PROTOCOL BASED ON BLOCKCHAIN

THE FUTURE OF MANUFACTURING

Projekt Description

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1. EXECUTIVE SUMMARY

Producers are challenged by the increasing speed of innovation and individualization of products. People like to have customized products or even to have the ability to produce their self-created products. Customers want more variants and that as soon as possible. Last-minute changes are also coming more and more frequently from customers. Companies are called upon to react quickly, with shorter innovation cycles that remain economically viable at the same time. In addition to innovation and individualization, manufacturers are challenged by globalization: products are produced and assembled locally and worldwide at different locations. Therefore, one of the greatest technical challenges facing manufacturing companies is to deal with the heterogeneous IT system landscape that this creates.

To fulfil customers demand and improve business processes, manufacturers need a digitalized production process and inter-connectivity with their suppliers. Driven by Industry 4.0, the vision of ARXUM is to provide a worldwide production protocol (ARXUM’s Production Protocol) that supports people and manufacturers to realize customized or newly created products by providing a set of DApps based on Blockchain technology. Manufacturers connected by ARXUM’s protocol benefit from robust and secure connectivity, worldwide accessibility, and the standardized production order protocol with rich data exchange. ARXUM’s protocol increases their processing speed and reduce their costs. Customers and manufacturers can use the AX token to further reduce their costs and access new markets.

All major strategy consultants confirm the need for cross-linked production networks and companies will invest heavily to drive technological change:

- It is highly likely that the world of production will become more and more networked until everything is interlinked with everything else (McKinsey Interview 2013)[1]

- The connectivity of IoT, data and physical objects makes it possible to build smarter supply chains, manufacturing processes, and even end-to-end ecosystems (Deloitte, 2016)[2]

- The best way to reduce the risk of supply chain failure is by achieving greater visibility, and managing it cross-functionally deeper into the end-to-end supply chain (KPMG, 2016)

- 43 % of companies admitted they had either limited or no visibility at all into their supply chain (survey of 360 senior executives, KPMG 2016)[3].

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3 https://assets.kpmg.com/content/dam/kpmg/pdf/2016/05/global-manufacturing-outlook-competing-for-growth.pdf
companies will spend an incremental €250 billion on IoT in 2020 (over and above their normal technology spending), services and IoT-applications grow fastest (Boston Consulting Group, 2018)[4]

Introducing Blockchain technology leads to several advantages: IP, product ownership, procurement process, and payment transactions will be secured. The Blockchain gives visibility to the supply chain and logistic processes and realize auditability and traceability of the manufacturing process.

While manufacturers would like to follow the individual ideas of their customers and proactively offer individual versions of their products, the manufacturers' business and production systems are organized according to the principle of the hierarchical automation pyramid. Each level has its own task and software system. Changes in the production process are therefore complex and expensive.

ARXUM's approach is disruptive. ARXUM does not implement a hierarchical, but rather a decentralized and cooperative network architecture that makes it possible to make cost-effective, rapid changes and optimal use of the resources. ARXUM's team has developed a connection box (ARXUM Connection Box) that is able to interconnect machines of all suppliers, without engineering effort, to the Blockchain. It provides a communication channel on the highest security level. The device allows to build up a network on machine level and give visibility and access to production capacities and capabilities.

However, the handling of production orders requires agreement on further commercial and technical conditions. ARXUM will develop corresponding templates and service specifications for this purpose and integrate them in ARXUM’s Production Protocol.

ARXUM’s Production Protocol comprehensively supports the complete handling of the production processes from design, production, business processes, logistics and payment processing. Via the web-based production network (ARXUM’s Production Network), every commercial or private customer can create a new product or adapt existing designs. ARXUM’s Production Network helps them to discover and evaluate potential manufacturers, to set up the request for proposal, and to select between customer-rated suppliers along defined criteria via a set of DApps. Supplementary service providers are integrated into the platform.

The decentralized ARXUM Production Network allows to produce your self-created products or to adapt products to your own ideas. The barriers to market entry for young entrepreneurs are therefore lowered. But the manufacturers also benefit enormously from ARXUM’s standardized protocol and processes.

2. INTRODUCING ARXUM

The Company

ARXUM Business GmbH, incorporated in Switzerland, has been founded by a team of managers and technical experts with long-time experience and sophisticated knowledge about process automation solutions, “Industry 4.0” (I4.0), “Internet of Things” (IoT), Software and Distributed Ledger Technology (DLT) and Blockchain technologies (BC). ARXUM is a spin-off of the longtime existing company Arend Prozessautomation GmbH, Wittlich, Germany[5], which is an engineering service provider in the field of process automation.

ARXUM combines software and hardware development competences with industrial production experience in order to attach physical machines to the Blockchain world.

The company is the entity organizing the Initial Token Sale and will control the funds received as well as coordinate and manage the implementation of the ARXUM Project.

