Fall 2021

GeoBlockchain: The Analysis, Design, and Evaluation of a Spatially Enabled Blockchain

Constantinos Papantoniou
Claremont Graduate University

GeoBlockchain: The Analysis, Design, and Evaluation of a Spatially Enabled Blockchain

By

Constantinos Papantoniou

Claremont Graduate University
2021

Approval of the Dissertation Committee

This dissertation has been duly read, reviewed, and critiqued by the Committee listed below, which hereby approves the manuscript of Constantinos Papantoniou as fulfilling the scope and quality requirements for meriting the degree of Doctor of Philosophy in Information Systems and Technology.

Brian Hilton, Ph.D., Chair
Claremont Graduate University
Clinical Full Professor of Information Systems and Technology

Terry Ryan, Ph.D., Committee Member
Claremont Graduate University
Professor of Information Systems and Technology

Chinazunwa Uwaoma, Ph.D., Committee Member
Claremont Graduate University
Research Assistant Professor of Information Systems and Technology

Abstract

GeoBlockchain: The Analysis, Design, and Evaluation of a Spatially Enabled Blockchain

By
Constantinos Papantoniou

Claremont Graduate University: 2021

Land ownership and supply chain use cases are an enormous business challenge for both the public and private sectors. Every organization has different needs and wants, and they are researching and exploring ways to add value and impact their ownership tracing processes. Geospatial and Blockchain technologies are two emerging trends that could help an organization add value in this manner. The combination of blockchain and geospatial technologies would result in the new concept of GeoBlockchain, defined here as an artifact that could be used to study the trends and behaviours of participants (users) geographically and spatially, based on distributed nodes, transactions, and geo-locations through the blockchain technology.

GeoBlockchain can also be used to visually display geo-ownership tracing processes (points, lines, and polygons) demonstrating the importance of geography. The result of this research was the design, development, implementation, and evaluation of a Spatially Enabled Blockchain ICT artifacts. Each prototype artifact was built using ArcGIS Enterprise and Hyperledger Fabric. The architecture designs were implemented with on-premises and cloud environments and evaluated based on users' usability and sociotechnical metrics. This research indicates that blockchain technology can be integrated with geospatial technology, resulting in the GeoBlockchain framework along with its attendant implementation criteria in the age of GeoBlockchain.

Dedication

I would like to thank my family for their inspiration and long-distance support over the years. Too much appreciation to my parents Andreas and Thalia for their love, trust, and encouragement, and my siblings, and nieces (Antonis, Maria, Irida, and Mariliza) for their beautiful moments spent through video calls.

Finally, to my beautiful wife, Anastasia. Her true love, patience, great support, belief, and motivation helped me to focus on my goals and dreams and to have fulfillment in life. Thank you so much for everything.

Acknowledgements

I want to acknowledge my dissertation committee and CGU advisor, for their empathy, support, and available time to guide and advise me during my PhD journey at Claremont Graduate University: Brian Hilton, Lorne Olfman, Terry Ryan, Chinazunwa Uwaoma and Afaf Igbaria.

Also, I would like to acknowledge Esri and specifically Jack and Laura Dangermond for their sponsorship and fellowship, and Professional Services management for their leadership, and mentorship on my career development.

Lastly, I want to thank the Advanced GIS Lab at Claremont Graduate University; Environmental Systems Research Institute, Inc.; Several Blockchain consortiums; and the various stakeholders that collaborated with this study.

Preface

This PhD dissertation research study contributed to the USPTO – Provisional patent application of "GEOBLOCKCHAIN AUTHENTICATION OF MAP RELATED DATA". Also, three preliminary published articles grounded the PhD dissertation with their literature reviews, artifact designs, methodologies and evaluations.

Preliminary Research

1. Papantoniou, C., & Hilton, B. (2021, January). *Enterprise Solutions Criteria in the Age of GeoBlockchain: Land Ownership and Supply Chain.* In Proceedings of the 54th Hawaii International Conference on System Sciences (p. 5307).

2. Papantoniou, Constantinos, "*Selecting Implementation Criteria in the Age of GeoBlockchain*" (2020). AMCIS 2020 Proceedings. 15. https://aisel.aisnet.org/amcis2020/data_science_analytics_for_decision_support/data_science_analytics_for_decision_support/15

3. Papantoniou, C., & Hilton, B. *Workflows and Spatial Analysis in the Age of GeoBlockchain: A Land Ownership Example*. (2020). AUTOCARTO 2020. https://cartogis.org/docs/autocarto/2020/docs/abstracts/3e%20Workflows%20and%20Spatial%20Analysis%20in%20the%20Age%20of%20GeoBlockchain%20A%20Land.pdf

Table of Contents

Table of Figures

Chapter 1: Introduction

Problem and Phenomenon

Blockchain is a new promising technology that can provide trust, immutability, and transparency to any organization's systems of systems. The first proof-of- concept using blockchain technology was cryptocurrency. This was later developed and implemented for public blockchains such as Ethereum and Bitcoin [12].

While unusual, this use case demonstrated that blockchain technology could orchestrate valid transactions across a distributed network and store those transactions in unalterable ledgers across multiple nodes [7, 8, 10, 11]. Every new ledger transaction is a new block, and all blocks construct the blockchain [9].

Today, we see considerable demand for enterprise technologies that could use private blockchains. The critical advantages of blockchain are the high speed of transactions, trust among participants, and valid, accurate data [11]. The value of its use is the increase in trust and fast data collaboration among users while reducing the risk of fraud and the overall cost of monitoring goods and assets through the business chain lifecycle [1, 2, 3].

We are also beginning to observe a high demand for blockchain across both the private and public sectors that incorporate geographic information systems; specifically, land ownership and supply chain use cases. Geographic Information System (GIS) technology, an inherently location-based technology, can help answer the question of where a blockchain transaction has occurred [10].

The combination, and integration, of blockchain with GIS underlie the concept of GeoBlockchain. This new tool can be used to support the analysis of spatial-temporal trends of blockchain transactions via a geospatially-enabled blockchain [6]. But why do we need to integrate geospatial technology with blockchain technology? It has been suggested that when designing a blockchain for real estate, it should provide a protocol that allows for a complete real estate transaction, which can offer at least the same guarantees for both the signatories and for third parties as current procedures. As such, this technology should meet the following criteria: 1) the permissioned blockchain should be controlled by public authorities, and 2) the blockchain should be linked to an official digital ID [4].

Related to supply chain technology, little is understood regarding the disruption blockchain adoption has had on transport and logistics, however, blockchain has the potential to be interlinked with a variety of transportation, logistics, and supply chain activities and methods that rely on organizational and process information [5]. Implicit in both use cases is the locational aspect of these activities. The solution designed, developed, and implemented as part of this study, explicitly includes location.

Purpose and Dissertation Method

The PhD dissertation includes four phases. Three combined articles, 1st Article as "Phase 1", 2nd Article as "Phase 2", and 3rd Article as "Phase3" and a Conclusion as "Phase 4".

Phase 1 - First Article: "A systematic literature review of GeoBlockchain"

The first article was a systematic literature review on blockchain and geospatial technology. The purpose of the first article was to examine any existing research and literature on Blockchain and Geospatial technologies via an extensive review of the literature to justify the significance of the problem including the key conceptual/theoretical underpinnings for the dissertation research as a whole.

In other words, we can call this marriage-integration a "GeoBlockchain". This study has examined the results and reported on the relationship between the two. The main reason that a systematic literature review was conducted to determine whether a GeoBlockchain exists, and to determine if studying it would add to the body of knowledge in the Information Systems domain.

The outline for the structure of the "Phase 1: First Article" document in "Chapter 2: A systematic literature review of GeoBlockchain" includes the following: Abstract, Introduction, Methods, Substantive Topics, Results, Discussion, Conclusion, and References.

Phase 2 - Second Article: GeoBlockchain Solutions Criteria for a Land Ownership and Supply Chain Use Case

For the second article, this research study conducted a Q Methodology as the main Kernel theory on blockchain. Utilizing the Design Science Research methodology, two ICT artifacts were designed, developed, and implemented. The first task was to generate a list of valid attributes/criteria (classify generic and custom attributes) for comparison between landownership and supply chain examples. The second, task was to design, develop, and implement the two ICT artifact prototypes (Landownership and Supply Chain) using the

Hyperledger Fabric and ArcGIS Enterprise platforms. Finally, the third task was to apply a comparison test and draw conclusions.

The outcome from this research was the identification and the importance of the GeoBlockchain implementation criteria between two significant technologies: geospatial and blockchain. These could impact participants and main stakeholders' involvement and work through real use cases such as supply chain and land ownership. This can be achieved by leveraging existing blockchain frameworks that use the proposed criteria: multi-party, trusted authority, centralized operation, data transparency and confidentiality, data integrity, data immutability, and high-performance.

The outline for the structure of the "Phase 2: Second Article" document in "Chapter 3: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case" includes the following: Abstract, Introduction, Methods, Artifact Designs, Results, Discussion, Conclusion, and References.

Phase 3 - Third Article: The Design Science Evaluation on GeoBlockchain

The third article expanded the outcomes from the first article "A systematic literature review of GeoBlockchain" and from the second article "GeoBlockchain Solutions Criteria for a Land Ownership and Supply Chain Use Case". This article evaluates the implementation of the GeoBlockchain architectures between on-premises and cloud environments based on two specific settings - a Supply Chain use case and Land Ownership use case. This included a pilot assessment (quantitative and qualitative evaluation of the ICT-artifacts) utilizing chosen metrics

to demonstrate the efficacy, utility, and performance along with domain expert evaluation to assess the effectiveness of the design solution and to propose the GeoBlockchain Framework.

The outline for the structure of the “Phase 3: Third Article” document in “Chapter 4: The Design Science Evaluation Research on GeoBlockchain” includes the following: Abstract, Introduction, Methods, Architecture Designs and Evaluation, Results, Discussion, Conclusion, and References.

Phase 4 - Conclusion

A general discussion follows in “Chapter 5: Conclusion” based on the results of the research outcomes from Chapter 2, Chapter 3, and Chapter 4, and identify the application to practice, implications for practice, and need for future research based on the limitations from each research article.

Research Questions

The research questions for each article are identified as:

- For the First Article: “A systematic literature review of GeoBlockchain”
    - What relationship, if any, exists between Blockchain and Geographic Information Systems Technologies as related to a combined integration?
    - Can these two technologies be integrated together?
    - What previous research exists regarding a GeoBlockchain combination?

- For the Second Article: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case
  - What is a possible design of a GeoBlockchain solution?
  - What are the main attributes of a GeoBlockchain solution?
  - What are the main criteria used in designing a GeoBlockchain enterprise solution and non-enterprise solution?
  - What is the importance of roles and rules, in order to build trust among participants, across these two types of solutions?

- For the Third Article: The Design Science Evaluation on GeoBlockchain
  - What attributes and criteria are effective in initiating and maintaining a GeoBlockchain solution?
  - What roles and rules are effective in initiating and maintaining a GeoBlockchain solution?
  - What are the differences among GeoBlockchain attributes, criteria, rules, and roles between an enterprise solution and a non-enterprise solution?

Research Methodology

- First Article: "A systematic literature review of GeoBlockchain":

The Systematic Literature Review Methodology for the first article includes four steps. The first step is to collect the existing literature from scholars' libraries databases. The following

library databases were used: Web of Sciences database, Claremont Graduate University library, MIT library, and Harvard Business School library. The reason for this selection was to have a valid content from previous research. I acknowledge that there is a limitation with the number of database libraries, but this approach was the best until more combined literature will be created between blockchain and geospatial technologies.

The second step will follow up with setting the criteria such as main keywords, terminologies related to both technologies (Blockchain and Geospatial), and it will include the publication years and number of citations. Keywords used: Geo-blockchain, Blockchain, Spatial, Geospatial, GIS, and Geographic Information Systems.

The third step has two sub modules. Module 1 includes a brief scanning of the title and abstract and the Module 2 has a full Scanning (proofread) for the whole article review. Step three was conducted after I applied the rules from step one and step two.

The fourth step is reporting the summary results with graphs and charts from previous steps and at the end a conclusion follows with recommendations and limitations. Finally, a systematic literature review methodology diagram is designed by illustrating the flow through the systematic literature review process.

- Second Article: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case.

The Design Science Research Methodology includes eight steps. The outline steps of the research process are:

1. Define the Problem and Motivation

2. Introduction Section
3. The Literature Review outlines the Geoblockchain components and objectives
4. Theoretical Background
5. Design integration of geospatial technology with blockchain technology
6. Implementation phases
7. Outcomes of the two solution prototypes
8. Discission and Conclusion Sections

For the "Second Article: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case" the research study used the following Research Methodologies:

- Peffers et al - DSR methodology (6 process cycle)
- Kernel Theories
  - Q-method a technique that is specialized for the analysis of peoples' subjective beliefs.
  - Q-Set for ranking and sorting specific statements, to identify the attributes and criteria for the GeoBlockchain land ownership and supply chain use cases.
- Design, Develop and Implement Proof of Concepts
- Evaluation Qualitative
  - 40 semi-structured interviews were conducted drawing on participants from a land ownership government organization and a private supply chain organization.
    - 20 interviews for each organization.

        - Semi-structured interviews, field notes and reports were collected from each organization to validate the responses using triangulation methods.
        - Data was analyzed by using the Strauss and Corbin coding technique.
    - Evaluation Quantitative
        - The Q sort process was used to analyze and factor the participants' responses from existing surveys within the organization.
        - A statistical quantitative factor analysis technique was used for data reduction and to summarize the variables for the Q Sorting.
    - Sociotechnical Evaluation
        - Performance, security, and metrics were analyzed by using enterprise monitoring tools.

- Third Article: The Design Science Evaluation on GeoBlockchain

The Design Science Evaluation Research Methodology includes eight steps. The outline steps of the research process are:

    - Introduction Section
    - Literature Review
    - Theoretical Background
    - Evaluation of the first ICT-Artifact
    - Evaluation of the second ICT-Artifact
    - Evaluation of Combined ICT-Artifacts
    - Outcomes from the three evaluations

- Discission and Conclusion Sections

For the “Third Article: The Design Science Evaluation on GeoBlockchain” the research study used the following Research Methodologies:

- Kernel Theory: Venable, Pries Heje, and Baskerville's design science evaluation framework, which outlines why, when, how, and what to evaluate in a design cycle.
- Evaluating each Cycle of the designed ICT Artifact based on Users and Stakeholders involvement.
    - Incorporating usability and user engagement in this process is very important.
    - Users and stakeholders were engaged during the design, development, and evaluation phases until the final production solution outcome.
        - 1st Cycle – Initial Requirements
        - 2nd Cycle – During Design Process
        - 3rd Cycle – During Development Process
        - 4th Cycle – During Initial Testing Process
        - 5th Cycle – During Evaluation Process
        - 6th Cycle – During Pilot Operation
        - 7th Cycle – Final Feedback/ Go Live – Production

Location and Collaboration

For the “First Article: A systematic literature review of GeoBlockchain” the study searched previous research on Online University Libraries and other scholars’ databases. For the

“Second Article: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case” and “Third Article: The Design Science Evaluation on GeoBlockchain”, users and stakeholders from land management and logistics industries provide feedback for a land ownership use case and supply chain use case scenarios during the design and evaluation processes.

Roles and Responsibilities

The researcher is the main role on the research under the “First Article”. The main responsibilities were to conduct the systematic literature review process and to provide the first article study as “A systematic literature review of GeoBlockchain”.

Following with the “Second Article” and “Third Article” the researcher, users and stakeholders are the main participants on both studies study. The researcher is the main role for “Second Article” and “Third Article”, and his responsibility was to conduct the Design Science Research methodologies and to collaborate with the users and stakeholders from the land management and logistics group, in order, to build and evaluate each cycle of the designed ICT Artifacts.

Duration and Overall Timeframe

For each article research study, a systematic scrum project management methodology which is a form of agile method for continuous improvement. The systematic iteration process was conducted with unique steps called sprints for specific assigned milestones. Each milestone was reviewed and refined in a sprint retrospective and any necessary changes were made before

starting the next sprint. Also, time was allocated for refinements, review, and feedback for each step as a result to minimize the risk and gaps through the full dissertation research study.

Table 1. First Article – Agile Scrum Methodology

Tasks	Month/Year	Sprint Milestones	Refine Milestones	Review and Feedback
1	March/2021	Step-1		Step-1
2	April/2021	Step-2	Step-1	Step-1, Step-2
3	April/2021	Step-3	Step-2	Step1-, Step-2, Step-3
4	May/2021	Step-4	Step-3, Step-4	Step-1, Step-2, Step-3, Step-4

Table 2. Second Article – Agile Scrum Methodology

Tasks	Month/Year	Sprint Milestones	Refine Milestones	Review and Feedback
1	June/2021	Step-1, Step-2		Step-1, Step-2
2	July/2021	Step-3, Step-4	Step-1, Step-2	Step-1, Step-2, Step-3, Step-4
3	August/2021	Step-5, Step-6	Step-3, Step-4	Step-1, Step-2, Step-3, Step-4, Step-5, Step-6
4	September/2021	Step-7, Step-8	Step-5, Step-6, Step-7, Step-8	Step-1, Step-2, Step-3, Step-4, Step-5, Step-6, Step-7, Step-8

Table 3. Third Article – Agile Scrum Methodology

Tasks	Month/Year	Sprint Milestones	Refine Milestones	Review and Feedback
1	September/2021	Step-1, Step-2, Step-3		Step-1, Step-2, Step-3
2	October/2021	Step-4, Step-5, Step-6	Step-1, Step-2, Step-3	Step-1, Step-2, Step-3, Step-4, Step-5, Step-6
3	November/2021	Step-7, Step-8	Step-4, Step-5, Step-6, Step-7, Step-8	Step-1, Step-2, Step-3, Step-4, Step-5, Step-6, Step-7, Step-8

Table 4. Full Research Dissertation - Agile Scrum Methodology

Tasks	Month/Year	Sprint Milestones	Refine Milestones	Review and Feedback
1	November/2021	Finalize Research Write Up	Finalize Research Write Up	Finalize Research Write Up
2	December/2021	Dissertation Day	Presentation	Finalize Research Write Up, Presentation

References

1. Croxson, A., Sharma, R., & Wingreen, S. (2019). Making Sense of Blockchain in Food Supply-Chains 2 Background Review. 1–11.

2. D. Oppong-Tawiah, J. Webster, S. Staples, A. F. Cameron, A. Ortiz de Guinea, and T. Y. Hung, "Developing a gamified mobile application to encourage sustainable energy use in the office," J. Bus. Res., vol. 106, no. November 2017, pp. 388–405, 2020.

3. Garcia-Teruel, R.M. (2020). "Legal challenges and opportunities of blockchain technology in the real estate sector", Journal of Property, Planning and Environmental Law, V ol. 12 No. 2, pp. 129-145. https://doi.org/10.1108/JPPEL-07-2019-0039.

4. H. Gimpel, V. Graf-Drasch, R. J. Laubacher, and M. Wöhl, "Facilitating like Darwin: Supporting cross-fertilisation in crowdsourcing," Decis. Support Syst., vol. 132, no. August 2019, p. 113282, 2020.

5. Koh, L., Dolgui, A., Sarkis, J. (2020). Blockchain in transport and logistics - paradigms and transitions, International Journal of Production Research, 58:7, 2054- 2062, https://doi.org/10.1080/00207543.2020.1736428.

6. Kamel Boulos, M. N., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. International Journal of Health Geographics, 17(1), 25. https://doi.org/10.1186/s12942-018-0144-x

7. Montes, G. A., & Goertzel, B. (2019). Distributed, decentralized, and democratized artificial intelligence. Technological Forecasting and Social Change, 141, 354- 358. doi:10.1016/j.techfore.2018.11.010

8. Pahl, C., El Ioini, N., Helmer, S., Lee, B., & Ieee. (2018). An Architecture Pattern for Trusted Orchestration in IoT Edge Clouds. New York: Ieee.

9. Ryskeldiev, B., Ochiai, Y., Cohen, M., & Herder, J. (2018). Distributed metaverse: Creating decentralized blockchain-based model for peer-To-peer sharing of virtual spaces for mixed reality applications. ACM International Conference Proceeding Series. https://doi.org/10.1145/3174910.3174952

10. Sharma, R. S., Wingreen, S., Kshetri, N., & Hewa, T. M. (2019). Design principles for use cases of blockchain in food supply chains. 25th Americas Conference on Information Systems, AMCIS 2019, 1–10. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1300 &context=amcis2019

11. Wingreen, S., Sharma, R., jahanbin, pouyan, Wingreen, S., & Sharma, R. (2019). a Blockchain Traceability Information System for Trust Improvement in Agricultural Supply Chain. Research-in-Progress Papers, 5–15. Retrieved from https://aisel.aisnet.org/ecis2019_rip/10

12. Yuan, Y., & Wang, F. Y. (2016). Towards blockchain- based intelligent transportation systems. IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC, (October 2017), 2663–2668. https://doi.org/10.1109/ITSC.2016.779598

Chapter 2: A Systematic Literature Review of GeoBlockchain

First Article

Abstract

Blockchain is primarily known for cryptocurrencies but has been proposed for a variety of other uses, such as smart contracts. Bitcoin, the main, and most demanding cryptocurrency have helped and hurt blockchain technology. This is because of people's uncertainty, luck of knowledge and the limited amount of successful deployed artifacts that little show the real value of blockchain. However, Bitcoin-cryptocurrency is a powerful blockchain use case, and it has proven that distributed ledger technology works. Also, Blockchain has also been proposed to be used for certain map applications. For example, blockchain has been described for storing differences between what a car sensor detects and a navigation map. It has been suggested to use geodesic grids of discrete cells to register land ownership on a blockchain.

