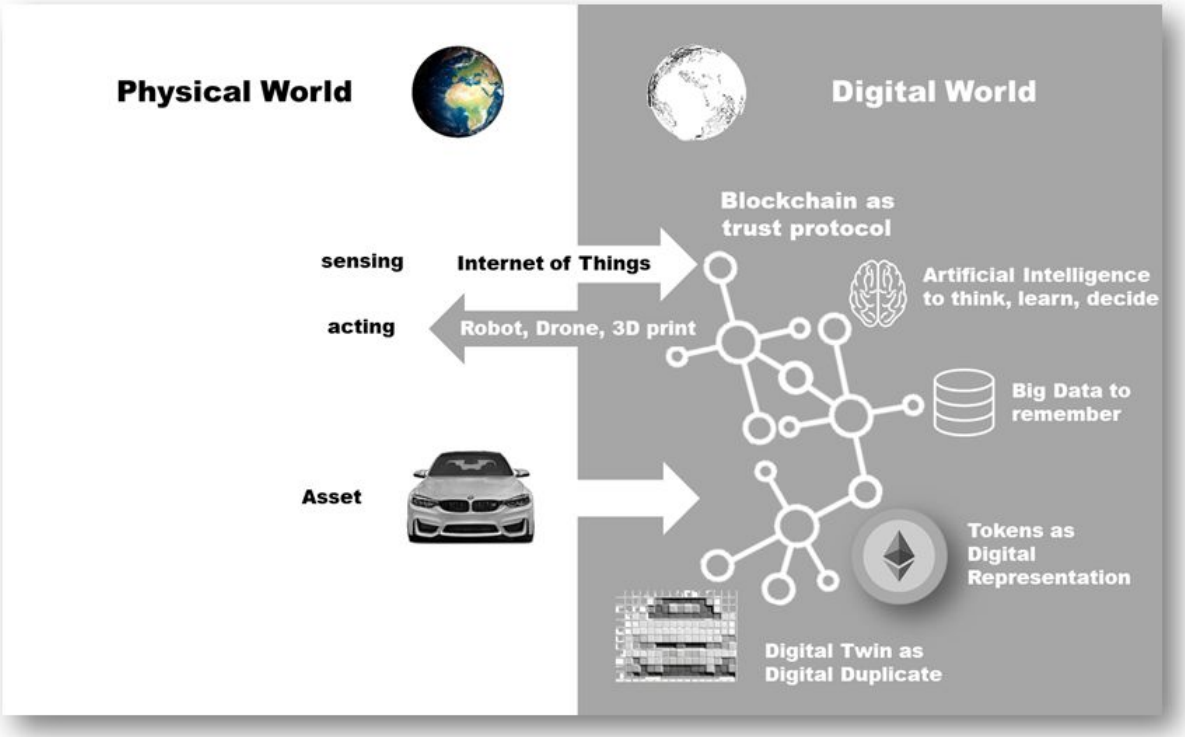

Figure 1: Physical and digital world

With this overall picture of a duplicate of our world in mind, the relevant technologies of the Digital Transformation can be classified as follows:

- The “Internet of Things” (IoT) provides the possibilities for recognizing and tracking physical objects. In addition to cameras, microphones and tracking systems, a variety of sensors are available to measure various attributes. IoT thus represents the senses of the digital world.
- On the other hand, robots, drones and other manipulators allow the intervention into the physical world. They represent the actuators of the digital world.
- “Artificial Intelligence” (AI) in the form of machine learning, computer vision, speech recognition, speech processing or optimization makes it possible to understand objects and processes in the physical world. Autonomous decisions can be made. AI thus represents the brain of the digital world.
- The storage of large amounts of data by means of “Big Data” and thus the possibility of storing all information in the long term is ultimately the memory of the digital world.

The digital world has significant advantages over the physical world. Distances can be overcome without loss of time. The time factor itself takes on a different meaning because time can easily be “rewound”. Objects can be copied and duplicated without further effort. The boundaries between real images and fictitious images also becomes blurred. Due to the exponential growth, which is described by Moore’s Law and many studies, the physical world will be exceeded by the digital world in the coming years. This means that speed, growth and complexity will increase by a multiple.

