Blockchain-based Collaborative Governance for enhancing Hong Kong's underground utilities management

The analysis of Excavation Permit Process Enhancement

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ABSTRACT

This project aimed to study the blockchain-based collaborative governance for enhancing Hong Kong's underground utilities management. Currently, the subject matter is centrally managed by the Highway Department. But, behind the scene, the excavation permit application process is contributed by cross departments such as Drainage Services Department, Water Services Department, Lands Department, and Electrical Mechanical Services Department. The reason is that the data used for the management of underground utilities are owned by different government departments separately, which causes the problem of data silos that lack of data standards and governance. In such a way, the application of an excavation permit which is highly dependent on the investigation of underground conditions encountered seriously delayed. As a result, the process which involves cross-government departments is the target area to study and enhance by the adoption of blockchain technology.

In this paper, we will discuss the motivation and problem statement of the current practice of underground utility management. Then, we will propose blockchain-based collaborative governance for enhancing the excavation permit application process. Further, we will discuss the state of art technologies adopted in the digitalization journey of the subject matter. And lastly, we will discuss the prosumer perception of blockchain adoption, its challenges and resolution.

CCS CONCEPTS

• Computing methodologies → Blockchain;

KEYWORDS

Blockchain, Distributed Ledger, Smart Government Service.

1. Motivation and Problem Statement

In Hong Kong, the usage of the public road is not intended for the flow of vehicles and pedestrians, it is also used to provide the underground space for the installation of public utility facilities such as electricity transmission and distribution cable, internet cable, gas pipe, and water and drainage system. And it is the reason excavation works are necessary and frequently happened underneath the public road such as installation, maintenance, repair, and improvement. Under the policy directives of the Development Bureau (DEVB), the Highways Department is the centralized party to coordinate and govern road works by issuing excavation permits (XP) to the work proponents, including government works departments and public utilities companies. The main purpose of issuing excavation permits target to minimize the impact on general public such as road traffic congestion, safety issue due to construction work and etc.

Upon issuing the excavation permit to the road works applicants, the Highway department have dual diligent responsibility to ensure the investigation of underground conditions before issuing the permit. For example, the last construction period of the location, the alignment and disposition of underground utility installation, the proper space occupation of certain underground utility facilities. Below figure illustrate the current practice of excavation permit application process.

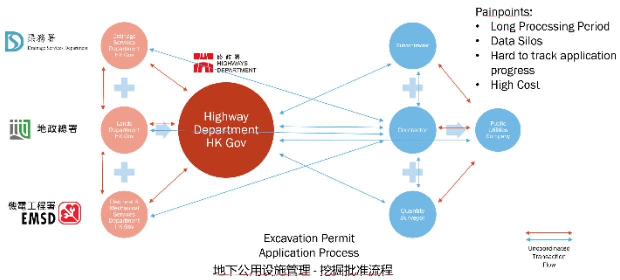


Figure 1: current practice of excavation permit application process

However, with the fact that the proposed work plan submitted by public utilities companies for the application of excavation permit do not show the details records of the underground facilities information. Also, the historical record such as as-built drawings from different government works department such as Water Supplies Department, Drainage Service Department and Electrical & Mechanical Service Department are not in the same standard or even store in separate standalone systems. Therefore, the Highways Department takes long time to collect sufficient and quality underground utility information to process the excavation permit application. As directed by DEVB, the Highways Department is reminded to strengthen the investigation of underground conditions before applying for excavation permit and, speed up the processing time of excavation permit application. [1]

Given the maturity of spatial data technology, the Highways Department response to DEVB in managing excavation works on public works by commissioned an IT consultancy study on the "Combined System Development Services of Prototype for Utility Management Information System". Having supported by different public utilities companies, as-built underground utilities information can be collected and shared which will be transformed from 2D to 3D. With the light of underground utilities digitalization, it is possible to transform the current excavation permit application practice by the adoption of blockchain and spatial data technologies. [2]

2. Related Work

In this section, we discuss the previous related work on the adoption blockchain technology application in public sector to enhance the government service. In our research, we identified 2 different materials from the internet which published by Organisation for Economic CO-operation and Development (OECD) in 2018 and World Bank in 2021.