The easy and trusted ARXUM Production Protocol utilizes the advantages of Smart Contracts and Blockchain technology. ARXUM creates a peer-to-peer production network to give anyone the access to manufacturing resources and to improve business processes for manufacturers. It is an eco-system of hardware, DApps and services for the future of manufacturing. ARXUM covers all dimensions of Industry 4.0 applications: IoT, Data, Cloud and Security, from device connectivity, data collection & validation, advanced analytics and automated operations. ARXUM’s Production Protocol is located in the intersection of Industry 4.0, Cyber Security and FinTech.

ARXUM’s vision for Manufacturing

First came steam and the first machines that mechanized some of the work our ancestors did. This was the beginning of industrialization (Industry 1.0). Second came electricity, the assembly line and the birth of decentralized mass production. The third era of industry came about with the advent of computers and the beginnings of automation, when robots and machines began to replace human workers on those assembly lines.

And now we enter Industry 4.0, in which computers and automation will come together in an entirely new way, with robotics connected remotely to computer systems equipped with machine learning algorithms, that can learn and control the robotics with very little input from human operators.

Industry 4.0 introduces what has been called the “smart factory,” in which interconnected cyber-physical systems monitor the physical processes of the factory and make decentralized

decisions. The physical systems become Internet of Things, communicating and cooperating both with each other and with humans in real time via the wireless web.

Consumers want individualized products but at the prices they’d pay for mass-produced goods (mass customization). As a consequence, production has to be more flexible than ever before. This increases pressure on the industry but opens new business opportunities at the same time.

It is time for a new approach to manufacturing!

Today manufacturers suffer by lack effective inter-connectivity with their suppliers to meet the needs of today’s customers. This has significant negative impact because of low speed, limited transparency and high cost associated with current production software solutions which do not provide end-to-end connectivity and visibility of the production process. Manufacturers are unable to deliver customized products on time and at the cost of mass products. Fraud and fake items as well as safety and security are further challenges of the digitalization of production processes.

By signing all digital assets with the blockchain, ARXUM ensures transparency and safety. The ARXUM Production Protocol establishes one smart contract for each production order between all involved parties worldwide like buyer, manufacturers, suppliers, transport agents and additional services. Smart contracts are needed to establish lean processes by ARXUM’s Production Protocol. Cryptocurrencies are most suitable as payment solution within the network. The Blockchain makes the entire ARXUM eco-system transparent, efficient and prevents any kind of manipulation.

An efficient production network relies on information about the availability of manufacturing equipment and its particular capabilities. Machines need to be seamlessly integrated into the Production Protocol through a gateway software. The gateway software provides machine information (e.g. XML based manufacturing meta language) and mediates the production orders brokered by the Production Protocol. ARXUM has developed the secure “ARXUM Connection Box” which allows interconnecting machines of all suppliers without engineering effort to the Blockchain and provides a communication channel on the highest level of security. ARXUM connects machines directly to the Blockchain.

ARXUM’s Production Protocol and integration on machine level is a disruptive approach to interconnect clients, manufacturers and their suppliers. The establishment of a production network based on this technology is a key milestone on the way to a fully interconnected production. It enables “cloud networked manufacturing”!
“Cloud networked manufacturing” or “Manufacturing-as-a-service (MaaS)” will change how goods are made around the world. MaaS is the shared use of a networked manufacturing infrastructure to produce goods. Manufacturers use the internet to share manufacturing equipment to reduce costs and make better products. Anyone also individuals with production capabilities, can offer their services via ARXUM’s Production Network.

Imagine someone has an innovative product idea. He/ she wants to manufacture and sell his/ her new product but doesn’t know how. Today he/ she has to search for potential suppliers, contact and evaluate them, negotiate contracts, construct a supply chain and convince customers.

With ARXUM’s Production Network the user will be able to upload his/ her digital description and ARXUM’s Production Protocol secures the user’s authorship of the digital asset. Many production facilities, large and small, or even individuals with a production capacity, will be connected to ARXUM’s Production Network and offer their different manufacturing services. The ARXUM Production Network supports customers to start a tendering process and evaluate manufacturers. The client can influence the manufacturing process of his/ her goods by different dimensions of manufacturer ratings, e.g. location of the manufacturer, CO2 footprint or sustainability, social standards or simply price. ARXUM's Production Network mediates the technological manufacturing capabilities, organize the supply chain and helps to connect customers. The new product is launched.

ARXUM’s Production Network offers everybody the chance to create and produce their own inventions, or even to become an entrepreneur and offer their own products to the market. ARXUM’s Production Protocol provides the technology for a truly interconnected production network on machine level. This enables manufacturers to offer their consumers to personalize the goods they buy. ARXUM’s Production Protocol drives down costs, increases processing speeds and delivers end-to-end visibility into production fees, timing and delivery. Thus, manufacturers can offer these customized products for prices at mass production level.
Team of Experts

The management team of ARXUM consists of many highly qualified people with experience in process automation, Industry 4.0, marketing and sales as well as Blockchain technology. They are working together with the founders and experienced managers to realize the vision of a decentralized ARXUM Production Protocol.

Markus Jostock, Ph.D.
Founder & Managing Director ARXUM

Markus is a seasoned management professional with more than 15 years’ experience in full-stack software design and development.