Blockchain technology plays a fundamental role in this overall picture of Digital Transformation. As a trust protocol it can be seen as the link between the physical world and the digital world. With its features of trust, distribution and value, Blockchain makes it possible to identify and connect physical objects and their digital representations.

Hereafter, concrete examples, research activities and products will underpin the overall picture described above. Important aspects of Blockchain technology in this environment will be described. First, the role of Smart Contracts will be clarified, as they represent an important basis for further understanding. Afterwards, it is explained how physical objects can be mapped and managed on the Blockchain using Tokens. Finally, the applications of Internet of Things and Artificial Intelligence are described and set into relation to the big picture.

2 The Role of Smart Contracts

"A smart contract is an automatable and enforceable agreement. Automatable by computer, although some parts may require human input and control. Enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code." [CBB16, page 2]

The name "Smart Contracts" was coined by Nick Szabo in 1994 [Sza94]. The two central promises of Smart Contracts are higher contract security and reduced contract costs [Gia17]. In 1994, without the possibilities of the Blockchain, an implementation was hardly possible. With the arrival of the Blockchain technology and the concept of executable programs on the Blockchain, this objective suddenly became reality. Today several Blockchain implementations are able to implement Smart Contracts.

Smart Contracts form an essential component when it comes to processing information on the Blockchain. If the Blockchain itself represents a distributed, permanent data storage, with the help of Smart Contracts it becomes an "autonomous Turing machine". An important aspect is that the programming language is Turing-complete [Dan17], which allows it to perform all required functions. Smart Contracts enable the triggering of complex transactions, the processing of data and thus the reaction to events. These events can occur either on the blockchain, like results of other Smart Contracts, or outside the blockchain, like occurrences in the physical world that can be detected by IoT sensors (see chapter 4). Today, there are different programming languages for Smart Contracts depending on the Blockchain used. These are either existing languages, like Go, Java or Javascript, or new programming languages, like Solidity.

The fact that the program code itself is stored on the Blockchain makes manipulation of the calculation steps impossible. Furthermore, the distribution and simultaneous execution of a Smart Contract on many nodes of the Blockchain avoids the execution from being prevented by manipulation of a node. Once stored and deployed, the autonomous execution is thus guaranteed. This is an essential feature when it comes to trusting a digital representation. However, it also requires high attention to testing and debugging of Smart Contracts since later changes are impossible. The deployed Smart Contract has an address similar to that of a user. It is also capable of receiving, storing and spending Cryptocurrencies and Tokens. Since the Smart Contract and the data stored in it consumes storage and calculation power this has to be paid for by the owner and user of the contract.

Smart Contracts themselves form the basis of almost all Tokens in existence today, which we will explain in the next section.

3 Tokenization - Bringing Physical Objects to the Blockchain

Since the massive increase in Token creation in 2018 with over 1,132 ICOs and STOs collecting nearly $20bn [PWC19], the concept of the Token has gained wide attention. In simple terms, a Token is the digital representation of an asset on the Blockchain or colloquially “programmable money”. This asset can be both digital or physical as well as tangible or intangible. A Token is not related to a Cryptocurrency like Bitcoin or Ether and is often compared to a security document. From a technical point of view a Token is an algorithm implemented as a Smart Contract on a Blockchain. The Smart Contract holds a list of all addresses of owners and their Token balance. Some Blockchain implementations use the UTXO (unspent transaction output) model proposed by Bitcoin [Nak09]. The algorithm defines all features of the Token like its value, how and how many Tokens are created, which denominations they allow, how Tokens are spent, and under which name and address they can be used. Even complex functionalities like voting can be implemented. The user gets access to her Tokens by identifying herself as owner of the address. Wallets simplify the usage as they hold the private keys of the user address and the contract address of the Tokens.