Jamie [3] focused on a structured study on the purpose of adopting blockchain technologies which is mainly used to eliminate central point of failure and enable trust among people or organization who don't know each other to directly conduct transaction. The mechanism to support the said purpose is based on the blockchain's property of immutability and the quality of transaction validation. The potential use case span across identity & personal records, land title registry, supply chain management, voting, streamlining interagency processes, social security and benefits, contract and vendor management which allow for the transparency of government expenditures.

Potential Use Cases

Use Case	Description
Identity	Establishing and maintaining identities for citizens and residents (birth certificates, marriage licenses, visas, death records).
Personal records	Interoperable health records, insurance records, etc.
Land title registry	Details and historic records related to real estate and property transactions.
Supply chain management, inventorying	Tracking an asset from its creation, transportation, purchase, and inventorying.
Benefits, entitlements, and aid	Social security, medical benefits payments, domestic and international aid. Anticipatory/automated payments could be automated through Smart Contracts.
Contract and vendor management	Tracking and paying vendors, managing purchase commitments and transactions, and monitoring schedule performance. Can allow for perfect transparency of government expenditures.
Voting	Enabling new methods of digital voting, ensuring eligibility, accurate counting, and auditing (e.g., to avoid ballot-rigging).
Streamlining interagency processes	Blockchains and smart contracts can automate transaction handling and improve information sharing – allows each agency to better focus on their own mission and tech without as much need to consider others tech.

Figure 2.1 Potential Use Cases of Blockchain technology adopted by worldwide government [3]

He also provides statistics to illustrate the rapid growth of adoption of blockchain application in worldwide government sector. In 2017, there are 117 Initiatives in 26 Countries while in 2018, there is 292 blockchain initiatives in 45 countries.

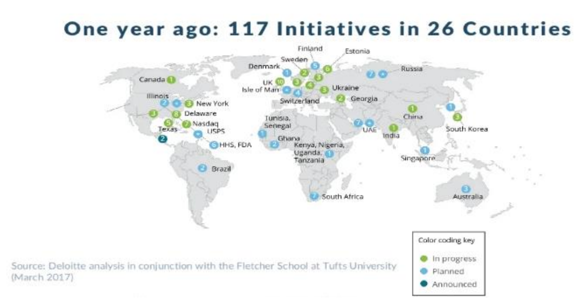


Figure 2.2 Status of blockchain technology adopted by worldwide government in 2017 [3]

Figure 2.3 Status of blockchain technology adopted by worldwide government in 2018 [3]

Victoria et al. [4] state their research work that blockchain has the potential to transform the government services by providing an innovative way to redesign processes and improve the information availability ad readiness. However, the strategy to realize the benefits brought by blockchain technology require a new "Three Layer" design and implementation framework to avoid misalignment between technology and application and also, speed the adoption. The 3 layers include:

1. social layer - human actors and social aspects such as user incentives and motivations, culture, levels of digital literacy, access to technology, etc.

2. Data Layer - the ledger itself as an" immutable" store of transactional data/records, including considerations of data usability, privacy, and security, authenticity, reliability, integrity, etc.

3. Technical Layer - the technology stack, including distributed ledger protocols, consensus mechanisms, architectures, peer-to-peer networks, data storage, etc.

3. Blockchain-based Collaborative Governance for enhancement of Excavation Permit Application

3.1 The collaborative governance architecture model

Blockchain-based Collaborative Governance provides the efficiency and quality of information sharing mechanisms between government works departments and external organizations. It revitalizes the current excavation permit application process by decentralizing the Highways Department's role to other government works departments which can self-assured the quality of their information such as historical work information and As-built drawings record. Below figure 3.1 illustrates the architecture of the blockchain-based collaboration governance system for the enhancement of the Excavation Permit Application.