On the other hand, it has led many people, including some business leaders, to believe that blockchain is not only useful for trading speculative currency but we are starting to see strong use cases for blockchain in business settings for supply chain and land management and specifically through the power of geospatial technology. The purpose of this study is to examine any existing research and literature on Blockchain and Geospatial technologies via an extensive review of the literature to justify the significance of the problem including the key conceptual/theoretical underpinnings for the dissertation research as a whole.

Keywords: GeoBlockchain, Blockchain, Spatial, Geospatial, GIS, Geographic Information Systems

Introduction

A blockchain is a growing list of records, called blocks, that are linked (chained) using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data (generally represented as a Merkle tree). A blockchain is typically, but not necessarily, a distributed ledger, managed by a peer-to-peer network collectively adhering to a protocol for inter-node communication and validating new blocks [13, 14, 15, 18, 22]. It is a way to build trusted data in a distributed, unalterable ledger that records the history of immutable transactions. When a record is submitted to the blockchain it is stored in a distributed network system with multiple ledgers. Transparency and visibility among participants are valuable benefits while the risk of non-accurate data and the overall cost of legal procedures to validate the information are minimized. Blockchain is a method to share and collaborate using trusted data across distributed ledgers and computers [20]. Every participant in the blockchain can validate any information at any time based on assigned rules and roles.

An alternative way to explain blockchain is a decentralized ledger that removes the middleman from the equation. That makes transactions faster and provides everyone on the blockchain one version of the truth [3]. It is also a purely digital technology, so it eliminates the inefficiencies and inaccuracies of paper-based transactions. Blockchain can be used to record the sale of personal property; for instance, a quantity of cryptocurrency exchanged between two parties [1, 5, 18]. It can also record the details of a land transfer, with two citizens exchanging the property and the assessor's office, tax department, and public records office recording it. The main advantages of blockchain are speed of transactions, data accessibility, and data accuracy [1, 6].

There are three main types of blockchain frameworks that have been designed, developed, and implemented into research and industry for the public and private sectors: Public, Private, and Hybrid Blockchain Frameworks.

A public blockchain has no access restrictions. Anyone with an Internet connection can send transactions to it as well as become a validator (i.e., participate in the execution of a consensus protocol) [9]. In the case of a public blockchain, it can comprise several thousand computers. Every transaction that occurs among those parties is validated by and recorded on each computer, or node in the blockchain. That transaction becomes a new block, and the blocks are organized chronologically to form a blockchain. Storing data redundantly across many computers makes it more accessible and transparent to all participants, and also much harder to alter or hack. Some of the largest, most known public blockchains are the Bitcoin and the Ethereum blockchains [10, 11, 12].

A private blockchain requires permission to join, as invited by the network administrators [15, 16]. Participant and validator access is restricted. To distinguish between open blockchains and other peer-to-peer decentralized database applications that are not open ad-hoc compute clusters, the terminology Distributed Ledger (DLT) is sometimes used for private blockchains [11, 12]. In the case of a private blockchain, the ledger might involve several computers run by business partners. Most of the private blockchains use a voting system to invite, request, accept and remove organization participants into the private blockchain network [13, 16]. Some of the largest, most known private blockchains are the Hyperledger Fabric and the Ripple (XRP) blockchains [16, 17].

A hybrid blockchain has a combination of private (centralized) and public (decentralized) features. A sidechain is a designation for a blockchain ledger that runs in parallel to a primary blockchain. Entries from the primary blockchain can be linked to and from the sidechain. The sidechain can otherwise operate independently of the primary blockchain (e.g., by using an alternate means of record keeping, alternate consensus algorithm, etc.).

Geographic Information Systems (GIS), also known as spatial information systems, are digital systems for collecting, storing, analyzing, and visualizing spatial data. GIS is a unique category of information system where the various spatial properties of data can be defined in space as points, lines, or polygons and that can be manipulated by a GIS system for spatial and non-spatial analyses [13, 14, 15].

GIS can be applied in many ways: urban planning, architecture, preservation of environment, cadaster, logistics, real estate, agriculture, and spatial planning. GIS has the power to analyze and incorporate a variety of datasets in infinite ways; therefore, it can be advantageous for every industry from agriculture, utilities, real estate, land ownership and supply chain to implement spatial information systems [7, 19, 21]. For instance, a cadaster is detailed recording of land information in a real estate system, which has comprehensive legal documentation, including the dimensions, and precise location of land parcels. Cadaster systems manage and control land ownership with diagrams, plans, maps, and charts to insure reliable facts about a specific land. This information forms the base attributes of GIS-based Cadaster Land Information Systems.

This research article includes a systematic literature review on blockchain and geospatial technology. In other words, we can call this marriage-integration a GeoBlockchain where a

transaction occurred, suggesting combining blockchain with GIS, and showing transactions on a map [2]. But how is that different from a typical blockchain and how Blockchain and Geospatial technologies work together?

The study will examine for any relationship between Blockchain, and Geographic Information Systems Technologies as related to a combined integration from previous research by examining the adoption within industry sectors, regions, and technology providers. Also, to identify the need for any new integration between the two technologies and if it can be used for cadaster-land ownership and supply chain examples.

For example, the study will research the need of a new GeoBlockChain ("GBC") tool that can be used to support the analysis of spatial-temporal trends of blockchain transactions via a geospatially-enabled blockchain. Also, the opportunity for a GeoBlockchain application for real estate that could provide a protocol that allows for a complete real estate transaction, which can offer at least the same guarantees for both the signatories and for third parties as current procedures.

Finally, the potential for a Geoblockchain supply chain web application, that companies might use a distributed ledger to record and to track the movement of goods geolocations. That could mean tracking where and how a shipment of fresh fruit changes hands during its journey to the supermarket.

Research Question

The purpose of this study is to examine any existing research and literature on Blockchain and Geospatial technologies and to compare the results and to report the relationship between the two. A systematic literature review is employed to explore if a GeoBlockchain could exists or not, and if it could contribute to knowledge. The research questions are defined as:

- What relationship, if any, exists between Blockchain and Geographic Information Systems Technologies as related to a combined integration?
- Can these two technologies be integrated together?
- What previous research exists regarding a GeoBlockchain combination?

SLR Analysis Methodology

The Systematic Literature Review Methodology will follow a waterfall approach with four main SLR objectives. This approach will be processed in a linear way from the beginning to the end, starting with the first SLR objective execution up to the fourth SLR objective as shown in Figure-1. Each SLR objective will include unique criteria processing steps and sub-steps for each objective.

- Objective-A

Starting with the first Objective and Step-1 criterion in Figure-1, existing literature was collected from existing scholars' libraries databases. The following library databases: Web of Sciences database, Claremont Graduate University library, MIT Library, and Harvard Business School library were used for Step-2 criterion. The main reason of this selection is because of the

valid content from previous reviews such as publication year and number of citations and secondly, based on the accessibility and permission to download the publication files. I acknowledge that might be a limitation with the number of database libraries and number of queries returns, but this approach was based on research interest and involvement on Blockchain and Geospatial technologies innovation and online curriculums.

- Objective-B

The first step (Step 1) in Objective-B, will continue after the finalization from Objective-A. The main goal was to identify the main settings criteria such as the main query keywords, terminologies that both technologies (Blockchain and Geospatial) often use. After the analysis and identification in Step-1, the final keywords that were used for the systematic literature review search queries are: blockchain, distributed ledgers, coordinates, spatial, GIS, and geographic information systems (Step-2). The total number of research article that were returned in Step-3 are 159 as shown in Figure-1 and Figure-2.

- Objective-C

The next phase of the analysis is the article scanning methodology with two main modules: Step-1 for a light scanning and Step-2 for a full scanning article. During high-level scanning, all the selected 159 selected articles, under Objective-B title, were read based on the title, abstract, and introduction sections. The outcome result from the first module was the selection of 72 articles and the remaining 87 were excluded because of unrelated described topics. In Step-2 the analysis will continue with the 72 articles for a full scanning and proofread.

The methodology that was used on this module step was to fully read, examine, and review each article separately.

- Objective-D

Steps 1 and 2 were focused on the pre-decision phase of the final selection that will be used during the final analysis as explained in Objective-E. Out of the 72 articles, 58 were not selected because of unrelated literature, content, methodology and concepts. The remaining 29 articles were selected for a final full analysis, and each article citation was exported for a sanity check to identify any duplicates (Figure-3).

- Objective-E

As a final step, Objective-E section will provide the detailed outcome from all the final 29 articles. The results will be presented with a visual aid such as table, graph and chart and each result will be explained based on the findings. At the end of this research a summary discussion and conclusion will follow to answer the research questions and to provide any recommendations and limitations.

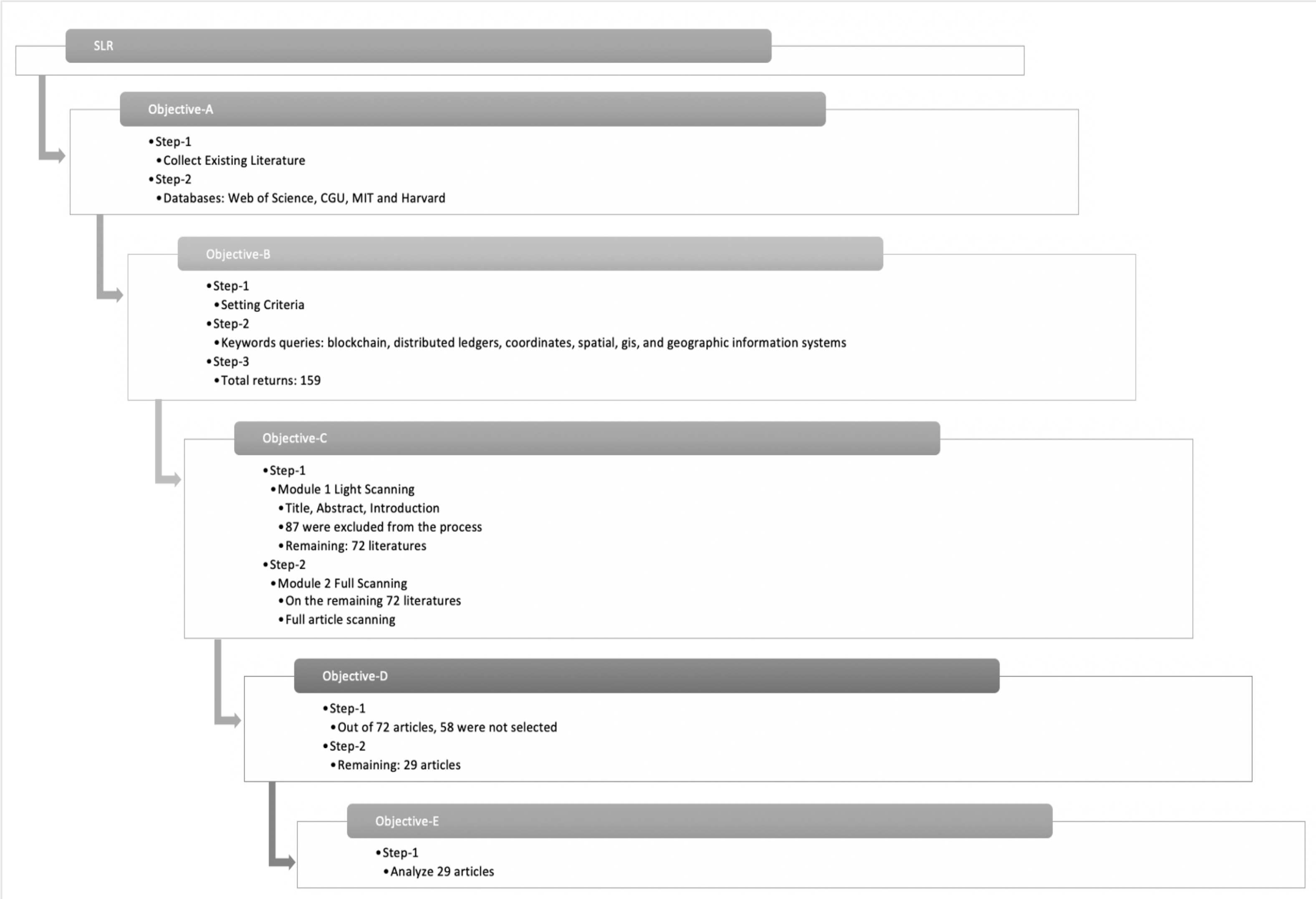
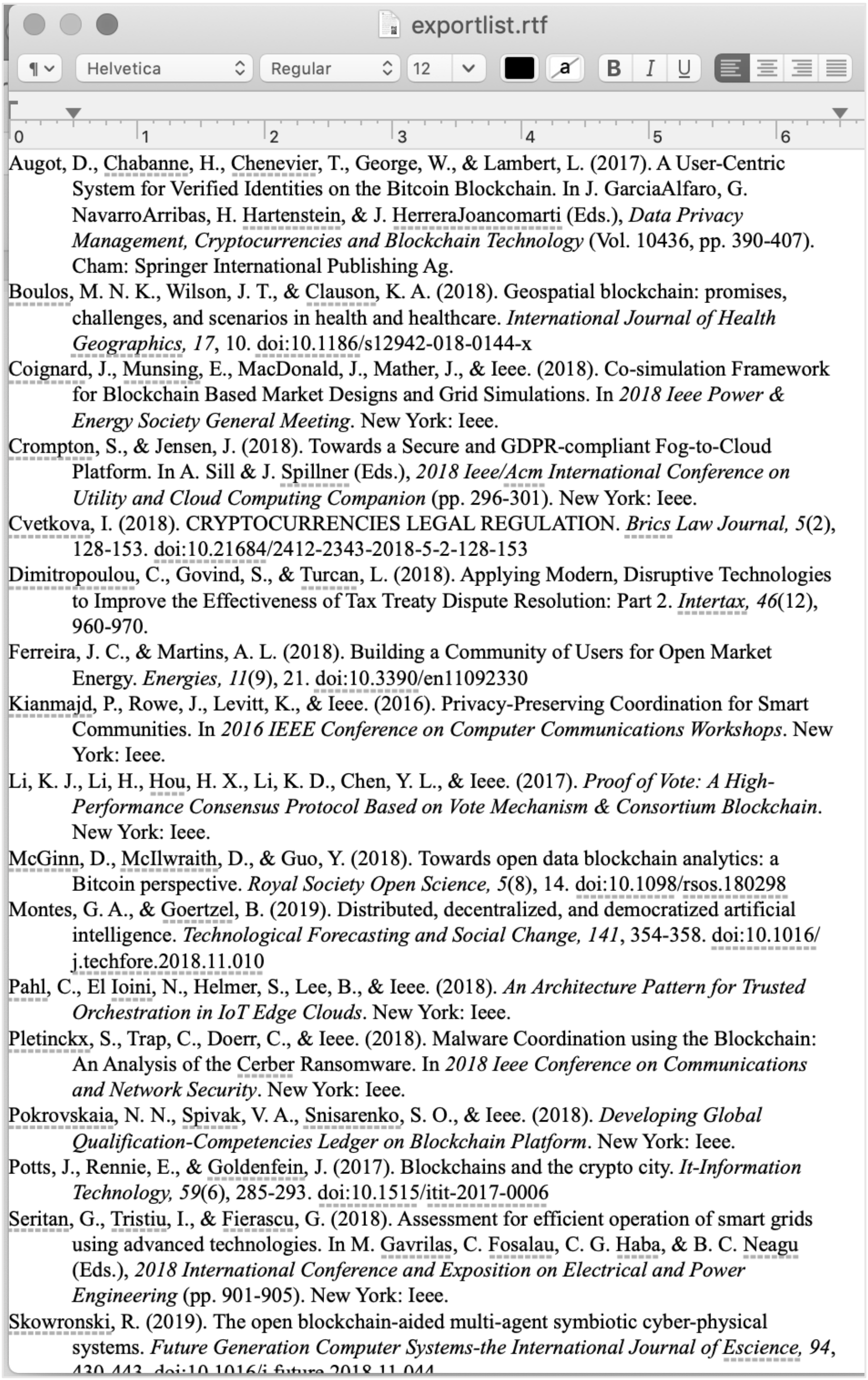


Figure-1: SLR Methodology

```
================================
PUBLICATION ARTICLES
KEYWORDS: blockchain, distributed ledgers, coordinates, spatial, gis, and geographic information systems
RESULTS: 159
================================

TY  - CHAP
A2  - GarciaAlfaro, J.
A2  - NavarroArribas, G.
A2  - Hartenstein, H.
A2  - HerreraJoancomarti, J.
AB  - We present an identity management scheme built into the Bitcoin blockchain, allowing for identities that are as indelible as the blockchain itself. Moreover, we take advantage of Bitcoin's decentralized nature to facilitate a shared control between users and identity providers, allowing users to directly manage their own identities, fluidly coordinating identities from different providers, even as identity providers can revoke identities and impose controls.
AD  - [Augot, Daniel
George, William] INRIA, Palaiseau, France. [Augot, Daniel
George, William] Ecole Polytech, Lab LIX, Palaiseau, France. [Augot, Daniel
George, William] CNRS, UMR 7161, Palaiseau, France. [Augot, Daniel
George, William] Univ Paris Saclay, Paris, France. [Chabanne, Herve
Chenevier, Thomas
Lambert, Laurent] OT Morpho, Issy les Moulineaux, France. [Chabanne, Herve] Telecom ParisTech, Paris, France.
George, W (reprint author), INRIA, Palaiseau, France.
George, W (reprint author), Ecole Polytech, Lab LIX, Palaiseau, France.
George, W (reprint author), CNRS, UMR 7161, Palaiseau, France.
George, W (reprint author), Univ Paris Saclay, Paris, France.
daniel.augot@inria.fr
herve.chabanne@morpho.com
thomas.chenevier@morpho.com
wgeorge@lix.polytechnique.fr
AN  - WOS:000463362100022
AU  - Augot, D.
AU  - Chabanne, H.
AU  - Chenevier, T.
AU  - George, W.
AU  - Lambert, L.
CY  - Cham
DO  - 10.1007/978-3-319-67816-0_22
KW  - Bitcoin blockchain
Identity proofs
Discrete Logarithm REPresentation
(DLREP)
Personal Identity Management Systems (PIMS)
LA  - English
N1  - ISI Document Delivery No.: BM4IG
Times Cited: 4
Cited Reference Count: 24
Cited References:
     Abiteboul S, 2015, COMMUN ACM, V58, P32, DOI 10.1145/2670528
     Ali M, 2016, PROCEEDINGS OF USENIX ATC '16: 2016 USENIX ANNUAL TECHNICAL CONFERENCE, P181
     Antonopoulos A. M., 2015, MASTERING BITCOIN
     Brands S., 2000, RETHINKING PUBLIC KE
     Camenisch J, 2012, IEEE SECUR PRIV, V10, P80, DOI 10.1109/MSP.2012.7
     Charlon F., 2011, OPEN ASSETS PROTOCOL
     Garay J, 2015, LECT NOTES COMPUT SC, V9057, P281, DOI 10.1007/978-3-662-46803-6_10
     Hardjono T., 2016, ANONYMOUS IDENTITIES
     Hay S., 2017, BITCOIN VS ETHEREUM
     Jacobovitz O., 2016, BLOCKCHAIN IDENTITY
     Liu YB, 2015, IMC'15: PROCEEDINGS OF THE 2015 ACM CONFERENCE ON INTERNET MEASUREMENT CONFERENCE, P183, DOI 10.1145/2815675.2815685
     Miers I., 2016, FINANCIAL CRYPTOGRAP
     Nakamoto S. 2008. BITCOIN PEER TO PEER
```

Figure-2: Articles Query Results


exportlist.rtf

Augot, D., Chabanne, H., Chenevier, T., George, W., & Lambert, L. (2017). A User-Centric System for Verified Identities on the Bitcoin Blockchain. In J. GarciaAlfaro, G. NavarroArribas, H. Hartenstein, & J. HerreraJoancomarti (Eds.), *Data Privacy Management, Cryptocurrencies and Blockchain Technology* (Vol. 10436, pp. 390-407). Cham: Springer International Publishing Ag.

Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. *International Journal of Health Geographics, 17*, 10. doi:10.1186/s12942-018-0144-x

Coignard, J., Munsing, E., MacDonald, J., Mather, J., & Ieee. (2018). Co-simulation Framework for Blockchain Based Market Designs and Grid Simulations. In *2018 Ieee Power & Energy Society General Meeting*. New York: Ieee.

Crompton, S., & Jensen, J. (2018). Towards a Secure and GDPR-compliant Fog-to-Cloud Platform. In A. Sill & J. Spillner (Eds.), *2018 Ieee/Acm International Conference on Utility and Cloud Computing Companion* (pp. 296-301). New York: Ieee.

Cvetkova, I. (2018). CRYPTOCURRENCIES LEGAL REGULATION. *Brics Law Journal, 5*(2), 128-153. doi:10.21684/2412-2343-2018-5-2-128-153

Dimitropoulou, C., Govind, S., & Turcan, L. (2018). Applying Modern, Disruptive Technologies to Improve the Effectiveness of Tax Treaty Dispute Resolution: Part 2. *Intertax, 46*(12), 960-970.

Ferreira, J. C., & Martins, A. L. (2018). Building a Community of Users for Open Market Energy. *Energies, 11*(9), 21. doi:10.3390/en11092330

Kianmajd, P., Rowe, J., Levitt, K., & Ieee. (2016). Privacy-Preserving Coordination for Smart Communities. In *2016 IEEE Conference on Computer Communications Workshops*. New York: Ieee.