The most important platform for the generation of Tokens today is the Ethereum Blockchain. It allows the straightforward technical implementation of Tokens through Smart Contracts. The connection between a Token and its asset is initially purely fictitious, as is the case with a security and its obligation. If it concerns a digital asset, the connection can usually be mapped via the program code of a Smart Contract and thus firmly anchored. CryptoKitties[1], an Ethereum-based collectibles game, is an example of this. It has been one of the first use cases where Tokens have been applied in a production environment. That is why it has attracted a lot of attention and a lot of money has been and is being invested in these virtual collectibles. Individual CryptoKitties are traded at over $100,000. As with stamps or coins, uniqueness and rarity determine the value. The algorithm of the Smart Contract guarantees the uniqueness since it doesn’t allow copies and limits the maximal number of Tokens available. In the case of physical assets, this connection becomes much more complex. Although there are companies which, for example, connect real estate or gold with Tokens, the proof of uniqueness and immutability is always based on trust outside the Blockchain, e.g. via audits or custodians.

Tokens represent the physical object in the digital world. This allows algorithms and Smart Contracts to access specific objects and makes the physical world “tangible” for the digital world. Furthermore, the use of Tokens for physical objects increases the transparency of possessions [Gar18]. Finally, tokens allow the division of large values into smaller units by their

[1] https://www.cryptokitties.co

arbitrary subdivision [VdB18]. For example, a property can be divided into units of €100. In this way, illiquid assets, such as large properties or art objects, are broken down into liquid, tradable pieces. This simplifies the investment in such assets and their trading. Furthermore, Tokens allow micropayments in very small fractions.

Ethereum is the prefered choice for Tokenization at the moment due to the possibilities of the programming language Solidity, the large community, existing code examples, the easy connection to the Cryptocurrency ether, and working implementations. Other Blockchain implementations e.g. Hyperledger Fabric or Corda also allow the creation of Tokens [And18][Bct18]. However, these systems have not yet gained widespread use for this kind of application. Like securities, there are different types of Tokens. The division of Tokens into fixed classes is made more difficult by the fact that any variation or functional enhancements can be programmed using Smart Contracts. In the Ethereum environment, the community has been agreeing on common implementations of Tokens and therefore creating certain standards. Since this process takes place within the framework of the "Ethereum Request for Comments", the Token standards carry the designation ERC and are numbered accordingly. The ERC-20 Token is probably the best-known Token [Fru18] and corresponds as far as possible to a movable asset that is arbitrarily exchangeable (fungible), i.e. analogous to a currency or gold. For this reason, this Token is primarily used in the area of ICOs. The most valuable ERC-20 Tokens at the moment are BNB, Maker, VeChain, USD Coin, BAT, and True USD, each with a market capitalization of over $200 million[2]. ERC-721 Tokens are non-fungible and can represent assets which differ in their kind. The most transactions of this standard are used for games e.g. for CryptoKitties or DozerDolls. With the increase of physical assets represented by Tokens this Token standard is on the rise. On Etherscan 1,185 ERC-721 Token Contracts can be found[3]. There are extensions to both standards, some of which are still in the review process. This includes the ERC-621 Token, which allows the later increase or decrease of the stock, or the ERC-998 Token, which enables non-fungible Tokens to contain further Tokens (non-fungible or fungible).

As shown above Tokens are already used to store and trade enormous amounts of value. This value extends more and more often into the physical world. Gold, real estate, diamonds and a lot more are being "tokenized". Due to this fact legislation and regulation becomes more important, on the one hand to prevent fraud and tax evasion, on the other hand to protect investors. From a regulatory point of view, Tokens are often divided into the following classes:

- *Payment Tokens:* Tokens with currency character. Their focus is on the exchange of value.
- *Utility Tokens:* Tokens that represent a right or a service. Their focus is on usage.

[2] https://etherscan.io/tokens?sortcmd=remove&sort=marketcap&order=desc (accessed 11.03.2019)
[3] https://etherscan.io/tokens-nft (accessed 11.03.2019)

- *Asset or Security Tokens:* Tokens that represent a share of an asset. Their focus is on the investment of value.

FINMA (Swiss Financial Market Supervisory Authority) published a regulatory framework for the handling of Tokens in February 2018 [FIN18]. This is the answer to the question of how ICOs should be assessed in terms of financial market regulation. Special attention will be paid, for example, to KYC, anti-money laundering supervision (AMLA) and prospectus requirements. Other countries have followed this example (Lichtenstein, Malta, Gibraltar, UK, and only recently Germany). It can be seen that today, from a regulatory point of view, the tax and financial market effects of Tokens are in the foreground.

