Software Engineering

Bachelor's Thesis

Exploring the Use of Blockchain Oracles in Physical Art Installations

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Abstract

Blockchain is a word that has a wide media appearance currently, with various degrees of implications depending on the industry it evolves in. This current paper examines the possibilities of using the blockchain, a permanent database, within the context of a physical Art installation using data sensors as an analog to digital bridge. It evaluates the cost associated with the usage of this technology, from storage to development via the creation of prototypes to recreate a limited real life scenario. The involvement of artists via interviews is also a necessary step in this research, in order to find and define use cases and/or needs. It appears that the usage of blockchain technology in this particular case necessitates a careful planning and designing of resources. Costs can be prohibitive, depending on the scale and goals of the installation. Nonetheless there is a markant interest from the artists that desire to push the boundaries of this recent technological development.

Introduction

A blockchain is in its simplest form a digital ledger containing records of transactions. Blocks of transactions are added one after another on this ledger. These transactions contain various types of data: from the hash of the previous transaction to a timestamp and additional data. These blocks are immutable. Meaning that they cannot be changed further down the line. Although this could be considered a double-edged sword, it is a powerful feature in the sense that data will not be lost unless the blockchain is destroyed, leaving it accessible to future generations. Furthermore, once the data is "etched", it cannot be removed, so care needs to be taken to consider what kind of data is recorded, and how it is recorded.

Thus, combining this powerful characteristic with a physical Art installation can open up various possibilities. Using the conceptual basis of immutability and authenticity as a seed for installations, to future artwork generation or fund collection through cryptocurrency would be just a few examples of what can be done. Sensors can provide data that can be recorded on this digital ledger. The data being immutable allows us to come back to what happened during the existence of the installation. It is a point of truth verified by the mere conceptual basis of blockchain technology. Note that this truth is granted its existence by the code, but that this truth

can be a falsehood, wrong data or an error, the fact that it is immutable doesn't guarantee its truthfulness.

Creating a digital existence for the installation can allow it to live independently from the physical constraints involved in its creation. Even allowing a rebirth of the same (or modified) installation in either a digital or physical world, at a further point in time, in another location.

Due to the complexity of the subject, it is to be noted that this research has a narrow scope in terms of defining what physical installations entail. But doesn't limit a future expansion into more complex arrangements. Developing this further could be explored in subsequent research.

In addition, while non-fungible tokens (NFTs) are a part of the interview questions, they are only meant to provide a basic overview of blockchain technology. The conversation revolves around what an immutable data ledger can do for the artists in the context of a physical installation.

Current state of blockchain art systems

The combined field of blockchain technology and physical art installation is a niche in itself. Thus literature or research papers on this exact subject matter are rare. Research papers on blockchain oracles exist but they mainly concern financial systems. Those oracles constitute a major part in decentralized finance systems (also known as DeFi [1]).

By expanding the concepts around oracles and blockchains to IOT, financial systems and sensor data, there is a higher chance of finding information pertaining to this research. The literature review has been using various sources of information, from research papers to books.

Table 1

Ref	Authors	Year	Title	Results
[x]	Malak Alamri et al.	2019	Blockchain for Internet of Things (IoT) Research Issues	Introduction to blockchain technologies, its applications to IOT and the challenges

			Challenges & Future Directions: A Review	incumbent from it. Proposes future directions that can be either directly or indirectly applied to this research.
[x]	Abdeljalil Beniiche	2020	A Study of Blockchain Oracles	Complete review of oracles (software / hardware / human) in a financial context (ChainLink) with added design patterns.
[x]	Yanhua Wang et al.	2020	Efficient Data Interaction of Blockchain Smart Contract with Oracle Mechanism	Proposing a extensive oracle mechanism as a middleware for data verification pre-blockchain registration
[x]	Ruth Catlow et al.	2018	Artists Re:thinking the Blockchain	Presents an extensive review of artists and projects utilizing the blockchain as a medium. Can be considered as a fundamental milestone in the field of Art and blockchain.

Research hypothesis

Our research hypothesis can be formulated as follows: physical installations artists interested in integrating blockchain technologies can benefit from the usage of an oracle to integrate external data on an immutable ledger.

Blockchain oracle for the arts

In order to test our hypothesis, three prototypes of oracles in the form of smart contracts were developed with a minimal sensor setup simulation and their cost metrics were measured. For a better understanding of the overall costs associated with blockchain development, an additional audit was necessary into the smart contract development costs.