He is responsible for the development of the ARXUM Connection Box with strong cyber security features and technology expertise in the field of Industry 4.0, Cyber Security and Blockchain applications.

Jens Harig, Dipl.-Ing.
Founder & Managing Director ARXUM

Jens is an experienced Manager with a technical background. A Venture capital investor in the phase of introducing the Internet and mobile technologies and experienced with IPO’s. He spent more than 15 years in the IT industry.

He was CEO/ CFO of a rapidly growing, listed IT-company (IT services, software and mobile technologies) with subsidiaries in Germany and other European countries.

Dirk Klein, Dipl.-Ing.
Business Development

Dirk has many years of experience as business unit manager and is an expert in the field of automation technology. In technical management and business development, he gained knowledge of the beverage industry in particular.

One of his strengths is customer management.
Joachim Mieves, M.Sc.

Software Development

Joachim has 30 years of experience in software development and design, ranging from programmable logic controllers, industrial SCADA systems, CNC manufacturing centres, web programming and service-oriented architectures. He is responsible for the architecture of the ARXUM Connection Box, its integration in external software systems and the integration with the embedded DApp for Blockchain access.

Christian Meisberger, B.Sc.

Software Development

Christian studied computer science with a focus on secure and mobile system. He gained deep knowledge in cryptography, computer system security and communication in distributed networks. In the ARXUM team his responsibility is the secure communication, system protection of the ARXUM Connection Box and the security of the embedded DApps.

Christoph Marx, M.Sc.

Hardware Development ARXUM Connection Box

Christoph is an electrical engineer with more than 20 years of practical hardware and embedded software development experience. He has comprehensive expertise in communication technology, hardware development for mobile terminals and payment systems. Christoph is responsible for the ARXUM Connection Box trusted hardware, including the secure boot foundations, hardware wallet and external machine interfaces.

Nicolay Todorov

Head of Blockchain team

Nikolay, CEO of Limechain, brings together business understanding and experience in applying Blockchain technology. This deep appreciation of business needs alongside a firm grasp of the technical capabilities of Blockchain allows him to act as the crucial link between product management and the Blockchain developers.
George Spasov
Blockchain Development
George, head of the technical team at Limechain, has experience in leading teams to deliver successful software projects for everyone from startups like pCloud to international companies like IBM. His Blockchain expertise has earned him recognition as a top performer of the inaugural Blockchain Developers Academy run by ConsenSys.

Chris Veselinov
Blockchain Development
Working on Blockchain technology since its early days, Chris has built enterprise systems and blockchain applications for both corporate and startup clients. This breadth of experience gives him unique insights into applying the right Blockchain solutions. Chris is part of the Limechain team.

Vladdy Ivanov
Blockchain Development
Vladimir is the high energy perfectionist of the Blockchain team. His knack for creating DApps stems from his combination of experience in building web applications and applying Blockchain technology. Vladimir is part of the Limechain team.

Disa Braun
Copywriter & Brand Manager
Disa has a thorough background in linguistics having earned dual degrees in linguistics and professional writing. Displaying high levels of competence, she has written for blockchain startups, co-founded and operated an advertising agency, and currently works as a linguistic consultant and copywriter.
Rainer Schmitz
Process Automation/ Industry 4.0
Rainer has many years of experience in managing major projects in the implementation of automation and control technology for machines and production plants.

Thomas Pauli
Process Automation/ Industry 4.0
Thomas has extraordinary competence in the system integration of machines and switchgear. He masters the corresponding data bus systems as well as programming languages and control hardware.

Berthold Frombach, Dipl.-Ing.
Process Automation/ Industry 4.0
Berthold stands out due to his long experience in PLC software development. He offers a broad portfolio of different systems with which he is very familiar. His numerous stays abroad during system integration projects lead to a deep competence in the field of automation technology.
Advisor team

The ARXUM Project is being advised by a number of very experienced personalities from entrepreneurship, industry, finance, universities and Blockchain technology, including the following:

Axel Haas, Prof. Dr. h.c.
Founder ARXUM

Axel is a serial entrepreneur in the field of automation technology, communication technologies and industrial technologies.

He has more than 30 years' experience in managing small and medium-sized growth companies (up to ~ 300 million EUR turnover) including experience in IPOs and management of listed companies.

Jörn Hendrich Block, Prof. Dr.
Professor of Corporate Management at the University of Trier

Jörn is among other things: Professor at the University of Trier since 2012. President of the FGF, the leading academic association for research about entrepreneurship, innovation and SMEs in the D/A/CH region. Member of the Round Table Mittelstand in the Federal Ministry of Economics and Energy. Active as a founder and advisor in the start-up scene.

