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Cultural heritage preservation by using blockchain technologies

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Abstract

Ubiquitous digitization enables promising options for cultural heritage preservation. Therefore, a new approach is presented that considers deployment scenarios by linking heritage science to tourism. Such an approach is necessary because neither technology nor society views can be treated separately to obtain deployable solutions of a wider social, and even national importance. Clearly, while the traditional approaches to cultural heritage preservation will remain a gold standard, they will be increasingly complemented by digital preservation techniques. Thus, based on practical implementations and lessons learnt in other areas, this multidisciplinary framework paper analyses existing disruptive information technologies deployments. In line with the findings it presents a novel technological architecture tailored to the needs of cultural heritage preservation that deploys an open blockchain architecture. The architecture preserves the advantages of traditional blockchains, which made this technology so important, while enabling energy efficient implementations that can be deployed in mobile applications. By additionally using the contributionware principle it links it to tourism, where the identification of users focused incentives and business models play a central role. It is obvious that tourism is a good candidate in such preservation efforts due to the organic links between it and cultural heritage and can support further developments in the heritage preservation domain.

Keywords: Cultural heritage, Preservation, Digitization, Blockchain, Business models

Introduction

About twenty years ago the Internet technologies started to spread in the business world. This was the beginning of digital transformation processes (or e-business era), which initially affected non-tangible segments ranging from office automation to e-commerce, including tourism [1]. In recent years, the mentioned processes started to affect also traditional industry, resulting in Industry 4.0. The main disruptive technologies, driving these transformations, are blockchains, quantum computing, augmented analytics and artificial intelligence (AI).[1] Due to the technological advancements, some disruptive technologies are being replaced by newer ones, but currently virtual and augmented reality, the Internet of Things (IoT), and cloud computing can also be considered disruptive technologies.

The above changes are now affecting, with some delay, societies on wider scale—including cultural heritage. One lesson learnt already in the nineties of the former century is that information technology (IT) is no longer an afterthought. It is something that should be understood and considered from scratch, because it is affecting business and public services sectors even at the strategic level. Another lesson learnt comes from the recent disruptive technologies deployments in other industries, where it became clear that blockchains in particular have to be backed up by appropriate business models. One such model has been developed for tourism and is presented in this research paper. Clearly, cultural heritage and its preservation are often naturally linked to tourism.

This study thus identifies strategic focal points based on anticipated developments in the field of cultural heritage preservation with links to tourism. It builds on

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[1] https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019.

lessons learnt with the experiences of using disruptive technologies in cultural heritage projects, and other sectors. As the cultural heritage sector is yet to be notably affected, the paper provides new solutions linked by a management pillar that consists of a ledger layer, a consensus layer and an incentives layer. The resulting paradigmatic approach starts with a novel blockchain architecture and a new consensus layer where users exchange their mobile phones computing resources for digital tokens. At the incentives layer, these two layers enable new business models. Regarding the reasons for using blockchain as a technological foundation, these are rather straightforward. Ideally, cultural heritage should be preserved as created for as long as possible, and blockchains are perfect for this purpose. They are distributed over the Internet, being resistant to particular computers' failures and many malicious users' attacks. They preserve the integrity of the contained materials through cryptography and consensus procedures among the participating nodes, which is crucial to ensuring that cultural artefacts remain as they are, immutable. Furthermore, this kind of ledgers remains widely accessible to the public, with all the relevant additional data (such as name, author, location, etc.). Consequently, this openness increases trust in the system, its security, transparency, and enables good traceability of the data.

The methodology used

The presented research is methodologically grounded in three areas:

- The blockchain related part rests on theoretical computing and cryptography.
- The complete IT solution rests on design science. The objective of design science is knowledge development that the professionals of particular discipline can use for designing solutions to solve their problems [2]. In specific case of IT, the following tenets are at the core of design science research [3]: A technological solution has to be relevant to a business problem (problem relevance). This is a starting point for a construction of appropriate model, method, or an instantiation of a technological solution (artefact design). The latter step depends on searching an effective solution that utilizes available means by considering laws of the problem domain (design as a search process). The quality, utility or efficacy of the developed solution has to be based on rigorous design and evaluation (research rigor and design evaluation), while clearly stating verifiable contributions (research contributions). Finally, these contributions need to be effectively presented to technology and management audiences (communication of research).
- The applications scenario in management domain rests on business models development methodology.

The structure of the paper

The paper is structured as follows. An analysis of the field is given in the second section. The necessary background of the deployed disruptive technologies is given in the third section to enable the derivation of the needed new solutions in the fourth section, where these solutions are put in a wider social context. The results are elaborated in the fifth section, while the conclusions are given in the sixth section. They are followed by acknowledgements and rounded by references.