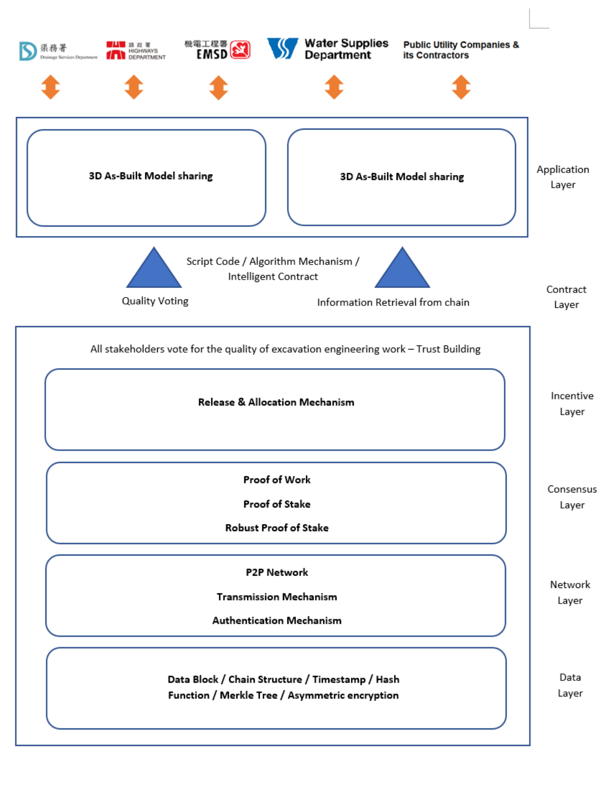


Figure 3.1 the architecture of the blockchain-based collaboration governance system for the enhancement of Excavation Permit Application

In 2009, in order to improve the efficiency and coordination of handling a large number of excavation work within Hong Kong, the Highways Department launched a centralized system called Excavation Permit Management System (XPMS). This system is open to public utility companies to submit their excavation engineering design and proposal so that the Highways Department can manage their application [5]. However, this centralized approach is not effective for information sharing between all stakeholders due to the information quality issue. From time to time, necessary manpower is required to make additional communication to ensure the trust of the information manually which leads to long application processing time and lack of transparency of application status.

Realizing the collaborative governance by a new system called MetaUU which enable the use of Blockchain Distributed Ledger Technology could potentially provide efficient and transparent management of underground utility information sharing:

1. Executed in real-time, eliminating the central role of HK Highway Department to reduce transaction cost and length of processing time by quality information sharing.

2. Available of distributed ledger, thereby increasing the quality and authenticity of underground utilities as-built drawings – 3D spatial data.

3. The identities of Public Utilities Company, Main Contractor, Subcontractor, Quantity Surveyor, and different Government Departments are verified, thereby reducing the risk of fraud record.

By replacing the heavy manpower resources and time-inefficient operating practice to provide or request information across government departments, the government can provide a much more efficient, high-quality, lower-cost, and one-stop excavation permit application service.

3.2 The Enablement of Collaborative Governance – MetaUU

The design and redefined collaboration process are the keys to enable collaborative governance based on blockchain technology.

3.2.1 Design Idea

MetaUU is designed to streamline the collaboration processes between Government Works Departments.

Public Utility Companies, and its Contractors can enjoy the real-time information sharing among every stakeholder by 3D As-Built model collected by IoT devices and each counterpart's excavation engineering project information submission.

For 3D As-Built Model, by taking a UHD video of a construction trench site in the panoramic view at anytime and anywhere, the video is transmitted from the construction site to the cloud via 5G for the computation of a high-quality 3D model in real-time.

Having the timely and accurate 3D model and data of the construction site built and shared in MetaUU, different stakeholders of the road work from different locations, either onsite or offsite, can collaborate effectively with the digital replica of the construction site.

