Design disclosure for Blockchain-based Application used in public education certificates with electronic hashes

Arno Pfefferling, Patrick Kehling
Hochschule Mittweida, Technikumplatz 17, 09648 Mittweida

Abstract: Blockchain Technology has become an innovative, mature tool for digital transformation, disrupting more and more application areas in their business processes, values, or even economic models. This paper leverages more than 30 academic publications on prototypes and their Blockchain-based use cases to transact certificates in the context of public education. The conceptual design and guiding ideas are reflected in the practical application development for the Federal Ministry of Education and Research ECHT! project within the showcase region WIR! in Mittweida and are used for the research design. During this approach we applied agile methods and the current certificate process to propose a comprehensive disclosure of a new software prototype including a three-layered architecture with multi-stakeholder components. The artefact instantiation contributes to the practical knowledge base within Information System Research and specifically in digital certificate processes starting from creation, searching, and proofing up to revoking by consideration of an existing IT landscape as well as organizational hierarchy.

1. Introduction

The last months and the following years are under tremendous changes worldwide due to the forced use of new digital tools in organizations or in remote home-offices up to fully virtual institutions. This digitalization can go hand in hand with adaption of disruptive technology to stimulate culture of innovation [1]. Gurhaxani and Dunkle propose the following dimensions: risk-taking, diverse perspectives, failure to be learned from and rewards for innovators by removed cultural resistance. The ECHT! project grasp to manifest these dimensions by designing a prototype for digital certificates created inside the University of Applied Sciences Mittweida (HSMW).

Blockchain Technology (BT) in its core offers and is demonstrating those values. Especially the application field data management is a realistic use-case far from hype [2]. Furthermore, academic literature has shown that through BT innovation is accelerated, just to cite a highlight “we have the chance to experiment with secure, decentralized systems, which could enable new social models that go well beyond the economy.” [3]. According to Beck and Müller-Bloch the innovation process fades boundaries by BT with discovery / conceptualization phase, incubation / experimentation loop and acceleration / commercialization stage [4]. For the WIR! showcase region Mittweida the statement we see describing us as best: “initiatives already moved beyond discovery, are fully immersed in incubation”. The main consequence is that with such decentralized approaches a complex way of managing and processing within governance becomes a critical success factor, so that we consider selected questions raised by [5]:

How is accountability determined and how is identity engrained in Blockchain economy?

How are disputed transactions resolved and how is then trust affected in the Blockchain economy?

What is the role of institutions in this economy?

Our practical solutions by prototyping are additionally under the scope of usability to ensure market readiness and maximized business values for the ECHT! project partners as well as be a lead example for the whole WIR! showcase region Mittweida. To govern the complex development of our minimal viable product we adapt aspects from Zavolokina et al. specifically “activities concerned with designing the system itself and identifying its business value for consortium members” [6] by permissioned BT to tackle governance tensions as trade-offs namely design openness versus competitiveness and hierarchical effectiveness versus democratic efficiency.

To consider the right decisions of the mentioned trade-offs we ultimately needed to evaluate BT impacts on a task level: “Routine tasks are explicit and codifiable. They include the calculations involved in bookkeeping; the retrieving, sorting, and storing of structured information in association with clerical work; and the precise execution of repetitive physical operations in a stable environment.” [7]. Whereby we define our use case of Certificates created in public education. The next crucial topic we considered is the General Data Protection Regulation (GDPR) in Europe. Rieger et al. proposed three potential approaches: “central authority, pseudonymization and shared responsibility.” [8]. Furthermore, current problems of centralized regulatory are found in data lineage “caused by data aggregations that occur at increasing distances from the source continue to grow.” [9]. Regulatory is helping us furthermore to understand consumer views of information privacy and future research in position to GDPR [10].