Gas fees and storage costs

Transactions (and operations based on transactions) generate a certain cost which has to be paid by the end user. To account for this, when submitting transactions, the user must include a gas fee. Bakers will then select transactions based on a low fee filter.
If the baker selects a transaction, it's going to be added to the block and propagated.
As a result, the fee is used to pay the bakers. Additional information can be considered as storage cost, an example being the storage of a smart contract - containing whichever information needed by the functionality provided by the smart contract. [2]

Oracles

Blockchain technology cannot integrate anything without the use of an oracle. An oracle, as per a classical definition, is a portal from which the gods were

communicating with the mortals. Translating that to modern day technology: a way to integrate real world data to computers (and by extension the internet). The earliest example of a functioning oracle would be the NTP (Network Time Protocol) which synchronizes the majority of servers and computers within milliseconds of the Coordinated Universal Time [3].

Trusted entities called oracles are needed to attest to facts in an effort to bring external data into the consensus mechanism of a blockchain [4]. And in the case of a physical installation, they would allow the data of sensor(s) to be registered in an immutable way on a blockchain.

Smart contracts

Smart contracts are pieces of code that can be run on top of a blockchain in order to facilitate, execute, and enforce an agreement between untrustworthy parties without the involvement of a third-party. [5][6]

The smart contracts on the Tezos blockchain are written in Michelson, which is a low-level stack based programming language [7]. Due to the complexity of this language, the usage of a high-level language is recommended. For the development of these prototypes, the usage of CameLIGO was necessary. It is a programming language which has its roots in the OCaml programming language, and is one of 4 syntaxes available around LIGO (PascaLIGO, ReasonLIGO, JsLIGO being the other ones) [8].

All three prototypes contain the same functionalities and entrypoints (which is how a function is defined in a smart contract on the Tezos blockchain), the main difference being the structure of storage used for each. Each structure involves another cost due to differences in types being used for on-chain storage.

The Tezos blockchain sets a certain cost for storage allocation to restrain storage usage [9]. The cost for current protocol Ithaca 2 released on the 1st of April 2022 is 0,00025 tezos per byte [10].

Data types

CameLIGO is a functional programming language, and its parent language LIGO is strongly and statically typed. LIGO types are built on top of Michelson's type system [11].

It is to be noted that Michelson and LIGO consequently don't support floating point numbers as they are not deterministic on hardware modules (which can be very different per node). [12]

The following types and structured types have been used in the development of the smart contracts - *records* being a composed type that the LIGO syntax allows us to create, *maps* and *big_maps* being native features from Michelson:

- *Nat and Ints:* Nat are converted to unsigned Ints. Encoded in binary schema during serialization, they have an arbitrary size that is determined by the provided data. [13]
- *Records*: "Often contracts require complex data structures, which in turn require well-typed storage or functions to work with. LIGO offers a simple way to compose simple types into structured types. The first of those structured types is the record, which aggregates types as fields and indexes them with a field name." [14]
- *Maps*: "Immutable maps from keys of type kty and values of type vty that we note { Elt key value ; ... }, with keys sorted." [15]
- *Big_maps*: "Lazily deserialized maps from keys of type kty of values of type vty. These maps should be used if you intend to store large amounts of data in a map. Using big_map can reduce gas costs significantly compared to standard maps, as data is lazily deserialized. Note however that individual operations on big_map have higher gas costs than those over standard maps. A big_map also has a lower storage cost than a standard map of the same size, when large keys are used, since only the hash of each key is stored in a big_map." [16]

"It is worth mentioning that there is no limit to the value of numbers (_nat_, _int_) or length of strings (_string_, _bytes_) other than the storage limit and gas limit (specified in the Tezos protocol). Therefore there is no risk of overflow errors." [17]

Prototypes

Both the big_map and the map prototype work in the same way. Data gets recorded on the sensor ledger, with the usage of either a big_map or map, which work in the same way: data is stored in a data structure with a key/value pair. In this case, the sensor_key is composed of a sensor_id, allowing the use of multiple sensors, and a data_id which is a numerical index for the data. The incoming sensor data value is recorded with its corresponding sensor_key composed type. It also allows historical archival of the sensor data for later retrieval of past events, as it all gets stored.

In the case of the record_big_map based storage, this is only a single value that gets stored and replaced every time a new value comes in. The big_map in this case is used to be able to store different sensors, and track the corresponding data.