Li, K. J., Li, H., Hou, H. X., Li, K. D., Chen, Y. L., & Ieee. (2017). *Proof of Vote: A High-Performance Consensus Protocol Based on Vote Mechanism & Consortium Blockchain*. New York: Ieee.

McGinn, D., McIlwraith, D., & Guo, Y. (2018). Towards open data blockchain analytics: a Bitcoin perspective. *Royal Society Open Science, 5*(8), 14. doi:10.1098/rsos.180298

Montes, G. A., & Goertzel, B. (2019). Distributed, decentralized, and democratized artificial intelligence. *Technological Forecasting and Social Change, 141*, 354-358. doi:10.1016/j.techfore.2018.11.010

Pahl, C., El Ioini, N., Helmer, S., Lee, B., & Ieee. (2018). *An Architecture Pattern for Trusted Orchestration in IoT Edge Clouds*. New York: Ieee.

Pletinckx, S., Trap, C., Doerr, C., & Ieee. (2018). Malware Coordination using the Blockchain: An Analysis of the Cerber Ransomware. In *2018 Ieee Conference on Communications and Network Security*. New York: Ieee.

Pokrovskaia, N. N., Spivak, V. A., Snisarenko, S. O., & Ieee. (2018). *Developing Global Qualification-Competencies Ledger on Blockchain Platform*. New York: Ieee.

Potts, J., Rennie, E., & Goldenfein, J. (2017). Blockchains and the crypto city. *It-Information Technology, 59*(6), 285-293. doi:10.1515/itit-2017-0006

Seritan, G., Tristiu, I., & Fierascu, G. (2018). Assessment for efficient operation of smart grids using advanced technologies. In M. Gavrilas, C. Fosalau, C. G. Haba, & B. C. Neagu (Eds.), *2018 International Conference and Exposition on Electrical and Power Engineering* (pp. 901-905). New York: Ieee.

Skowronski, R. (2019). The open blockchain-aided multi-agent symbiotic cyber-physical systems. *Future Generation Computer Systems-the International Journal of Escience, 94*, 430-443. doi:10.1016/j.future.2018.11.044

Figure-3: Articles Export List

SLR Analysis Results on Final Articles

This research study analyzed the final 29 articles on blockchain and geospatial technologies adoption and reported the results based on industry sectors (financial, automotive, manufacturing, pharmaceutical, logistics, retail, and healthcare). Also, each industry sector is analyzed against regions (Europe, Asia, North America, Middle East, and the remaining as Others). Next, each region is analyzed against technology providers and specifically on cloud services that they offer blockchain and geospatial infrastructures [4]. For example, Amazon, IBM, Microsoft, Oracle, and SAP. At the end a summary section describes the overall results and provides the relationship between Blockchain, and Geographic Information Systems Technologies as a combined concept.

- Industry Analysis

The financial industry has the most involvement into the selected literature and specifically with cryptocurrency concepts [18]. The results showed that 13 out of the 29 articles are researching cryptocurrency use cases that are based mostly on blockchain and less on geo locations. Also, there is evidence of research on blockchain for smart contracts, online identity management, and transfer of money between financial institutions.

However, In the automotive sector, two articles reference automobile use cases for testing blockchain on vehicles such as BMW, Porsche, and Volkswagen. Also, there is evidence of artifacts that provide simple solutions on web applications that leverage a digital identity capability on blockchain frameworks, such as Bitcoin, Ethereum and Hyperledger Fabric.

Finally, the last 18 articles for the remaining industries (manufacturing, pharmaceutical, logistics, and healthcare) as shown in Table-1 have an interest in blockchain and geospatial technologies. The SLR analysis identified two articles for the manufacturing industry, pharmaceutical with one article, logistics with six articles, retail with three articles and healthcare with two articles. In general, Blockchain and Geospatial technologies are attractive to research that explore tracking problems for the provenance of goods, record of transactions, and management security in distributed databases.

Table 1. Findings based on Industries

	Financial	Automotive	Manufacturing	Pharmaceutical	Logistics	Retail	Healthcare	Total
Final Number of articles	13	2	2	1	6	3	2	29

- Region Analysis

European and Asian regions are the first adopters and existing research shows that work has been done on designing and developing blockchain artifacts for all industries (Table 2). Also, there is an interest of adding location information to the blockchain and to investigate the potential value out of it. This combination could create future use cases and examples that will contribute to knowledge and provide new ground theories. Finally, North America compared to the Middle East region are concentrating mostly on the financial and logistics sectors with more interest on smart cities and government operations (Figure-4) [8].

Table 2. Findings based on Regions and Industries

	Financial	Automotive	Manufacturing	Pharmaceutical	Logistics	Retail	Healthcare
Europe Region	x	x	x	x	x	x	x
Asia Region	x	x	x	x	x	x	x
NA Region	x		x		x	x	
Middle East Region	x				x	x	
Others	x						

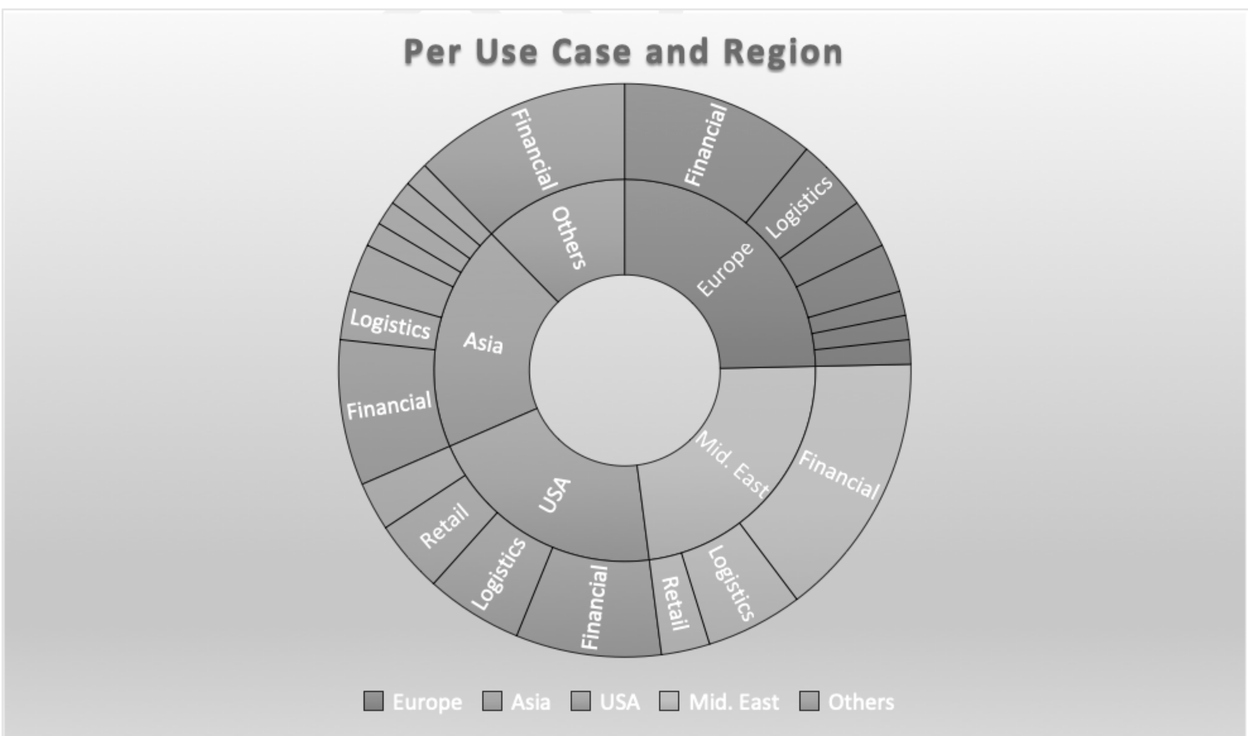


Figure 4. Findings based on per use and regions

- Blockchain Provider Analysis per Region

Infrastructure providers (Amazon, IBM, Microsoft, Oracle, and SAP) are the main technological resources that offer services and tools to develop, implement, test, and deploy either blockchain or GIS in most of the regions (Table-3). Specifically, through cloud services which is easier to access and allocate hardware and software for a short or long period of time. This analysis shows that cloud services are the preferred ways to develop blockchain and geospatial artifacts in most regions. There is an exception in Middle East region, and this might be because of the interest on specific cloud providers that are specialized more in the financial sector.

However, research shows that cloud blockchain providers are the most preferred environments to use because of their scalability and efficiency. Also, another reason is the way blockchain frameworks are developed and architected, so they could communicate through highly available networks and large distributed environment.

Table 3. Findings based on Technology Providers and Regions

	Amazon	IBM	Microsoft	Oracle	SAP
Europe Region	x	x	x	x	x
Asia Region	x	x	x	x	x
USA Region	x	x	x	x	x
Middle East Region	x	x			x
Others	x	x			

Discussion and Summarization

The systematic literature review process helped to explore from existing research the connection between Blockchain, and Geographic Information Systems Technologies as related to a combined integration. The study results shows that the main two regions that are leveraging the two technologies are Europe, and North America, follow by Asia, Middle East, and other regions. We can conclude that the most demanding industry is the financial sector, and the logistics sector ranked at the second place. Also, we have seen a lot of discussion for cloud providers such as IBM, Microsoft, AWS, and others.

Besides that, the systematic literature review analysis provides the insights that these two technologies could be integrated together. There is existing research that demonstrates implementation of blockchain with few geospatial components such as point of interest on the map. Also, specific use cases were mentioned on previous literature such as land information systems and supply chain. Land Information Systems use cadastral maps to show boundaries and ownership of land pieces and detailed information such as identifying numbers, district names, structure, boundaries, and the area size. Most countries today use outdated cadastral management systems, such as the legacy systems explained above, to manage their land ownership. It is important now more than ever to invest in improving these systems of land ownership to be able to fully trust, manage, and exchange the information regarding land ownership among participants such as owners and legal authorities.

On the other hand, the combination of the two technologies can be used to manage real estate transactions. The transaction will be recorded into the ledger with the exchange of a Bitcoin or Ethereum cryptocurrency between two parties. Alternately, traditional financing can

be used, with, for example, wire transfer information being recorded. It can also record the details of the land or property transfer within the legal, tax, and government authorities' systems for confirmation and validation of the transaction. Finally, In the supply chain industry, business leaders can use blockchain to record and monitor the location of any product. For instance, to record where, when, and how a shipment of fresh coffee was transferred from the warehouse to the supplier, and finally, to the local store.

Limitations

Blockchain is a new technology and not easily understood or adopted. There is no clear understanding if the analyzed articles have used public, private, or hybrid blockchain frameworks. Also, there is not sufficient evidence to prove that blockchain could work with other new technologies besides GIS. For example, integration with artificial intelligence, virtual reality, machine learning, and deep learning technologies. Besides that, there is limitation on the low number of published articles, and it will take time until literature will become more mature.

Conclusion and Recommendations

More research should be done into blockchain, geospatial, and other areas so existing literature, artifacts, and the theoretical background can mature. There is a huge benefit as the speed of business and the demands on the industries in different regions continue to intensify. Any new blockchain study that examines the integration with GIS technology as a new GeoBlockchain concept would be an engine for improved research. GeoBlockchain can be

straightforward to conceptualize. That said, the integration of the two technologies, blockchain and geospatial, present some innovative and technological challenges.

By incorporating location intelligence in blockchain, you could give geographic context to blockchain transactions to answer, verify, and secure the “where” of a transaction. In other words, we can assume that GeoBlockchain could study the trends and behaviors of participants (users) geographically and spatially, based on distributed nodes, transactions, and geo locations through the blockchain technology. GeoBlockchain might be used to map visualize points, lines and polygons and shows the importance of geography. Through the power of geography, data scientists should analyze spatially and execute spatial statistics to understand and predict models.

References

1. Augot, D., Chabanne, H., Chenevier, T., George, W., & Lambert, L. (2017). A User-Centric System for Verified Identities on the Bitcoin Blockchain. In J. GarciaAlfaro, G. NavarroArribas, H. Hartenstein, & J. HerreraJoancomarti (Eds.), *Data Privacy Management, Cryptocurrencies and Blockchain Technology* (Vol. 10436, pp. 390-407). Cham: Springer International Publishing Ag.

2. Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. *International Journal of Health Geographics, 17*, 10. doi:10.1186/s12942-018-0144-x

3. Coignard, J., Munsing, E., MacDonald, J., Mather, J., & Ieee. (2018). Co-simulation Framework for Blockchain Based Market Designs and Grid Simulations. In *2018 Ieee Power & Energy Society General Meeting*. New York: Ieee.

4. Crompton, S., & Jensen, J. (2018). Towards a Secure and GDPR-compliant Fog-to-Cloud Platform. In A. Sill & J. Spillner (Eds.), *2018 Ieee/Acm International Conference on Utility and Cloud Computing Companion* (pp. 296-301). New York: Ieee.

5. Cvetkova, I. (2018). CRYPTOCURRENCIES LEGAL REGULATION. *Brics Law Journal, 5*(2), 128-153. doi:10.21684/2412-2343-2018-5-2-128-153

6. Dimitropoulou, C., Govind, S., & Turcan, L. (2018). Applying Modern, Disruptive Technologies to Improve the Effectiveness of Tax Treaty Dispute Resolution: Part 2. *Intertax, 46*(12), 960-970.

7. Ferreira, J. C., & Martins, A. L. (2018). Building a Community of Users for Open Market Energy. *Energies, 11*(9), 21. doi:10.3390/en11092330

8. Kianmajd, P., Rowe, J., Levitt, K., & Ieee. (2016). Privacy-Preserving Coordination for Smart Communities. In *2016 IEEE Conference on Computer Communications Workshops*. New York: Ieee.

9. Li, K. J., Li, H., Hou, H. X., Li, K. D., Chen, Y. L., & Ieee. (2017). *Proof of Vote: A High-Performance Consensus Protocol Based on Vote Mechanism & Consortium Blockchain*. New York: Ieee.

10. McGinn, D., McIlwraith, D., & Guo, Y. (2018). Towards open data blockchain analytics: a Bitcoin perspective. *Royal Society Open Science, 5*(8), 14. doi:10.1098/rsos.180298

11. Montes, G. A., & Goertzel, B. (2019). Distributed, decentralized, and democratized artificial intelligence. *Technological Forecasting and Social Change, 141*, 354-358. doi:10.1016/j.techfore.2018.11.010

12. Pahl, C., El Ioini, N., Helmer, S., Lee, B., & Ieee. (2018). *An Architecture Pattern for Trusted Orchestration in IoT Edge Clouds*. New York: Ieee.

13. Papantoniou, C., & Hilton, B. (2021, January). Enterprise Solutions Criteria in the Age of GeoBlockchain: Land Ownership and Supply Chain. In Proceedings of the 54th Hawaii International Conference on System Sciences (p. 5307).

14. Papantoniou, Constantinos, "Selecting Implementation Criteria in the Age of GeoBlockchain" (2020). AMCIS 2020 Proceedings. 15. https://aisel.aisnet.org/amcis2020/data_science_analytics_for_decision_support/data_science_analytics_for_decision_support/15

15. Papantoniou, C., & Hilton, B. Workflows and Spatial Analysis in the Age of GeoBlockchain: A Land Ownership Example. (2020). AUTOCARTO 2020. https://cartogis.org/docs/autocarto/2020/docs/abstracts/3e%20Workflows%20and%20Spatial%20Analysis%20in%20the%20Age%20of%20GeoBlockchain%20A%20Land.pdf

16. Pletinckx, S., Trap, C., Doerr, C., & Ieee. (2018). Malware Coordination using the Blockchain: An Analysis of the Cerber Ransomware. In *2018 Ieee Conference on Communications and Network Security*. New York: Ieee.

17. Pokrovskaia, N. N., Spivak, V. A., Snisarenko, S. O., & Ieee. (2018). *Developing Global Qualification-Competencies Ledger on Blockchain Platform*. New York: Ieee.

18. Potts, J., Rennie, E., & Goldenfein, J. (2017). Blockchains and the crypto city. *It-Information Technology, 59*(6), 285-293. doi:10.1515/itit-2017-0006

19. Seritan, G., Tristiu, I., & Fierascu, G. (2018). Assessment for efficient operation of smart grids using advanced technologies. In M. Gavrilas, C. Fosalau, C. G. Haba, & B. C. Neagu (Eds.), *2018 International Conference and Exposition on Electrical and Power Engineering* (pp. 901-905). New York: Ieee.

20. Skowronski, R. (2019). The open blockchain-aided multi-agent symbiotic cyber-physical systems. *Future Generation Computer Systems-the International Journal of Escience, 94*, 430-443. doi:10.1016/j.future.2018.11.044

21. Wang, N., Xu, W. S., Xu, Z. Y., & Shao, W. H. (2018). Peer-to-Peer Energy Trading among Microgrids with Multidimensional Willingness. *Energies, 11*(12), 22. doi:10.3390/en11123312

22. Zhou, L. J., Wang, L. C., Sun, Y. R., & Lv, P. (2018). BeeKeeper: A Blockchain-Based IoT System With Secure Storage and Homomorphic Computation. *Ieee Access, 6*, 43472-43488. doi:10.1109/access.2018.2847632

Chapter 3: GeoBlockchain Implementation Solutions Criteria for a Land Ownership and Supply Chain Use Case

Second Article

Abstract

Today, the growing use of public blockchain, private blockchain, and hybrid blockchain advances in geospatial technology. Geography is a significant factor in identifying locations and spatial trends related to blockchain activities through distributed and immutable networks. Besides that, there is a growing understanding that both blockchain and location intelligence have value for many organizations. This study examined the integration of the two technologies and identified the implementation criteria in the age of GeoBlockchain.

The combination of blockchain and geospatial technologies would result in the new concept of GeoBlockchain, defined here as a solution artifact that could be used to trace the trends and behaviors of participants (users) geographically and spatially, based on distributed nodes, transactions, and geo-locations via blockchain technology. Moreover, it will examine the rules and roles of participants within GeoBlockchain by using Q Methodology and Q set.

The result of this research was the design, development, and implementation of two enterprise solution prototypes for land ownership and supply chains. This research indicates that blockchain technology can be integrated with geospatial technology, resulting in the GeoBlockchain implementation.

Keywords: Geospatial, GeoBlockchain, Blockchain, Q-Methodology, Supply chain, Land Ownership

Introduction

Blockchain is a new promising technology that can provide trust, immutability, and transparency to any organization's systems of systems. The first proof-of-concept using blockchain technology was cryptocurrency. This was later developed and implemented for public blockchains such as Ethereum and Bitcoin [33]. While unusual, this use case demonstrated that blockchain technology could orchestrate valid transactions across a distributed network and store those transactions in unalterable ledgers across multiple nodes [23, 24, 28, 32]. Every new ledger transaction is a new block, and all blocks construct the blockchain [27].

Today, we see considerable demand for enterprise technologies that could use private blockchains. The critical advantages of blockchain are the high speed of transactions, trust among participants, and valid accurate data [32]. The value of its use is the increase in trust and fast data collaboration among users while reducing the risk of fraud and the overall cost of monitoring goods and assets through the business chain lifecycle [7].

We are also beginning to observe a high demand for blockchain across both the private and public sectors that incorporate geographic information systems; specifically, land ownership and supply chain use cases. Geographic Information System (GIS) technology, an inherently location-based technology, can help answer the question of where a blockchain transaction has occurred [32].

The combination, and integration, of blockchain with GIS underlie the concept of GeoBlockchain. This new tool can be used to support the analysis of spatial-temporal trends of blockchain transactions via a geospatially-enabled blockchain [15]. But why do we need to integrate geospatial technology with blockchain technology? It has been suggested, that when

designing a blockchain for real estate, it should provide a protocol that allows for a complete real estate transaction, which can offer at least the same guarantees for both the signatories and for third parties as current procedures.

As such, this technology should meet the following criteria: 1) the permissioned blockchain should be controlled by public authorities, and 2) the blockchain should be linked to an official digital ID [12]. Related to supply chain technology, little is understood regarding the disruption blockchain adoption has had on transport and logistics, however, blockchain has the potential to be interlinked with a variety of transportation, logistics, and supply chain activities and methods that rely on organizational and process information [17]. Implicit in both use cases is the locational aspect of these activities. The solution designed, developed, and implemented as part of this study, explicitly includes location.

For this study, the design science research (DSR) methodology was used [18] while the Q Methodology [10] was utilized to investigate participant viewpoints of blockchain and geospatial technologies. Accordingly, the first task was to identify the main components for the GeoBlockchain implementation. For the second task, a list of metrics and criteria were created for the participants for a private blockchain and geographic information system scenario. The third task included the design, development, and implementation of two artifacts using the Hyperledger Fabric framework as the blockchain platform and ArcGIS Enterprise as a geospatial technology platform. The fourth, and final task, included the evaluation of the artifacts and documentation of the findings.

The outcome from these activities is two GeoBlockchain enterprise proof-of-concepts. The first, a web application for a land ownership, and the second, a web application for supply

chain. Both solutions are the result from a co-simulation GeoBlockchain Enterprise framework activity [5].

Literature Review

Geographic Information Systems (GIS), also known as spatial information systems, are digital systems for collecting, storing, analyzing, and visualizing spatial data. GIS is a unique category of information system where the various spatial properties of data can be defined in space as points, lines, or polygons and that can be manipulated by a GIS system for spatial and non-spatial analyses [16].

GIS can be applied in many ways: urban planning, architecture, preservation of environment, cadaster, logistics, real estate, agriculture, and spatial planning [31]. GIS has the power to analyze and incorporate a variety of datasets in infinite ways; therefore, it can be advantageous for every industry from agriculture, utilities, real estate, land ownership and supply chain to implement spatial information systems [14].