The cited chances and already demonstrated success in academic publications with BT make us strongly agree on what Altketbi et al. wrote: "huge potential in the use of Blockchain for government services since it can deliver government services in a cheaper, distributed and voluntary way." [11]. For our practical instantiation we supplementary tackle the recent question: "How to increase interoperability of existing information systems?" [12] and see this as central technical development research gap.

To answer this motivated situation this paper builds first the Fundamentals of BT and Trust. Followed by explaining the research approach using Literature review as foundation for agile prototyping. Final Insights of our prototype design represents the main findings and are rounded up in the last chapter as conclusion.

2. Fundamentals

For better understanding of the scope of Blockchain-based applications this section is structured in two parts first a more technical description and the second part with frameworks to describe social-economic relations.

2.1. Technology behind Blockchain

BT can be described as a distributed database build up by interconnected Transactions (Tx) that are protected by cryptographic private and public key mechanisms which can be seen as digital signatures. The distribution can be realized over a peer-to-peer network whereby participants act via nodes to ensure consensus about status of the data at a certain time. Nodes can have a full copy of the distributed database or depend on another node by lightweight blockchain data. Tx are put together in blocks (data packages) which uses protocol-specific fields and a defined block header. For most BT the hash of the previous block, a timestamp, the Merkle root and additional Tx data is stored for the whole network to create a chain where the consensus is built in. The Merkel root represents a single hash of the included Tx with consideration of order and single data status. In other words, the Merkle root is the last hash value of the Merkle tree constructed from hashes of up to thousand Tx. So called hash or hashing stands for mathematical one-way functions that transform input data to a defined alphanumeric string depending on a standardized algorithm. Important is that the same input always hashes to the same value [13].

Over time these basic technical mechanisms got developed in very different ways and directions to solve problems in new application areas so that up to now a very wide and heterogenous variety of BT is created. According to Sanka et. al the following features, benefits and importance of BT include distributed/decentralized nature, data integrity and security, anonymity, transparency and traceability, cost saving, increased speed, efficiency, interoperability, verifiability and right to be forgotten [14]. These factors strongly depend on the chosen Blockchain type (public, private, consortium/federated) as well as the used technology. Casino et al. define the following property for BT with consensus mechanism, identity anonymity, protocol efficiency and consumption, immutability, ownership, management and transaction approval [15]. To choose the right BT Labazova et. al proposed a configuration process model with the attributes 1) Governance 2) properties and 3) deployment depending on the application area [16]. In short researchers and practitioners evoked a wide space of Blockchain-based applications for mass adaption.

2.2. Frameworks for Trust and Governance

Besides the technical part we see the success of applications only if they are user-centric (UC). Specifically for BT Fleischmann et al. differentiates between functional and emotional benefits which are brought together of the emerging codes of security with trust and states "shifting the research discussion from a predominantly technology-oriented design angle to a UC perspective, present research reminds researchers and practitioners alike that for the acceptance and sustainable success of blockchain applications, it is critical to develop the underlying technology against the backdrop of UC needs, as it is those UCs that finally decide on the success or failure of any application" [17]. User in the public deal with lack of Trust and reputation or incomplete information where central trusted party such as an insurance company, a central bank, or the government are the problem solver [18]. The conclusion for us is that the BT is not a standalone solution instead it is designed to support the whole Certificate process in public education meaning our work contributes to the digital transformation of government starting by finishing a single module exam up to reaching the final degree at a university. Treiblmaier et al. mention for this transformation already BT for digital identity as the unique identity assigned to an individual under a particular digital identity scheme, typically a government-backed scheme [19]. We see BT as enabler for collaborative governance, which is stated as "the processes and structures of public policy decision making and management that engage people constructively across the boundaries of public agencies, levels of government, and/or the public, private and civic spheres in order to carry out a public purpose that could not otherwise be accomplished" [20]. If collaboration with Trust is enabled we expect that "Firms can gain many benefits from inter-firm cooperation, such as activities with a broader scale and scope, shared costs and risks, improved ability to deal with complexity, enhanced learning effects that lead to improved returns on research and development (R&D) investments, and enhanced flexibility and efficiencies and a shorter time to market" [21].