- Prototype 1 - Big_map based storage

```
type sensor_id     = nat
type data_id       = nat
type sensor_key    = (sensor_id * data_id)
type sensor_ledger = (sensor_key, nat) big_map

type storage =
{
    sensor_ledger : sensor_ledger;
    n_data_ids    : (sensor_id, data_id) map;
    admin         : address
}
```

- Prototype 2 - Map based storage

```
type sensor_id     = nat
type data_id       = nat
type sensor_key    = (sensor_id * data_id)
type sensor_ledger = (sensor_key, nat) map
```

```
type storage =
{
    sensor_ledger : sensor_ledger;
    n_data_ids    : (sensor_id, data_id) map;
    admin         : address
}
```

- Prototype 3 - Record and big_map based storage

```
type sensor_id     = nat
type sensor_ledger = (sensor_id, nat) big_map

type storage =
{
    sensor_ledger : sensor_ledger;
    admin         : address
}
```

Procedure

In order to get the costs associated with uploading the data into the storage of the smart contracts, the following procedures were used:

Simulation with random data

1. Set up a Flextesa sandbox, which is a Tezos blockchain sandbox contained in a Docker container. It allows for fast iteration on smart contracts as the block time can be set to a lower time than on testnet or mainnet. Current block time on protocol Ithaca 2 is around 30 seconds [18]. This sandbox's block time was set to 3 seconds.
2. The following has been developed into a small program for ease of reproduction:
    a. Deploy all three smart contracts onto the sandbox
    b. Call the add_data entrypoint with a random parameter given by Math.random() from Javascript's library. It generates a number

between 0 and 1. This needs to be multiplied by 100 and rounded to the nearest unsigned integer as the float type is not available. The data size is arbitrary, between 1 and 2 integers. It simulates random data coming from a sensor. The sensor_id is set to number 0.

c. The latter step is repeated 2880 times (which corresponds to the maximal amount of operations per 24 hours on a 30 seconds block time - 86400 seconds per day / 30 seconds per block time)

d. Each smart contract fee estimation is then saved into a csv file for further analysis.