From a civil law perspective, property rights play an important role. It is extremely relevant how a transfer of ownership using Tokens takes place, whether it is legally permissible at all, and what effects this has on current jurisprudence [Her18]. The connection between Token and asset is not yet in the focus of jurisprudence. Furthermore the Blockchains and Tokens used for specific assets have not yet been defined. Therefore it is possible to double spend one asset on different Blockchains or under different Token names. Since the particular legal understanding of the individual countries has a great influence on the significance of Token transfers, this must be clarified for each country. The Swiss Federal Council clearly stated its position in its report paper at the end of 2018 [FC18]. It considers that no additional legal basis is necessary and that the existing legislation covers all issues related to the transfer of ownership. Other countries take a different view and are in the process of drafting specific laws (Lichtenstein [Li18]) or have already introduced them (Malta [Ma18]).

4 The connection of IoT with Blockchain

Network attached sensors and IoT devices are the prerequisite for linking the Digital Twin to its physical origin [Del17]. They transfer the static representation into a dynamic duplicate. The sensors provide information about the environment they are in or the object they are attached to. Actuators allow the manipulation of the physical world. Blockchain technology introduces trust, automation and accountability into this system. Today Blockchain is being used in the upper levels of the IoT value stack (see Figure 2). In future Blockchain will be extended down to the device level.

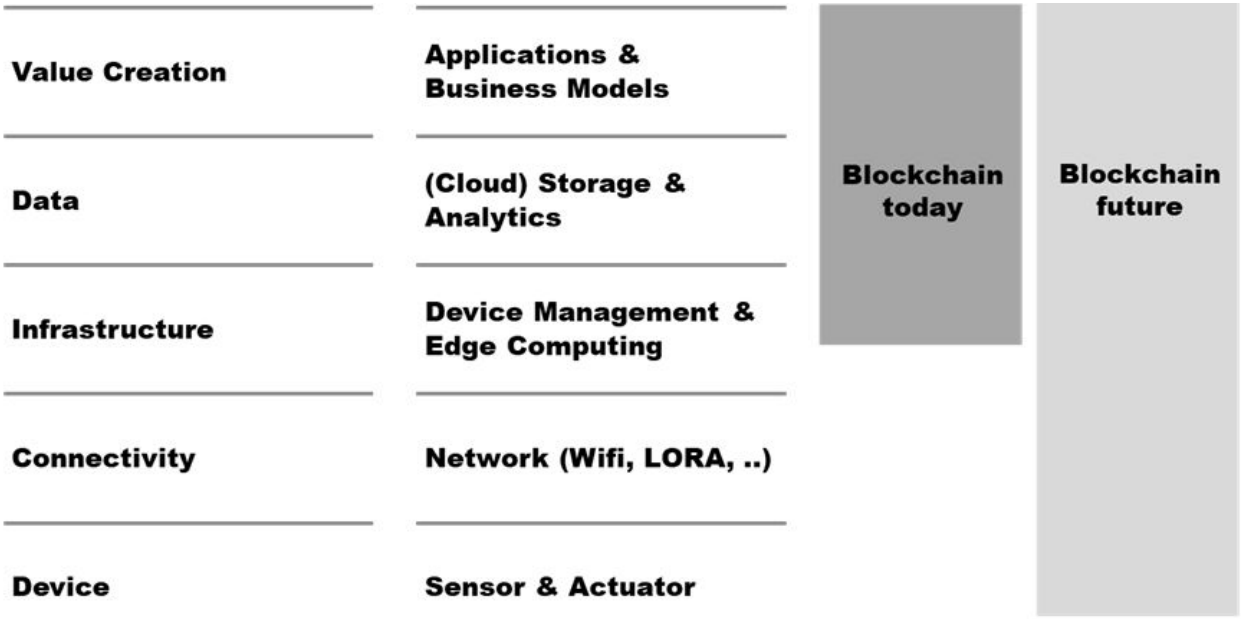

Figure 2: IoT Value Stack

4.1 Use Cases

To illustrate the importance of Blockchain for IoT five domains of use cases are presented:

1) Supply chain management

Trust is one of the most important features in supply chain management. When it comes to tracking goods, monitoring conditions and guaranteeing provenance IoT devices in combination with a Blockchain have great advantages. For example perishables in a cold chain can be traced by IoT sensors and documented on the Blockchain. This helps to retrace longer transport routes. Also the origin of commodities can be recorded and traced back from the final product. Startups like Modum[4], ZetoChain[5] or VeChain[6] focus on this kind of business. Tokens can be used for payment or as representation of a physical good. Rarely they are used as representation of intangible values like rights. In supply chain management each transfer point tracks the status of the IoT devices and stores the data onto the Blockchain. This is how trust is built.