In Summery digital Certificates in public education play a major role for Trust and Security in Governments. Requirements for public sector are generally described by

the Confidentiality-Integrity-Accessibility (CIA) triad [22] which can be fully applied on our proposed prototype.

3. Research Approach

The hermeneutic framework for literature review by Boell et al is used in this paper. Whereby the following two circles could be fulfilled – (1) search and acquisition, (2) analysis and interpretation [23] to guide the artefact creation by deriving knowledge from existing prototypes within applied sciences. Circle (1) included grouping by a Process- and System-view since we wanted to differentiate between more practical and theoretical work. In (2) we categorized the paper content by Assets, Conditions and Capabilities to find easier decision making for our own prototype. The full summary is given in Table 1. Literature was gathered by the following keyword combinations: "blockchain-based certificate" + "application" and "blockchain-based application" + "education" with a careful forward and backward examination in four bibliographic databases: Google Scholar, Scopus, IEEE Xplore and AIS Library.

We used agile software development for instantiation included evaluation by feedback of stakeholders from the current certification process. This way we tried to maximize research output and keep the project work efficient driven as well as follow an approach to contribute to the knowledge base in the emerging field of BT.

Ref.	Process-view (Use Case)			System-view (Architecture)			Month Year
	Asset	**Condition**	**Capability**	**Asset**	**Condition**	**Capability**	
[24]	issuer, recipient, verifier and blockchain in between	enable cross-university student records and achievements	request for BT Tx a/o verification of Tx	EduCTX platform, 2-2 multisig addresses	DPOS (delegated proof of stake) consensus in permissioned Ethereum	ECTX tokens as equivalent for ECTS, issuing and revoking Certificates	Jun-21
[25]	issuers, recipient, consumers	online environment as an alternative for paper-based certificates	give a/o maintain a/o tracking of academic transcripts	QR-code	hash values for certificate stored on-chain with proof of work consensus	generation tamper-proof record	Apr-21
[26]	university, accreditation body, employer	user input of encryption and private key needed	responsibilities verify a/o creating a/o signing a/o issuing a/o revoking	verification app, university and accrediting interface	Truffle suite of Ethereum in testnet Rinkeby	automation and immutability	Apr-21
[27]	client, provider, authority and auditor	eHealth composite service	continuous monitoring and coordinated activities	Ethereum with evidence generation and workflow coordination	public cloud interface for blockchain	authentication, management, storage of Certificates for services	Nov-20
[28]	recipient, owner, authorities	gateway with defined policy	register personal data, grant a/o revoke access, access a/o verify a/o delete data, request logs	hybrid model with off-chain data and linked tokens	GDPR compliance of data (content)	control and audit network with untransparent (private) transactions	Oct-20
[29]	creator, verifier, content, user	controllable reward for intellectual property, unique password and documents with keys	issuing a/o access a/o authenticate a/o verification records	Ethereum Blockchain	remove intermediaries, obtain transparency, immutable information	Navigator Web3.JS with metamask and React including Truffle and Ganache	Oct-20
[30]	admin, owner, user	digital Certificates if paper-based document gets lost	request for secret a/o file download, view a/o control request and files	Name, Course, Date of Issue, Institution, Document Hash, IPFS	Hyperledger fabric with JSON-files in IPFS via URL	user and access management	Sep-20
[31]	issuer, owner, verifier technical system	review of existing blockchain-based solutions	assign a/o verify user, crossmatch data and de-encryption with on-chain hash	Hyperledger Fabric storage and identification framework	previously Certificate solution is open to vulnerability and data security is inadequate	verification in the blockchain are authentication, authorization, privacy, confidentiality, ownership	Jul-20
[32]	certificate authority, MSChain user	secure transparent Certificates	issuance, querying and revocation	wrapper to server layer	Hyperledger Fabric Blockchain network	microservices	Jul-20