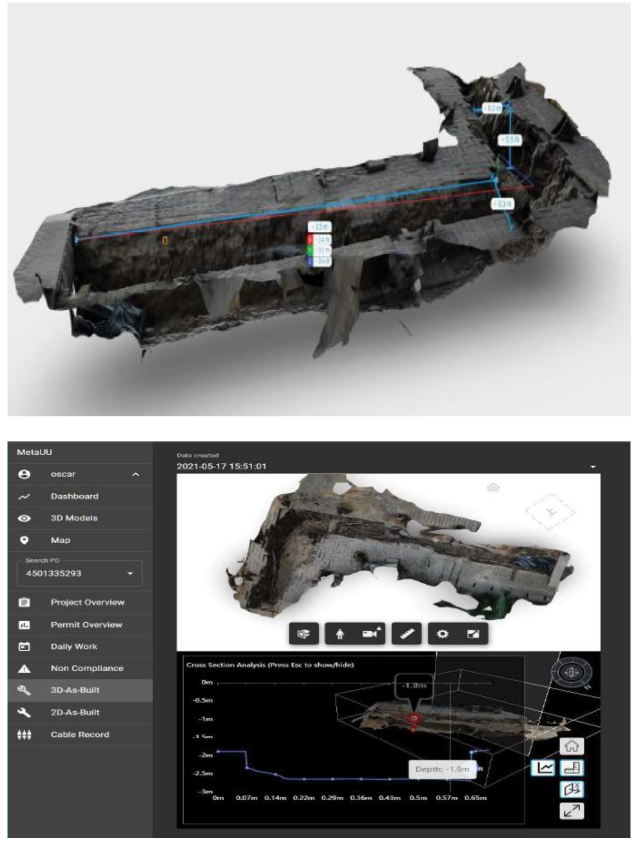


Figure 3.2.1a 3D As-Built Model sharing in MetaUU

For excavation engineering project information sharing, it is vital for all stakeholders to get informed about any changing project information which is crucial to excavation permit control. Especially, there are some changes that are deviated from the original engineering design. Below information will be shared between stakeholders:

- Non-Compliance Issue which audited by the Highway Department
- Revised Excavation Route Width and Depth due to unexpected underground conditions such as pipe congestion
- Materials underlaid

Figure 3.2.1b Excavation Project Information sharing in MetaUU

3.3 Stakeholder Analysis

For all stakeholders, in the blockchain-based collaborative governance model, the collaborative governance process involves all the government works departments such as the Highway Departments, Water Supplies Department, Drainage Services Departments, Electrical & Mechanical Services Department, and Public Utility Company plus its Contractors.

As illustrated in figure 3.3, the starting point of the process is for the Public Utility Companies, or its Contractors to submit the 3D As-Built model which is a point cloud file and the excavation engineering project information. Then, all the government works departments review all the submitted 3D As-Built model and excavation engineering project information and check if it complies with the requirements from each government works department or ensure there is no compatibility and compliance issue that occurs among all the underground utility facilities.

The basic idea is to enhance the decision-making of the excavation permit approval process. This collaborative governance approach follows the behavior of "rational people" from the perspective of game theory such that the goal is to maximize self-interest and the benefits are for the sake of public interests, cost, efficiency, transparency, and authenticity of information to be shared. Finally, win-win cooperation of all parties can be achieved.

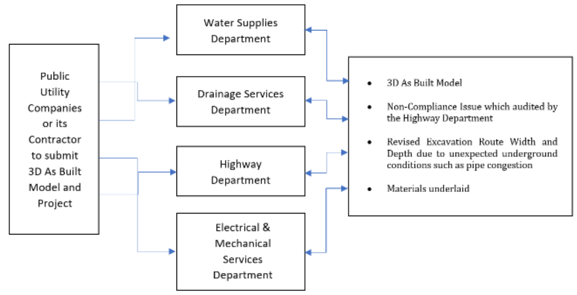


Figure 3.3a the stakeholder analysis diagram

When compared with the current collaboration practice which illustrates in figure 1, through the adoption of blockchain technology to streamline the collaborative governance process of the underground utility management for enhancing the excavation permit application, this strategy becomes clean and much more responsive to every stakeholder within the ecosystem.

More importantly, this collaborative governance model can greatly improve the quality of engineering work and data trust between all the stakeholders. In financial benefits point of view, it significantly improves the cashflow performance of contractor and CAPEX efficiency of Public Underground Utility owner.

4. State of the Art

In this section, we discuss the technologies used to develop the decentralized part of MetaUU on the Ethereum blockchain. It involves the implementation of a smart contract that consensually governs the quality of underground utility work by all government works departments' vote.

For demonstration purposes, the below sections cover only the quality voting of project information in Ganache only, the testing environment of Ethereum. Having this voting mechanism can ensure the excavation engineering work is compliant and compatible with the requirements held by different parties.

4.1 Blockchain Distributed Ledger Technology (DLT)

In the typical web2 environment, when you communicate with a web application, a web browser is used to connect to the central server which contains all the application source code and database. Every time when you request or submit information from the web application, this centralized server will be accessed. The web2 approach raises trust issues such that the data lived in the central database can be changed by the central party who manages the system anytime. Also, the source code can also be changed by the same central party anytime. In the operating environment which involves cross-organization collaboration such as information sharing, it is not an agreed approach.

Instead, in the web3 environment, which is backed by blockchain DLT technology, a peer-to-peer (P2P) network of computers (node) will be used to store and share the data and source code in the (P2P) network. In this P2P blockchain network, data and source code are no longer controlled by one central party instead, each computer or node in the blockchain network holds a copy of the data and source code, to ensure the authenticity of the digital asset.