On the other hand, when it comes to blockchain technologies, there are mixed views and attitudes from users due to the complexity of the technology, its maturity level, and unconventional initial usage that does not highlight the real value of blockchain. As was mentioned previously, the first implementations of blockchain were public implementations for cryptocurrencies.

Blockchain is a way to build trusted data in a distributed, unalterable ledger that records the history of immutable transactions. When a record is submitted to the blockchain it is stored in a distributed network system with multiple ledgers. Transparency and visibility among

participants are valuable benefits while the risk of non-accurate data and the overall cost of legal procedures to validate the information could be minimized. Blockchain is a new method to share and collaborate using trusted data across distributed ledgers and computers. Every participant in the blockchain can validate any information at any time based on assigned rules and roles.

Some of the more promising applications for blockchain systems are cadaster-land ownership and supply chain. A cadaster is detailed recording of land information in a real estate system, which has comprehensive legal documentation, including the dimensions, and precise location of land parcels [29]. Cadastre systems manage and control land ownership with diagrams, plans, maps, and charts to insure reliable facts about a specific land [4]. These are the base attributes of GIS-based Cadaster Land Information Systems [30].

Land Information Systems use cadastral maps to show boundaries and ownership of land pieces and detailed information such as identifying numbers, district names, structure, boundaries, and the area size [13]. Most countries use outdated cadastral management systems, such as the legacy systems explained above, to manage their land ownership. It is important now more than ever to invest in improving these systems of land ownership to be able to fully trust, manage, and exchange the information regarding land ownership among participants such as owners and legal authorities.

Blockchain can be used to manage real estate transactions. The transaction will be recorded into the ledger with the exchange of a Bitcoin or Ethereum cryptocurrency between two parties. It can also record the details of the land or property transfer within the legal, tax, and government authorities' systems for confirmation and validation of the transaction. In the supply chain industry, business leaders could use blockchain to record and monitor the location

of any product. For instance, to record where, when, and how a shipment of fresh coffee was transferred from the warehouse to the supplier, and finally, to the local store.

As such, the GeoBlockchain can answer questions such as where, why, and how; for example, how might a land transaction or a shipping container take place as a trust-trade exchange between different owners and how might that be verified by legal and private authorities? That brings us to the idea of “trust-free”, the same approach as cryptocurrency’s legal regulations [8].

How is that different from a typical traditional land ownership and supply chain transaction systems, and how might blockchain and geospatial technologies work together to answer the where and why [7, 28, 32]? By incorporating rules and roles into the blockchain, you can provide a trust context based on location to the tabular transaction to answer and explore the “trust” of a transaction [2].

Fundamentals and Theoretical Background

According to Peffers et al., and Hevner et al., the DSR methodology is a design method to build and evaluate an artifact by using existing kernel theories, design principles, design guidelines and providing contribution to practice and knowledge [1, 18]. This study utilized Peffers 6-step process to guide the research activities which include: (1) identify the problem and its motivation, (2) define objectives and components of the solution, (3) design the artifact and its development, (4) demonstrate usage of the artifact, (5) evaluate the artifact by using technological performance and socio-technical assessments, and (6) communicate the findings and contribute to the knowledgebase [18] (Figure 1). This process is an iterative loop that can be

modified and evaluated in each step by having users and stakeholders test and evaluate each step. The goal is to solicit feedback from users and stakeholders in a manner that constantly improves the artifact and at the same time, provides relevance in practice, and rigor in knowledge [1].

This study utilized Q Methodology to solicit participant viewpoints regarding blockchain and geospatial technology to evaluate the industry's implementation and integration perspectives. According to Dennis et. Al, "The main principle of the Q Methodology is to enable researchers to discover and learn about human subjectivity" [10]. Also, in a Q study, "each factor demonstrates a key perspective that exists within the group of study participants". [3]

However, Brown et. al, described Q Methodology as a way to "enable the analysis of these viewpoints holistically, employing a deep quantitative and qualitative investigation", [3, 7, 28, 32].

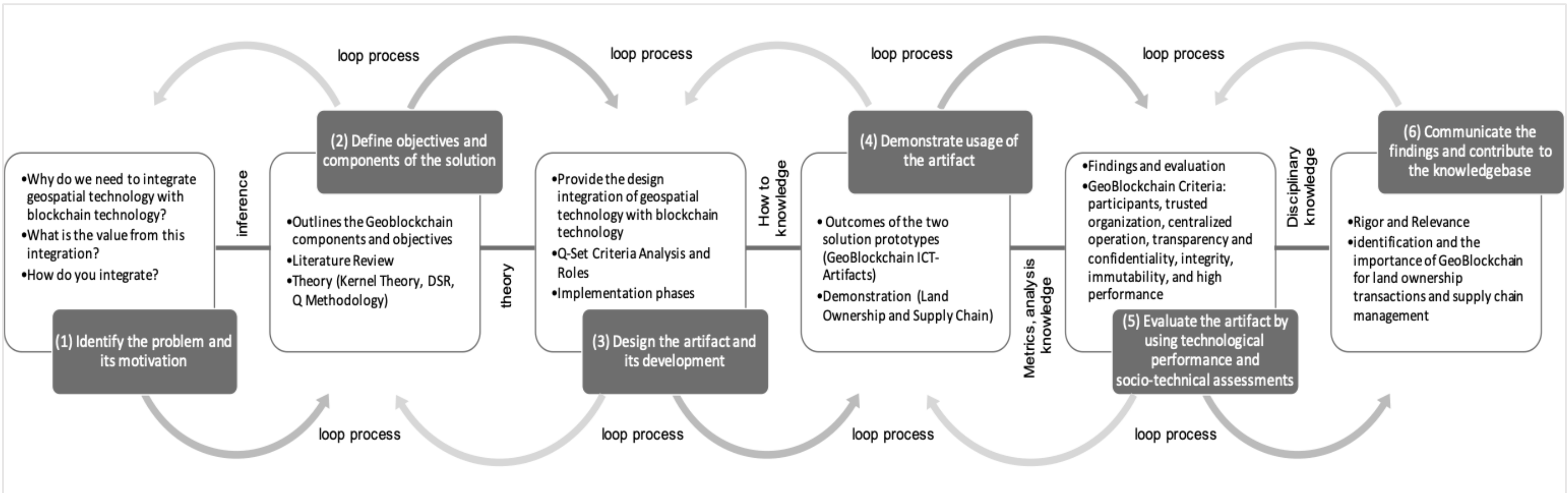


Figure 1. Applied six-step process of Design Science Research

Research Questions

The research questions were defined as:

- What is a possible design of a GeoBlockchain solution?
- What are the main attributes of a GeoBlockchain solution?
- What are the main criteria used in designing a GeoBlockchain enterprise solution and non-enterprise solution?
- What is the importance of roles and rules, in order to build trust among participants, across these two types of solutions?

Methodology

The problem and motivation (1st step of Peffers et al.) is discussed in the Introduction Section. The Literature Review (2nd step) outlines the Geoblockchain components and objectives. Here, Section 4.1 and Section 4.2. (3rd step) provide the design integration of geospatial technology with blockchain technology; Section 4.3 discusses the implementation phases; Section 5.1 and Section 5.2. discusses outcomes (4th step) of the two solution prototypes; the demonstration is provided in Section 5.3.; findings and evaluation (5th step) are explained in Section 6; and rigor and relevance (6th step) are discussed in the Discission and Conclusion Sections.

Since the Q-method is a technique that is specialized for the analysis of peoples' subjective beliefs [7, 32], Q-Set was used for ranking and sorting specific statements and to identify the attributes and criteria for the GeoBlockchain. Land ownership and supply chain use

cases were selected independently for this research because the results from the first article "A Systematic Literature Review of GeoBlockchain", documented that most of the current work in research and industry is mostly focused on those two specific industries. 40 semi-structured interviews were conducted drawing on participants from a land ownership government organization and a private supply chain organization; 20 interviews for each organization. Field notes and reports were collected from each organization to validate the responses using triangulation methods. This activity used the CAQDAs software to analyze the semi-structured interviews, field notes, and reports by using the Strauss and Corbin coding technique [26]. The Q sort process was used to analyze and factor the participants responses from existing surveys within the organization. A statistical quantitative factor analysis technique was used for data reduction and to summarize the variables for the Q Sorting.

As mentioned, blockchain and geospatial are the main technologies that could connect the front-end and back-end components. Specifically, Hyperledger Fabric, an IBM blockchain cloud service provider, was the primary high-performance consensus protocol for the blockchain component [19]. While ArcGIS Enterprise provides the geospatial capabilities and is also used as the cloud technology integration platform.

First Task - Identify GeoBlockchain Components

The conceptual diagram (Figure 2) provides a high-level, conceptual overview of how the Hyperledger Fabric blockchain provider is integrated with ArcGIS Enterprise. Through that combination, the blockchain provider provides encrypted and trusted information to the

geospatial secured cloud that manages the multiple participants that are involved in land ownership and supply chains [6].

The high-level GeoBlockchain architecture illustrates how a blockchain provider (104), e.g., IBM Hyperledger Fabric, is integrated with a mapping program (102), e.g., ArcGIS Enterprise. A server (106), e.g., SQL server, hosts the transactional or other data associated with a location. Spatial data about the location, along with custom user data (108) is provided. The combined spatial and user transaction or other data is provided to blockchain provider (104) to be encrypted as a block on a blockchain. The block is then incorporated into a map by mapping program (102) as one of multiple layers (110) of a map. The information is then stored on server (106). The map and transactional, or other data from the blockchain, can be accessed and viewed by a GeoBlockchain dashboard (112), which may be hosted on server (106) or another server.

The blockchain provider (104) thus provides encrypted and trusted information to a geospatial secured cloud from multiple participants that are involved in the transaction or use case (e.g., land ownership use case). The blockchain can be public, private, hybrid, or a sidechain. For a private blockchain, the validators of the blockchain could be, for example, an administrator of the blockchain provider, the two parties to the transaction, and the server (106). Other combinations of validators are also possible. This provides a private blockchain, keeping the data private, while having the data validated by multiple computers for the various involved parties.

The mapping software (e.g., ArcGIS Enterprise) will leverage the spatial information from the blockchain provider, and it will transform, analyze, and visualize data from the blockchain and geospatial clouds in a GeoBlockchain dashboard. For example, blockchain data is

standardized transactions, legal contracts, private personal information, and financial information from multiple participants, and in the land ownership case, land ownership information [21].

Also, land-cadaster ownership geospatial data includes spatial property data, such as points, lines, and polygons. Spatial data is the geographic representation of the land property parcel data that is exchanged from the blockchain procedure. A cadaster is detailed recording of land information in a real estate system, which has comprehensive legal documentation, including the dimensions, and precise location of land parcels [25]. Cadaster systems manage and control land ownership with diagrams, plans, maps, and charts to insure reliable facts about a specific land. This information forms the base attributes of GIS-based Cadaster Land Information Systems. Conversely, ArcGIS Enterprise leverages the spatial information from Hyperledger Fabric blockchain, and transforms, analyzes, and visualizes the data from both the blockchain and geospatial clouds, and presents that information in a GeoBlockchain dashboard.

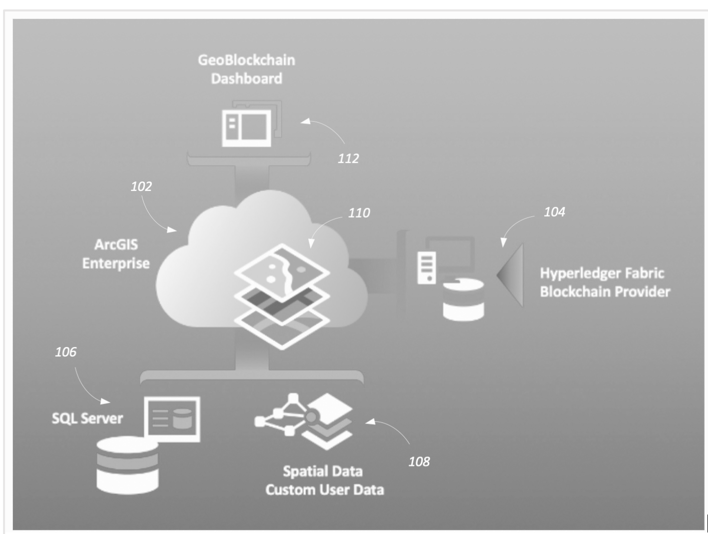


Figure 2. High level block diagram of a GeoBlockchain architecture

Second Task - Q-Set Criteria Analysis

Seven Q-Set criteria were defined for the two GeoBlockchain enterprise solution-prototypes based on the Q methodology fundamentals (Table 1). Participants are power users from different entities, departments, and divisions that could participate in a GeoBlockchain scenario, specifically in a land ownership and supply chain examples. Trusted Organizations are the authorities that could control the policies, rules, and roles between the participants. Centralized operation is unique for each participant. All participants could share secured information which was made transparent through the Geoblockchain. Any transaction data that is written cannot be manipulated as a result to have integrity and immutability. Lastly, the high-performance criterion is important for system scalability and system performance due to the huge amount of data that is recorded from spatial and non-spatial transactions.

Table 1. Q-Set Criteria

N/A	Q-Set Criteria	Description
1	Participants	Multiple organizations participated in the land ownership and supply chain examples
2	Trusted Organization	The main authority in the blockchain that controls policies, rules, and roles
3	Centralized Operation	Every participant control and manages their transaction information from the GeoBlockchain
4	Transparency and confidentiality	All participants could share encrypted information through the GeoBlockchain
5	Integrity	All transactions are written into the blockchain history for provenance
6	Immutability	Data on the GeoBlockchain cannot be changed easily or deleted
7	High Performance	System scalability and system behavior from big GeoBlockchain datasets either text (blockchain) or spatial (geospatial)

Third Task - GeoBlockchain ICT Artifacts

For the third task, the artifacts were created with the integration of Hyperledger Fabric Cloud and ArcGIS Enterprise. GeoBlockchain roles were identified for all participants for both scenarios (Tables 2 and 3). Both GeoBlockchain examples used the same number of participant roles for better comparison and evaluation.

Table 2 displays GeoBlockchain participants and roles for a land ownership example, artifacts are created with the integration of Hyperledger Fabric Cloud and ArcGIS Enterprise. GeoBlockchain participant roles are set forth in Table 3. The cloud-based GeoBlockchain Web Dashboard of Figure 4 can be used by participants. Different roles with specific profiles are used, and all transactions (spatial and not spatial) are recorded into the GeoBlockchain. Different roles with specific profiles were leveraged through those scenarios, and all transactions (spatial and not spatial) were recorded into the GeoBlockchain.

In this study, the GeoBlockchain is a private blockchain, with validating computers for the blocks of the blockchain being limited to those granted permission under the established rules and roles for the private GeoBlockchain. The validating computers can be all the participants listed in Table 3, or a subset.

Table 3 displays GeoBlockchain participants and roles for a supply chain, the participants in this example include an administrator, supplier, port, distribution center, shipping and trucking participants. Each has specific controlled roles, as set forth by the GeoBlockchain tool rules. The purpose of the unique roles and rules is to provide trust and transparency through the workflow process. Trusted Organizations, in this case, are private and legal authorities who orchestrate and manage the interaction between participants in the GeoBlockchain. The

orchestrators are responsible for the approved rules, roles, and the smooth transaction between participants in order to establish transparency and confidentiality. The goal is to have integrity through the process and between the participants.

Table 2: GeoBlockchain participants and roles for a land ownership example

Land Ownership Example	
Participants	Responsibilities
GeoBlockchain-Administrator	Administrator has full privileges to Hyperledger Fabric and ArcGIS Enterprise
GeoBlockchain-Seller	Participant that is added to GeoBlockchain with controlled roles only for "Seller" Group
GeoBlockchain-Legal Authority	Participant that is added to GeoBlockchain with controlled roles only for "Legal Authority" Group
GeoBlockchain-Land Owners	Participant that is added to GeoBlockchain with controlled roles only for "Land Owners" Group
GeoBlockchain-Customers	Participant that is added to GeoBlockchain with controlled roles only for "Customers" Group
GeoBlockchain-Stakeholders	User that is added to Blockchain with controlled roles only for "Stakeholders" Group

Table 3: GeoBlockchain participants and roles for a supply chain example

Supply Chain Example	
Participants	Responsibilities
GeoBlockchain-Administrator	Administrator has full privileges to Hyperledger Fabric and ArcGIS Enterprise
GeoBlockchain-Supplier	Participant that is added to GeoBlockchain with controlled roles only for "Supplier" Group
GeoBlockchain-Port	Participant that is added to GeoBlockchain with controlled roles only for "Port" Group
GeoBlockchain-Distribution Center	Participant that is added to GeoBlockchain with controlled roles only for "Distribution Center" Group
GeoBlockchain-Shipping	Participant that is added to GeoBlockchain with controlled roles only for "Ship" Group
GeoBlockchain-Trucking	User that is added to Blockchain with controlled roles only for "Trucking" Group

Implementation Phases

There were three main implementation phases for the creation of the two GeoBlockchain prototypes.

Phase-1 was the design and development of the back-end components where the Hyperledger Fabric blockchain API service was utilized along with the ArcGIS Enterprise API rest service. Phase-2 was the creation of various coding artifacts that connect the blockchain API services and geospatial API services resulting in the creation of the GeoBlockchain.

Finally, Phase-3 involved the creation of the front-end; an interactive dashboard that visualizes the GeoBlockchain results in a web-based application that includes various widgets and map-based output. This dashboard also allows the participants to interact with the two main systems, and to add and edit land ownership transactions.

- Architecture Diagram

The GeoBlockchain architecture outlines these three main phases with four main important processes: Configure (202), Collaborate (204), Blockchain (206), and Visualize (208) processes (Figure 3).

- GeoBlockchain Workflow Processes

The configure process (202) contains the implementation and integration of Hyperledger Fabric (216) API's with ArcGIS Enterprise (102) API's. Hyperledger Fabric API will communicate with ArcGIS Enterprise API through a custom API. The KOOP API framework (210) is utilized, a compatible provider for ArcGIS Enterprise. The purpose of a custom KOOP REST API is to translate the data record into a geospatial format such as the GeoJSON format. GeoJSON is an open standard format designed for representing geographical features, along with their non-spatial attributes. The features include points (e.g., addresses and locations), line strings (e.g., streets, highways, and boundaries), polygons (e.g., countries, provinces, tracts of land), and multi-part collections of these types.

GeoJSON provides the capability to geolocate all the raw location data from the blockchain, for example, latitude and longitude coordinates into GeoJSON points. These points

are included in GeoJSON layers (212), which are provided to ArcGIS Enterprise (102). On the other hand, ArcGIS Enterprise datasets include spatial information; for example, spatial points, lines, and polygons which is necessary for a land ownership use case as land datasets include polygons, lines, and points.

The collaborate process (204) uses this custom API (210) with the main goal to share trusted and valid information between blockchain and geospatial platforms. In addition, the two technologies create and update records, either into the ArcGIS Enterprise or into Hyperledger Fabric, or a separate server. A dashboard (214) associated with ArcGIS Enterprise (102) is used to update web maps.

The Blockchain process provides the technological foundation for all participants involved in a land ownership transaction. Each participant (buyer, seller, and legal authority) has specific roles and rules assigned within the blockchain. This process provides each participant the ability to agree or not agree with information that is to be recorded into the blockchain ledger. For instance, financial information such as cost and price, legal information such as land titles and land property history, spatial information such as parcel area and parcel measurements.

The various computers of the blockchain (104) in Figure 2 access a Hyperledger Fabric (216) in Figure 3. The Hyperledger Fabric (216) has its own APIs, one of which can be used to access a Blockchain JS Web App transactions interface (218). Another API can be used to access a Blockchain Representational State Transfer (REST) Web service (220). The Visualize process (208) provides a map dashboard component that will be the front-end interaction between the participants into the land ownership and supply chain transactions.

