



NON-FUNGIBLE TOKENS: THE ART & SCIENCE OF WEB 3.0



FEATURED PEER-REVIEWED RESEARCH

Non-Fungible Tokens as an Alternative Investment: Evidence from CryptoPunks

Blockchain in Fisheries Supply Chain: A Systematic Literature Review

Can Blockchain Take Smartphones Out of Contact Tracing?

Creation of a Self-Sustaining Token Economy

Proceedings of 4th Blockchain International Scientific Conference ISC 2022



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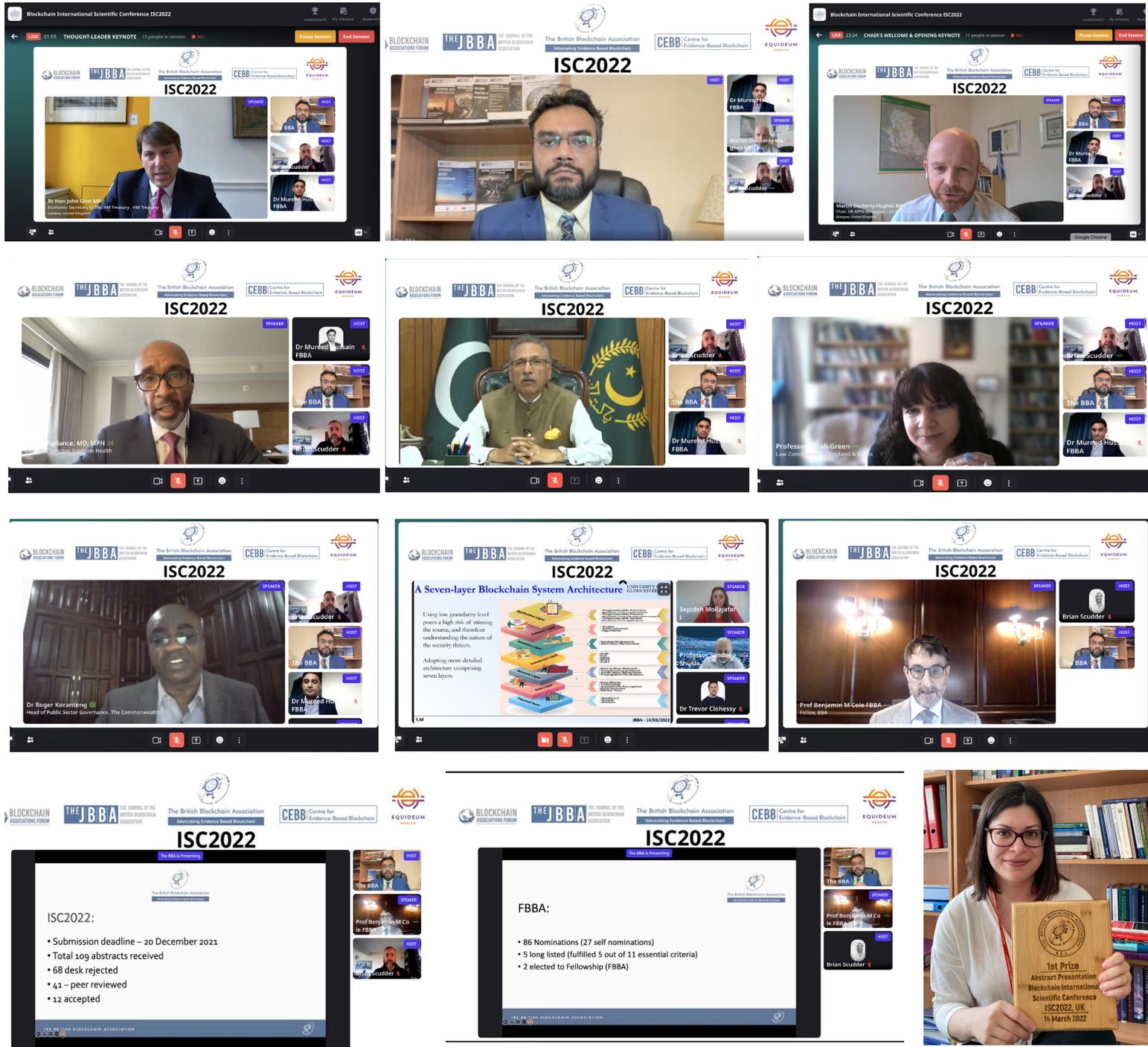
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4TH BLOCKCHAIN INTERNATIONAL SCIENTIFIC CONFERENCE 14 MARCH 2022, #ISC2022, UK



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Newly Elected Fellows of the British Blockchain Association, March 2022

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Blockchain in Fisheries Supply Chain

OPERATIONS
 Planning, Tracking & Sharing Information
 Reduced Payments & Costs
 Information Management