[4] https://modum.io/
[5] https://www.zetochain.com/
[6] https://www.vechain.com

2) Sharing

Like participants in a supply chain, participants in the sharing economy rely on reputation and trust. One does not give one's property to a stranger without any kind of trust. Trust can either be represented by a deposit or by a good reputation. Both can be achieved by using a Blockchain. One example could be a general rental system. Objects or rooms in the physical world can be rented via Smart Contracts, so that the registration of the objects, the release for the tenant, the settlement of the rental fee and the return of the object can be handled via the Blockchain. The Lokkit[7] application awarded with the Siemens Excellence Award is one example [Sch18]. Multiple lockers of a locking box system are controlled by Smart Contracts. IoT devices are used to detect the state and to open and close the lockers. The rental contract includes direct access to the used Token or Cryptocurrency - in this case ether - to pay the rental fee and the deposit. Since computational power and storage on the Blockchain is costly the Whisper protocol has been used for the opening mechanism once the rental contract has been concluded. This type of application excludes Trusted Third parties and creates a trust based Peer-to-Peer system. This approach opens up new areas of application for the shared economy (mutual sharing of tools and goods) or radically changes existing business models (AirBnB, Uber, etc.). Again, Tokens play a fundamental role for exchange of value and representation of rights in the physical world. Special attention must be given to the exchange protocol. Since changes in state of the Smart Contract are triggered automatically by external events the motivation of users or devices for sending these events must be questioned. Most protocols work with deposits or custodians to reduce the risk for deadlocks. Companies like Slock.it[8], HireGo[9], or MixRent[10] focus on this use case.

3) Trading of data

Another field of application is the trading and monetization of data. Since the data collected by IoT sensors represent a large value, they can be publicly offered for sale. For example, weather data can be offered and paid through Tokens like WXB from Weatherblock[11]. The Blockchain technology fulfils two tasks in this case: On the one hand, the contractual processing between data supplier and data receiver by the use of Smart Contracts, on the other hand payment by utilizing Tokens. This way IoT sensors

[7] https://github.com/lokkit
[8] https://slock.it/
[9] https://www.hirego.io/
[10] https://mixrent.io/
[11] http://weatherblock.org/

can act autonomously and trading is not tied to human influence. In a sense, the IoT sensor turns into a self-acquiring market participant.

4) Identity and network management

Identity is becoming the most relevant good in future. On the one hand identity of persons or physical objects, on the other hand identity of IoT devices. Sensors can ensure identity using various techniques like fingerprints, iris scanner, face recognition, private key infrastructure (PKI), GPS trackers, built in sensors, or markers. Furthermore, devices or objects joining a network have to be identified and communication must be set up. Non-fungible tokens can help to implement this uniqueness. A tamper-proof link between object and Token will help to build up trust and is a prerequisite for any further use cases.

5) Automatisation

Finally, automatisation of processes and workflows creates a strong demand for sensing objects in these processes as well as monitoring and recording their progress. The combination of IoT devices and Smart Contracts on a Blockchain allows fully automated Machine-to-Machine communication and contracting. Even payments can be realized by using Tokens. This takes automatisation to a new level since isolated production units suddenly become able to interact. Interfaces can be reduced to the negotiation of Smart Contracts and their execution.