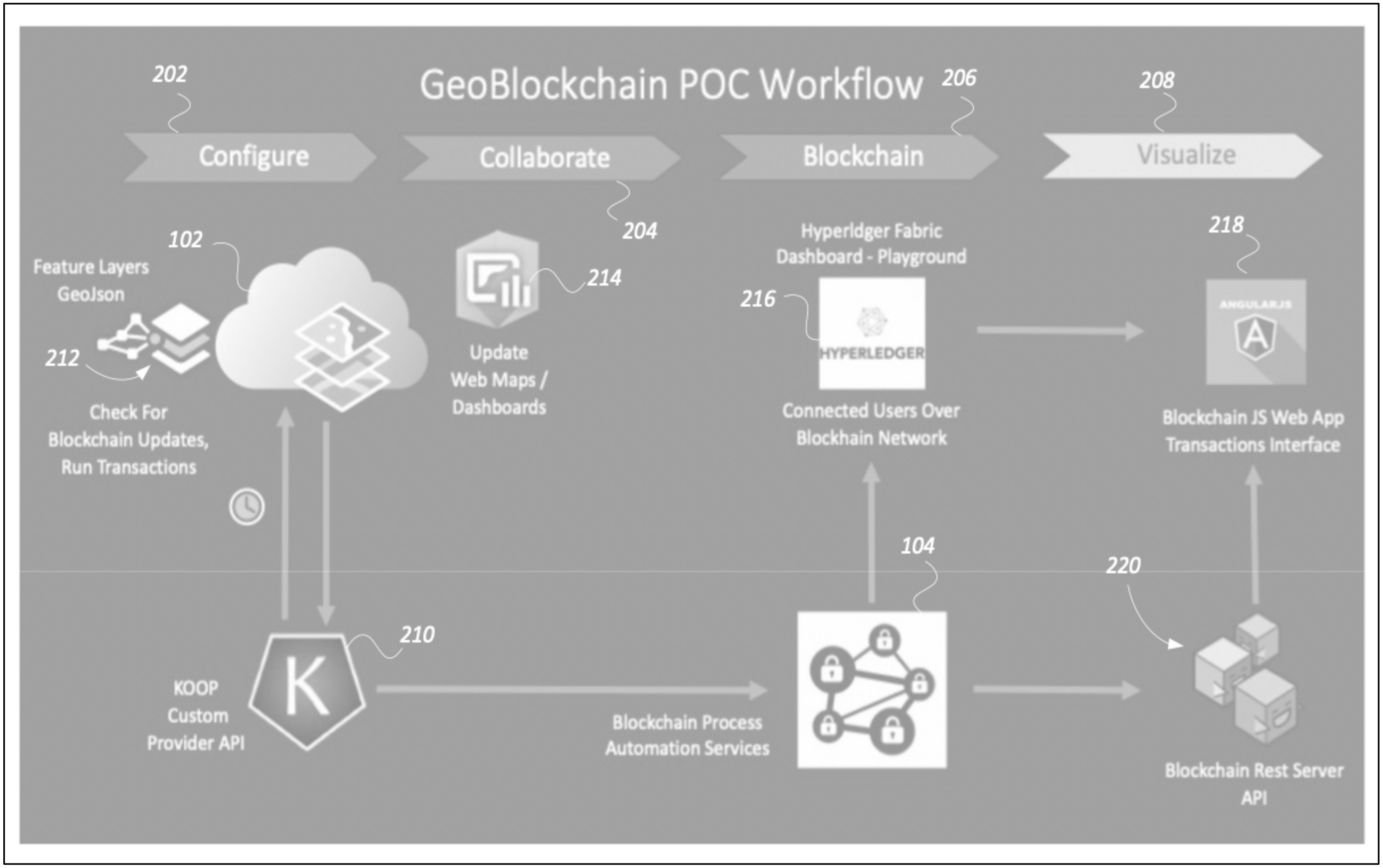


Figure 3. GeoBlockchain Workflow Architecture

- GeoBlockchain ICT- Artifacts Outcomes

The first artifact of this study was the instantiation of a GeoBlockchain for land ownership transactions and a related dashboard. Through this prototype, participants (landowners, customers, and other stakeholders) can exchange (buy or sell) land through the blockchain component, and instantly view the results through the GIS component.

As displayed in Figure 4, a single-family property parcel (402) is described in a window (404) with ID 2001, and USD price of $750,000. It was transferred from Owner A to Owner B. This prototype dashboard visualizes the property locations on a map and can answer “where” the transaction occurred and “why” the event happened based on historic transaction events.

The dashboard of Figure 4 has a map (401), on which a polygon representing a parcel (402) is displayed. Below the map (401) are multiple tabs for more information about various parcels on map (401). A tab (406), shown, sets forth the assets. Another tab (408) provides details on participants, while another tab (410) provides details on transactions. The displayed assets tab (406) has multiple columns of information, with a title registration ID column (412), description column (414), exchange currency column (416), price column (418), parcel (polygon) geometry column (420), owner column (422) and an actions column (424) for adding and updating new records. An icon (426), when activated, provides a pop-up window for creating a new asset to add. Widgets (428 and 430), shown separately in Figure 4A, provide various statistics, and are examples of widgets that can be provided.

Figure 4A is a diagram of specialized widgets of the GeoBlockchain dashboard of Figure 4 and one widget (428) shows the average land price for the area on map (401) of Figure 4.

This can change with the area displayed on the map, as the user moves the map location or zooms in or out. One widget (430) shows the breakdown of the prices for the individual parcels, both as a number along the x-axis, and as a bar graphic in the y-axis direction. The power of geospatial technology is applied to the dashboard with the addition of the specialized widgets that display statistics from the blockchain and geospatial technologies.

The GeoBlockchain tool web application artifacts allow participants and stakeholders to track overall land ownership and various statistics such as the average price at the selected geographic location and/or examine the individual land price using geospatial and blockchain statistical tools. There are a wide variety of other widgets that could be implemented. For example, a widget could indicate average prices over the past 5-10 years. An average price per square foot for a particular area can be shown. Demographic information about the buyers and sellers can be provided, such as their age ranges, number of children or pets, etc.

The power of geospatial technology is applied to the dashboard with the addition of specialized widgets (Figure 4A) that display statistics from the blockchain and geospatial technologies.

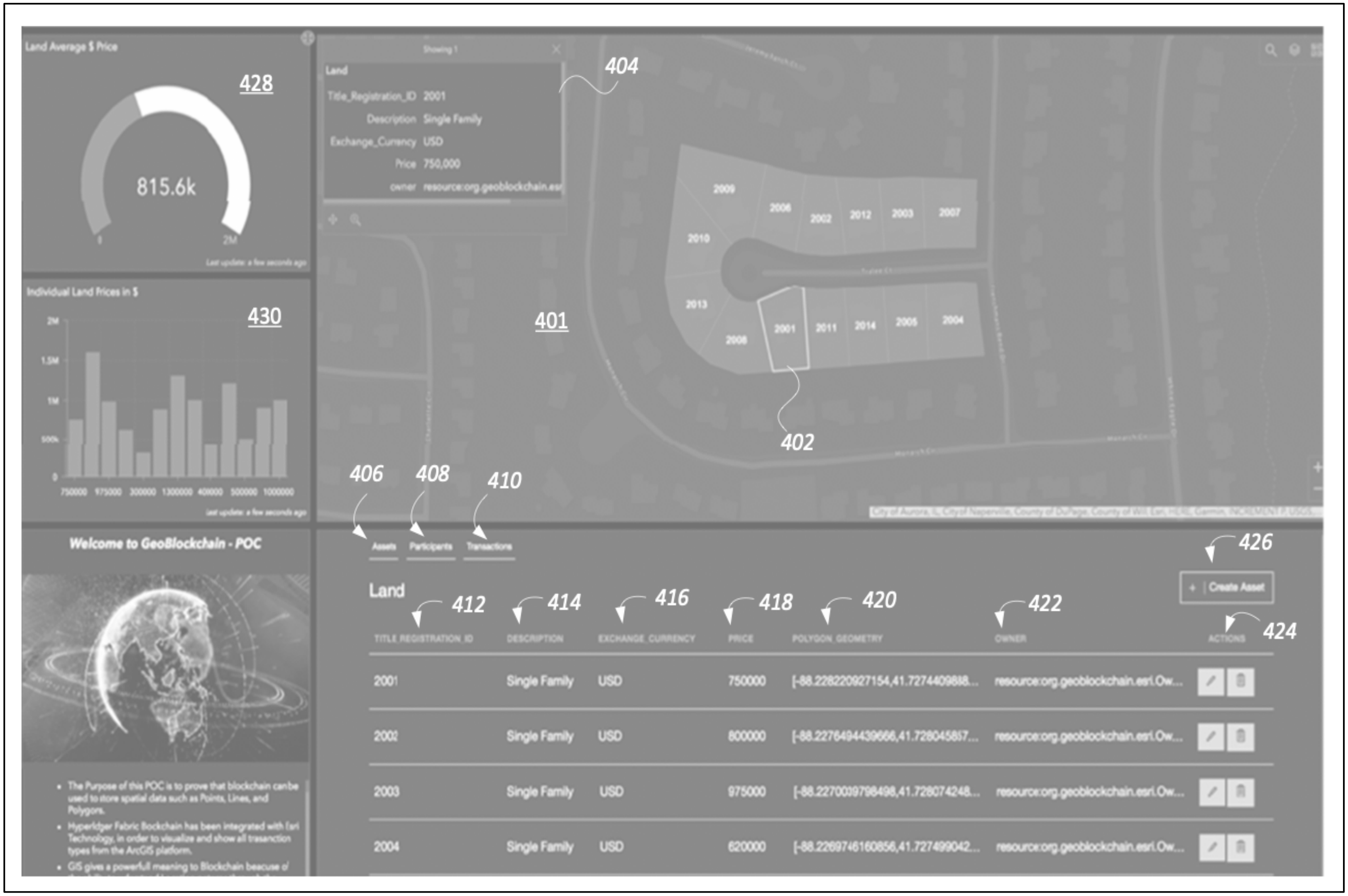


Figure 4. GeoBlockchain Dashboard - Land Ownership

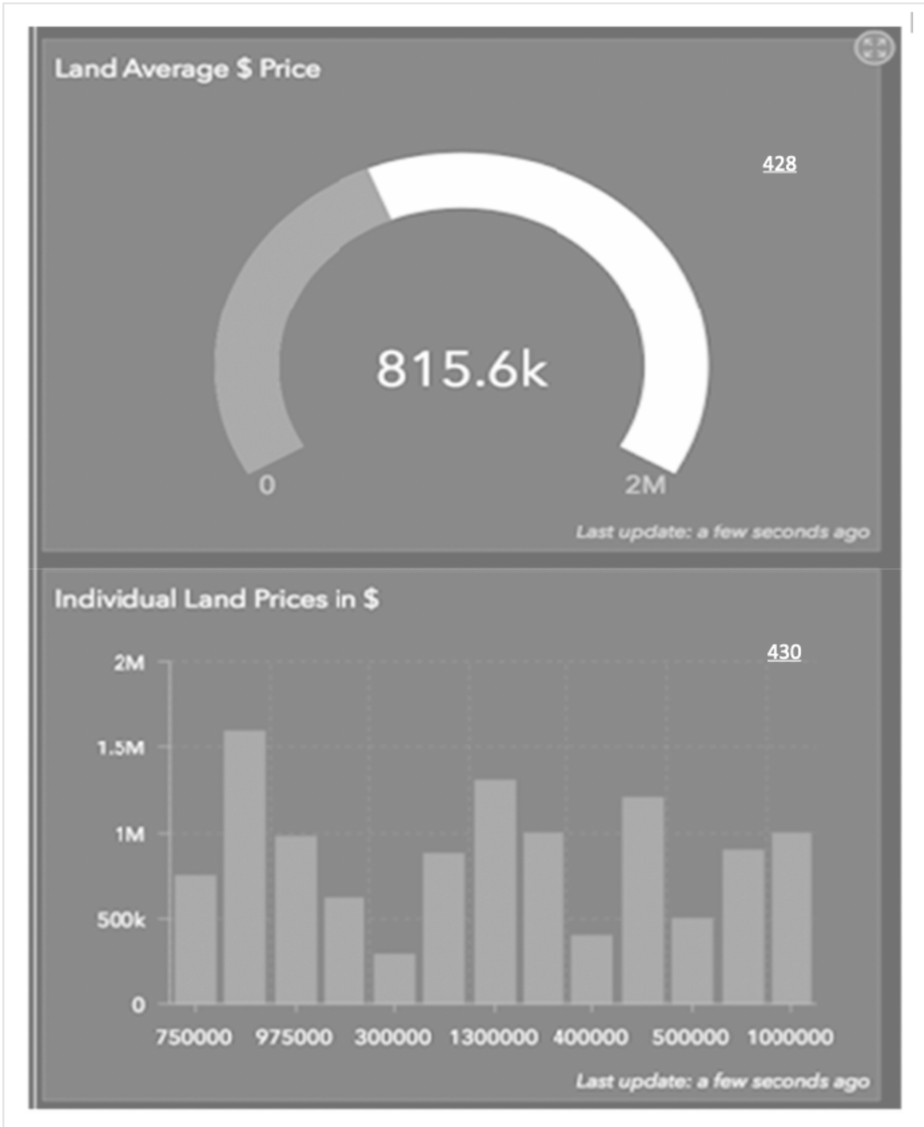


Figure 4A. Specialized widgets of the GeoBlockchain dashboard of Figure 4

The second artifact of this study is a GeoBlockchain supply chain dashboard web application (Figure 5). This example allows participants and stakeholders to track overall supply chains and various statistics using geospatial and blockchain statistical tools. A map (601) shows the route (602) of a tracked product during shipping. This can be done with a GPS tracking

system on a container in which the product is shipped. Such a tracking system can also have additional sensors, such as a temperature sensor.

A dot (604) shows a container location with the associated temperature graphically illustrated with a blue dot, indicating a temperature below a desired maximum temperature. Red dots (606 to 608) indicate a temperature above the desired maximum temperature. Each dot corresponds to a block of captured data that forms one block of the blockchain. In addition to location and temperature, other data is captured in the block, such as the data shown below map (601) on the dashboard.

Below the map (601), three tabs are shown for displaying additional data. An assets tab (612), illustrated, provides data on the asset tracked – the container. A participants tab (614) would show data on the various participants in the shipping supply chain. A transactions tab (616) provides data on "transactions," which are events that are recorded on the blockchain. In this example, the event is a status of the container at a particular location and time – including the temperature and other parameters. The locations and corresponding event information are recorded as blocks in the blockchain. Thus, the line of dots (602) visually represents the GeoBlockchain, with each dot corresponding to a block in the GeoBlockchain.

Widget (642) in Figure 5A diagram of specialized widgets shows the average temperature of the container over the entire trip. Widget 644 shows the details of the individual container temperature readings at each recorded location (such as by indicating the owner, or custodian, of the container at that point).

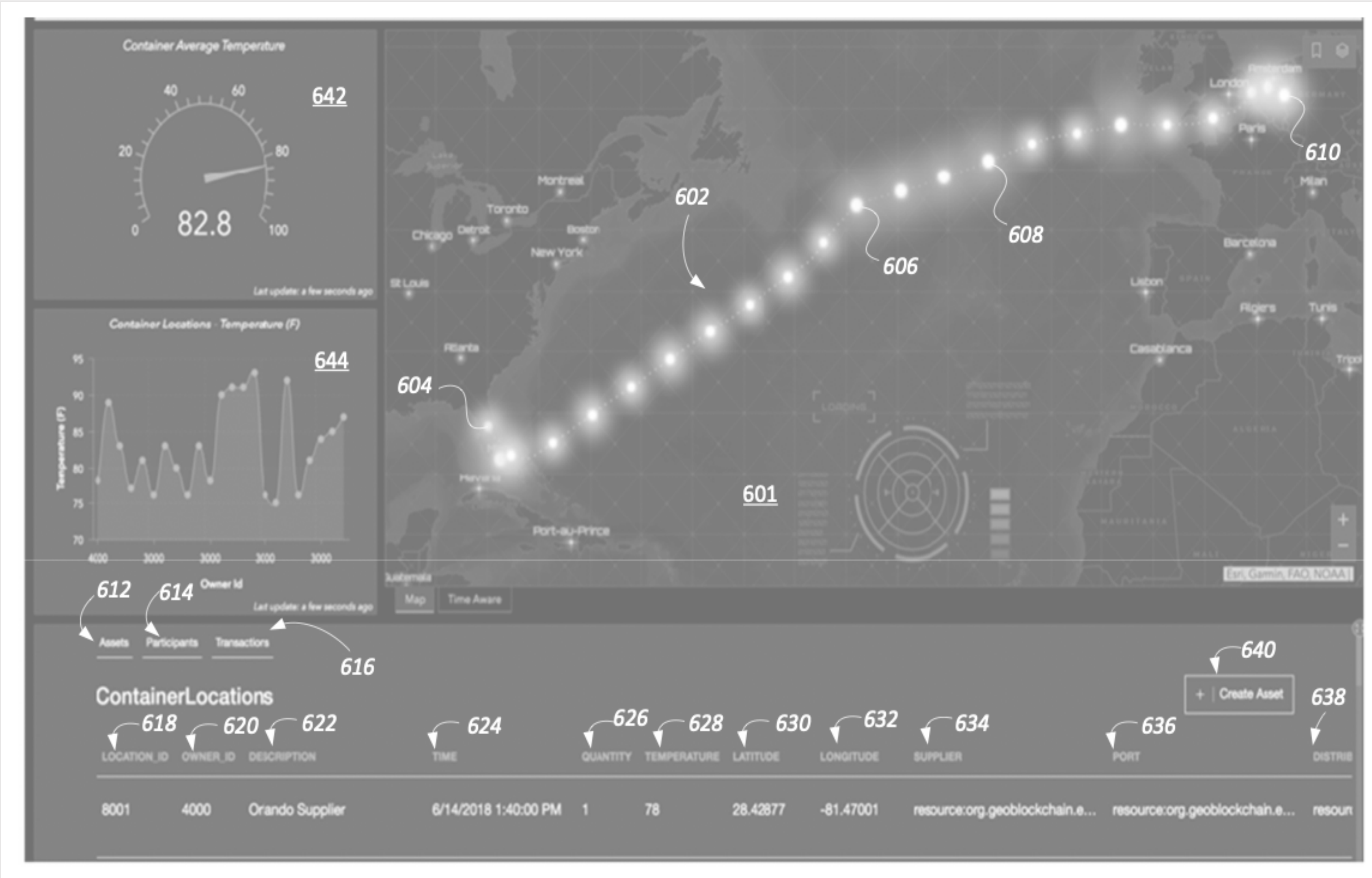


Figure 5. GeoBlockchain dashboard for real estate

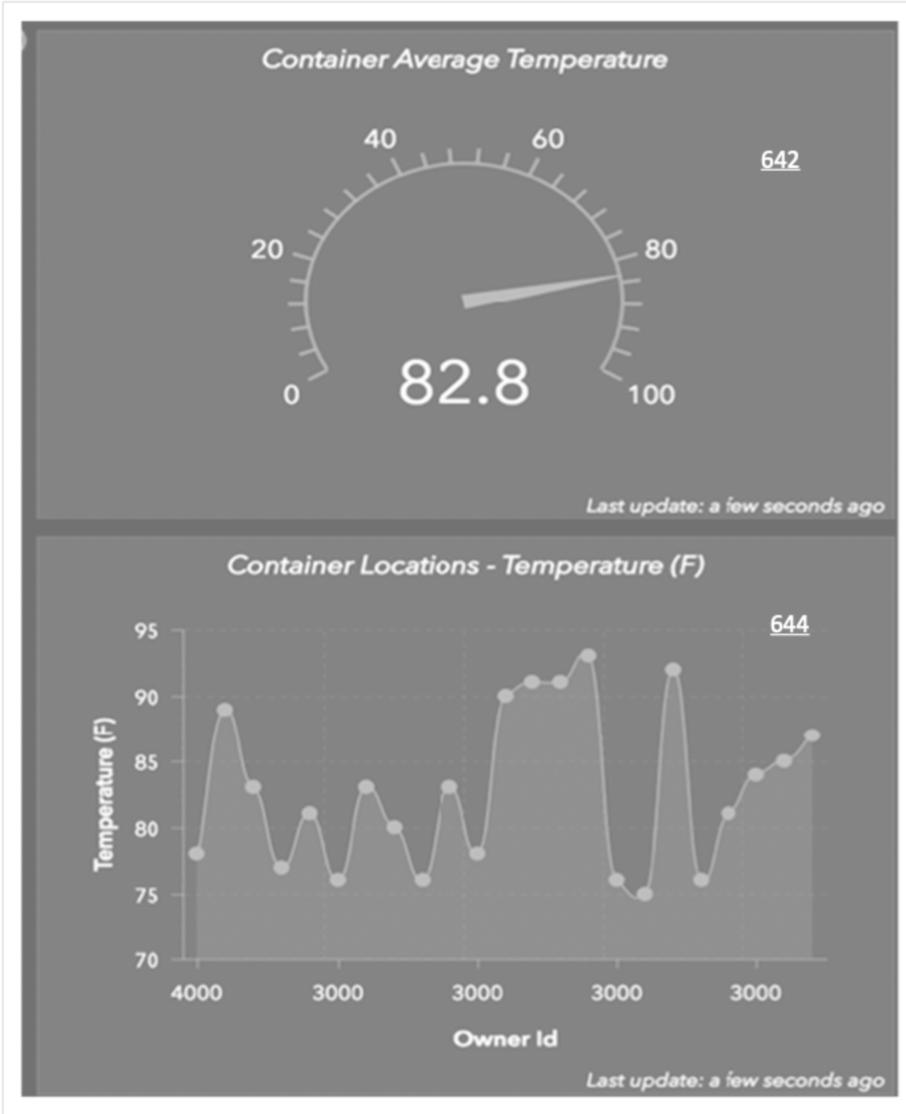


Figure 5A. Specialized widgets of the GeoBlockchain dashboard of Figure 5

Findings and Evaluation

The seven criteria defined in the Q-Methodology study (participants, trusted organization, centralized operation, transparency and confidentiality, integrity, immutability, and high performance) were examined and generalized against the two GeoBlockchain web dashboard prototypes. All the participants had been assigned specific rules and roles in the GeoBlockchain workflow processes. The purpose of the unique roles and rules was to provide trust and transparency through the land ownership and supply chain workflow processes.

Trusted Organizations, in this case, are private and legal authorities who orchestrate and manage the interaction between participants in the GeoBlockchain and for better interaction with matters related with tax regulations and legal concerns [11, 20]. The orchestrators were responsible for the approved rules, roles, and the smooth transaction between participants in order to establish transparency and confidentiality [24]. The goal was to have integrity through the process and between the participants.

The Immutability criterion of the GeoBlockchain provided the ability to answer questions related to the "where and why" questions. The "where" is the location of the land ownership transaction such as the real geographic representation of the property parcel. The "why" is the recorded history of the of all the approved land ownership transactions into the GeoBlockchain.