Hans-Georg Scheibe
Managing Director ROI Consulting GmbH

Hans-Georg’s expertise covers supply chain management, operational excellence and business IT alignment. ROI is the leading Management Consultant in the field of Engineering & Production in Germany. Clients include renowned companies from the automotive, mechanical engineering and industrial goods sectors. Since 2013, Hans-Georg has led the ROI Management Consulting AG and Süddeutsche Verlag's Industry 4.0 Award.
Philipp Sandner, Prof. Dr.  
(subjected to final approval)

Head of the Frankfurt School Blockchain Center

Philipp is Head of the Frankfurt School Blockchain Center at the Frankfurt School of Finance & Management. The center analyzes implications of Blockchain technology on companies and business models. Philipp is also a member of the FinTechRat of the Federal Ministry of Finance. His expertise includes digitization, entrepreneurship and innovation management.

Kersten Schütze

Head of Strategy at ETHLend, Blockchain advisor

Kersten has a background in the financial industry, having worked with FinTech companies in Europe and Hedgefunds in Asia. He is engaged in the international Blockchain world as part of the ETHLend team. Kersten is also a start-up founder and working as consultant for ICOs and the Blockchain industry. He is active in the Blockchain community and seeks to bring Blockchain innovation into the industry.

Sergej Stein

Co-Founder DLT Capital GmbH

With a finance degree from Germany's leading business school, Sergej is an expert in executing ICO campaigns. His company DLT Capital supports promising Blockchain projects with the necessary experience to initiate successful project launches. The last ICO he advised raised more than $16 million.
3. **ARXUM’S ECOSYSTEM FOR MANUFACTURING-AS-A-SERVICE**

**Build to scale**

The question is not if Industry 4.0 is coming, but how quickly. As with big data and other business trends, we suspect that the early adopters will be rewarded for their courage jumping into this new technology, and those who avoid change risk becoming irrelevant and left behind.

The ARXUM eco-system embraces a large number of users, manufacturers and other service providers. The open API universe will allow ARXUM’s Production Network to scale fast and grow exponentially.

**Use Cases**

Today’s consumers want something more, something unique and tailored just for them. The market, crowded by makers, hackers, DIYers and individualists, is begging for customization, for a return of craftsmanship on a massive, industrial scale.

Through lean manufacturing, just-in-time inventory and digital technologies today customized manufacturing isn’t just a dream anymore. It becomes simple and easy thanks to new technologies like 3-D printing capabilities.

You might design your own smartphone: The phone is a puzzle of components, modules and hardware features that promise to be as customizable and upgradable as its users’ imaginations and budgets allow, and as powerful as the crowdsourced developer ecosystem makes it. The phone is basically just an endoskeleton packed with magnetized sockets for any kind of screen, hardware or feature the consumer decides to pop in. By tapping into the developer community, new 3-D printing capabilities, electronic component providers and ARXUM’s Production Network, the puzzle is complete, and the project could be realized.

You might have a classic car and now a gear is worn out and defective. You need a spare part. However, these are no longer available due to the manufacturer’s insolvency. But you have the defective part and can record shape and dimensions. You can look for a metal processing company on the ARXUM Production Network. You select the potential manufacturers according to high quality and minimum manufacturing tolerances as well as local proximity. With the support of ARXUM, you would be able to have the no-longer-available gear unit produced. The Blockchain also ensures that the supplier receives his/ her money step by step as he/ she completes the job. Now the classic car is saved.

A shoe retailer chain wants to open a new shopping experience for its customers. A new leisure shoe is to be produced as a private label and is to offer customers the opportunity to design it according to their own ideas. As the dealer operates internationally in many countries, short production times can only be achieved through various local producers and a complete network
of suppliers right through to production. With the help of a web configurator for shoes, developed with the support of ARXUM for the implementation of the customer's creation (model selection, colour / material / motif on the shoe, colour of the sole, etc.) the production data are generated. Thanks to ARXUM's Production Protocol the production data can directly be routed to any machine of its suppliers, which uses the ARXUM Connection Box to connect production machines directly to ARXUM's Production Protocol and Blockchain. Efficient processes are achieved in commissioning and production through direct delivery of the relevant production data to the machine. Production and delivery can be tracked by the customer at all times. The customer is virtually "live". In this way, a new and very personal shopping experiences can be achieved.

Why Blockchain

ARXUM's Production Network features a Blockchain ledger which can deal with more complex transactions than merely sending and receiving value. Decentralization brings in a number of advantages, including greater robustness, fault tolerance, lower cost, and the potential for anonymity.

Thanks to the technology of the Smart Contracts over the Blockchain, there is no longer any need for a trust account. Smart Contracts provide a solution to deploy commands on the Blockchain network, which executes but cannot be modified once deployed. This can save a lot of money because the process is automatic and is able to bypass barriers. For ARXUM's Production Protocol true peer-to-peer interaction is essential: digital assets are transferred from users to manufacturers and from manufacturers to their suppliers, and vice versa, without an intermediary. This increases trust due to transparency. It also speeds up the process of design and manufacturing.

Blockchain technology secures their intellectual properties, the procurement process, the proof of the manufacturing process and makes the process traceable and auditable. Blockchain proofs the existence and ownership of the product, the logistic process and the payment of service.

A number of Smart Contracts support the operation of the ARXUM Production Network. ARXUM uses Smart Contracts for incentivization, coordination, permissioning, and integrity checking. Each production order is mapped in a Smart Contract between all involved parties and executed reliably and safely.