Nodes in the network are working together to ensure all copies of data distributed across the network are identical. And, inside the node, transaction data are stored in groups, called block, which is used as the data structure to record the data in a chained manner. Each record of transaction data stored in the blockchain network is called distributed ledger which is encrypted by cryptographic hashing and validated by a consensus algorithm.

4.2 Solution Architecture

The overall solution comprised of below:

1. Smart contract for the quality vote, and

2. Distributed application (dApp) network gateway for the communication between the client-side app, MetaUU, and the smart contract, and

3. Client-side application used by the public utility management stakeholders

Below diagram illustrate the solution architecture of the dApp:

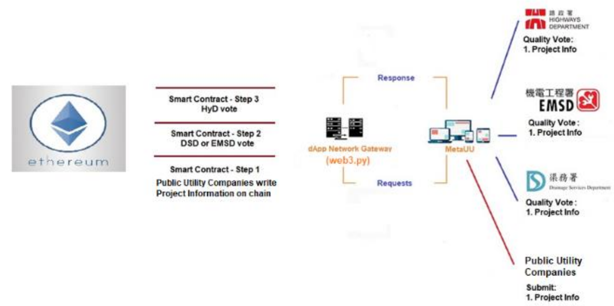


Figure 4.2 Solution Architecture of MetaUU

4.2 Smart Contract

In the Ethereum environment, Smart Contract is the programming code stored in the blockchain network which is compiled to low-level bytecode and executed in the Ethereum Virtual Machine (EVM) where it is the decentralized part of the dApp. It is invoked and runs when predefined conditions are reached.

Normally, the Smart Contracts are implemented based on the business logic which can be the execution of the agreement. In our study, there are two types of business logic implemented in Smart Contract, one is the quality vote, and another one keep track of the changing project information in the blockchain network.

4.2.1 Implementation

The implementation of a smart contract requires the programming language called Solidity and the development tool called Remix.

4.2.1.1 Solidity – the Programming Language for Smart Contract

Smart Contract is written by the programming language called Solidity which is an object-oriented, high-level language within the Ethereum state. If you are a JavaScript developer, you will definitely find that Solidity is just like JavaScript[6].

When the smart contract is deployed to EVM, the best practice is to use the latest released version of Solidity.

The reason is that we should ensure the security fixes will be taking effect. In our case, since the fast-changing of version, we allow the Solidity version from 0.4.22 to 0.9.0. [6]

Below shows the Solidity code of our project:

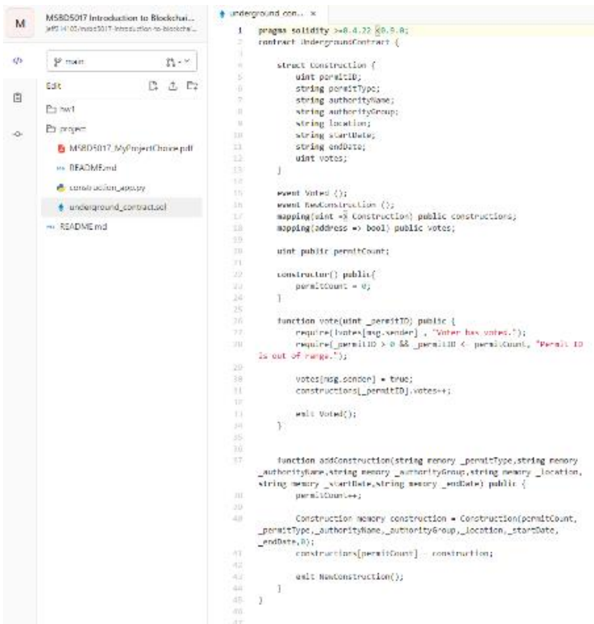


Figure4.2.1.1 Solidity Code of MetaUU

4.2.1.2 Remix and Ganache – the development tool and local Ethereum Blockchain for testing

Remix is the integrated development environment that is designed to provide a great user experience for blockchain developers to write, test, debug and deploy smart contract code through a web browser or locally installed software. Below show the User Interface of Remix IDE for the project [6].