An analysis of the field

Authoritative organizations such as ICOMOS and UNESCO have significantly extended the traditional definitions of cultural heritage in recent years. These now include not only historical-artistic artefacts, but also their environments, which is referred to as cultural landscape [4]. In addition, attention is paid to non-tangible elements, so that cultural landscapes include also literature, poetry, myths, folklore, historical events, and traditions [5].

During these years, digitization became ubiquitous in the field of cultural heritage. It started with digital photogrammetry and laser scanning that represented a remarkable advance in documenting the cultural heritage status [6]. These initial efforts became more sophisticated with the deployment of the Internet of Things (IoT) and artificial intelligence (AI) to enable better monitoring of cultural heritage in-situ conditions in hard to access, remote or unsafe locations [7]. Such basic kinds of IT deployments soon led to adding value for consumers of cultural heritage in more innovative ways, such as using virtual reality to enhance museums experiences [8], or sensation seeking by utilizing augmented reality [9].

To justify the relevance of the contributions of this article, it is important to consider some key facts from the IT domain. First, 45% of the world's population owns a smart phone [10]. In the top-ten developed countries this percentage is over 73% [10]. Further, the Internet is now used by almost 60% of the world's population, while in the US and Europe it is almost 90% [11]. Even in less developed countries such as Tanzania (GDP per capita in 2018 was approx. 1,050 US$ [12]), which has considerable cultural heritage (e.g., seven UNESCO World Heritage Sites), the mobile phone subscriber percentage is approx. 80% [13], and already in 2018 82% of this population had access to the Internet via mobile phones [14].

Second, the average smart-phone replacement time in the US is less than 3 years [15], so a model like Galaxy S9 is a relevant representative nowadays in the developed world. This model has eight cores in its CPU, which can run at ~ 3 GHz, it has a powerful graphical processing unit, at least 3.5 GB RAM, and its permanent storage capacity easily exceeds 50 GB. Although mobile phones are architecturally different from desktop and laptop computers, the differences are getting smaller. No wonder—mobile phones can even be used for Bitcoin mining with applications such as MinerGate (albeit without profitability), while certain digital currencies are specifically aimed at mobile phones such as Monero.

Third, the IoT will be soon the dominant contributor to the global big data pool—these devices are expected to exceed 14 billion by 2022 [16]. They will outnumber other devices like desktops, laptops, and smart phones. The IoT comprises interconnected, uniquely identifiable devices that communicate with each other, ranging from sensors to electronically driven mechanical devices like actuators [17]. However, this diverse population of devices typically lacks computational resources.

Fourth, blockchains are becoming the norm. They are already implemented in many sectors ranging from state administration [18] to healthcare and industry, including companies such as Renault and IBM [19]. In addition, there are many specific deployments ranging from intellectual property management [20] to smart contracts [21]. It is clear that, although still at the early stages of their development, blockchains are already penetrating all kinds of businesses [22].

Fifth, AI and big data penetration is ubiquitous, from online services to cars and household assistants. These twins go hand in hand—the more data there is, the better AI solutions are. Also, in core cultural activities AI is playing an increasingly important role: “AI can help to empower numerous creators, make the cultural industries more efficient and increase the number of artworks, which is in the interest of the public” [23].

These facts will now be placed in an appropriate context of cultural heritage management linked to tourism. Interestingly, there is still a lot of room for disruptive technologies deployments in this area [24].

Understanding disruptive technologies

The design and evaluation of the developed artefacts in this paper requires familiarity with IT basics. To make this paper readable to the intended multidisciplinary audience, the theory behind disruptive technologies is given informally first.

Cryptography and blockchain technologies

The core element of blockchain technology are strong one-way hash functions, OHFs (for their detailed formal treatment the reader is advised to look at [25]). OHFs can be viewed as functions that take any kind of a digital input, e.g., a photo, a video, a 3D model of a sculpture, and produce an output that uniquely identifies the input. This output represents a digital fingerprint of the input file:

- Finding an output (fingerprint) based on the input is fast and computationally undemanding, while finding an input knowing only the output is practically impossible.
- The input can be practically of any length, while the output has a fixed length, nowadays usually 256 bits.
- Although the same input always produces the same output, one cannot know in advance what the output value will be if one only knows the input. Put another way, when submitting an input to OHF for the first time, all outputs are equally likely.

Another core element is public-key cryptography, PKC. In this type of cryptography, a user has a private key and the corresponding public key. The first is kept secret, while the second is publicly available. When a file is encrypted with a public key, only the owner of the private key can decrypt it—so anyone can send a confidential message to the owner of the private key. However, if a file is encrypted with a private key, anyone can decrypt it with the public key. This way, everyone knows that the file comes from the owner of the corresponding private key, and that it is unchanged (if it decrypts properly). This last option provides the functionality of a digital signature. The most common type of asymmetric cryptography in blockchains is elliptic curve cryptography (ECC). As the name suggests, the applied algebraic structures are based on elliptic curves. ECC enables more efficient applications compared to a widespread RSA (Rivest-Shamir-Adleman) algorithm, since an order of magnitude shorter key is needed to achieve comparable cryptographic strength (a detailed treatment can be found in [25]).