3. The csv files are analyzed and graphed out.

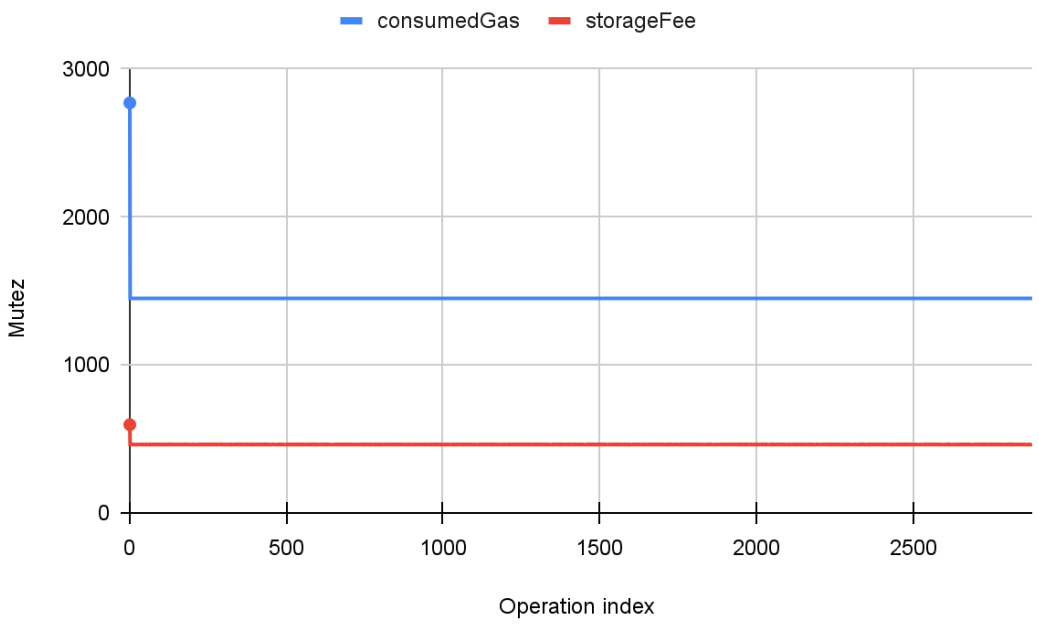
Equipment

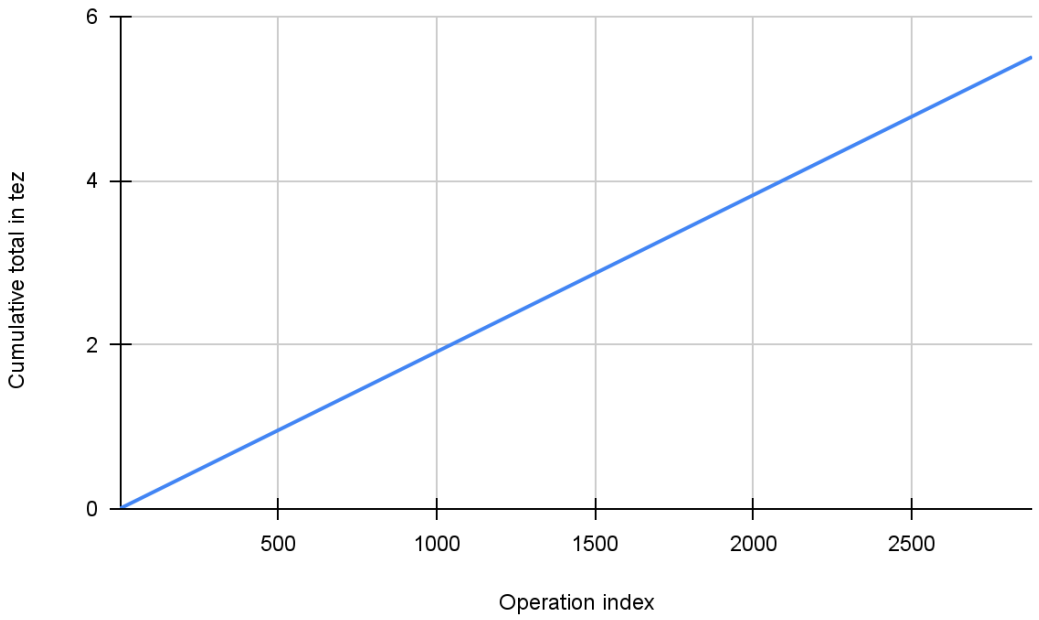
Laptop with Docker and Node.js installed

The following pages contain both charts on their own page for the sake of readability.