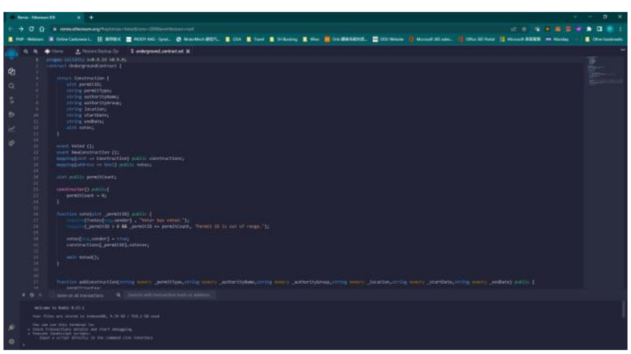


Figure 4.2.1.2a The user interface of the Remix IDE

Within the Remix, you can config which blockchain network you connect to and which Ethereum Wallet you use to pay the transaction fee charged by the Ethereum nodes. Due to the gas fee of a transaction being determined by the busy level of the Ethereum Network, the gas fee fluctuation occurs when you deploy the smart contract to the Ethereum network. Luckily that Remix provides a very good feature for the developer to control the consumption of gas fees by setting a gas limit. It can greatly help to avoid the expensive expenses of gas fees when you deploy the smart contract at a network busy time [6].

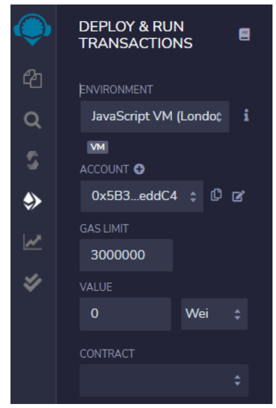
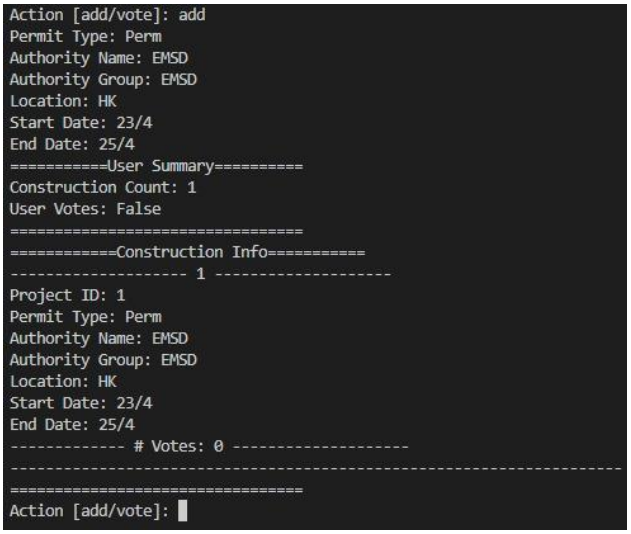


Figure 4.2.1.2b Feature for the developer to control the consumption of gas fees

In our project, we use Remix to compile the solidity code into byte code and ABI. Such that no python solidity compiler is required. Therefore, we are only considering byte code and ABI of sol. The reason for doing that is to prevent Solidity version issue with python, since python solidity needs to match with the solidity compiler (which is clumsy thing, two different tools).

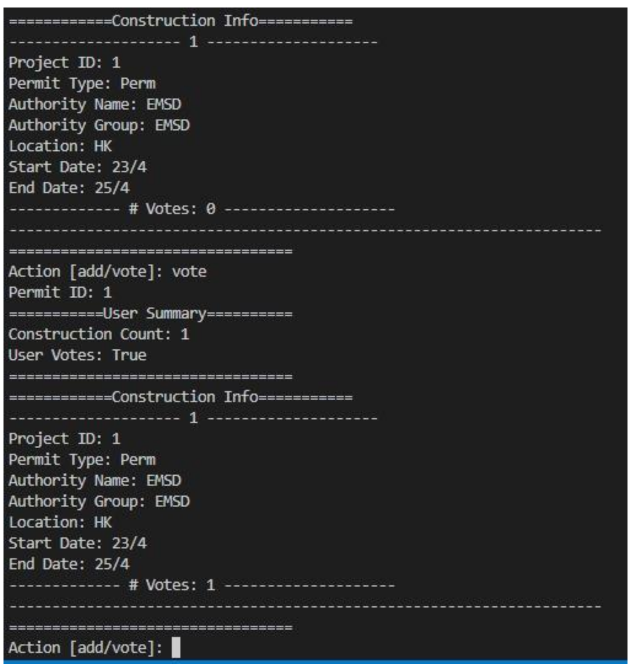
Below shows the Remix runtime and the transactions in Ganache of our project:

```
Login to User [1-10]: 1
Created contract address: 0xB6addA3A604AFD774e44a2d047041D65E4a8d2ca
==========User Summary=========
Construction Count: 0
User Votes: False
================================
===========Construction Info==========
There is no construction
================================
Action [add/vote]:
```



```
Action [add/vote]: add
Permit Type: Perm
Authority Name: EMSD
Authority Group: EMSD
Location: HK
Start Date: 23/4
End Date: 25/4
==========User Summary=========
Construction Count: 1
User Votes: False
===============================
===========Construction Info==========
-------------------- 1 --------------------
Project ID: 1
Permit Type: Perm
Authority Name: EMSD
Authority Group: EMSD
Location: HK
Start Date: 23/4
End Date: 25/4
------------ # Votes: 0 --------------------
--------------------------------------------------------------------
===============================
Action [add/vote]:
```