These two core elements are sufficient to introduce blockchain, which is shown in Fig. 1.

To understand how the block-chain operates, the Bitcoin scenario will be explained, since its architecture is central to the majority of recent ledger implementations (the reader should pay attention to the structure in Fig. 1, which essentially consists of transaction/hash trees that are linked to a sequence of cryptographically coupled blocks). When a new block is created using the latest transactions, and before it is added to the existing blockchain, the nodes of a peer-to-peer network try to

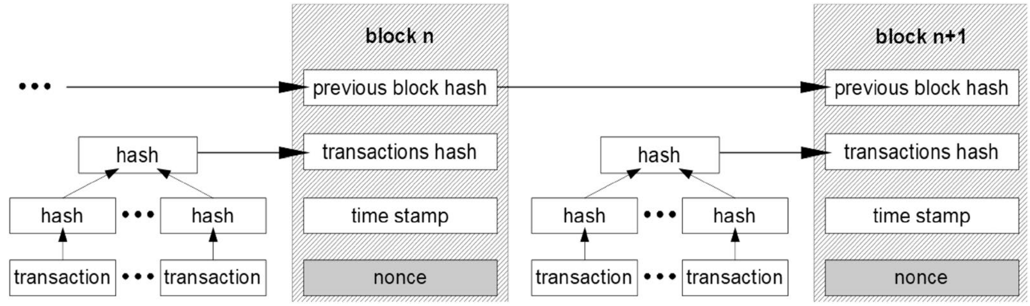

Fig. 1 Blockchain building blocks and its architecture

find such a value (a nonce) for the block that will result in a certain number of leading zeros when the block is hashed. Once a node finds such a nonce, the candidate block along with the nonce is sent to the entire peer-to-peer network for verification. If correct, this new block becomes a part of the blockchain, while its link to the existing blockchain is ensured by including the hash of the formerly last legitimate block (see Fig. 1). In addition, the node that found the correct nonce is rewarded with Bitcoins. Once rewarded, the owner can spend its Bitcoins via transactions, where a transaction means that the owner digitally signs a transfer of a certain number of Bitcoins to another owner (e.g., in exchange for receiving a product or hard currency).

Quantum computing and blockchain technologies

As the developed solution takes into account the expected advancements in the field of computing, the quantum computing basics are given in this subsection.

The quantum world consists of (subatomic) particles that have specific properties, which can be used to build more effective computing devices than the ones we currently use (and which are made with semiconductors). While a cell in a classical computer register, where a bit is stored, has only two possible values, a register cell containing a quantum particle (representing a qubit) can take not only two possible values, but also all their possible linear combinations (superpositions). Thus, if a conventional register has n cells, only one particular n-bit value can be processed at a time. If there are n cells in a quantum computer register, with each cell in a superposition of two states, then that computer can process 2^n different values simultaneously. This is a great advantage, but not for every kind of problem.

Unfortunately, this is the case with the most widely used asymmetric cryptographic algorithms, RSA and ECC. For example, the strength of RSA is based on the premise that factoring composite numbers that are products of large primes, is computationally hard. But this holds true if parallelism is not possible, which is a native property of quantum computers, and for which there exists an appropriate algorithm. ECC systems are even more vulnerable than RSA [26].

To the best of our knowledge there is no blockchain that addresses this problem by incorporating suitable, quantum computer resistant solutions from scratch into its architecture. One rare research involving Merkle signature scheme can be found in [27], but this is only used for IoT devices authentication in e-health applications when the data is transmitted over the network to be written into a ledger.

Last but not least, for mass deployment, the developed architecture should be such that it can be effectively executed on mobile phones, which have rather limited computational resources and energy. For this reason, performing traditional core operations on smartphones for "mining" is almost non-existent.

The important points discussed so far are elaborated in more detail in the next subsection.

Countering the weaknesses of the mainstream blockchain technologies

For mainstream ledger technologies such as those mentioned above the following drawbacks can be identified. Starting with the Bitcoin blockchain, its size is becoming a concern—as of November 2021, it was approaching was approaching 380 GB [28]. The growth rate of its size, which is rather constant, is about 7 GB per month. Due to its size, the communication costs are growing accordingly (to keep the blockchain in a distributed, synchronized and sufficiently redundant form). Further, the basic proof of work (PoW) principle is energetically unsustainable—the global energy consumption for Bitcoin (mining) exceeds the needs of some developed economies such as Switzerland [29]. Further, public key cryptography based on elliptic curves is still quite demanding in terms of computational resources, while being exposed to quantum computing advances. Finally, the current incentives to keep ledgers operational are rather rudimentary—direct payment (monetary reward) in return for the efforts expended, while this monetary reward is highly volatile.