Usage Costs

- Prototype 1 - Big_map based storage

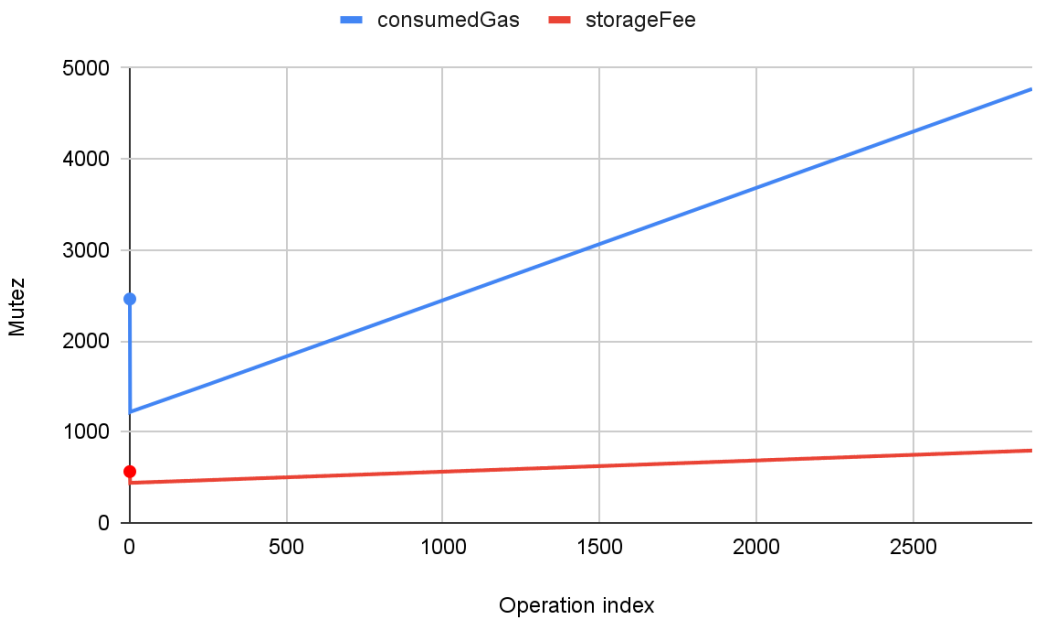


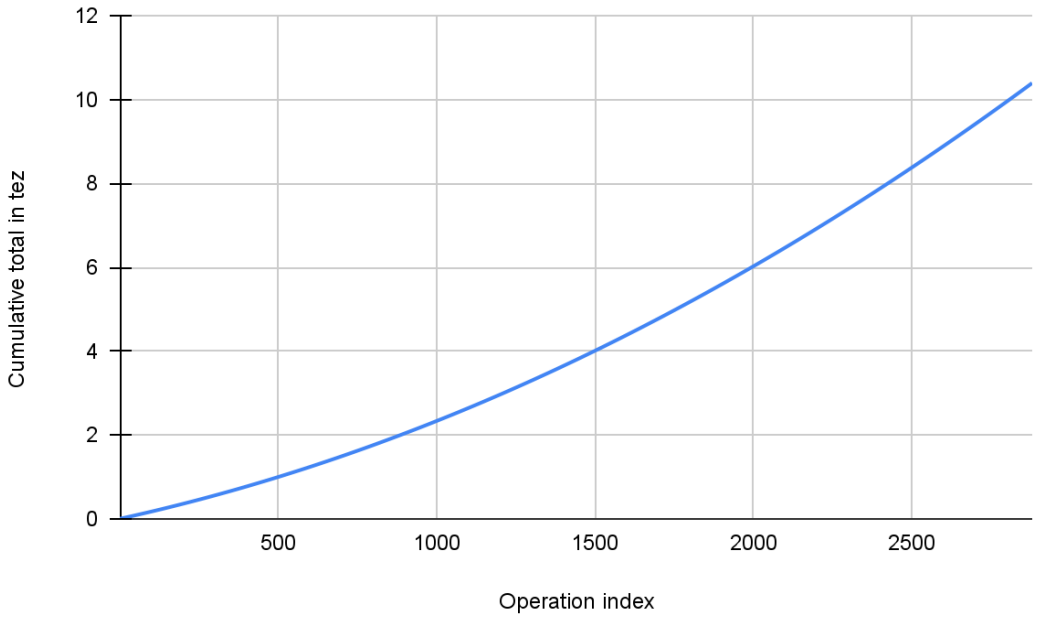


Cumulative total over 24h (simulated): 5.51 tezos

Average cost per operation (storage + gas fee): 0.0019 tezos

- Prototype 2 - Map based storage

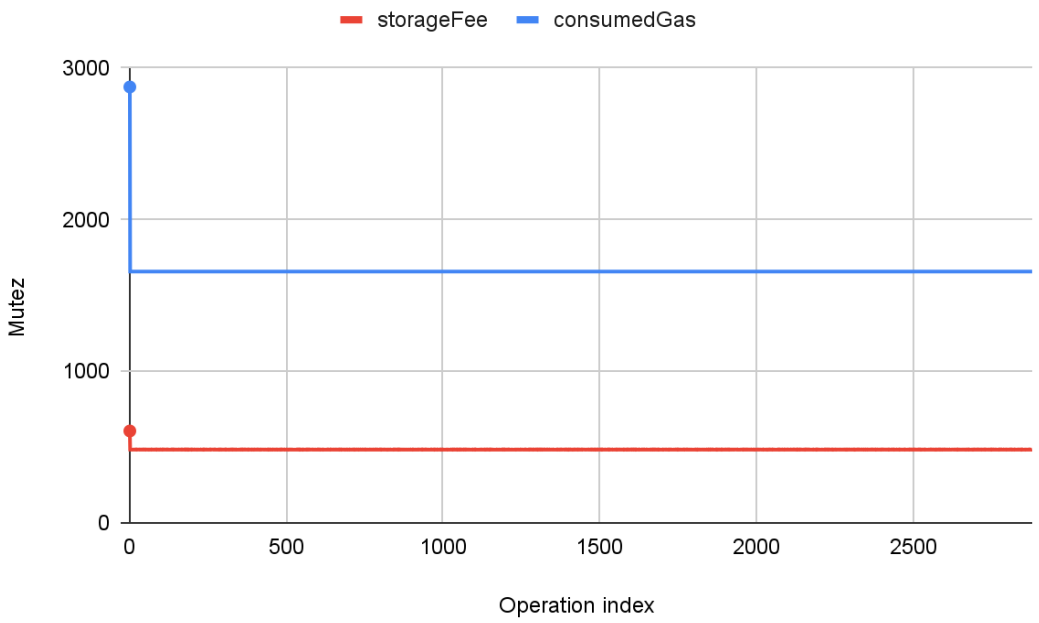


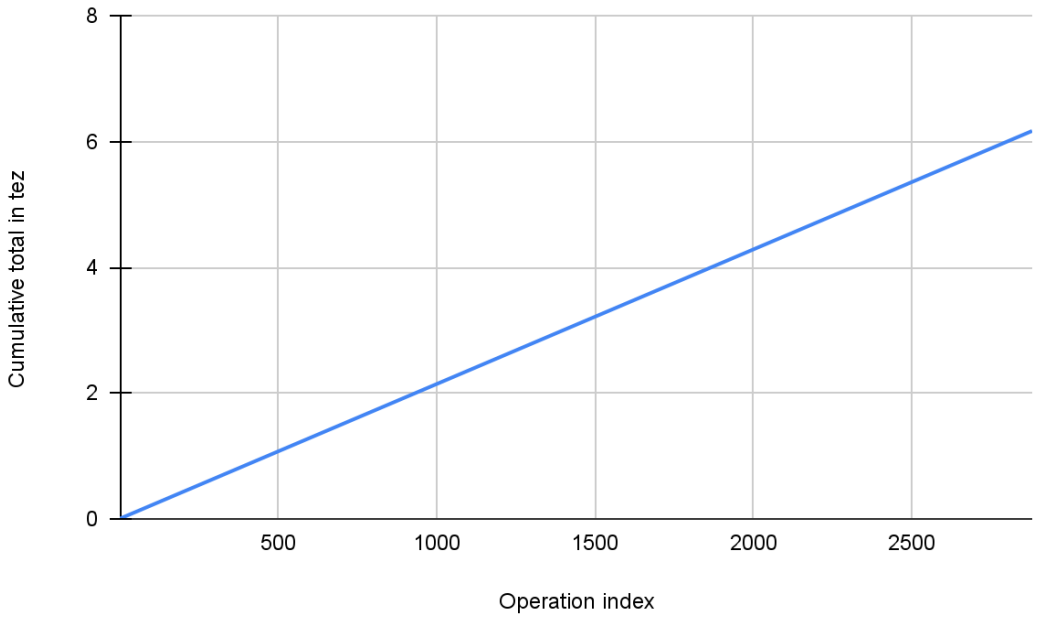


Cumulative total over 24h (simulated): 10.39 tezos

Average cost per operation (storage + gas fee): 0.0036 tezos

- Prototype 3 - Record and big_map based storage





Cumulative total over 24h (simulated): 6.17 tezos

Average cost per operation (storage + gas fee): 0.0021 tezos

As we can see from the charts, the big_map storage is the lowest costing storage structure available. Both in terms of average pricing and daily cost. Note that this is for a single sensor.

At the beginning of each graph, there is an initial deployment cost for storage and gas fee that is needed to be paid to the baker in order for the transaction to be included on the chain. [19]

Development costs

- Small scale installation (single artist / low budget)

  Blockchain development is very costly, due not only to the smart contract development but also to the security audits and extensive testing needed. For small projects / installations, the lowest cost given to develop the smart contracts needed to interact with the oracles is for the artist / artists collectives to learn smart contract development. It is also recommended to avoid handling an extensive amount of funds if the contracts are not properly audited. This recommendation comes from the analysis of the budget needed for larger scale projects.
- Medium to large scale installation (commercial)

  An estimation of the costs involved for the development of the blockchain aspect can be calculated as is:

  The salary of a software engineer at TQ Tezos (one of the daughter companies of the Tezos foundation responsible for technological implementation) corresponds to 133K - 171K$ yearly, which is around 1880 working hours per year (with a 5 weeks holiday span). This translates to an hourly salary of 133K$ / 1880 hours = 71$ per hour to 171K$ / 1880 hours = 91$ per hour. So for a development time of 4 months, it roughly costs 45K$ to 58K$ per developer involved [20]. This leaves out any additional cost related to the creation of the actual physical installation, development of the interactions and subsequent refinements.

User interviews