Ref.	Process-view (Use Case)			System-view (Architecture)			Month Year
	Asset	**Condition**	**Capability**	**Asset**	**Condition**	**Capability**	
[33]	employe(e)rs and trust (as third party)	online survey and semi-structured interviews	authenticate and record Certificates	specify nothing more	specify nothing more	digitalization of key learning activities / achievements	Jul-20
[34]	Issuer (students), verifier (employers) and institutions	Education sector in India	store a/o request a/o view Certificates	Ethereum blockchain in Securecert platform	hash values for Certificate stored on-chain	smart contract with IPFS connection	Jul-20
[35]	Institution, registrar, employer	storing of digital Certificates	verification and validation	Three interfaces and Blockchain	chaotic algorithm for hashing	specify nothing more	Jul-20
[36]	certification authority and issuer	agencies with database	management, issuing, verification and revocation	Certificate template and receiver	smart contracts (Ethereum)	Web3.JS compatibility	Jun-20
[37]	specify nothing more	design needs to be close to R3 Corda Blockchain	specify nothing more	agents and DAG Tx tree as communication layer	pointer with hash value in the block description to constructed Tx	only every participant grows and maintains their own chain of Tx	Jun-20
[38]	education dept. with teacher and student, Certificate authority	Vietnam education system	writing a/o finding of Certificates	Hyperledger on public cloud infrastructure with off-chain 2-layer architecture	testing a/o evaluating platform and performance and operations measurement	input a/o write a/o validate a/o seal	Mar-20
[39]	issuer, recipient, credential issuer a/o verification and 3rd party	Thailand education system	match making for credentials controlled by owner	data models build in Merkel trees	Blockcerts infrastructure	manifest and credential files for privacy granted verification	Dec-19
[40]	university, student, employer, Certificate, observer and accreditation body	Pakistan education system	issue a/o share a/o verify a/o revoke Certificates and single records	Cerberus PoA (proof of authority) implementation of Ethereum	data models build in Merkel Trees	Parity and JSON compatibility with batch processing	Dec-19
[41]	user group students, teachers, academic staff, external	data aggregation in Minister of Education and Research	creation, verification a/o simulation, ordering a/o endorsement, adding by Blockchain Tx	application layer (each user group app), virtual state machine / data / network layer	smart contracts as bridge for Apps and Ledger entries	data models with dlock, Tx, Blockchain with world state for academic record and Certificate	Nov-19
[42]	issuer, recipient, verifier and Blockchain in between	Compliance with the EU eIDAS regulation	signing a/o check of validity of Certification authentication	Ethereum implementation	Blockcerts with open badges standard	Additional format validation	Oct-19
[43]	student, coordinator	scalable exchange of academic records in different formats between academic institutions	automated reliable request, upload, transfer and validate records	web browser based front-end and Hyperledger Middleware-Backend	accuracy and integrity not checked of academic records and no payment system	access control, Transcript request a/o process, Validation	Jun-19
[44]	review of existing blockchain-based solutions	Slovenia education system	record keeping a/o sharing	EduCTX platform	student-centric or institution-centric design	central Platform to combine investigated project solutions	May-19
[45]	student, institution, ledger, organization and validating entity	3rd party portal to validate certificates	validation request with institution private key signing of Certificate hashes	WAMP Server as bridge for PHP, HTML front-end and mySQL, Blockchain back-end	Multi-sig for every user authentication	combined structure to alter Certificates	Mar-19
[46]	student, coordinator	register a/o initiate a/o validate transaction, get a/o operate information, create certificate	decentralized distribution	web browser-based front-end and Hyperledger backend	separate configuration and operation components	selective visibility of Educational records	Mar-19