As to the public key cryptography, there exists a digital signature scheme that is based solely on OHFs. It was developed by Lamport (and extended by Merkle) in the seventies of the former century [30]. Since it is based solely on OHFs it is computationally less demanding, but the drawback is that the keys can be used only once. The principle behind this scheme is as follows. Suppose we want to sign a file *F* that is 160 bits long, and we have an OHF like SHA-1 [31] that produces 160 b long outputs:

1. First a signer generates a secret key *sk*, which consists of two sequences of 160 b long random outputs:

$$sk_0 = sk_{0,1}, sk_{0,2}, \ldots, sk_{0,160}$$

$$sk_1 = sk_{1,1}, sk_{1,2}, \ldots, sk_{1,160}$$

2. In the next step the signer generates the corresponding public key *pk*, which also consists of two sequences of 160 b long outputs, obtained by applying a hash function *H* to the secret key. These sequences are publicly available as they represent the signer's public key:

$$pk_0 = H(sk_{0,1}), H\left(sk_{0,2}\right), \ldots, H\left(sk_{0,160}\right)$$

$$pk_1 = H\left(sk_{1,1}\right), H\left(sk_{1,2}\right), \ldots, H\left(sk_{1,160}\right)$$

3. To sign a file *F*, the signer first hashes it, and looks at the *i*-th bit in the hash—if this bit equals 0, the signature value is $sk_{0,i}$, otherwise it is $sk_{1,i}$.
4. When a verifier checks the signature, (s)he hashes the *i*-th position in the hash of *F*. If this position in the message equals 0, the check is made with $H(sk_{0,i})$ (if its value is $pk_{0,i}$); for value 1 at the *i*-th position, $pk_{0,i}$ is compared with $H(sk_{1,i})$.

The details given in this section are essential for better understanding of the contributions of the whole solution, which will be elaborated further in the rest of the paper.

New solutions for blockchain based cultural heritage preservation

Lessons learnt so far (including the success of Bitcoin) tell us that for a ledger technology to be successfully applied in real environments, the wider social context has to be taken into account.

Cultural heritage and tourism can be considered organic twins, since tourism is highly dependent on culture, current and past. This section therefore identifies anticipated courses of developments in the aforementioned field, and the appropriate management strategies (strategic foci) with regard to these developments. To do this in a reasoned manner, links are first made to the latest developments related to cultural heritage and tourism in relation to IT.

The most common use of recent information and communication technologies is based on multimedia. In [32] the authors present a framework that supports a photorealistic superimposition of virtual objects onto virtualized real scenes by deploying spherical aerial images. More precisely, the framework utilizes image-based rendering that allows users to change their viewpoint in a real-world virtualization.

Similarly [33] presents a multimedia approach to the dissemination, communication, and exploitation of cultural heritage that enhances the way culture is experienced. Virtual reality plays a central role, but is complemented by its relatives, augmented and mixed reality.

Another research focused on IT to enhance the experience at historical sites can be found in [34], where virtual reality technology is used in tourism and archeology for virtual reconstructions that go beyond the traditional visualization of 3D architectural models. This is achieved by making these virtual environments feel like traveling back in time through responsive characters, enhanced interaction, and multisensory realism. Such an approach adds new dimensions to the user experience where gamification is just one step away. Indeed, a somewhat recent work addresses this dimension via subjunctivization of visitors' experience at cultural heritage locations [35]. This subjunctivization is about gamification approach using augmented reality. Such approaches in this field are particularly suitable for children and young people.

However, as early as in 2017, a research paper hinted at the change of course of the above developments, based almost entirely on multimedia [36]. Although the paper essentially presents a multimedia solution for an improved user experience at archeological sites, the solution already employs big data. The paper also mentions the growing importance of disruptive technologies, especially sensor networks (IoT). Another rare paper that mentions the growing importance of disruptive technologies for cultural heritage is [37]—in this case block-chains are mentioned.

Thus, the existing research mainly focuses on multimedia in the form of enhanced or mixed or virtual reality modalities, while other disruptive technologies are more or less briefly mentioned. Moreover, none of these papers considers their potential for heritage preservation.

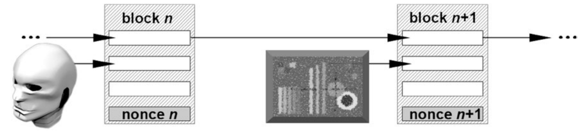

Fig. 2 Incorporating one natively digital (e.g., a 3D sculpture) and one digitized classical heritage object (e.g., a painting) into a blockchain via hashed links

Aligning technological and managerial elements

To further illustrate how block-chains can be deployed for cultural heritage (and its preservation) Fig. 2 is given. Based on the technological foundations presented so far it should be obvious that all transactions are, in the last instance, just bit strings. Digital or digitized artworks (or any other cultural heritage related artefacts like documentation) are sequences of bits as well. Therefore, they can all be embedded in a blockchain by deploying the same mechanisms as this is the case with ordinary transactions (payments) in existing applications like Bitcoin.