ARXUM's Production Protocol

Today's IT-systems of manufacturers are organized according to the principle of the hierarchical automation pyramid. Each level has its own task: from top-level corporate planning (Enterprise Resource Planning) to the planning and control of production processes, to the individual control of plants and machines at the lowest level. Everywhere own software systems and often own communication technologies are used. Changes in the production
The lack of end-to-end connectivity in the world of production leads to several serious issues for manufacturers. The innovation cycles for products are long, the coordination process with suppliers is complex and the lack of transparency in the supply chain increases the risks of production losses. All major strategy consultants confirm the need for cross-linked production networks.

In order to overcome the deficits, ARXUM chooses a disruptive approach to interconnect production more efficiently and consistently.

Intelligent production facilities (so-called cyber-physical production facilities) consist of intelligent machines, storage systems and equipment that can exchange information, trigger actions and control each other. In contrast to hierarchically structured communication processes, intelligent systems can react quickly to changing requirements.
ARXUM introduces a standardized protocol with rich data attachments (ARXUM’s Production Protocol) for end-to-end networking.

Via ARXUM’s Production Protocol machines, means of transport and workpieces are combined virtually in one production line. PLCs (programmable logic controllers) of machines, software and communication technology are connected to each other. ARXUM’s Production Protocol forms an intelligent and networked production system that is controlled decentrally. In this way, manufacturing processes at suppliers and producers are integrated across production sites. In addition, the system can be quickly and easily adapted to new production processes.

Thanks to the integrated networking of the intelligent components and the standardization of communication technologies, all production processes are then interlinked with the business processes and can therefore be flexibly controlled and changed. ARXUM does not implement a hierarchical, but rather a decentralized, cooperative network architecture that makes it possible to make optimal use of the resources. On the one hand, it is intended to network the entire intelligent production system, including all machines. On the other hand, it should be able to link several systems and integrate stand-alone solutions.

ARXUM's Production Protocol comprises a set of fundamental rules which govern the agreement on production orders between two or more partners in the ARXUM network.

The protocol consists of the following main components:

- An Ethereum smart contract for payment and escrow of funds.
- A Ricardian smart contract with bindings for all manufacturing partners.
- An off-chain secure storage for digital assets and rich context data.

As the ERC20 AX token is used in the Smart Contract, all payment and settlement related activities are executed in Ethereum. In some cases, this can be just one final payment.
A Ricardian Smart Contract (RSC) contains all conditions relevant to the execution of a manufacturing process. This smart contract is usually implemented in another technology, such as Hyperledger. To take advantage of Blockchain implementation benefits such as proof of existence, ownership and traceability of manufacturing progress, the Ethereum network is far too costly and the application requires higher transaction throughput.

For a manufacturing order it is imperative to provide specifications at a sufficient level of detail, e.g. in form of a computer aided design file or blueprint as a digital asset. This data is securely stored off-chain and only relevant parties of a production order have access to their respective data.

When a user triggers a product manufacturing sequence, a Smart Contract is established between all involved stakeholders or peers of the production process, for example:

- Inventor, prosumer or professional purchaser of a company
- Manufacturer
- Freight transport service
- Digital service provider

The Smart Contract regulates the service to be performed, the ownership and protection of assets, the payment and cost modalities. Several distributed ledgers are involved in order to fulfill the Smart Contract.

A Ricardian contract places the defining elements of a legal agreement in a format that can be expressed and executed in software. The key is to make the format both machine readable, such that they can easily be extracted for computational purposes, and readable as an ordinary text document, such that the users and contracting parties may read the essentials of the contract more or less conveniently.

To be machine readable or software executable, the terms and conditions are formatted in JSON with a hierarchy of attribute-value pairs: the contract schema. As there are different industry sectors and thus multiple types of production orders ARXUM strives to support, each will have its own contract schema. Common to all schemas are the following modules:
Using a Ricardian Smart Contract provides a very flexible way to adapt to different industrial sectors. The same flexibility is provided for the adaptation to different needs over time. Using the JSON format in the contract and including extended version information in the metadata section of the contract provides a downward compatibility of future protocol adaptations.

The user can follow all steps of the unfolding production process through his/her DApp and watch the single steps being performed as they appear in the main distributed ledger (Main DL).

First, the platform transfers the digital description file of the component to be manufactured and all necessary technical and commercial ancillary conditions. All relevant files are securely stored decentrally on each peer's DApp. Access to these files is only granted to relevant participants in the Smart Contract. They are needed for the tendering process and the production of the different components of the product to be manufactured. A high level of protection is necessary as the files may constitute an IP such as schematics or blueprints. The inventor has a sincere interest to protect his/her invention from plagiarism.