4.2 Hazards using IoT with a Blockchain

Looking at the connection of physical objects with their Digital Twin from a technical point of view, the part outside the Blockchain is still the most delicate link in the chain of trust. As described in the Introduction, the Internet of Things (IoT) plays a decisive role in creating this trust. The task of IoT sensors is to recognize and track objects or events in the physical world. Two major areas of manipulation can be distinguished:

1) Manipulation of the IoT sensor and the network

It is obvious that a temperature sensor that is artificially heated by a malicious actor leads to an incorrect result of the room temperature. Disconnecting the sensor from the network

also prevents the transmission of any data. Physical attacks, software attacks on the IoT devices, and network attacks on the transmission channels can be distinguished [Fec18].

Cryptographic functions can prevent some of the possible manipulations. Above all, the infiltration of false sensors and thus the conscious manipulation of processes can be prevented in this way. For example, the company Riddle and Code[12] manufactures sensors which can be registered on a Blockchain and achieve a high reliability of the values by signing the data. The use of processors with a TEE (Trusted Execution Environment) enables the encryption and signing of data directly on a CPU level.

2) Manipulation of the interface to the Blockchain

The processing of data on the Blockchain is made possible by the forwarding of the data by means of so-called "Oracles" to the respective Smart Contract. An Oracle is a kind of agent that examines physical world events and passes them on to Smart Contracts. A distinction is made between inbound and outbound Oracles. Inbound Oracles bring information onto the Blockchain or to Smart Contracts, outbound Oracles execute actions of Smart Contracts in the physical world. The use of an Oracle does not yet make communication secure. Therefore, research is concerned with how this communication path can be secured. To solve the so-called Oracle problem [Mod18], i.e. the manipulation of the interface to the Blockchain, the properties "distribution", "redundancy" and "transparency" of the Blockchain can be used.

A common approach is not to rely on one Oracle, but to use a consensus-based Oracle, i.e. to connect several Oracles. The multitude of sensor data can be compared and "outliers" can be eliminated. The risk of attack can be further minimized by using a large number of distributed Oracles. As with the consensus algorithm of the Blockchain, 51% of the Oracles would have to be manipulated in order to write the changed truth to the Blockchain. Solutions like ChainLink [EJN17] realize such a concept. Finally, there is also the possibility to create an incentive system for Oracles or people acting as Oracles. Attention must be paid to the fact that the incentive is chosen correctly with respect to the value of the decision to avoid corruption.

As described above, IoT serves as the essential foundation for linking the physical world with the digital world. All areas of application are characterised by a high degree of autonomy. Processes that span the physical and digital world can run autonomously over a longer period of time and

[12] https://www.riddleandcode.com/

accept support processes that are also executed autonomously. Within the framework of these process chains, decisions that are more complex become necessary. The role of Artificial Intelligence can be to make these decisions based on learned knowledge.

5 The role of Artificial Intelligence

Artificial Intelligence (AI) is considered to be of great importance in the future of computer science. Disciplines such as machine learning and especially deep learning or speech processing allow computers to support and even replace people. For this reason, visions of the future vary from positive belief, like a harmonious cooperation between humans and machines, to a neutral view, where machines make humans irrelevant, to dark scenarios, with an omnipotent and human controlling AI. At this point we will not discuss further developments of AI. Rather, their influence on the Blockchain and vice versa should be explored. Many possible applications of a linkage between Blockchain and AI are currently being discussed in the literature [DT18, MG18, MX18]. The most important are:

1) Democratisation of data

Data is referred to as the gold of the 21st century. Today, however, the largest amounts of data are in the hands of a few companies or governments. Machine learning requires large amounts of data. Thus, the development of efficient and powerful AI is in the hands of a few [MG18]. Blockchain enables the creation of marketplaces for data. Self-sovereignty of data allows everyone to release their data in a targeted manner. In this way, access to data can be globalized and availability increased. Tokens can be used to ensure financial compensation and thus encourage the sharing of data. Ocean[13] or OpenMined[14] are examples for this kind of application. Even new business models such as the renting of data for training AI models without disclosing this data are possible through the use of Blockchain technology.

2) Authenticity of data

In the digital world, the boundaries between reality and fiction are blurring. The buzzword “fake news” shaped the last election campaign in the USA. Today,

[13] https://oceanprotocol.com
[14] https://www.openmined.org/

computer-generated images can no longer be distinguished from real ones[15] [KAL17]. At this point, Blockchain technology can be used to prove the authenticity of the data. Due to the property of immutability, the origin of the data can also be guaranteed at a later point in time.