Moreover, a blockchain can be implemented to act as a virtual machine (a virtual machine is a piece of software or hardware that behaves like an ordinary computer towards an application, so that this application "thinks" it is running on some computer's operating system). In the case of such a blockchain (a typical example is Ethereum, www.ethereum.org) the embedded transactions can also contain programming code that leads to the so-called smart contracts. Smart contracts are automatically executed when certain conditions are met. So, they can be used for non-fungible tokens, NFTs, which are now revolutionizing the art domain. These types of "transactions" provide proofs of authenticity for digital artefacts, as well as the ability for a smart contract to be executed when a piece of fine art is sold by its current owner, and a certain percentage of the sale goes to the author of this artefact.

It is now possible to address further specificities related to cultural heritage.

Aligning technological and managerial elements

> *In order to achieve an appropriate positioning of the technological and managerial elements, two pillars are introduced in each domain, aligned accordingly (see Fig. 3):*

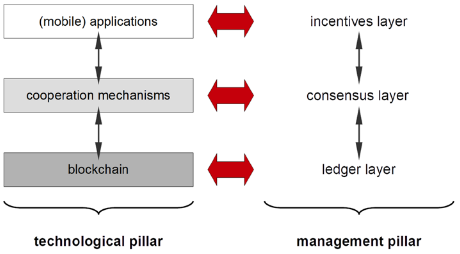

Fig. 3 Aligning the technological pillar with the management pillar

- At the core there are ledgers implemented as blockchains. They represent the central cultural repository and preservation mechanism for the future.
- Next comes the IoT, which is becoming the main contributor to bigdata, stored in ledgers.
- Big data, generated by the IoT and stored in ledgers, are intensively processed by AI applications.
- Based on big data, ledgers and AI, virtual and augmented technologies are deployed to develop new applications and services.
- Ledgers do not store core files; hence clouds are needed for their storage. Clouds also provide processing power for AI, and virtual and augmented technologies.

  Based on the anticipated scenarios, the layers (i.e., the strategic foci) of the management pillar are given below to precisely specify the design of the required artefacts.

Managing the ledger layer

The first improvement is that the core ledger in the proposed architecture is based solely on one-way hash functions, including signatures, where Lamport scheme is used. By doing so we reduce the processing requirements for asymmetric cryptography, while preserving resilience to attacks even with quantum computers. Further, although Lamport keys can be only used once, this is not a serious problem for heritage. As opposed to digital currency, where transactions are occurring one after another, digital heritage "transactions" are digital files that are burnt into the ledger "once and forever". Further, the complexity of the computations for adding new blocks (see the second section on hashing the latest transactions and a nonce) can be adjusted to mobile phones by reducing the number of leading zeroes that need to be found when mining a new block.

Further, transactions in traditional blockchains are small files usually containing two addresses and a digitally signed transfer of a certain amount of digital currency from one address to another. In the case of cultural heritage, these "transactions" will be large files (high resolution photos, 4K videos, large 3D vector files of scanned sculptures, etc.). Hence, the traditional approach, where a blockchain also stores the core transaction files, has to be modified.

Therefore, separating the core blockchain from the data it manages is necessary. Our architecture stores the core blocks (which consist of the hashes of the previous block, data tree top-level hashes, timestamps, and nonces) in a