Upon completion of the selection process, the selected manufacturer will receive the digital description of the component in the manufacturer's DApp. There are two types of manufacturer DApps: an interactive version which allows to manually review and manage incoming production orders as well as a machine bound version which is integrated into one specific production machine. The machine bound DApp version autonomously manages the machine availability, capacity and workload. It has to be integrated into the machine and needs to be configured exactly to the capabilities of the production machine. A very quick way to connect production machines directly to the ARXUM Production Network is through the ARXUM Connection Box. The ARXUM Connection Box has an embedded DApp integrated and provides physical machine connectivity (with digital and analog inputs, PLC communication), extremely high security standards and a plug-and-produce approach to machine configuration. The ARXUM Connection Box is described in detail in the subsequent section.

When the manufacturer accepts the manufacturing order, a smart contract is instantiated and all peers are included with the respective manufacturing conditions. Once the items are manufactured, the existence of the components are documented in the Main DL, thus their existence cannot be denied. For some items, a personalized ID might be integrated in the product (serial number, ID or RFID tag or specific design characteristic). This is particularly relevant for high price products or high quality materials. The ownership of an item is stored in the Asset Transfer DL. The principle is similar to e.g. Everledger[6], only that in ARXUM's Production Network this aspect is fully integrated and applies directly from the moment of manufacturing. Using the embedded DApp, either in the production machine or in the Arxum Connection Box, the proof-of-existence and proof-of-ownership transactions are inserted into

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6 https://www.everledger.io/
the distributed ledgers directly by the machines. No manual interaction is necessary. This is one of the first implementation of IoT devices autonomously creating Blockchain transactions.

Once the number of ordered items has been produced (proof-of-existence), the Smart Contract can automatically generate a transport order for the identified freight transport agent. The manufacturing order does already contain the information about the next recipient of the products. The recipient may be a further production stage where several components are joined into one, or it may be the final destination. Thus, the manufacturer can seamlessly hand over the delivery to the freight transport agent. Documenting the handing-over of the products to the transport agent in the Main DL also cares for the transfer of perils from the manufacturer to the freight transport agent. This will then trigger the crypto-payment for the manufacturer as foreseen in the Smart Contract, as his/her duty is fulfilled through production and handing-over to the freight transport agent.

With each stage of the production chain completed, each peer receives its respective crypto payment.

As is currently implemented by several transportation companies, the tracing of a delivery can be monitored in near real-time by the recipient. Thus the connection of a freight transport agent to ARXUM’s Production Network is similar to the connection interface of a digital service provider.

Digital service providers connect their services, as well as the freight transport agents, to the Digital Service Provider DApp version via the published application programmer’s interface. Digital services can be of different nature. They are needed partly during the manufacturing process, but partly also in the preparation phase.

The following digital services are either provided by ARXUM or offer an opportunity for third parties to participate in ARXUM’s Production Network:

- Providing geographic data and calculation of geographic distances
- Solving the traveling salesperson problem (finding the shortest possible trajectory between multiple destinations)
- Calculating a complexity of digital designs of physical goods
- Splitting and exploding digital designs into sub-components
- Mapping a production technology to specific designs
- Providing transportation or default insurance services
- Providing metadata about country specific social and environmental standards
Connecting the Manufacturers

ARXUM Connection Box (ACB)

The ARXUM Connection Box provides a direct access for production machines to the ARXUM Production Network. It has been developed by ARXUM staff with a focus on real industrial needs and provides various means to interact with a wide range of industrial machines.

Thanks to the diverse connection possibilities for sensors and data, any type of production data can be captured and linked to the ARXUM Production Network through the embedded M2M DApp.

Digital and analog sensors can be directly connected to the ARXUM Connection Box, as well as serial interfaces or IO-Link for intelligent sensors. A LAN interface provides internet connection with secure access to an integrated web server, and a separate LAN interface allows for reading data from several control systems via the OPC-UA or S7 protocol. In different production scenarios, the ARXUM Connection Box enables access to the machine controller and offers various options for interacting with the production machine.

Most companies use machines from different manufacturers. This means that each component has its own proprietary software. In general, these different software systems are initially incompatible. A resilient industrial standard has not yet been established in the production facilities. This makes it difficult for systems to work together. It also creates security vulnerabilities that allow cybercriminals to infiltrate malicious code without much effort.

The ARXUM Connection Box is equipped with an extensive, integrated security concept and has been developed in a secure development lifecycle as per the security-by-design principle. Protection from malware is guaranteed as the operating system is safeguarded with an integrated TPM2.0 crypto-processor, a hardware security anchor and key store. Each single TPM chip provides a unique ID and a set of public / private key pairs, partly not extricable. A node like this, with a strongly protected private key, is an ideal participant in a distributed ledger.
application. The ARXUM Connection Box is an IoT node which can directly create transactions in a Blockchain though the embedded M2M DApp.

Essentially the ARXUM Connection Box does contain a secure hardware wallet and can thus equip production machinery not only with the ability to interact with a Blockchain, but also provides a budget to these machines and the ability to pay for their services. The ACB contains the private keys to sign all Blockchain transactions.

Also, larger production facilities can be connected through ARXUM’s Production Protocol. Production lines with multiple production machines and larger facilities are equally connected through the ARXUM Connection Box. But instead of connecting single machines to one ACB, the ACB acts as security anchor and hardware wallet interconnecting the complete production facility to the different ARXUM ledgers.