Ref.	Process-view (Use Case)			System-view (Architecture)			Month Year
	Asset	Condition	Capability	Asset	Condition	Capability	
[47]	examination of Blockchain initiatives	Blockchain used in eGoverment	adoption brings openness and transparency for services	specify nothing more	specify nothing more	specify nothing more	Jan-19
[48]	user, data purchaser a/o validators	GDPR compliance	service provider for "handling" data with monetization	platform	smart contracts, access and identity Blockchain	view a/o verify a/o governing datasets	Jan-19
[49]	issuer, Certificate authority	digital signatures on documents	create, use and check certificates	smart contracts	Pyethereum (Python Ethereum implementation)	gen-keys, issue, get-cert, sign, check-sig, revoke-cert	Oct-18
[50]	institution, registrar, employer	aim to further extend solution with medical recording system	register and populate student cohort, issuing a/o verify certificates	off-chain storage system and blockchain smart contract structure (holders a/o Certificate ID)	scalability not solved	database json export and Blockchain as bridge for interface	Jul-18
[51]	school, student, company with electronic Certificate system and Blockchain	QR-code and certificate serial number	mobile app and direct print on Paper-based certificates	Ethereum with smart contract interactions	service provider for maintaining blockchain system	Certification unit w/o generation, logout, query and student or company w/o inquiry	Apr-18
[52]	external companies, institution and educational organizations	ECTS harmonization within Europe and equal verification of Certificates			INFURA Ethereum node including solidity smart contracts	multi-step signing process scheme	Jan-18

Table 1: Overview of references (ordered by Month-Year) for Blockchain-based Certificates in public education.

4. Final design disclosure

The first (core) layer of our design is the Certificate as an object itself. It can be digital, analogue and is bound to one single person handed out from an institution at a fixed date to represent entirely accountability. This issued Certificates as objects are for students or attendants of seminars and lectures from public education of one certified institution. This unique relationship (object <-> person <-> institution) builds a trust anker as single identities from an offline network which can be verified as combination online by users with inbuild electronic hashes of documents and signatures. With this definition we are close to the new age of digital twins enhanced by BT [53].

Verification of objects include the proof attributes: authenticity, immutability and ownership. Different situations verify selectively on those attributes e.g., if the object is lost a re-creation process for all three attributes needs to be done. In case of job applications only authentic prove is needed. This business logics are programmed in the second (application) layer with user interfaces (human person interacts with data) and machine interfaces (automatic algorithms processing data). This logic space is in continuous growth to be able to solve disputed Tx by being under the overarching Governance of all users.

Our prototype is using a combination of Java and RESTful APIs within the HSMW network and a separate sandbox IT-infrastructure with docker to allow cloud-compatibility and have increased platform flexibility. The implemented system components are called modules which can interact via different communication protocols. Main driver for us is the https protocol with TLS encryption. Functions and actions from modules are declared as capabilities. The third (Trust) layer is based on a USB card reader device in combination with unique signature card to comply with the EU eIDAS regulation. This way the trust anker is built by qualified electronic signature stored directly on the digital Certificates e.g., as PDF files. The BT is placed as the overarching interface for public connection and outside networks (see Figure 1). The used BT for our prototype was in the beginning a cloud-based Hyperledger Fabric and shifted to a permissioned Ethereum-hybrid environment to get more user and first public institutions on board.

Following the definition of trust ankers a characterization between assets and conditions describes the functionality of Trust for granted valid or faked certificates. The data model for BT interaction is a simple JSON object with strings of electronic hashes. In detail it is a SHA256 hash for the PDF file itself and additional hash of three variable data fields e.g., last name, birthday and student ID plus a random generate string as pointer used in the verification process of the Certificate itself.

5. Conclusion and Outlook

From the last four years more than thirty peer-reviewed publications about Blockchain-based applications for Certificates in public education could be found and analyzed. A trend towards one single BT could not be found.