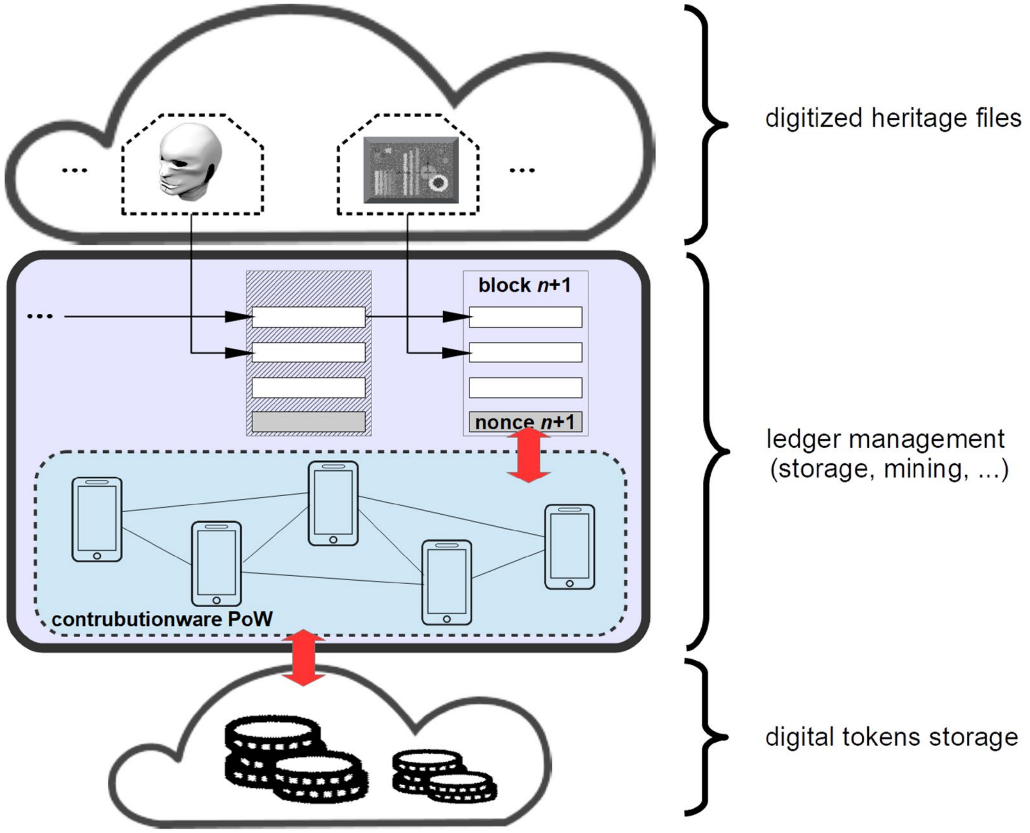

Fig. 4 The ledger layer and the consensus layer of a novel cultural heritage IT architecture (block $n + 1$ is being mined, while the previous block has already been mined and already provides integrity)

mobile phones-based peer-to-peer (P2P) network. The cultural heritage related (and digitally signed) files with their derived hash trees, however, are stored in a cloud (see Fig. 4). These trees are linked through the top-level hash nodes to the core blockchain. The core chain can be stored on a mobile phone-based network, as it is lightweight. Each block has only two hash values, one timestamp and one nonce, where 64 bytes for each of them, plus some overhead data, can be considered sufficient. On the other hand, each heritage data files tree can range from a few MB to a few GB. Therefore, a nationwide cultural heritage ledger could easily grow to TBs. Consequently, these trees need to be stored in a cloud.

Managing the consensus layer

Consensus protocols are central to maintaining ledger integrity in distributed environments where some nodes may be malicious, or communications failures may occur. To ensure that transactions are valid, there exist several protocols. The most important representatives are proof of work (PoW), proof of authority (PoA) and proof of stake (PoS).

The majority of blockchains uses the PoW principle. A node that finds the correct nonce has done a certain amount of work. Therefore, it is rewarded with Bitcoins, while its result helps maintaining transparency and integrity of all transactions involved. PoA and PoS are also potentially interesting. In the first case, a competent and trusted authority verifies all the transactions, and simply digitally signs a new block. PoS is a variant of the PoA approach, where the signing is done by an entity that has most interest in the correctness of the blockchain—in the case of digital currencies, this is the entity that owns the largest share of the digital currency in use.

Our architecture uses PoW for the following reasons. PoW is the most widely used blockchain consensus protocol. It is of a dynamic nature and its hardness can be adjusted for a particular environment. Reducing the required number of leading zeroes when hashing (i.e., mining) blocks, the computational difficulty is reduced as well. In this way, an optimum can be found between the value of a digitized heritage, and capabilities and motives of users that participate in the mining process with their mobile phones. PoA and PoS are less suitable.

PoA requires an authority to take care of a ledger, which imposes additional costs on cultural institutions that are under constant pressure to lower costs. PoS, on the other hand, is not suitable because there is usually not much at stake in cultural heritage blockchains. So, it is hard to find a reasonable interest for an identity to take on this role. This is where incentives come in.

Managing the incentives layer

For the proper management of disruptive technologies, user incentives must be considered accordingly. The motivation for PoW in traditional blockchains is simple—Bitcoins. But digital currencies related incentives are one thing, while digital cultural heritage ledger is another. Therefore, a different incentive is introduced, which is based on contributionware.

The concept behind contributionware software is that users can exchange their smart-phone computing resources for digital tokens. Based on the spent resources, a mobile application generates digital tokens, which in this case are not a part of the central blockchain. These tokens intentionally do not reflect the characteristics of a digital currency. Being a kind of bonus points they can be exchanged only once for cultural goods (such as catalogues) or services (such as museum passes). Further, risk analysis given in the next subsection shows that the generation of these tokens can be left completely to mobile phones, based on their computational input, and stored in a cloud database. One appropriate application programming interface (API) for this purpose is offered by IBM.[2]

Next, the contributionware incentive is put into the business perspective via a business model, which is about how an organization creates, captures, and delivers value to customers [38]. This is achieved through the nine building blocks: customer segments, value proposition, key activities, key resources, channels, customer relationships, key partnerships, cost structure, and revenue streams.