Lastly, the Performance criterion is examined based on the total time for the land ownership transaction to be completed. The GeoBlockchain system was developed in the cloud; here available resources can be modified and adjusted based on systems transaction load. In addition, the entire land ownership process is faster than the traditional land ownership transaction process as most of the mediators are not needed and the process is more

automated. The time needed from the beginning to the end of the land ownership transaction would be less as it requires less face-to-face interactions, less bureaucracy, and wait times.

The seven Q-set criteria, for the two artifacts, were examined in relation to the three research questions. The results were evaluated with unique measurement values such as required and not required. The evaluation methodology is motivated from recent study "Evaluating Suitability of Applying Blockchain", [29].

The resultant findings (Table 4) support the evaluation of the criteria and the research questions.

Table 4. GeoBlockchain Criteria Evaluation

GeoBlockchain Criteria (Q-set) Evaluation	GeoBlockchain (Hyperledger-Fabric/ArcGIS Enterprise)		
	Q1	Q2	Q3
Participants	Req.	Req.	Req.
Trusted Organization	Req.	Req.	Req.
Centralized Operation	Req.	Req.	Req.
Transparency and Confidentiality	Req.	Req.	Req.
Integrity	Req.	Req.	Req.
Immutability	Non- Req.	Req.	Non- Req.
High Performance	Req.	Req.	Non- Req.

For the first research question (Q1), only the organizations participating in a transaction will have knowledge about it, whereas the others will not be able to access it; as a result, data immutability is not fully applied and is not required for the GeoBlockchain. Only participants, trusted organizations, data transparency and confidentiality, data integrity, and high-performance criteria are required for the main attributes of GeoBlockchain.

The second research question (Q2) is the only one that entirely encounters all the blockchain criteria (participants, trusted organizations, data transparency and confidentiality, data integrity, and high-performance) as GeoBlockchain attributes. However, generic attributes and custom attributes are required for GeoBlockchain use cases. The main reason is that every single use case is a unique study, and flexibility is needed for generalization.

Lastly, the third research question (Q3) encompasses the GeoBlockchain criteria as seen in Tables 2 and 3. For instance, the centralized operation is required for trust between participants. However, data immutability and high performance are not obligatory either for participants' or trusted organizations.

Discussion

The main limitations of the current study include: (1) further iterations are required to improve this prototype, (2) a production enterprise environment is required for real-world testing, and related to this, (3) the prototype needs to be tested with a larger data set, and finally, (4) a formal end-user assessment needs to be conducted. Upcoming plans include: (1) completing the next generation solution prototype artifact; (2) completing multiple iterations to improve the GeoBlockchain design; (3) improving the suitability evaluation analysis; (4)

researching other types of blockchains such as hybrid blockchains for suitability and relevance; and (5) completing the pre-test and post-test evaluation in order to assess the GeoBlockchain framework.

This research indicates that blockchain technology can be integrated with geospatial technology, resulting in the GeoBlockchain. Both GeoBlockchain web application artifacts allow participants and stakeholders to track overall land ownership and supply chains and various statistics such as the average price at the selected geographic location and/or examine the individual land price using geospatial and blockchain statistical tools [22].

Conclusion

The outcomes of this research are the identification and the importance of GeoBlockchain for land ownership transactions and supply chain management. As demonstrated, this can be achieved by leveraging existing blockchain and geospatial frameworks and utilizing the identified Q-set criteria from the Q-Methodology approach.

The two working prototypes demonstrate that blockchain technology can be integrated with geospatial technology resulting in a GeoBlockchain. The three tasks, implementation phases, and workflow processes answer the first and second research questions and provide the main components and criteria for GeoBlockchain land ownership and supply chain examples. For the third research question, it is argued that the value that blockchain makes available to geospatial technology is its transparency, real-time, security, cost-effective recording, immutability, and storage of trusted data information [9]. On the other hand, geospatial technology provides the power of location to the blockchain.

The GeoBlockchain dashboard is a prototype system designed to record, analyze, share, and visualize a variety of blockchain and geographical data. The result is a concept that should impact society by simplifying the supply chain management and land ownership transaction experience for organizations, citizens, and governments. This presents an opportunity for supply chain and land ownership stakeholders to take advantage of these new blockchain-based datasets and access that data using their geospatial system to see and understand their world like never before.

Private blockchains such as Hyperledger Fabric and geospatial technologies such as ArcGIS could potentially be used for any GeoBlockchain use case. This research will continue with enhancements and refinements through development and testing which will be demonstrated through next generation releases.

References

1. A.R. Hevner, S.T. March, J. Park, S. Ram, design science in information systems research, MIS Quarterly 28 (2004) 75, https://doi.org/10.2307/25148625.

2. Brambilla, G., Amoretti, M., & Zanichelli, F. (2016). Using Blockchain for Peer-to-Peer Proof-of-Location. Retrieved from http://arxiv.org/abs/1607.00174

3. Brown, S. R. (1996). Q Methodology and Qualitative Research. Qualitative Health Research, 6(4), 561–567. https://doi.org/10.1177/104973239600600408

4. Bureau of Land Management, "Programs: Lands and Realty: Cadastral Survey," Aug. 17, 2016. https://www.blm.gov/programs/lands-and-realty/cadastral-survey (accessed Apr. 25, 2020).

5. Coignard, J., Munsing, E., MacDonald, J., Mather, J., & Ieee. (2018). Co-simulation Framework for Blockchain Based Market Designs and Grid Simulations. In 2018 Ieee Power & Energy Society General Meeting. New York: Ieee.

6. Crompton, S., & Jensen, J. (2018). Towards a Secure and GDPR-compliant Fog-to- Cloud Platform. In A. Sill & J. Spillner (Eds.), 2018 Ieee/Acm International Conference on Utility and Cloud Computing Companion (pp. 296-301). New York: Ieee.

7. Croxson, A., Sharma, R., & Wingreen, S. (2019). Making Sense of Blockchain in Food Supply-Chains 2 Background Review. 1–11.

8. Cvetkova, I. (2018). Cryptocurrencies Legal Regulation. Brics Law Journal, 5(2), 128-153. doi:10.21684/2412-2343-2018-5-2-128-153

9. Dasu, T., Kanza, Y., & Srivastava, D. (2018). Unchain Your Blockchain. Proc. Symposium on Foundations and Applications of Blockchain, 1(March), 16–23.

10. Dennis, K. E. (1986). Q methodology: Relevance and application to nursing research. Advances in Nursing Science, 8(3), 6–17. https://doi.org/10.1097/00012272-198604000-00003

11. Dimitropoulou, C., Govind, S., & Turcan, L. (2018). Applying Modern, Disruptive Technologies to Improve the Effectiveness of Tax Treaty Dispute Resolution: Part 2. Intertax, 46(12), 960-970.

12. Garcia-Teruel, R.M. (2020). "Legal challenges and opportunities of blockchain technology in the real estate sector", Journal of Property, Planning and Environmental Law, Vol. 12 No. 2, pp. 129-145. https://doi.org/10.1108/JPPEL-07-2019-0039.

13. J. D. McLaughlin and I. P. Williamson, “Trends in Land Registration,” The Canadian Surveyor, vol. 39, no. 2, pp. 95–108, Jun. 1985, doi: 10.1139/tcs-1985-0012.

14. J. Patel, “Exploring Enterprise Resource Planning (ERP) And Geographic Information System (GIS) Integration,” Dec. 2013.

15. Kamel Boulos, M. N., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. International Journal of Health Geographics, 17(1), 25. https://doi.org/10.1186/s12942-018-0144-x

16. K. Clarke, “Advances in Geographic Information Systems,” Computers, Environment and Urban Systems, vol. 10, pp. 175–184, Dec. 1986, doi: 10.1016/0198-9715(86)90006-2.

17. Koh, L., Dolgui, A., Sarkis, J. (2020). Blockchain in transport and logistics – paradigms and transitions, International Journal of Production Research, 58:7, 2054-2062, https://doi.org/10.1080/00207543.2020.1736428.

18. K. Peffers, T. Tuunanen, M.A. Rothenberger, S. Chatterjee, A design science research methodology for information systems research, Journal of Management Information Systems 24 (2007) 45–77, https://doi.org/10.2753/MIS0742-1222240302.

19. Li, K. J., Li, H., Hou, H. X., Li, K. D., Chen, Y. L., & Ieee. (2017). Proof of Vote: A High-Performance Consensus Protocol Based on Vote Mechanism & Consortium Blockchain. New York: Ieee.

20. Lin, Y.-P., Petway, J., Lien, W.-Y., & Settele, J. (2018). Blockchain with Artificial Intelligence to Efficiently Manage Water Use under Climate Change. Environments, 5(3), 34. https://doi.org/10.3390/environments5030034

21. Lynch, S. (2018). OpenLitterMap.com – Open Data on Plastic Pollution with Blockchain Rewards (Littercoin). Open Geospatial Data, Software and Standards, 3(1). https://doi.org/10.1186/s40965-018-0050-y

22. McGinn, D., McIlwraith, D., & Guo, Y. (2018). Towards open data blockchain analytics: a Bitcoin perspective. Royal Society Open Science, 5(8), 14. doi:10.1098/rsos.180298

23. Montes, G. A., & Goertzel, B. (2019). Distributed, decentralized, and democratized artificial intelligence. Technological Forecasting and Social Change, 141, 354-358. doi:10.1016/j.techfore.2018.11.010

24. Pahl, C., El Ioini, N., Helmer, S., Lee, B., & Ieee. (2018). An Architecture Pattern for Trusted Orchestration in IoT Edge Clouds. New York: Ieee.

25. P. F. Dale and J. D. McLaughlin, “Land information management: an introduction with special reference to cadastral problems in Third World countries,” 1988, Accessed: Apr. 25, 2020. [Online]. Available: http://agris.fao.org/agris-search/search.do?recordID=XF2015016826.

26. R. LaRossa, “Grounded theory methods and qualitative family research,” J. Marriage Fam., vol. 67, no. 4, pp. 837–857, 2005.

27. Ryskeldiev, B., Ochiai, Y., Cohen, M., & Herder, J. (2018). Distributed metaverse: Creating decentralized blockchain-based model for peer-To-peer sharing of virtual spaces for mixed reality applications. ACM International Conference Proceeding Series. https://doi.org/10.1145/3174910.3174952

28. Sharma, R. S., Wingreen, S., Kshetri, N., & Hewa, T. M. (2019). Design principles for use cases of blockchain in food supply chains. 25th Americas Conference on Information Systems, AMCIS 2019, 1–10. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1300&context=amcis2019

29. S. K. Lo, X. Xu, Y. K. Chiam and Q. Lu, "Evaluating Suitability of Applying Blockchain," 2017 22nd International Conference on Engineering of Complex Computer Systems (ICECCS), Fukuoka, 2017, pp. 158-161, doi: 10.1109/ICECCS.2017.26.

30. T. Wade and S. Sommer, A to Z GIS: An Illustrated Dictionary of Geographic Information Systems. ESRI Press, 2006.

31. V. Maliene, V. Grigonis, V. Palevičius, and S. Griffiths, “Geographic information system: Old principles with new capabilities,” Urban Design International, vol. 16, Mar. 2011, doi: 10.1057/udi.2010.25.

32. Wingreen, S., Sharma, R., jahanbin, pouyan, Wingreen, S., & Sharma, R. (2019). a Blockchain Traceability Information System for Trust Improvement in Agricultural Supply Chain. Research-in-Progress Papers, 5–15. Retrieved from https://aisel.aisnet.org/ecis2019_rip/10

33. Yuan, Y., & Wang, F. Y. (2016). Towards blockchain-based intelligent transportation systems. IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC, (October 2017), 2663–2668. https://doi.org/10.1109/ITSC.2016.779598

Chapter 4: The Design Science Evaluation on GeoBlockchain

Third Article

Abstract

Blockchain is a cutting-edge and emerging technology today. The first implementations of blockchain artifacts were developed with public type frameworks such as Ethereum and Bitcoin. Afterwards, Hyperledger Fabric and Ripple XRP, private type frameworks, continue the development of industry use cases such as real land management, supply chain and real estate. The main advantages of both type of blockchain frameworks are the speed of transactions, data accessibility, and data accuracy. The value of both use is the increase in transparency and visibility among partners while reducing the risk of corrupted information flow and the overall cost of moving items within the system chain and organization network.

From previous chapters, this study identified that, blockchain and GIS are the main technologies that connect the front-end and back-end components for the GeoBlockchain concept. Specifically, Hyperledger Fabric, was the primary framework for the blockchain component while ArcGIS Enterprise provided the GIS capabilities and is also used as the technology integration platform. This study used the design science evaluation methodology to examine the two combined technologies architectures and to propose the GeoBlockchain framework.

Keywords: geospatial, geoblockchain, blockchain, cloud environments, infrastructures.

Introduction

According to previous articles on this dissertation, a method of providing a map with imbedded, authenticated data as a GeoBlockchain is described. A geographic feature was represented on a map with one or more of points, lines, and polygons in a first layer of the map. Data corresponding to the geographic feature is provided and it is encoded, in a first block, with the one or more of points, lines and polygons from the first layer of the map. The block is combined with other blocks of a GeoBlockchain locations attributes that were associated with the geographic feature such as record of transactions, ownership, tracking, temperatures, and environmental conditions.

ArcGIS is a Geographic Information System (GIS) for working with maps and geographic information. This technology was used for creating and using maps, compiling geographic data, analyzing mapped information, sharing, and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database [2]. Also, it helped the GeoBlockchain concept to provide an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the Web.

The two GeoBlockchain ICT-artifacts examples for land ownership and supply chain according to the 2nd article, have used spatial data encoded in transaction data block, which is spatial information about an event that is recorded on the GeoBlockchain. For example, an event can be a sale of property, or the location of a shipping container. The block also includes other data, such as identification of an asset (e.g., property parcel or shipping container) and a participant (e.g., purchaser, seller, supplier, shipper, etc.) [5].

This research study will expand the outcomes from the first article “A systematic literature review of GeoBlockchain” and from the second article “GeoBlockchain Solutions Criteria for a Land Ownership and Supply Chain Use Case”. It will evaluate the implementation of the GeoBlockchain architecture between on-premises and cloud environments infrastructures based on two specific setting. A supply chain use case and land ownership use case. The evaluation process will include a pilot assessment (quantitative and qualitative evaluation of the ICT-artifacts) utilizing chosen metrics to demonstrate the efficacy, utility, and performance along with domain expert evaluation to assess the effectiveness of the design solution.

According to Venable et.al, choosing an evaluation method and designing the appropriate evaluation strategy, which is very important fact for design science research and information systems. This study will be grounded with rigor and relevance by adopting the FED paradigm; a Framework for Evaluation in Design Science Research that contributes to existing research by evaluating ICT-artifacts and design theories [6, 8].

Finally, the study will propose a GeoBlockchain Framework that could contribute to knowledge, research, and industry, in order, to solve real problems related with financial losses from the shipping-food supply chain, difficulties to validate cargo shipping conditions, liability and litigation issues, food spoilage, inadequate storage, inefficient routing and food waste, and lack to authenticate environmental conditions during shipping routes [19, 20, 21]. For instance, a framework for an effective information-sharing that could provide trust, authentication, and validation through the shipping routes and to build a collaborative environment that improves productivity, security, resilience, speed, and efficiency [3].

Research Question

The purpose of this study is to evaluate the GeoBlockchain design architecture, compare the results and to report the findings. The main reason that this study asses a design science evaluation is to explore if a GeoBlockchain framework could exists or not, and if it could contribute to knowledge.

The research questions for this study are defined as:

- What attributes and criteria are effective in initiating and maintaining a GeoBlockchain solution?
- What roles and rules are effective in initiating and maintaining a GeoBlockchain solution?
- What are the differences among GeoBlockchain attributes, criteria, rules, and roles between an enterprise solution and a non-enterprise solution?

Methodology

This article will conduct a Design Science Evaluation framework on the two GeoBlockchain ICT-artifacts. The research study used the Design Science Evaluation framework (FED) from Venable, Pries Heje, and Baskerville's as the main kernel theory. The main objective is to evaluate the research by using two types of evaluation from FED framework. The first type is the technical risk and efficacy, which will support the sociotechnical evaluation of GeoBlockchain architecture design and infrastructure. Also, cloud and GIS monitoring tools will be used, and they will provide technical risk and efficacy statistics and findings on GeoBlockchain overall

performance, system capacity workflows flow, API communication, REST services status and security [4].

The second type from FED framework that will be conducted, is the human risk and effectiveness strategy. This method will evaluate each cycle of the designed ICT Artifacts based on users and stakeholders' involvement [7,]. Also, it will evaluate GeoBlockchain criteria and participants roles and rules. Incorporating usability and user engagement in this process is very important and it will support the second evaluation type of human risk and effectiveness according to Venable et.al., Peffers et.al., and Hevner et.al [6, 8, 18]. Users and stakeholders were engaged from the beginning of this study until the final production solution outcome. For example, during the design, development, and evaluation phases, 20 participants from each use case (supply chain and landownership) provided feedback and worked with the researcher to follow each step of the cycle into an iteration process. Environmental System Research Institute (Esri) in Redlands California is the research site for this research study. A group of Esri users and stakeholders from an independent GIS land management project team and a second group of Esri users and stakeholders from an independent supply chain project team were assigned with various roles (specialists, project managers, consultants, technical advisors, engineers, developers, and analysts) and were the main participants roles. However, due to the Covid-19 pandemic event, the research process to collect the evaluation feedback with the Esri project stakeholders was made through internal Microsoft Teams Video conference calls.

The evaluation collection technique included 2 focus groups (the first was assigned to land ownership Esri team and the second to the supply chain Esri team). Each focus group participated to all seven cycles and each cycle session took 90 minutes. Also, each focus group

session was video recorded and transcribed with the Microsoft Streaming, and the content was exported in multiple text files and then imported into Leximancer, a qualitative data analysis software system (CAQDAS). Each cycle step had multiple refinements based on the collected user information. The overall procedure followed a nonlinear process, for example, each step of the cycle followed Peffers et.al and Hevner et.al. iteration methodology [6, 8, 18].

Figure-1 “Users and Stakeholders Involvement” demonstrates participants interaction on each cycle. Each cycle is unique and an average refinement time of three was conducted. The evaluation meeting date for each cycle evaluation was scheduled during business working days according to users and stakeholders’ availability and accessibility to the system. The researcher was the organizer, coordinator, and project management for each remote session. Each session was organized with specific assigned tasks for each cycle focus group. The feedback was collected with an online application “ArcGIS Survey 123”, which is a simple and intuitive form-centric data gathering solution that manages multiple teams.

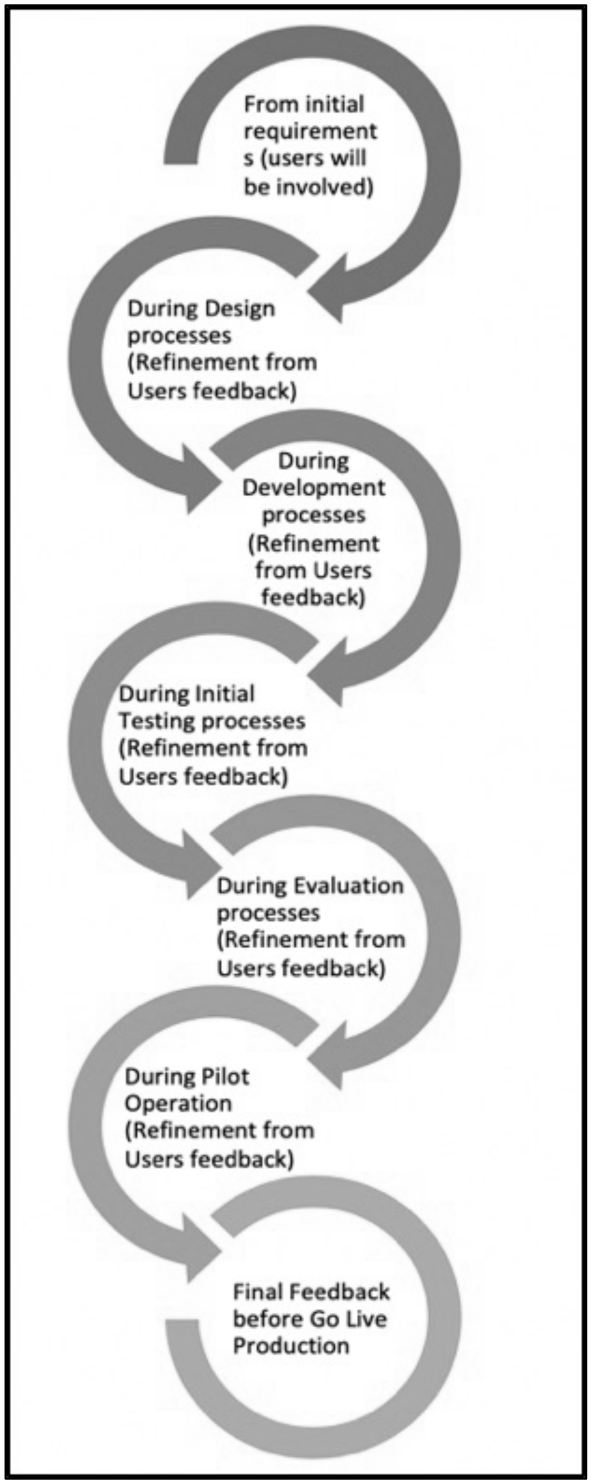


Figure 1. Users and Stakeholders Involvement

Analysis and Evaluation Findings

The complete process has 7 cycles phases, and each cycle is evaluated on each phase separately and evaluation refinements could happen independently and jointly. The evaluation was conducted on two different architecture scenarios (on-premise and cloud) with Hyperledger Fabric blockchain and ArcGIS Enterprise. The two types of technologies that could be combined and deployed on GeoBlockchain. The main cycles are identified as:

- 1st Cycle – Initial Requirements
- 2nd Cycle – During Design Process
- 3rd Cycle – During Development Process
- 4th Cycle – During Initial Testing Process
- 5th Cycle – During Evaluation Process
- 6th Cycle – During Pilot Operation
- 7th Cycle – Final Feedback/ Go Live – Production

For the first two cycles (Initial requirements and design process) the main actors were facing the challenge to select the correct type of Blockchain framework. Users, stakeholders, and researcher identified that public blockchain frameworks are easier to use but private and hybrid blockchains are more appropriate for industry enterprise problems. Also, private blockchain frameworks such Hyperledger Fabric are more flexible to control and to maintain.