User interviews were conducted during a period of 4 weeks with a total of 2 participants. These were semi-structured interviews with a duration of 30 minutes containing a set of 11 questions, divided into 3 different topics, on a remote basis via video call.

The users/artists were selected on the basis of their general Art practice and history, interest in NFTs and blockchain technology, with the added physical installations edge.

To introduce the interview, the first topic was a general art history overview of the interviewee. This topic was then subdivided into 3 questions:

- Art history - the relationship to Art and how it came to be, through education, self-learning or generational acquisition through parents and/or siblings
- The kind of Arts created - analog, digital
- And the role of technology in their Art production

Next topic is centered around NFTs (Non Fungible Token [21]) as a gateway to blockchain technology. This was subdivided into 4 different questions:

- Genesis story, or what brought them to NFTs
- Role of NFTs in current status, is it a livelihood or a hobby?
- Changes in Art production after NFTs
- Usage of blockchain as a medium

Last topic was around installations, this research and a general discussion concerning the usage of blockchain as a technology and further applications outside of a financial scope. This again was divided into 4 different questions:

- What brought the artist to the world of physical installations
- Interest in adding blockchain technology to installations
- Presentation of the research and introduction to the concept of oracles
- Discussion and brainstorming around the topic of oracles.

It is to be noted that while around 10 interviews were initially planned, only less than half of those actually happened. This being due to the complexities of organizing remote video interviews and the often quickly changing schedules of artists.

A qualitative inductive coding process was initiated once the qualitative data had been collected in order to refine and detect common traits among the interviews. Interpretation, organization, and structuring of the observations allow the results to be understood. It begins with the transcription of recorded material, which takes place through an automated transcription service [22] that contains tools for coding

this information. Quotes and markant words or sentences have been extracted from the conversations and grouped together to form recurring themes.

Once the conversations were analyzed, the themes and patterns extracted, a mixture of deductive and inductive methods was chosen to explore the data in a semi-structured way while allowing for new insights to emerge freely.