Typical participating organizations in the cultural heritage sector are non-profit private organizations, and public (community or state funded) organizations. For these organizations, the contributionware based business model with a focus on tourism is as follows:

- Customer segments: In addition to the usual segments, our approach reaches not only domestic, but also foreign tourists by deploying smart phones.
- Value proposition: Tourists become a part of a larger story, where they can contribute to something of greater significance, i.e., cultural heritage preservation. In addition, this approach is suitable for educating children and the younger generations. It also reduces the costs for specialized cultural heritage management organizations.
- Key activities: The identified activities comprise digital culture activities, which are extended through digitization processes of cultural heritage to keep pace with the general development trends in societies.
- Customers' relationships: Not only traditional customers, but also new groups, especially tourists, are increasingly involved in the above processes through digital tokens by exchanging something that is considered "free" (underutilized mobile phone capacity).
- Channels: Current digital culture and heritage preservation remains rather unaddressed via mobile applications that are becoming increasingly important in all areas of business and personal life.
- Key resources: These include computing resources in smartphones, a growing number of digital cultural products and services, digitized cultural heritage, and new APIs (free and paid) that can facilitate the development of new services and applications for the tourism sector.
- Key partnerships: It is straightforward to identify them, and these are key software outlets (such as Google play), tourism and heritage organizations, operators of other ledgers for horizontal and vertical integration (cross-ledger integration), and virtual or augmented reality services providers.
- Cost structure: This includes lower cultural heritage management, and lower marketing and human resources costs due to deployed disruptive technologies (for example, ledger costs and maintenance are outsourced to domestic and foreign tourists via mobile phone applications).
- Revenue streams: The primary stream comes from contributionware users, while related APIs can be made available (and charged) for new services (e.g., virtual reality). Moreover, operations can be optimized by using big data and AI. Last but not least, horizontal and vertical integration in tourism sector can be promoted for the benefit of customers.

Summing up, the key technological elements of the above business model are a blockchain architecture based solely on OHFs, blockchain separated from heritage artifacts files via clouds, and digital tokens separated from the blockchain, while mining is performed with a contributionware application—all in a computationally lightweight manner.

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[2] See https://www.ibm.com/cloud/learn/what-is-cloud-database. This interface enables a database service through a cloud platform, so traditional database is improved with the flexibility of cloud computing.

Discussion and evaluation

A more detailed evaluation of the presented solution starts with the implementation of the blockchain. From the cryptographic perspective, this blockchain uses only strong one-way hash functions, including digital signatures. While digital signatures based on asymmetric cryptography are computationally demanding, strong one-way hash functions are much less demanding. There exist even OHFs that are very lightweight and designed particularly for blockchains (examples include Spongnet and Photon implementations [39]). So, the required computing resources (and consequently energy consumption) are notably lowered.

Next, the size of the ledger grows much slower compared to the traditional blockchains. In principle, a heritage artifact will be incorporated in the blockchain only once, while in ordinary ledgers every artifact (like Bitcoin) will produce numerous (unlimited) number of transactions for all its possible values (denominations). In addition, the "heavy" part of the ledger, which is a digital or digitized heritage artifact, is stored in a cloud, so the rest of the blockchain that is stored on mobile phones, remains slim. Last but not least, the architecture is resistant to quantum computing.

As to the human resources optimization of the entire solution in relation to the business model—many of the needed (heritage preservation related) processes are outsourced at a low cost. In fact, this solution is another example of disruptive outsourcing [40], which is important for cultural heritage organizations that typically operate with very limited financial resources. In addition, considering the ubiquitous availability of mobile phones and increasing access to the Internet, the proposed model is also promising for less developed countries. The entire solution requires an easily accessible mobile application, and widely available cloud services.

Now a deeper analysis is still needed for incentives and risk management of the mobile application that these incentives are based upon. One pivotal part of the presented approach is the mobile application, i.e., the contributionware. Its basic purpose is to involve users in exchanging unutilized computing resources of their mobile phones for cultural heritage domain benefits. Nothing comes for free, but people are often willing to neglect this fact, especially when it comes to exchange their data for some service. Trading "free" computing resources for a service is psychologically similar to what has been used successfully in SETI@home project [41]. SETI@home was UC Berkeley based experiment searching for extra-terrestrial intelligence that was analyzing large amounts of telescope data. To make their analysis more efficient, a free application was offered for home desktops that was exploiting resources of these computers, which are usually underutilized, even when users are using them.

As to the mobile application risk analysis, it is tempting to assume that an entity could steal a tangible value by, e.g., falsifying tokens. First, to lower attackers' trade-offs, the amount of value mined in cultural heritage ledger (as opposed to Bitcoin) is low to moderate. The target value of tokens ranges from a few tens to one or two hundred Euro or US Dollars per user per year. Second, the tokens scheme is intentionally designed to resemble a bonus system rather than a digital currency. Third, the digital tokens are stored in a cloud database that is professionally managed. Fourth, if an attacker tries to tamper with an application, this is prevented by various means: Android phones security architecture is very comprehensive, and Google Play applies additional security measures to applications distributed there. So, it is no surprise that security issues with these applications are negligible (similar is true for iPhones).