Conditions (Trust and Security) and capabilities (create/revoke and verify Certificates) are following the same problem space only the used assets vary in on- and off-chain solutions for data storage. We tried to use high citied and top ranked references but might missed more insightful ones. This lack of practitioners we covered by our own prototyping and development experience during creation of the shown design disclosure. BT singled out and endorsed as an interface for Trust in public open networks but strongly needs additional technology like the underlying USB reader device to manifest real-life states to digital objects.

Further research can follow on one hand the theoretical construction and modelling as well as comparing of our proposed work to existing solutions or on the other hand a practical testing how compatible our conceptual design is to include other innovative technology for digital Certificates.

Our prototype itself is going in continues development by two-week sprints parallel to a GO-live state.

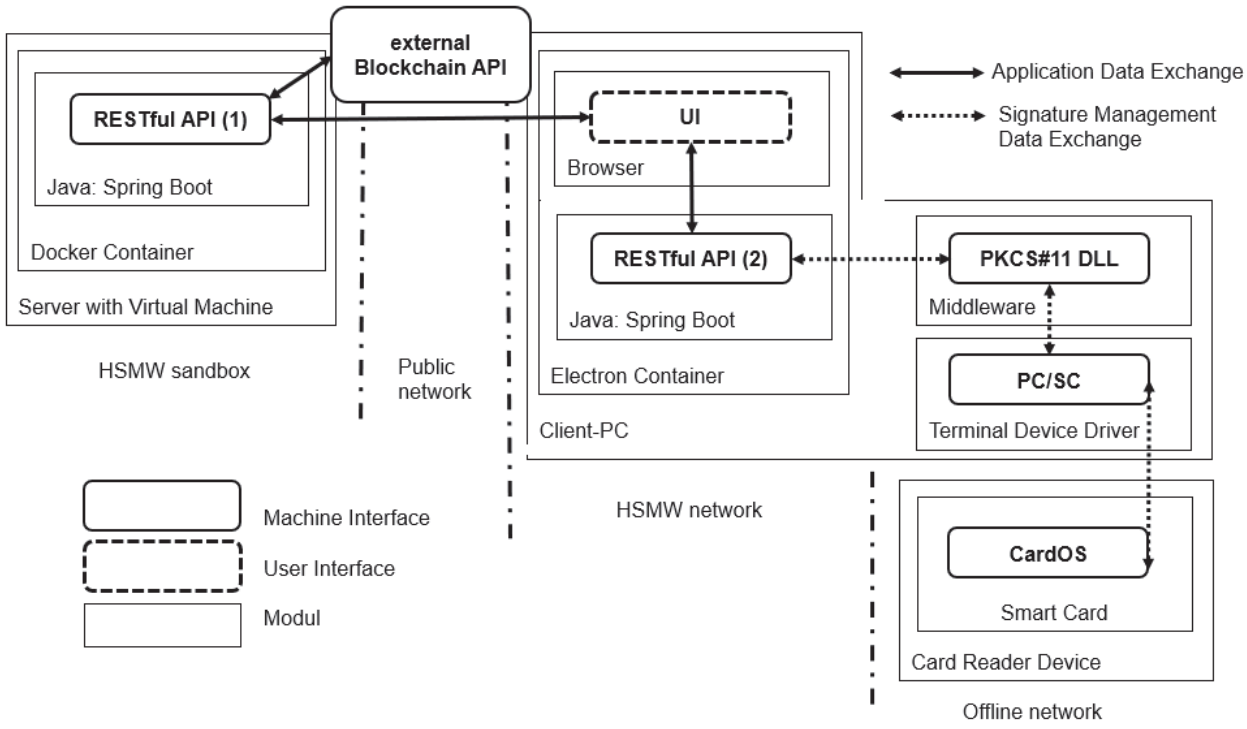

Figure 1: Design disclosure of our prototype with external USB card reader, HSMW sandbox and a secured software client including web User Interface (UI) for Microsoft Windows environment - arrows show communication routes.

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