For this purpose, the different LAN interfaces of the ACB will be used. LAN1 will connect to the production protocol via an internet connection. LAN2 will connect to the manufacturer’s intranet and interact with company IT systems.

ARXUM provides standard interfaces to major order processing systems. These are located on two levels:

- ERP level (enterprise resource planning)
- MES level (manufacturing execution system / production planning system)

The most important level is the manufacturing execution system or production planning system, as these care for the job order for all manufacturing tasks, take care of prioritizing special jobs, circumvent unavailable production machines and regulate all production execution related issues.

Currently a MES usually collects active production orders from the ERP system and the production manager arranges for their execution. ARXUM simply provides a further channel to collect production orders.

**Architecture of ARXUM’s Production Network**

ARXUM provides the tools and the environment for a frictionless and fully decentralized production organization.

Core elements of the decentralized production architecture are set of DApps tailored to the respective stakeholders and participants of the system. There are the following roles are present in the ARXUM universe: Inventors and prosumers, digital service providers and other external partners, manufacturers and their suppliers.

Inventors have designed a potentially producible product and provide a digital description of the product. It might consist of multiple parts and pieces of different materials which need to be separately manufactured and assembled.
Prosumers have an interest in acquiring customized versions of existing products. They might apply a personalized customization to the product/invention they choose. It is possible that the role of inventor and prosumer is unified in the same person.

Manufacturers offer production facilities with specific capabilities. They may be able to perform 3D printing of plastic and/or metal, they may be able to provide metal milling and drilling capabilities, metal sheet laser and folding services, plastic extrusion, provide drilled and milled wooden parts, or simply provide human or robotic resources to assemble multiple different parts into a product. Their capabilities are subject to conditions, e.g. for plastic extruded parts a minimum quantity is needed, or the pricing is strongly depending on the number of ordered parts. Some manufacturers offer higher precision than others, some have short term production capacity available while others have waiting time.

For each of the different roles in the ARXUM production network a specialized DApp is provided, linking its services to the other stakeholders.

The DApps exchange information via Swarm, Whisper or Hyperledger Channels, depending on the chosen implementation.
A User DApp is installed on personal computers and is used by inventors to provide digital assets. A prosumer uses this app to view, select and order items.

A DSP DApp is used by the digital service providers to provide access to their services. Most of these DApps are provided by ARXUM in order to execute the manufacturing broker process. ARXUM anticipates the advent of many service providers who will offer auxiliary services useful and required in an industrial production environment.

For the production ledgers, ARXUM provides a base infrastructure for the Blockchain transaction execution for all instantiated networks. ARXUM will run several node instances in different geographic locations.

Any partner, customer or manufacturing company participating in a permissioned Blockchain implementation of the ARXUM network is required to maintain an AX token deposit and to run at least one instance of an ARXUM node for each network it is participating in. It is possible that one manufacturer participates in multiple ARXUM networks (as it supplies products to several buyers).

ARXUM provides incentives to node operators who provide computing power but who are not participating in any manufacturing activities and who remain outside of Smart Contracts. These can also be e.g. digital service providers.

Several other peers have a valid interest in the correctness and accuracy of the ledger state and correctness of the system. These are among others the institutions which act as auditors on the production conditions. These can be e.g. state institutions caring for social standards in manufacturing, consumer protection and food safety agencies (stately or non-profit), agencies surveilling dual use products, and many more.

Machine-2-Machine DApps are used by the manufacturers and are directly installed on or at the production machines. Either the machine has an open operating system which allows to install additional software, like industrial PCs controlling production machines via a Soft-PLC, or the DApp can directly be installed on modern PLCs (programmable logic controllers) if this is permitted.

Alternatively, if the production machines are controlled by an encapsulated PLC, ARXUM provides a device (ARXUM Connection Box) with an integrated M2M DApp preinstalled. The device allows to physically connect digital and analog sensors of production machines and can interact with most available PLC systems. It allows to physically interact with machines on a deep control level and provides direct connectivity to the communication layer and the distributed ledgers.

The ARXUM Connection Box has already been developed by the core team members of ARXUM and is already available.

The M2M DApp provides the machine and manufacturing capability description and ontology aligned to the XML based language <AutomationML/>. This description is the basis for the internal broker process of the User DApps as it describes all technical aspects of the production facility. A tree-ordered ontology of production capabilities is used to identify the nature of the provided production service.
Apart from solving the problem of physical connection of machines directly to the ARXUM Production Network, a major problem for the integration of industrial production systems into e-commerce solutions is the lack of existing "generic" industry-specific concepts for the service description of a machine. Thus, the potential of e-commerce is not utilized for “industrial product-service systems” so far [7]. Services are more difficult to describe than products for various reasons. A service is the process of doing something rather than the outcome/result. Hence, service description needs to specify the service provision process besides the service result. Another reason that makes service very difficult to describe is its heterogeneity. A semantic description should include the capabilities that a service can provide, what the service requires and what results can be delivered [8].