Figure 4.2.1.2c Runtime information for submitting the project info



```
===========Construction Info==========
-------------------- 1 --------------------
Project ID: 1
Permit Type: Perm
Authority Name: EMSD
Authority Group: EMSD
Location: HK
Start Date: 23/4
End Date: 25/4
------------ # Votes: 0 --------------------
--------------------------------------------------------------------
===============================
Action [add/vote]: vote
Permit ID: 1
==========User Summary=========
Construction Count: 1
User Votes: True
===============================
===========Construction Info==========
-------------------- 1 --------------------
Project ID: 1
Permit Type: Perm
Authority Name: EMSD
Authority Group: EMSD
Location: HK
Start Date: 23/4
End Date: 25/4
------------ # Votes: 1 --------------------
--------------------------------------------------------------------
===============================
Action [add/vote]:
```

Figure 4.2.1.2d Runtime information for quality voting

4.2.2 Testing

From time to time, when we do testing of our smart contract, we don't directly deploy the smart contract to the Ethereum network. Instead, we would like to test this in a testing environment to save the development time and cost.

In our project, we use Ganache, as the testing environment, to deploy our smart contract from Remix IDE. The steps are simple and are shown below [6]:

Step 1: Open Remix IDE

Step 2: Import the Smart Contract to the Remix workspace

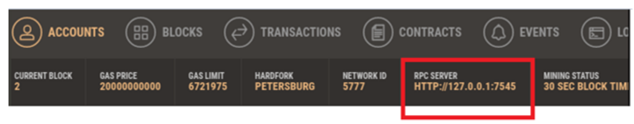
Step 3: Compile the smart contract

Step 4: For the Environment setting in Deploy and Run Transactions, you will see the below options as shown in figure 4.2.1.2b

· JavaScript VM: this executes the smart contract in the browser using a JavaScript-based local EVM

· Injected Web3: The interface to connect the Ethereum node.

· Web3 Provider: The endpoint to connect to an Ethereum node via HTTP, in our case the local Ganache. The address can be checked from Ganache which is shown below:



Step 5. Deploy the Smart Contract to the local Ethereum Blockchain provided by Ganache.

4.3 dApp Network Gateway

After the successful implementation and deployment of our smart contract, we need to build the dApp network gateway so that our client-side app, MetaUU can access the Ethereum network to execute the Quality Vote Smart Contract and further write the Project Information to Ethereum Node for storage.

For the implementation of the dApp network gateway in this project, we choose the web3.py library for MetaUU to interact with Ethereum for which, our project is based on the local Ethereum Environment, Ganache, to showcase the implementation.

More specific, Web3.py is a collection of libraries that enable blockchain developers to invoke and execute transactions in the Ethereum network, by accessing the data and smart contract.

Web3.py uses the JSON RPC protocol, realized by Application Binary Interface (ABI), to communicate with the Ethereum node, such that it allows the developer to make a request to an endpoint node on behalf of the whole Ethereum network with the JSON RPC protocol [7].