As to the latest developments in this field, Russia is seriously considering the use of blockchains for heritage preservation,[3] while China has just implemented a testbed solution for the famous murals of the UNESCO World Heritage Mogao Caves.[4] This latest implementation is based on a private blockchain owned by the giant company Tencent. It does not use cryptography as is commonly the case in the rest of the blockchain world because of the recent Chinese government interventions. These ban blockchain operations that cannot be fully controlled by the government. But the proposed solution in this paper preserves all the properties that have made blockchains so attractive, it is an open platform with the right balance of cryptography, addressing energy issues, post-quantum computing issues, IoT readiness, and related important business issues inked to tourism. It is also worth adding that the presented solution is in line with the recent incentives to enable ubiquitous access to digital heritage [42] by providing digital infrastructures for cultural heritage [43].

Finally, it is worth to highlight the importance of the presented solution from a more arts and humanities perspective. With every kind of cultural heritage related activity its documentation has a high priority. Cultural heritage pieces are typically entered into national registers with all the necessary details that range from basic descriptive data to photos, recordings, etc. (this documentation depends on the nature of the heritage, which can be movable, immovable, or intangible). But lately a

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[3] https://beincrypto.com/russia-to-create-a-cultural-heritage-blockchain-register/.

[4] https://www.theblockcrypto.com/post/117245/tencent-nft-mogao-caves-crypto.

new trend has emerged in heritage field that is referred to as *documentary (archival) protection*. So, for example, according to the Slovene registry of cultural heritage, if a unit of cultural heritage»looses« its heritage properties and is not protected anymore in its original form (e.g., by being destroyed or left to decay), it remains thoroughly documented in the registry of cultural heritage—and this is what archival protection is about.[5] In such cases, the presented solution can well serve this purpose by providing an advanced ledger for such registers, not to mention the possibilities for storing perfect digital duplicates of the extinguishing artefacts (the so-called digital twins). And the archival protection approach is on the rise.

Conclusions

Digitization has entered all segments of our lives, including cultural heritage, where digital photogrammetry, digital 3D models, laser scanning and similar methods already belong to the traditional scientific tools of the trade. However, we are now witnessing the latest digitization wave, driven by disruptive technologies. And the impacts of these technologies in the cultural domain, especially on cultural heritage and its preservation, are mainly yet to be seen—not to mention the potentials of linking them to tourism.

In short, this paper presents a multidisciplinary approach to heritage science by linking heritage focused methodologies to tourism. By extending the methodological arsenal in the core cultural heritage domain, the developed solutions increase the awareness of the importance of cultural heritage preservation by engaging new targeted audiences, in particular tourists. Next, by outsourcing certain operations these solutions lead to optimized operations of the involved segments. Next, they provide a basis for horizontal and vertical integration in the mentioned segments, as well. Next, they are aligned with the incentives for increased involvement of disruptive technologies in tourism [40]. Next, the importance of disruptive technologies has been recognized in many sectors by initiatives like European Commission's EU Blockchain Observatory & Forum [44]—and cultural heritage should be no exception. Consequently, the presented research also aims at accelerating the developments in these important fields. By deploying design science, this paper provides an analysis of disruptive technologies based on existing applications. It anticipates the main development directions and introduces a new approach for culture and cultural heritage preservation. The approach is based on a pillar with technological, consensus and incentives layers, which is aligned with the blockchain technology as one of the main drivers in the background of the mentioned changes. The architecture is open, can run on mobile phones, is energy efficient by deploying appropriate balance of cryptography, while being even quantum computing resistant.

However, focusing solely on technology is not enough. Therefore, through its understanding, the paper provides disruptive technologies-based solution complemented with a managerial framework, applied to cultural heritage. The framework focuses on enabling and developing links to tourism, which so dependent on cultural heritage, and it addresses users' incentives and a business model. By doing so the road for blockchain based cultural heritage preservation is paved.

Finally, the presented solution also provides improvements to traditional approaches in arts and humanities like registers of cultural heritage, or archeological sites documentation. While understanding these improvements is more straightforward than the one described in the paper, these kinds of applications are by no means excluded. And the expected areas of application will likely exceed the mentioned ones—just like this was the case with Bitcoin. It has first entered the financial sector, but now its ledger technology is revolutionizing processes ranging from states' administration services to digital arts trading with NFTs.

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Authors' contributions
All the work from its conceptualization to the final results has been done by the stated author. The author read and approved the final manuscript.

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Availability of data and materials
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Declarations

Competing interests
There exist no competing interests.

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[5] https://www.gov.si/teme/register-kulturne-dediscine/.

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