During the 3rd Cycle "Development Process" the participants for both use cases, supply chain (administrator, supplier, port, distribution center, shipping and trucking) and land

ownership (buyer, seller, and legal authority) had challenges to understand if spatial data could be hosted and if it should be stored on the Blockchain, and why.

This evaluation continues jointly with the 4th Cycle to test different types of spatial datasets formats such as shape files, file geodatabases and live data from REST API's. The result showed that large datasets could slow down the network. Also, it was not easy to develop a cryptographic algorithm to authenticate the GeoBlockchain spatial transactions. The evaluation indicated that each participant (administrator, supplier, port, distribution center, shipping and trucking) and (buyer, seller, and legal authority) from the two use cases had the need to use authoritative geospatial source. For instance, authentication on spatial layers from different sources and analysis to maps. Other expectations from users, were associated with authoritative sources: from surveyors for each polygon of the parcel, a title company for the chain of title, an attorney for compliance with covenants and restrictions.

The next two cycles, 5th, and 6th were evaluated with the use of monitoring tools and specifically, with software tools from ArcGIS and AWS cloud that offer reports based on the infrastructure, performance, scalability, and security. The assessed procedure on the two cycles reported that for a small-scale deployment and large-scale deployment, the system was preforming reasonable between on-premises and cloud networks. Also, the report output from the monitoring tools captured the uptime and performance of the full system against the GeoBlockchain integrated REST services.

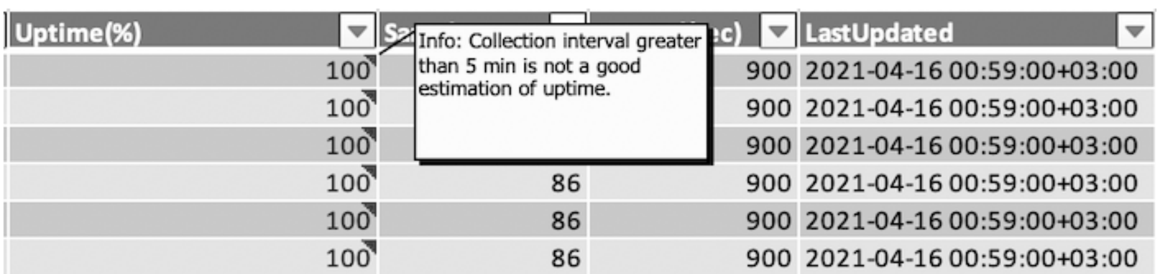
However, the overall consumption infrastructure had few issues with "High Utilization" but no evidence on the system "Low Utilization". Besides that, few alerts were reported on the usage and on the main web application site (Figure 2).

Report Summary

Category	Type	Name	Source	Time	Uptime	Performance	HighUtilization	LowUtilization	Alerts	Errors
Site	Alerts	List	AdminAPI	Timespan					■	
ArcGIS	Site	Configuraton	AdminAPI	Last						
ArcGIS	Services	Summary	AdminAPI	Last						
ArcGIS	Requests	Count	AdminAPI	Timespan						
ArcGIS	Requests	Requests/sec	AdminAPI	Timespan						
ArcGIS	Services	Instances	AdminAPI	Timespan	●					
ArcGIS	Services	Response Time(sec)	AdminAPI	Timespan		▲				
ArcGIS	Services	Response Time(sec)	AdminAPI	Hourly		■				
Database	DB query	DB query	DB query	Timespan	●					
Infrastructure	Summary	Summary	AdminAPI	Last						
Infrastructure	CPU	Utilization(%)	AdminAPI	Timespan	▲		▲	●		
Infrastructure	CPU	Utilization(%)	AdminAPI	Hourly			▲	●		
Infrastructure	Memory Physical	Utilization(%)	AdminAPI	Timespan	▲		■			
Infrastructure	Memory Physical	Utilization(%)	AdminAPI	Hourly			■			
Infrastructure	Memory Virtual	Utilization(%)	AdminAPI	Timespan	▲		■			
Infrastructure	Memory Virtual	Utilization(%)	AdminAPI	Hourly			■			
Infrastructure	Disk Utilization	Utilization(%)	AdminAPI	Timespan	▲		▲			
Infrastructure	Disk Utilization	Utilization(%)	AdminAPI	Hourly			■			
Infrastructure	Disk Space	Utilization(%)	AdminAPI	Timespan	▲			●		
Infrastructure	Network Received	mbps	AdminAPI	Timespan	▲		▲			
Infrastructure	Network Received	mbps	AdminAPI	Hourly			▲	●		
Infrastructure	Network Sent	mbps	AdminAPI	Timespan	▲		▲			
Infrastructure	Network Sent	mbps	AdminAPI	Hourly			■	●		
Usage	Requests	OK	WebLogs	Timespan	●					
Usage	Requests	Failures	WebLogs	Timespan	●					
Usage	Rt Histogram	Count	WebLogs	Timespan	●					
Usage	Throughput	Count	WebLogs	Timespan	●					
Usage	Urls	httpError	WebLogs	Timespan					■	
Usage	Urls	Slow	WebLogs	Timespan					■	
Site	Alerts	Configuraton	ArcGIS Monitor	Last						
Site	Alerts	Not Configured	ArcGIS Monitor	Last						
Site	Collection	Configuraton	ArcGIS Monitor	Last						
Site	Counters	Configuraton	ArcGIS Monitor	Last						
Site	Collection Time	Utilization(%)	AdminAPI	Timespan	●			●		

Figure 2. Summary Statistics of GeoBlockchain System

Also, the report summary provided the uptime, and performance metrics for the GBC services, database queries, CPU and memory utilizations, network communication, rest requests, and collection times for the site instances. Uptime is a metric that represents the percentage of time that GeoBockchain system was successfully operational. The GoeBlockchain instances reported 100 percentage uptime on the instances and a warning message with a suggestion reported that collection interval greater than 5 min is not a good estimation of uptime. This is because of the 900 sec interval that was initially configured (Figure3).



Uptime(%)	Sa	ec)	LastUpdated
100		900	2021-04-16 00:59:00+03:00
100		900	2021-04-16 00:59:00+03:00
100		900	2021-04-16 00:59:00+03:00
100	86	900	2021-04-16 00:59:00+03:00
100	86	900	2021-04-16 00:59:00+03:00
100	86	900	2021-04-16 00:59:00+03:00

Info: Collection interval greater than 5 min is not a good estimation of uptime.

Figure 3. Uptime (%) Alerts Report

Besides that summary report in Figure 2 provided a few alerts on the total number of deployed instances. The sub-report in Figure 4 showed that there is high processor utilization based on the total time the web application servers were used. Also, the system was running low in memory, while the Geoblockchain Web Application was trying to do more work than it has the capacity for.

CounterName	Instance	AlertType	ValidationValue	Hours	Note	Created	Closed	TimeZone	Hour	Day	GMT
Log-WARNING	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-16 00:14:00	2021-04-16 00:29:00	North America	0	Friday	1618521240
% Processor Time	_Total	$gt	85	0.02	High processor utilization	2021-04-15 20:47:00	2021-04-15 20:48:00	North America	20	Thursday	1618508820
Log-WARNING	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 20:31:00	2021-04-15 20:46:00	North America	20	Thursday	1618507860
Log-SEVERE	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 15:05:00	2021-04-15 15:20:00	North America	15	Thursday	1618488300
Log-WARNING	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 12:37:00	2021-04-15 12:52:00	North America	12	Thursday	1618479420
Log-SEVERE	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 12:37:00	2021-04-15 12:52:00	North America	12	Thursday	1618479420
Log-WARNING	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 11:08:00	2021-04-15 11:23:00	North America	11	Thursday	1618474080
Log-WARNING	Summary	$gt	0	0.23	Check ArcGIS Enterprise logs	2021-04-15 10:09:00	2021-04-15 10:23:00	North America	10	Thursday	1618470540
Log-SEVERE	Summary	$gt	0	0.23	Check ArcGIS Enterprise logs	2021-04-15 10:09:00	2021-04-15 10:23:00	North America	10	Thursday	1618470540
Log-WARNING	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 08:54:00	2021-04-15 09:09:00	North America	8	Thursday	1618466040
Log-SEVERE	Summary	$gt	0	0.25	Check ArcGIS Enterprise logs	2021-04-15 07:55:00	2021-04-15 08:10:00	North America	7	Thursday	1618462500
Log-WARNING	Summary	$gt	0	0.5	Check ArcGIS Enterprise logs	2021-04-15 07:40:00	2021-04-15 08:10:00	North America	7	Thursday	1618461600
Available Memory GB	_Total	$lt	1	5.03	Running low on memory	2021-04-14 20:38:00	2021-04-15 01:40:00	North America	20	Wednesday	1618421880

Figure 4. Utilization Report

Furthermore, a sub report provided results for the Geoblockchain services timespan and response time (Figure 5). Map Server and Geo Processing services type reported a slow response time with Max(sec) 8.52 and 3.96 because they exceeded the 3.0 service level agreement (SLA) (Figure 5). Besides that, to understand the problem, further investigation was conducted and the root of the problem was originated from two specific services. The "GeoBlockchain Map Server" and the "Publishing tools GPServer" services which were flagged and noted with a comment to "investigate slow response times" as show in Figure 6.

ServiceType	TrSum	Min(sec)	Avg(sec)	p5(sec)	p50(sec)	p75(sec)	p95(sec)	p99(sec)	Max(sec)	Uptime(%)	Samples	Interval(sec)	Alerts(%)	LastUpdated	Comments
GPServer	169	0	1.52	1.54	1.57	1.59	1.63	1.71	1.75	100	86	900	0	2021-04-16 00:59:00+03:00	
MapServer	1262	0	0.18	0	0	0.02	0.28	4.52	8.62	100	86	900	0	2021-04-16 00:59:00+03:00	Investigate geoblockchain slow response times.
MapServer	208	0	0.01	0	0	0	0.06	0.15	0.24	100	86	900	0	2021-04-16 00:59:00+03:00	
MapServer	124	0	0	0	0	0	0	0.08	0.1	100	86	900	0	2021-04-16 00:59:00+03:00	
MapServer	24	0	0	0	0	0	0	0.03	0.06	[illegible]	86	900	0	2021-04-16 00:59:00+03:00	
GPServer	1	0	0.05	0	0	0	0	0	3.96	[illegible]	86	900	0	2021-04-16 00:59:00+03:00	Investigate geoblockchain slow response times.

Exceeded SLA=3.0

Figure 5. Service Type and timespan responses

Service	ServiceT	Min(sec)	Avg(sec)	p95(sec)	Max(sec)	Uptime(	Samples	Interval(	GMT	Date	Hour	Weekda	Comments
GeoBlockchain	MapServer	4.52	6.57	4.52	8.62	100	2	900	1.62E+09	2021-04-15	9	Thursday	Investigate slow response times.
PublishingTools	GPServer	3.96	3.96	-99	3.96	100	1	900	1.62E+09	2021-04-16	0	Friday	Investigate slow response times.

Figure 6. Services and timespan responses

The last sub-report on REST API calls and infrastructure utilization, recorded two important alerts on the 95th percentile latency. The first one reported a value of 97.06, higher than the p95(%), and the second one reported 78.13, which is very close to p95(%). Those events were occurred during the QA evaluation testing cycle, where all the users were testing the application. The monitoring tool suggested that the Geoblockchain system should reduce and distributed load and resources, in order to handle the heavy load.

p95(%)	p99(%)	Max(%)	Uptime(%)	Samples	Interval(sec)	Alerts(%)	LastUpdated	Comments
97.06	97.57	97.91	100	1711	60	0	2021-04-16 01:08:00+03:00	Reduce load, distribute load, add resources.
79.13	79.18	81.53	100	1711	60	0	2021-04-16 01:08:00+03:00	Prepare to reduce load, distribute load, add resources.
56.1	56.35	57.36	100	4277	60	0	2021-04-16 01:08:00+03:00	
40.56	45.04	45.15	100	1713	60	0	2021-04-16 01:08:00+03:00	
25.01	25.05	25.21	100	1715	60	0	2021-04-16 01:08:00+03:00	
24.28	24.52	24.65	100	1714	60	0	2021-04-16 01:08:00+03:00	
23.19	23.36	23.57	100	1714	60	0	2021-04-16 01:08:00+03:00	
21.05	21.13	21.2	100	1712	60	0	2021-04-16 01:08:00+03:00	

Figure 7. REST API Calls and timespan responses

The final evaluation step was conducted on the 7th Cycle to compare the overall architectures between the two production ready use cases. On-premises infrastructure couldn't meet participants expectations and technical requirements. Also, few concerns were noted from stakeholders regarding the overall long-term cost and maintenance. The on-premise architecture solution could not meet budget and projects timelines overall. The system was not scalable enough without the ability to join blockchain networks and GIS environments outside the distributed blockchain network. Also, the overall hardware resource capacity was predicted very costly for the long term. Besides that, the system requires to have power users with extra knowledge and experience on blockchain and geospatial development to troubleshoot technical issues.

On the other hand, the cloud solution met participants expectations due to the limitations of the on-premises solution. The cloud infrastructure was more friendly to deploy and user friendly on Hyperledger Fabric and ArcGIS Enterprise deployments. Participants had the ability to have their own cloud secured account and privileges to join a voting system that will control the relationships, rules, and roles of the GeoBlockchain network. Also, deployments were more automated, easier to monitor and scale. Finally, they did not require special technical knowledge and experience, as a result users and stakeholders could focus more on the use case problem and spend less time on technical issues [7,9].

Figure 8 and Figure 9 demonstrate the two architecture solutions that were designed and evaluated. Both, solutions applied the same GeoBlockchain criteria, rules, and roles. The on-premises solution in Figure 8, has used the main two technologies Hyperledger Fabric and ArcGIS Enterprise. The connection between the two is the custom API that works as a bridge communication to send transaction and spatial information between the two technologies. Also, the Hyperledger Fabric channels represent the relationship between the participants. Each channel has specific rules for specific participants roles. The rules and roles are written into blockchain called chain codes, or smart contracts, which ensure that the conditions and agreements are met between participants.

However, the cloud solution in Figure 9 was created with the same approach but there are few main differences. The cloud solution used cloud functions such as AWS Lambda function for connecting and creating the API. The lambda function runs your function only when needed and scales automatically. Also, each participant has its own virtual private cloud environment account. This adds more security and privacy to the system because of the cloud private links.

Besides that, the custom integrated API on both architectures was successfully developed and implemented. However, on the first architecture (on-premises), the ArcGIS Koop custom API has a limitation on the compatibility with the blockchain APIs because of data formats specifications. The on-premises use cases were tested only with GeoJSON and JSON data compatible formats. Finally, the cloud solution was more flexible to test data from existing enterprise spatial databases (SQL, Oracle), cloud storages (AWS S3), the InterPlanetary File System (IPFS), which is a protocol, and peer-to-peer network, for storing and sharing data in a distributed file system [4, 10, 12]. This method could reference existing large volume of datasets with the power an SSH Hash. The technical evaluation demonstrated that this method adds integrity, immutability, and transparency because the data does not need to be stored as a geospatial shape but what it is important is the metadata of the shape that is linked with the geospatial shape.

Architecture Solutions:

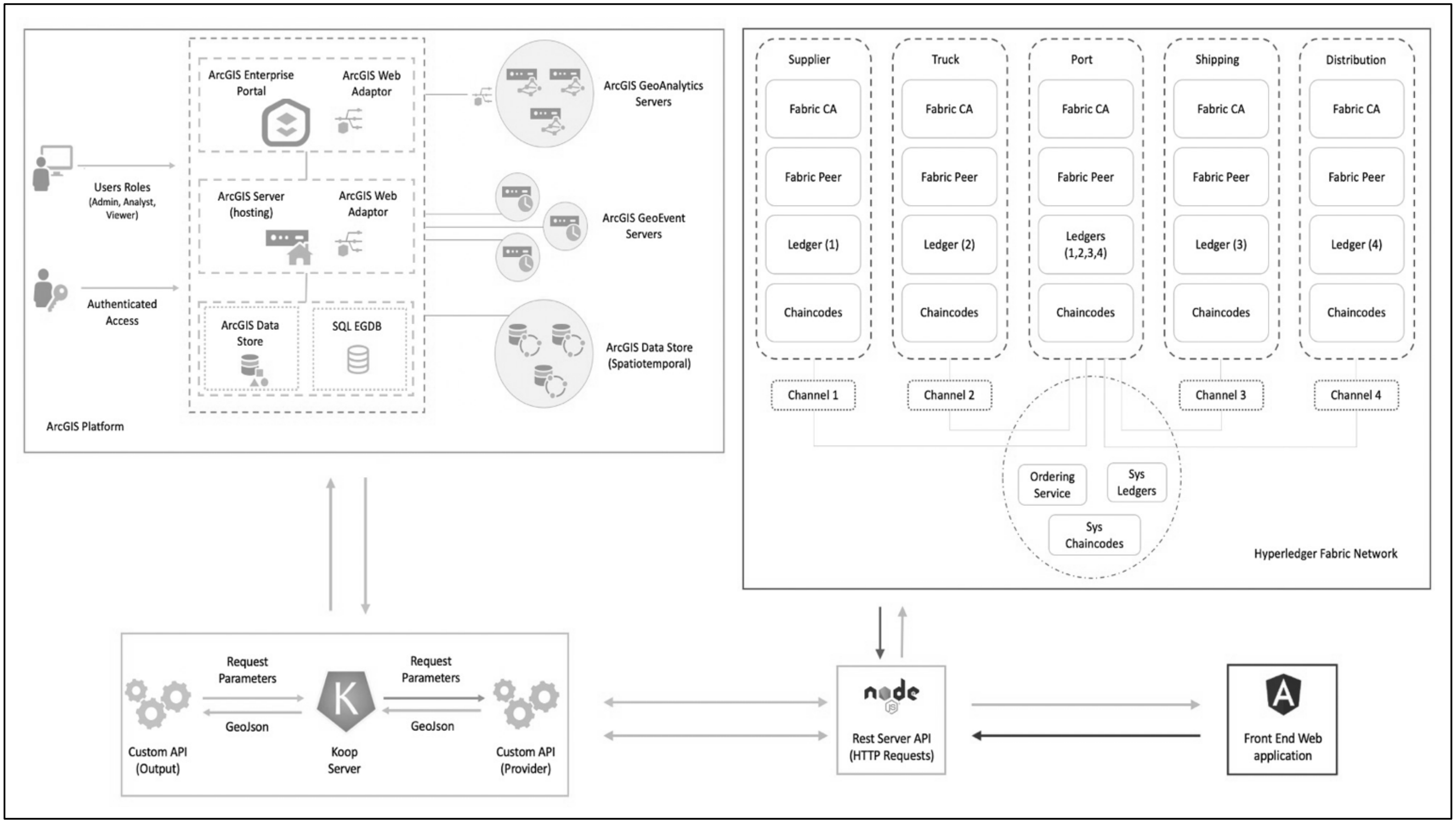


Figure 8. On-Premises Solution Architecture

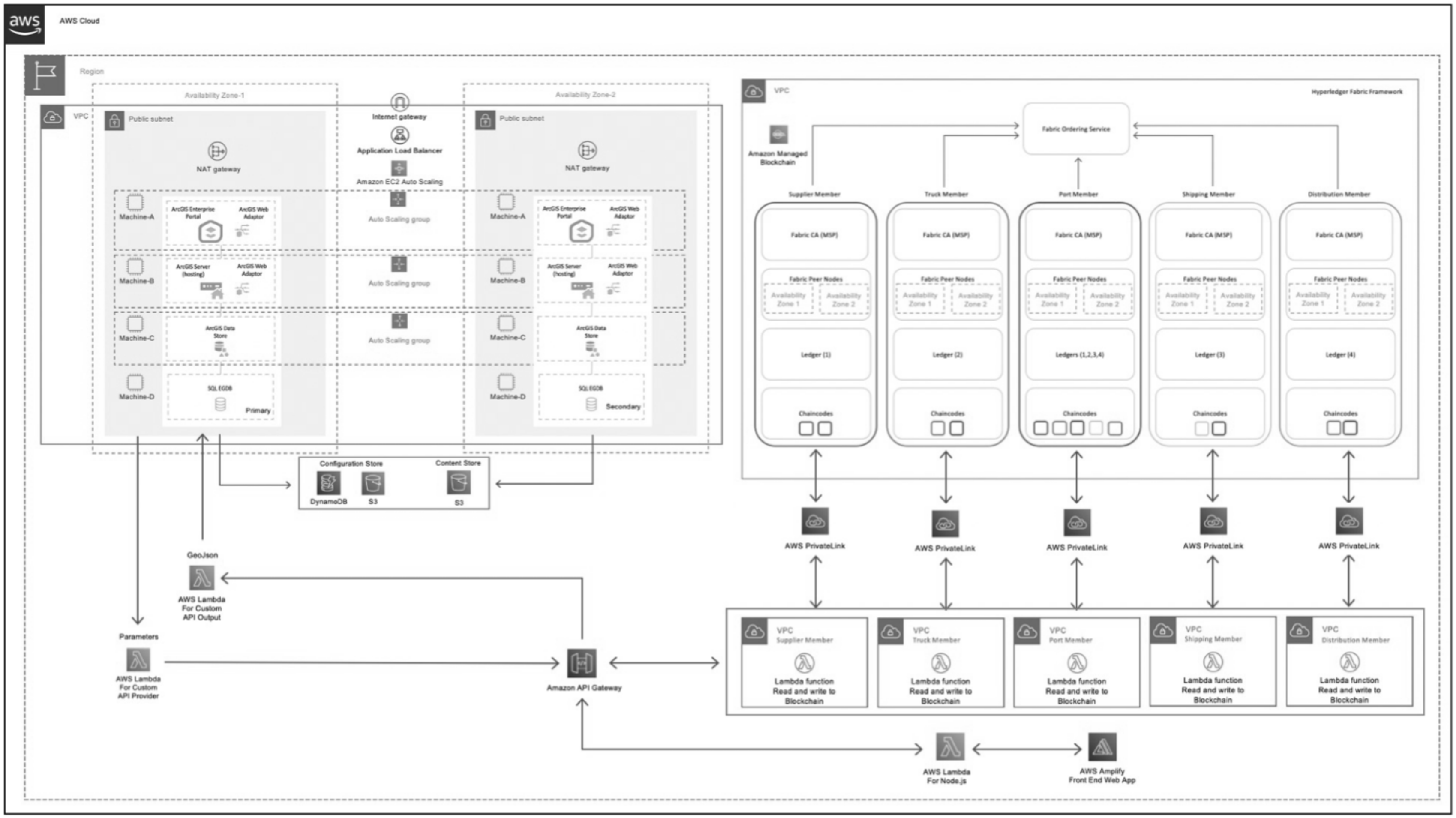


Figure 9. Solution Architecture on Amazon cloud

Proposed GeoBlockchain Framework

The seven cycle process analyzed and evaluated the GeoBlockchain components, rules, roles, and infrastructure criteria with two evaluation types: technical risk and efficacy, and human risk and effectiveness. The study has generalized all the evaluation results along with the previous interviews during the Q-Methodology process in Article 2. The method that was used is a computer assisted qualitative data analysis software (CAQDAS) to explore the connecting dots, rules, roles, and relationships for GeoBlockchain.