In our project, we invoke the web3 object to establish the connection by below code segment:

```
url = "HTTP://127.0.0.1:7545"
web3 = Web3(Web3.HTTPProvider(url))
```

Then, we execute the smart contract by below code segment:

```
Voter = web3.eth.contract(abi=abi, bytecode=bytecode)

tx_hash = Voter.constructor().transact()

tx_receipt = web3.eth.waitForTransactionReceipt(tx_hash)

address=tx_receipt.contractAddress
```

4.4 Client-Side App - MetaUU

For simplicity of the demonstration, we didn't implement the API for our Client-Side App, MetaUU, to directly invoke the API call to the dApp Network Gateway which is discussed in section 4.3. Instead, we demonstrated the solution execution flow by using a text file for the data which we want to store on the local Ethereum Network, Ganache.

5. Prosumer perception of blockchain application in the public sector

With the discussion with selected industry representatives, the main concern of adopting blockchain technology to serve the collaborative governance purpose of underground utility management is the public awareness and knowledgebase of the blockchain technology.

5.1 Public Awareness of Blockchain Technology

Firstly, not difficult to imagine and most of the public perception treated blockchain as the technology to serve cryptocurrency and NFT-related marketing purposes due to social influence.

The public's knowledge is still insufficient about the Distributed Ledger Technology (DLT) for immutable Information Sharing which is also the application area offered by blockchain.

To attain the successful adoption of blockchain technology in the subject matter, public acceptance is the key to our consideration, and to achieve this, education to the public is required to let them know the difference between cryptocurrency, NFT, and DLT. [8]

5.2 Blockchain scalability and Cost issue

The scalability issue and slow performance of blockchain network is another issue. As we all know, the performance of blockchain is highly dependent on the complex encryption logic and the number of users in the network such that the more is the user concurrently put execution in the network, the slower is the response time and the higher is the cost, as we discussed in the earlier section about the gas fee. In reality, the transactions triggered by the collaborative governance process and the excavation permit application are frequent in nature.

Judging the intended purposes of blockchain adoption for underground utility management is to enhance efficiency enhancement and drive down the operating costs, this may need further study if this issue can be solved. [8]

5.3 Privacy Issue

Since underground utilities are city infrastructure that provides Telecomm, Electricity, Water, and Drainage services to the public, the privacy of the corresponding information should attain a high level of privacy for the sake of public goods.

However, Ethereum is a kind of public blockchain network that cannot ensure the full privacy protection of the said matters. It is an essential requirement of the government and public utility owners to limit the access of this sensitive information which are stored in the public blockchain network. [8]

5.4 Environmental Sustainability

Energy consumption is also a concern of adopting blockchain technology in the public sector. The reason is that blockchain highly consumes electricity to support the proof of work and the consensus mechanism to assure transaction validation through mining. At present, miners are using 0.2% of the total electricity of the world.

If it keeps increasing, miners will take more power than the world can provide. Thus, it now becomes one of the primary challenges of this network. Especially, the government over the world is targeting decarbonization, blockchain technology adoption may create contradiction with the environmental sustainability. [8]

6. Opportunity – Private Blockchain Network

To address the scalability and privacy issues, a private blockchain is a solution. Unlike a public blockchain such as Ethereum, permission can be set up in the private blockchain in order to control the privacy of information by limiting the data access by anyone.

The private blockchain is controlled by a single private chain provider which can handle this well because access controls can be implemented to manage the privileges of users in the network. Except for the private chain provider itself, no one else has knowledge or access to the private blockchain network.

Also, private chain networks provider commercially manage for better performance and competitive pricing model to their customer, the price is not based on the busy level of the network.

7. Conclusion and future work

In conclusion, in terms of functionality, we find that blockchain is the best fit technology to transform the current practice of underground utility management which the Highway Departments take the central role to coordinate the excavation permit application process.

Due to the nature of decentralization, blockchain can offer a new way to strengthen the governance of underground utility engineering work and, greatly improve the efficiency of the excavation permit application process.

Despite there are challenges to the adoption of blockchain technology such as Public Awareness of Blockchain Technology, Blockchain scalability & Cost issues, Privacy Issues, and Environmental Sustainability, most of the challenges can be addressed by using a private blockchain network.

For future works, it is expected the blockchain implementation demonstration should be implemented in a private blockchain network in order to match the industry requirement. Obviously, Ethereum is not the target blockchain network for consideration.

Furthermore, further study should also cover the 3D As-Built model which requires large size file storage which is suggested to study the use of Ether Data or IPFS platform.

Additionally, the dApp implementation between the web3 network gateway should be fully integrated with MetaUU by API instead of using text file to store the static project information.

ACKNOWLEDGMENTS

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