The following presents the findings of this process:

For the first part of the conversation, a theme emerges through the various participants: all the interviewees have been involved with Arts and technology to a certain extent before blockchain technology was a part of their practice. They've all had an artistic practice or interest coming from either their parents, their environment or scholastic influences. Participant 1 notes that his parents were filmmakers so he was always present in and around this particular context mixing Art and technology.

A notable second theme surfacing across all conversations is the multidisciplinary approach to their practices. They've all had multiple types of education and interest that combine together to form the hybrid experimentation shaping their world view. Participant two notes "I think I've always been doing some art along with my tinkering and engineering. And in university, I studied mechanical engineering, and did a lot of theater as well", participant four notes "I have quite a mixed background.[...] I started studying computer science at university originally, and then I didn't enjoy it. [...] I went and studied photography [..] And then I went on and did a master's in design, performance and interaction". Participant three notes "[...] started out more of as a fashion illustrator in like, my early career [...] was doing a lot of graphic design, particularly in the music industry [...] I did a Diploma of multimedia, which, I guess was the real kickoff for me to, you know, you know, call myself an artist". There seems to be a common point between all these artists, looking for a lifelong multidisciplinary learning experience and applying this knowledge to their work, artistic practice or even both.

While not all their produced Art has been digital, there is always a strong bond to technology. These topics are not separated and influence each other.

Blockchain technology and NFTs seem to have been approached at a relatively later stage. Most of the participants note that though they have heard of it in the past, the real interaction with it has only started later. Participant one notes that while he has been getting a lot of information from his network around this subject, he started only paying attention to it in 2019. Participant two was already more involved, started by mining bitcoin in 2015 and was part of the first version of Foundation: “And so I played in that space, that early Foundation space for a while. Just because I was really interested in this kind of model”. He also notes that this emerging model of selling and trading art fueled his interest in the crypto space: “the questions around like, what it meant to commodify art in a way that made it transferable and tradable and all these sorts of things”. Participant three was hearing about fellow artists starting to mint NFTs in late 2019, spiking her interest due to the nature of the produced work, which centers around Virtual Reality. She notes: “I saw another couple of virtual reality artists in late 2019 start to release their work on blockchain. [...] there's not much for virtual reality artists, [...] you make assets for games and designs or you [...] do training or work in other areas of VR. So, there's not that many opportunities to make, [...] find a financial income from that”.

An important point made in those discussions is that the environmental part is quite critical to their involvement in this space. The Ethereum blockchain is considered a dirty blockchain for many artists in the Tezos ecosystem and more than a few can relate their starting point to articles like “The Unreasonable Ecological Cost of #CryptoArt” by Memo Akten [23] and similar ones [24][25]. Participant three notes: “Late that year, though, as others did slow the impact energy. So like, you know, Memo started to research[26]. [...] Fast forward to February in 2021, we created the clean NFTs community, because, [...] a lot of my work was climate focused”. Participant four notes: “I mean, I had my reservations at first, [...] mainly from the environmental side, and I've definitely done a lot more on tezos than I have on Ethereum for that reason”.

In terms of being able to live from the selling of their art as crypto tokens, participants three and four either supplement their earnings with cryptocurrency or completely live off it. Participant three notes: “but I see it as just another sort of

distribution model that I can gain supplementary income, you know, as an artist" and participant four notes: "currently, I'm living from it. So previously, I was a UX designer. And I've been doing that, like, freelance contracting for about six or seven years. So I haven't had a permanent job in a very long time. [...] And I haven't had a contract for just over a year now. So I've just been living off the NFT." On another note, participant two is using this whole context as a way of collecting Art and pushing boundaries in terms of Art creation. Supporting fellow artists and getting inspired by them: "I'm not someone who's ever really participated in the market that much, you know, I make installation art work. I lose money when I make it. [...] All the money I make goes into collecting other people's work. You know, I have a university professor job, I don't need more money from my nfts. [...] that's a privilege. [...] I can put all that money back into the field and support other artists. [...] there's like a drive: oh, if you want to collect this month, you need to make some new art. And so it's been a really interesting driver to keep me moving and keep me creative and keep me pushing myself in a way that I haven't had for a few years".

These last insights also give us a glimpse into the way NFTs have changed the way artists produce Art since their "career switch". All in all, it seems to be a potent driver for creation and interaction. But also as participant four notes: "Because as soon as you start making the thing that you love, be the thing that helps you buy food. It changes the nature of that process."