In Figure 10, is a diagram of a GeoBlockchain framework that generalizes all the processes and connections. Individuals, Teams, Departments, Organizations, and Communities are examples of the main participants (311) of a System of Systems (313). Those participants perform geospatial processing (316) using a variety of data format and types (315) and to have solutions and artifacts (314) for their own specific industry sectors (312).

This specific geospatial workflow is the backbone of the GIS Infrastructure framework process, which is described as the "Distributed Geospatial Nervous System" according to Jack Dangermond (Esri Founder and President) indicated by dotted lines (330). Sensing (320), Cognition (318), Understanding (319), and Responding (317) are the main attributes of the "Distributed Geospatial Nervous System" (317).

"GeoBlockchain Authoritative Distributed Spatial and Non-Spatial Data and Transactions" (328) are the Trusted Distributed Ledgers where Public, Private, and Hybrid Blockchains exist [15]. A Hybrid Blockchain is the combination of a Public and Private Blockchains. Public is the permissionless blockchain such as Ethereum, and Private is a Permission Blockchain such as Hyperledger Fabric. Through the GeoBlockChain ("GBC") process and the agreed Spatially Smart

contracts (322) Participants (311) from different organizations will agree on specific rules and roles that will shape the spatially smart contracts (322). The overall Spatial Location Intelligence process (311-316) must be verified, validated, and confirmed at the GBC process during step (328). All confirmations through blockchain frameworks (Public, Private, and Hybrid) could be authenticated with the peer-to-peer protocols and Spatial protocols (324). Then they are recorded as Trusted and Authenticated into the Blockchain Ledgers (328).

The result of the “GBC - Spatially Enabled Blockchain” framework in Figure 10, provides a generalization on GeoBlockchain components, attributes, rules, and roles. The GeoBlockchain framework is suggested to be used as the starting template to support the design, development, and evaluation of artifacts that will explore industry problems related with blockchain and GIS spaces.

Also, the GBC framework could be tested on public and private blockchain and with any type of GIS provider either on-premises or cloud environments. Besides that, it is suggested that the design of this framework could be compatible with multi data and format types. Such as, unstructured data, tabular, lidar, terrain, imagery, raster, voxels, vector, 3D, CAD, BIM, big data, real time, and multidimensional data [17].

Finally, the GBC framework provides a system of systems interface with multiple projects and systems that could collaborate on enterprise and online interconnected solutions. Also, it is scalable enough to leverage multiple ledgers, multiple storage type formats, and communication protocols. This capability is aligned with the main blockchain design characteristics, which are based on distributed systems, peer-to-peer networks, and cryptographic algorithms [1, 13, 16].

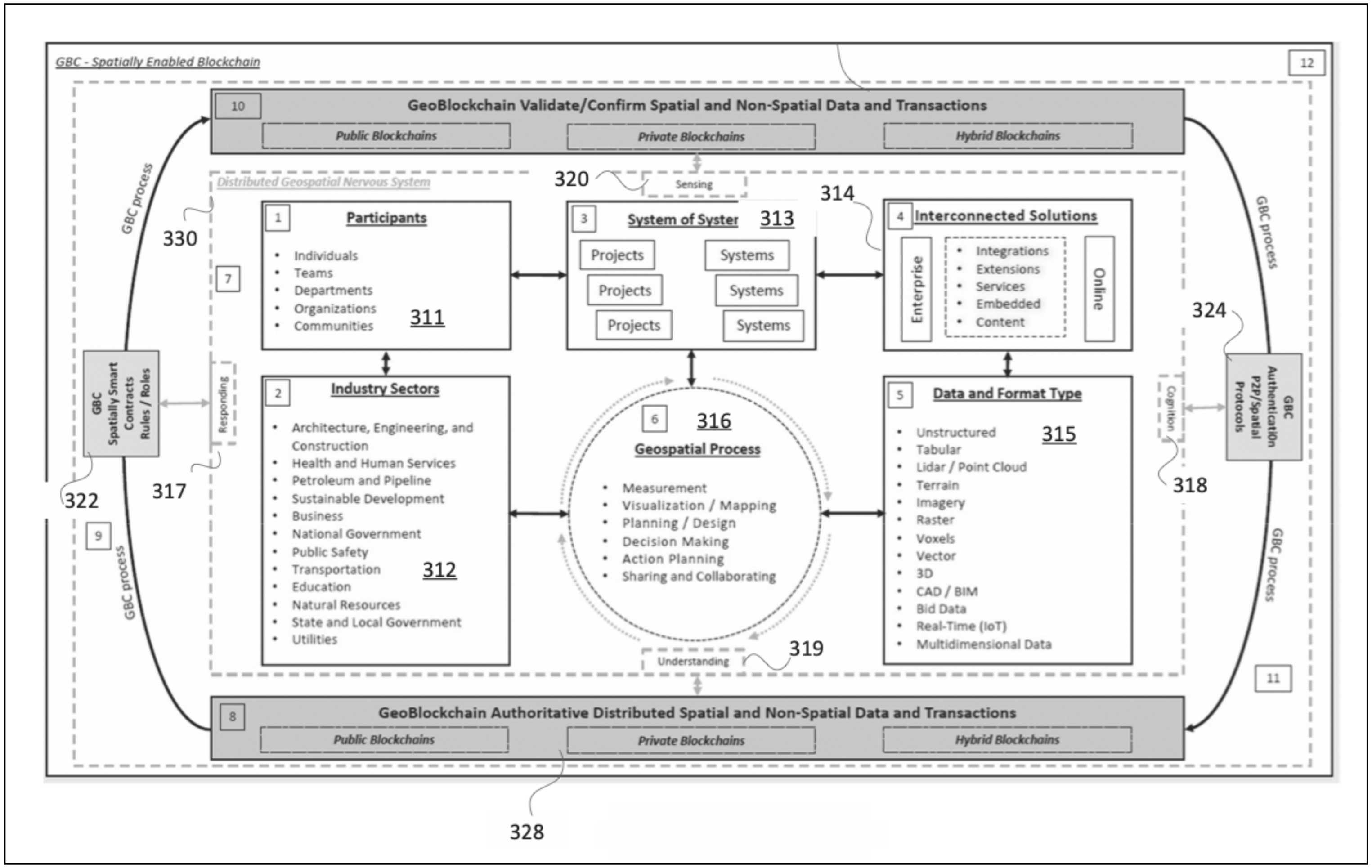


Figure 10. GeoBlockchain framework

Limitations

The main limitations of the current research include: (1) time and data availability constraints, during the seven cycles evaluation processes; (2) there is a need for a further iteration to ground the GeoBlockchain framework; (3) have not tested additional criteria for the study yet; (4) fully enterprise environments are required for more real-world solution prototypes; and (5) need to test the ICT solution prototypes with more organizations.

Discussion and Conclusion

The main important criterion of any GeoBlockchain solution is to be approached as a combined geospatial and blockchain process and not as an integration method that could store multiple data formats into ledgers by using cryptographic methods. This process, as explained on the proposed GBC framework, involves design science research and evaluation principles adopted from Peffers et.al (6-process cycle), and from Venable et.al (human risk and effectiveness strategy, and technical risk and efficacy).

The main attributes and criteria that the GBC process should have in order to answer the first research question (What attributes and criteria are effective in initiating and maintaining a GeoBlockchain solution?) are identified as:

- Involve multiple participants during the process
- Explore pragmatic industry problems and use cases

- Treated as system of systems, that will be flexible with multiple projects and systems together
- Implemented as an interconnected solution for enterprise and cloud systems
- Tested with multiple data formats
- Create a process for decision making with geoprocessing tools
- Develop a distributed nervous system that could provide responding, sensing, cognition and understanding
- Design as authoritative capability for spatial, non-spatial and transactional information data
- Adopt spatially smart contracts, rules, and roles
- Design a validation and confirmation process
- Design an authentication methodology for peer-to-peer and spatial protocols

However, this study is validating Article 2 findings on GeoBlockchain rules and roles implementation requirements. The GBC framework must include participants, trusted organizations, a decentralized and or centralized operation (Hybrid approach), transparency and confidentiality, integrity, immutability, and good performance [14]. Both studies (second and third articles) are confirming that GBC rules and roles are required for an effective and efficient GeoBlockchain solution. Also, they are very important to exist and to be maintained as necessary for the GBC overall process, which is answering the second research question on this article.

Besides that, the study evaluated and compared the GBC attributes, criteria, rules, and roles (as GBC designed principles) between an enterprise and non-enterprise architecture

solutions. The recommended GBC design principles had few differences between the two solution architectures. Most of the design principles listed in Table 1 are required for both solutions (Enterprise, and Non-Enterprise). The only exception is the criterion of Immutability that is not required for both solutions. This is because changes could be allowed or not allowed on private blockchain but not for public blockchain frameworks.

On the other hand, the comparison showed that non-Enterprise does not require to be interconnected with other solutions besides Blockchain and GIS technologies. Also, it is optional and up to the user to leverage multiple data formats, and to have an environment that will perform and scale well [12]. Those optional design principles are difficult to apply to local and centralized environment according to users' feedback during the seven cycle evaluation process. Table 1 is providing the overall differences based on the third research question on this study.

Table 1. Differences between Enterprise and Non-Enterprise

GeoBlockchain design principles (attributes, criteria, rules, and roles)	GeoBlockchain (Hyperledger-Fabric/ArcGIS Enterprise)	
	Enterprise	Non-Enterprise
Participants	Req.	Req.
Industry Sectors – Use Cases	Req.	Req.
System of Systems	Req.	Req.
Interconnected Solution	Req.	Non- Req. (Optional)
Multiple Data Formats	Req.	Non- Req. (Optional)
Geoprocessing Process	Req.	Req.
Distributed Nervous System	Req.	Req.
Authoritative Process	Req.	Req.
Spatially Smart Contracts, Rules, Roles	Req.	Req.
Validation and Confirmation Process	Req.	Req.
P2P Authentication Method	Req.	Req.
Trusted Organization	Req.	Req.
Centralized Operation	Req.	Req.
Transparency and Confidentiality	Req.	Req.
Integrity	Req.	Req.
Immutability	Non- Req. (Optional)	Non- Req. (Optional)
High Performance	Req.	Non- Req. (Optional)

In conclusion, the third article designed an evaluation methodology to validate the two ICT-artifacts designs from the second article. The methodology has used the seven cycle evaluation processes with two different architectures based on two use cases from 2nd article (supply chain and land ownership). Also, the findings were generalized and summarized into a GeoBlockchain framework that could contribute to research, industry, and knowledge. The next step of the proposed GeoBlockchain framework is to be verified and confirmed with other use cases from other industry sectors and to embed in other research disciplines.

References

1. Augot, D., Chabanne, H., Chenevier, T., George, W., & Lambert, L. (2017). A User-Centric System for Verified Identities on the Bitcoin Blockchain. In J. GarciaAlfaro, G. NavarroArribas, H. Hartenstein, & J. HerreraJoancomarti (Eds.), Data Privacy Management, Cryptocurrencies and Blockchain Technology (Vol. 10436, pp. 390-407). Cham: Springer International Publishing Ag.

2. Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. International Journal of Health Geographics, 17, 10. doi:10.1186/s12942-018-0144-x

3. Coignard, J., Munsing, E., MacDonald, J., Mather, J., & Ieee. (2018). Co-simulation Framework for Blockchain Based Market Designs and Grid Simulations. In 2018 Ieee Power & Energy Society General Meeting. New York: Ieee.

4. Crompton, S., & Jensen, J. (2018). Towards a Secure and GDPR-compliant Fog-to-Cloud Platform. In A. Sill & J. Spillner (Eds.), 2018 Ieee/Acm International Conference on Utility and Cloud Computing Companion (pp. 296-301). New York: Ieee.

5. Croxson, A., Sharma, R., & Wingreen, S. (2019). Making Sense of Blockchain in Food Supply-Chains 2 Background Review. 1–11.

6. D. Oppong-Tawiah, J. Webster, S. Staples, A.-F. Cameron, A. Ortiz de Guinea, and T. Y. Hung, “Developing a gamified mobile application to encourage sustainable energy use in the office,” J. Bus. Res., vol. 106, pp. 388–405, 2020.

7. Ferreira, J. C., & Martins, A. L. (2018). Building a Community of Users for Open Market Energy. Energies, 11(9), 21. doi:10.3390/en11092330

8. John Venable, Jan Pries-Heje & Richard Baskerville (2016) FEDS: a Framework for Evaluation in Design Science Research, European Journal of Information Systems, 25:1, 77-89, DOI: 10.1057/ejis.2014.36

9. Kianmajd, P., Rowe, J., Levitt, K., & Ieee. (2016). Privacy-Preserving Coordination for Smart Communities. In 2016 IEEE Conference on Computer Communications Workshops. New York: Ieee.

10. Li, K. J., Li, H., Hou, H. X., Li, K. D., Chen, Y. L., & Ieee. (2017). Proof of Vote: A High-Performance Consensus Protocol Based on Vote Mechanism & Consortium Blockchain. New York: Ieee.

11. Lo, S. K., Xu, X., Chiam, Y., & Lu, Q. (2017). Evaluating Suitability of Applying Blockchain. https://doi.org/10.1109/ICECCS.2017.26

12. McGinn, D., McIlwraith, D., & Guo, Y. (2018). Towards open data blockchain analytics: a Bitcoin perspective. Royal Society Open Science, 5(8), 14. doi:10.1098/rsos.180298

13. Montes, G. A., & Goertzel, B. (2019). Distributed, decentralized, and democratized artificial intelligence. Technological Forecasting and Social Change, 141, 354-358. doi:10.1016/j.techfore.2018.11.010

14. Pahl, C., El Ioini, N., Helmer, S., Lee, B., & Ieee. (2018). An Architecture Pattern for Trusted Orchestration in IoT Edge Clouds. New York: Ieee.

15. Pokrovskaia, N. N., Spivak, V. A., Snisarenko, S. O., & Ieee. (2018). Developing Global Qualification-Competencies Ledger on Blockchain Platform. New York: Ieee.

16. Potts, J., Rennie, E., & Goldenfein, J. (2017). Blockchains and the crypto city. It-Information Technology, 59(6), 285-293. doi:10.1515/itit-2017-0006

17. Seritan, G., Tristiu, I., & Fierascu, G. (2018). Assessment for efficient operation of smart grids using advanced technologies. In M. Gavrilas, C. Fosalau, C. G. Haba, & B. C. Neagu (Eds.), 2018 International Conference and Exposition on Electrical and Power Engineering (pp. 901-905). New York: Ieee.

18. Sharma, R. S., Wingreen, S., Kshetri, N., & Hewa, T. M. (2019). Design principles for use cases of blockchain in food supply chains. Americas Conference on Information Systems, 1–10. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1300&context=amcis2019

19. Skowronski, R. (2019). The open blockchain-aided multi-agent symbiotic cyber-physical systems. Future Generation Computer Systems-the International Journal of Escience, 94, 430-443. doi:10.1016/j.future.2018.11.044

20. Wang, N., Xu, W. S., Xu, Z. Y., & Shao, W. H. (2018). Peer-to-Peer Energy Trading among Microgrids with Multidimensional Willingness. Energies, 11(12), 22. doi:10.3390/en11123312

21. Wingreen, S., Sharma, R., jahanbin, pouyan, Wingreen, S., & Sharma, R. (2019). a Blockchain Traceability Information System for Trust Improvement in Agricultural Supply Chain. Research-in-Progress Papers, 5–15. Retrieved from https://aisel.aisnet.org/ecis2019_rip/10

Chapter 5: Conclusion

This dissertation followed a systematic approach on a GeoBlockchain concept, and each article was a continuous research process. All findings, evaluations, and conclusions from each article were used as inputs and contributions on the next article study, as described in Chapter 2, Chapter 3, and Chapter 4.

The first article followed a systematic literature review process to explore existing research on Blockchain, and Geographic Information Systems Technologies. The findings drove the study to examine four main regions (Europe, North America, Asia, and Middle East), industries from the financial, and logistics sectors., and cloud providers such as IBM, Microsoft, and AWS. The systematic literature review analysis provided the signal that these two technologies could be integrated together and specifically on land information systems and supply chain use cases.

However, few limitations were identified because blockchain is a new technology and it requires time to add more findings into research. Also, there is no clear understanding if the analyzed articles have used public, private or hybrid blockchain frameworks. The main conclusion from the first article recommended that more research should be done into blockchain, geospatial, and other areas so existing literature, artifacts and theoretical background could mature.

Also, any new research study that will examine the integration with blockchain and GIS technology as a new GeoBlockchain concept, might be a challenge but this dissertation could contribute to knowledge and to be used as an example for other related studies.

The second article indicated that blockchain technology can be integrated with geospatial technology, resulting in the GeoBlockchain. The outcome of this study provided 2 ICT-artifacts on a land ownership transactions and supply chain use cases. The study followed a design science research methodology, Peffers et.al 6-steps process, and Q-Methodology with Q-set criteria were used as a theoretical background to provide GeoBlockchains' main components and implementation criteria for land ownership and supply chain examples.

However, the ICT-artifact outcome from this study was a GeoBlockchain proof-of-concept dashboard for each separate use case to record, analyze, share, and visualize a variety of blockchain and geographical data. The GBC application is a concept that should impact society by simplifying the supply chain management and land ownership transaction experience for organizations, citizens, and governments. This presents an opportunity for supply chain and land ownership stakeholders to take advantage of these new blockchain-based datasets and access that data using their geospatial system to see and understand industry problems from a different point of view.

It was suggested that a few more refinements should continue with enhancements during the development and testing phases until the next generation release of GeoBlockchain web application. Also, the main technology providers used on this study, Hyperledger Fabric for Blockchain and ArcGIS Enterprise for Geographic Information Systems, were capable to support research's design and methodology.

On the other hand, the GeoBlockchain proof-of-concept could contribute to industry by providing the main fundamentals from this research. For example, companies that work on new innovations, ideas, and solutions in order to solve problem for their clients.

Lastly, the third article provided a designed evaluation methodology to validate the two ICT-artifacts designs from the second article. The methodology designed a 7-cycle process for two different architectures based on two use cases (supply chain and land ownership). Also, the findings were generalized and summarized into a GeoBlockchain framework that could contribute to research, industry, and knowledge. Besides that, the FED framework was used as the main kernel theory that supported Geoblockchain concept.

The third article evaluated all the attributes, criteria, rules, and roles between an enterprise and non-enterprise architecture solutions. Few differences between the two solution architectures were identified with the only exception on the criterion of immutability. Also, the comparison showed that non-Enterprise does not require to be interconnected with other solutions besides Blockchain and GIS technologies.

Finally, it is suggested that GeoBlockchain framework must include participants, trusted organizations, decentralized and or centralized operation (Hybrid approach), transparency and confidentiality, integrity, immutability, and good performance. Moreover, the main important criterion of any GeoBlockchain solution is to be designed as a process and not as an integration method that could store multiple data formats into ledgers by using cryptographic methods. It is suggested as next steps that the GeoBlockchain framework must be verified and confirmed with other use cases and disciplines in order to provide contribution, rigor and relevance.

Currently, some of the findings from this dissertation process contributed to research, industry, and innovation by providing three research articles, two industry online articles, one interview to industry leaders, multiple conference presentations, and a provisional patent application with USPTO.