Manufacturing Service Description Language (MSDL) is an ontology developed by Ameri and McArthur [9] for formal representation of manufacturing services capabilities in the mechanical manufacturing domain. The ontology modeling language of MSDL is OWL-DL. It describes the manufacturing service capabilities with a model of four different capability levels: the supplier, shop, machine, and the process capability of the provider. In this perspective, the four levels contain all required information for searching a manufacturing service. The “supplier-level capability” describes, for example, machining skills, years of experience, industry focus, product focus, and quality assurance standards. The “shop-level capability” describes supporting systems of the manufacturing facilities, for example, control systems. The “machine-level capability” derives its capabilities, for example, speed or length of movement from the machine components. The “process-level capability” describes the machining process. MSDL describes manufacturing capabilities and its capability limitations. The problem of this approach is that it is assigned to a concrete technology; Ameri and McArthur [10] developed this language for machining services.

The discovery, evaluation, and the selection process of services is in praxis more complex and done by professional purchasers. Thus, only the first question to be answered is what capability/machinery a supplier offers. When the purchaser finds a match to his or her needs, in the second evaluation step the technical and commercial framework conditions of the supplier have to be provided. This description incorporates the necessary customer input, acceptance criteria or additional services that can be added. Also, commercial data are required for the service evaluation. The following commercial data are requested, for example: price and price split, currency, quantity, payment terms, delivery time/throughput time, tax, sales terms, validity/availability of offer and payment method. The third step is to evaluate the trustiness of the provider itself. Therefore, data of the provider is also part of this evaluation. Information about reference customers and projects, branch experiences, other services or products offered, existing business relationships, proof of required competences, company

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certificates (ISO 9001, etc.), and interaction standards such as engineering and construction standards (for technical drawings, material description, metrics, etc.) are displayed.

ARXUM will develop corresponding templates and service specifications for this purpose. This information is not only used for the tendering process. They also define a set of contractual and business parameters for the whole production and delivery process and are documented in Smart Contracts established between the involved stakeholders of the project.

Nevertheless, the purchase of production services entails risks. The service and product quality are subject to uncertainties. Inappropriate service performance could result in high follow-up costs. ARXUM aims to reduce this risk for the purchaser. The evaluation of trust information plays a major role at the service discovery and evaluation process. We will integrate a recommender system (comparable to eBay) to support the manufacturers evaluation procedure as a semi-automatic approach. Feedback data based on KPI to evaluate manufacturer will be used to realize rankings based on consumer experiences.

**Benefits of ARXUM’s Production Protocol**

ARXUM’s Production Protocol leads to a democratization of access to manufacturing equipment. Many more people can afford to become a producer of their own products, or design their own customized products without any initial investment.

For an eco-system to be successful over time, it must become the driver for a sustainable economy. Like every economy supply and demand determine the ARXUM’s Production Network universe. The various parties and stakeholders making up the ARXUM network have different incentives, but due to the AX token their interests are aligned.

**Consumers:**

Consumers receive democratic and barrier-free access to products of which they can determine the manufacturing standards. Users can decide whether their customized goods shall be produced to certain social standards, if it should be manufactured in closest possible proximity, or simply for the cheapest production price or according to any other selection criteria provided by the Production Network.

**Inventors:**

Inventors get an easy access to consumers and potential buyers for their product inventions and to suitable manufacturing infrastructure. Their designs are accessible to mass customization manufacturing facilities and the integrated BC bases digital asset protection secures their ownership of their inventions. Payment mechanisms care for immediate P2P payment when their inventions are manufactured.
Manufacturers:

Manufacturers participating in ARXUM’s network have the chance to win new clients and to grow faster than the competition ignoring the chances of new digital technologies. Even private owners of production machines, e.g. 3D-Printers, can offer their services. Offering more customized products leads to competitive advantages. Direct interaction with end-customers reduces cost by eliminating middlemen. Manufacturers benefit from secure worldwide end-to-end connectivity by driving down costs, increasing processing speeds and delivering visibility into production fees, timing and delivery. The ARXUM Protocol makes an important contribution to the digitization of processes and networking with their suppliers.

They thus follow the recommendations of the leading strategy consultants and achieve important milestones on the way to the age of Industry 4.0.

Their access to ARXUM’s Production Protocol is subject to a Loyalty Deposit in ARX. Thus, their interest in creating long-term value for the ARX is aligned with other Token holders. Further they are incentivized by discounts on service fees by using ARX.

Digital Service Providers:

In order to route digital descriptions of good to the most suitable manufacturer within the ARXUM Production Network - according to the consumer paradigm selection - a multitude of digital services is required. E.g. a service provider explodes a computer aided design file into to product components, allowing to select the correct manufacturer for each single component. Further services are e.g. digital transformations, manufacturer evaluation, product tracing, machine capability description design and many more.

AX token Holders:

Since participation in the ARXUM ecosystem requires users and manufacturers to acquire ARX, demand for the token will grow in proportion to the number of active users/ manufacturers and the number of transactions they execute.