The same applies to the training data used for AI algorithms. In order to be able to prove that machine learning algorithms have been trained with correct data, Blockchain technology with its properties of immutability and transparency is an ideal supplement. The origin of data can be documented and its utilisation can be traced.

3) Explainability of AI decisions

Not only the authenticity of the training data, but also the traceability of decisions of AI algorithms can be achieved by Blockchain. Today AI systems are a black box. Decisions cannot be traced back to the "experiences" made by the algorithm during training. This is a big problem, especially in medical applications, and limits the use of AI. By documenting decisions on a Blockchain, confidence in these decisions can be increased. "Through tracking behaviors of AI-based systems across different data input and application scenarios, we gain more understanding of and confidence in the decisions made by those systems" [DT18, page 51]. With the growing understanding and confidence, trust in AI algorithms will grow too. This leads to a broader application of AI.

4) Auditing and ensuring quality of smart contracts

The immutability of Smart Contracts holds a great danger [Fa17]. Programming errors, for example, can have major consequences because once deployed on the Blockchain, they cannot be stopped or reversed. AI can help to make programs safer and to detect errors early [MX18]. The absence of errors in Smart Contracts is an essential prerequisite for the widespread use and acceptance of such solutions. Solutions such as ChainSecurity [16] already offer formal verification, security reports and audits of Smart Contracts.

[15] https://www.thispersondoesnotexist.com/
[16] https://chainsecurity.com/

6 Conclusion and potential actions

The explosive development of the digital world and its influence on our daily lives cannot be stopped. As shown in the report, the megatrends Blockchain, Artificial Intelligence and Internet of Things are merging. In this digital world Tokens represent the physical assets and can act as connection between both worlds in terms of value. Smart Contracts form the basis for Tokens. They allow arbitrary functionality and a maximum of flexibility. To synchronize both worlds regarding data IoT is predestined. These data are used by Smart Contracts and AI algorithms to analyse specific situations in the physical world, make decisions and trigger actions either in the digital or physical world. In this workflow AI takes the role of adaptive decision engine. All together they form Digital Twins of objects or even persons from the physical world. Having a digital duplicate enables a wide range of applications. Since the digital world has different "physical laws" regarding time, location, size, resources, etc. the Digital Twin is much more powerful than its physical original. Today the Digital Twin is primarily used in a passive way. It is observed and used as blueprint for the physical object. In future it will operate more and more actively. Simulations will be run on Digital Twins and they will take an active role in direct Machine-to-Machine communication as well as in collaboration between machines. The convergence of already existing but siloed developments of AI, IoT and Blockchain in the form of a learning, sensing and trusted Digital Twin will increases the frequency of innovation. Future scenarios of human Digital Twins acting autonomously with other digital objects or humans are not so far away as science fiction wants us to believe. First AI based personal assistants are already existing and conducting simple tasks like making a haircut appointment [Wel18]. Digital avatars like the ones Facebook is developing [Fac19] allow us to participate in distant meetings. In parallel the next generation of internet, the semantic web, is evolving. It will connect knowledge in a structured way and therefore allow the use of the internet for machines. This will blur the border between human and machine in the digital world.

In this world trust will have a crucial meaning. Trust in content, trust in identity, trust in ownership, trust in authenticity, and trust in truth. Blockchain technology can be used to enable and ensure this trust on a protocol level. Tokens will have an important role in this ecosystem since they represent physical assets in the digital world and enhance them with functionalities. Tokens will embody the aspect of identity and value in the protocol.

What is of relevance for the European Union? Legal and regulatory frameworks are crucial. Many new business models only become possible once the legal foundations have been created and secured. Legal uncertainty leads to the paralysis of innovation or to migration to legally secure countries. Stability in these two domains is essential. To ensure a leading role for Europe substantial efforts in research and innovation are required. At the moment a competition for supremacy can be observed. Various countries and large enterprises are investing substantial

sums in innovation either on a university level or on a company level. Since there is no time for decades of research short term programs and sandbox approaches with simplified regulatory requirements seem promising.

The digital world does not stop at national borders. Attempts to limit freedom in the digital world will fail since it takes only a click to relocate to another country.

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