Last point in this topic concerns the usage of the blockchain as a medium and/or additional technological point. The general consensus is that while NFTs are based on smart contracts and blockchain technology, learning to handle the underlying technology is another thing. And is considered to be something complicated, needing a higher degree of involvement to be able to learn it. Participant two notes: "it's still one level too much trouble for me. Just because, you know, I'm learning so much all the time for what I have to teach". Participant four notes: "But it's not something that I personally like spent time looking into or thought about creating projects in that way. [...] if you're living from creating art, you have priorities, obviously. So you need to set them, because it takes a lot of time to learn something that is completely new". Though the fact that artists are becoming developers is something that can extend the possibilities and scope of this certain technology as participant one notes:

“we as artists have more tools that integrate better with what people have been working on, not only technologically but also ideologically, I see a very bright and interesting future. [...] But for me, that's one of the interesting aspects, because that also, for me, would integrate better with installations or physical projects“.

The last topic was a presentation and discussion centered around the development of an oracle for physically based installations. A few questions arose, with one rising over the others: “What is the most useful data to put on such an archive?”. And the main theme of this topic revolved around the creation of easy to use solutions for integrating sensor data on the blockchain, due to the inherited complexity of smart contracts development. Participant three notes: “I guess a plug and play type approach would be terrific. [...] it's just about making something that's [...] for artists who don't have a development background. There's just really good guides on how to implement it. [...] Maybe it's not so much about what you do to make it super easy for artists. It's about the tools that you provide with it, I suppose.”. Participant one notes: “I'm thinking perhaps, like an electronic module or something, also, like, that could be raspberry based or something. And that will help others to make projects, I guess, if you develop or like, like a kit or something that could be integrated easily into other kinds of projects. I think it will help us to bridge that gap in the arts.”

With the subtheme of data usage in such a context - what could be done with this data: further refinement, creation of NFTs, funding mechanisms for future installations as participant four notes: “Perhaps it will be interesting, as the installation progresses, that data starts to somehow get used in the installation. [...] so there's kind of that sort of feedback loop by the time”. Immutability as a concept, etching data on the blockchain for everyone to see, as long as the technology exists as participant four notes: “I guess the thing that stands out to me there is the thing about it being immutable, [...] within the theme of the installation that made it more meaningful that the output of whatever sensors you're using was going to be, permanent in some way. [...]. You’re sort of etching something in a punching, quote, unquote, sort of permanent way”.

Discussion

The results indicate that with careful planning and development, artists can integrate external data onto an immutable ledger. There is not only an interest in working with blockchain technology as the interviews show us, but also a need for an easy to use framework. The scale of the installation influences the feasibility of development in terms of cost and involvement. Small to medium installations can be done by a small team of committed artists but larger scale projects need a specialized dedicated development team which can be very costly. A security audit is also very important to ensure that the installation runs smoothly in terms of smart contract programming. And extensive testing is recommended.

In line with the hypothesis, data can be indeed registered in a simple and cost effective way on the blockchain. And data structures need to be carefully designed and planned ahead of time to avoid inflation in terms of storage cost. The inherent limitations of this technology in terms of data rate (the block time limit) and bandwidth issues have also to be considered.

Limitations

This research is limited by the amount of time available for development and investigation into the various technicalities. It is a simple prototype upon which a solid base can be built. A larger scale interview procedure would also identify more accurately the needs and requirements of the various artists interested in this technology. And build personas which in turn can be used to build a comprehensive framework easy to understand, use and deploy.

Recommendations

There are a few recommendations that have sprung out of the analysis of this research. On a technical level, combining an IPFS decentralized storage system with the developed smart contract can reduce costs further, making it more accessible. But that introduces other issues as IPFS brings its own set of constraints such as garbage collection and the need for pinning data on a node [27]. An additional recommendation would be to add timestamps on every data input as the blockchain doesn't keep track of the recorded time.

Additionally further research is needed to avoid data congestion when a large scale installation's data is being recorded on the blockchain. As the current state of blockchain systems shows, there are few installations that actually use only the ledger to record data. Those who rely entirely on it have a limited amount of data recorded, and mostly on ineffective types of blockchains in terms of costs.

Conclusion

While the field of blockchain development is not the most recent, there have been recent developments these last few years which have opened up the field to a variety of personas not directly related to it. Amongst those, artists willing to create, define and explore new ways of interacting with a new type of immutable database.

NFTs are really one small part of this technology. While the technology is not the easiest to work with due to it still being a niche that few hold the keys to, there is quite some potential that should be explored. The interest is here, and with time and proper education it will flourish. The added bonus of having various blockchains that are accessible in economics terms is also a notable factor of adoption amongst artists.

Should blockchain be integrated with physical installations? Maybe. It depends on the scope, on the willingness of the artist to learn a new technology, on the budget behind. Is there potential behind it? Absolutely, albeit with reasonable demands. The creativity of artists is limitless, so time will show if that technology is suited for that particular case.

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