AUDITING & FRAUD DETECTION
 Transparency
 Cost Savings
 Information Asymmetry

COMPETITIVENESS
 Transparency

SUPPLY CHAIN MANAGEMENT
 Governance Structure
 Visibility, Optimization & Demand Forecasting
 Collaboration, Automation

ACTIVITY CONTROL
 Increased Trust
 Efficiency

LOGISTICS
 Customer Value

SPEAKERS:
 Colin Callinan
 Matthias Hafner
 Dr Sara Hourani

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TOKEN ECONOMY COMPONENTS

White Paper
 Investment Rounds of ICO

Exchange Listing (Centralized, Defi)

Trading
 Sell
 Buy
 Hold
 Liquidity

Blockchain-based Service Description
 Incentives
 Locking
 Punishment and Penalties
 Voting

Token Distribution

SPEAKERS:
 Professor Sandeep Shukla
 Dr Muneed Hussain FBBA
 Sepideh Mollajafari

ISC2022

Fashion industry

Replace
 Activities
 Production
 Consumption

Change

1000 garments produced per year
 1 in 5 never sold

20% of industrial water pollution
 10% of carbon emissions
 25% of all chemicals produced

SPEAKERS:
 Prof Kristi Yuthas
 Prof Melissa Appleyard
 Professor Marc Pilkington FBBA

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RESEARCH FRAMEWORK

Blockchain and DLT European State of the Art 2021

Rating Scale

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Unique digital consciousness

Branching identity, as described by Horta in discussing the notion of latent potential (conscious) identity means, complexifies notions for individual identity of even a conscious digital agent.

Blockchain technology using non-judible tokens, offers a way for us to ensure that digital objects are eventually incapable of branching, and so too could help ensure the uniqueness of digital assets and their possession, ensuring significantly advanced computing power eventually makes it possible to create sufficiently complex programmable NFs.

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Barriers

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Blockchain Interdependence Framework

Consortium interdependencies across business contexts

Economic: Incentives, Governance, Standards, Ecosystem interdependencies

Socio-technical: Interoperability, Scalability, Security, Privacy, Transparency, Accountability, Sustainability

Legal/regulatory: Regulatory, Compliance, Legal, Policy, Standards

Standards: Standards, Interoperability, Scalability, Security, Privacy, Transparency, Accountability, Sustainability

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Blockchain International Scientific Conference #ISC2022

BioNFETs: Enabling Decentralized Consented Genomics

Authors: Gisela Waters, PhD
 Daniel Uribe, MBA

March 14th, 2022

SPEAKERS:
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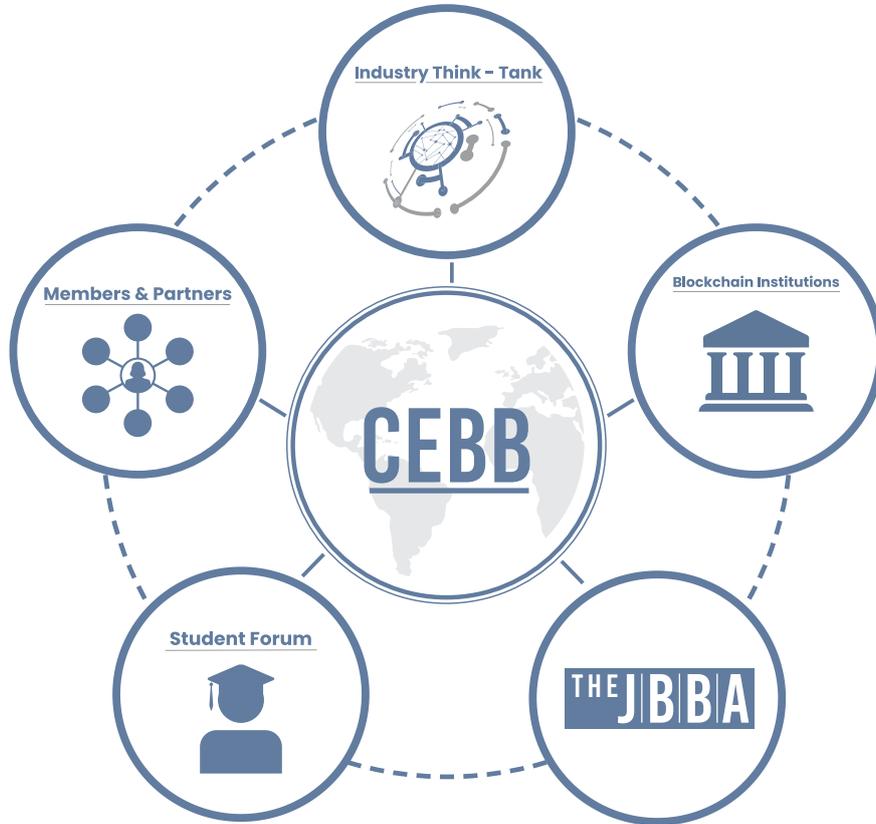
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Blockchain Arbitration: A Forum For Improving Access to Justice?

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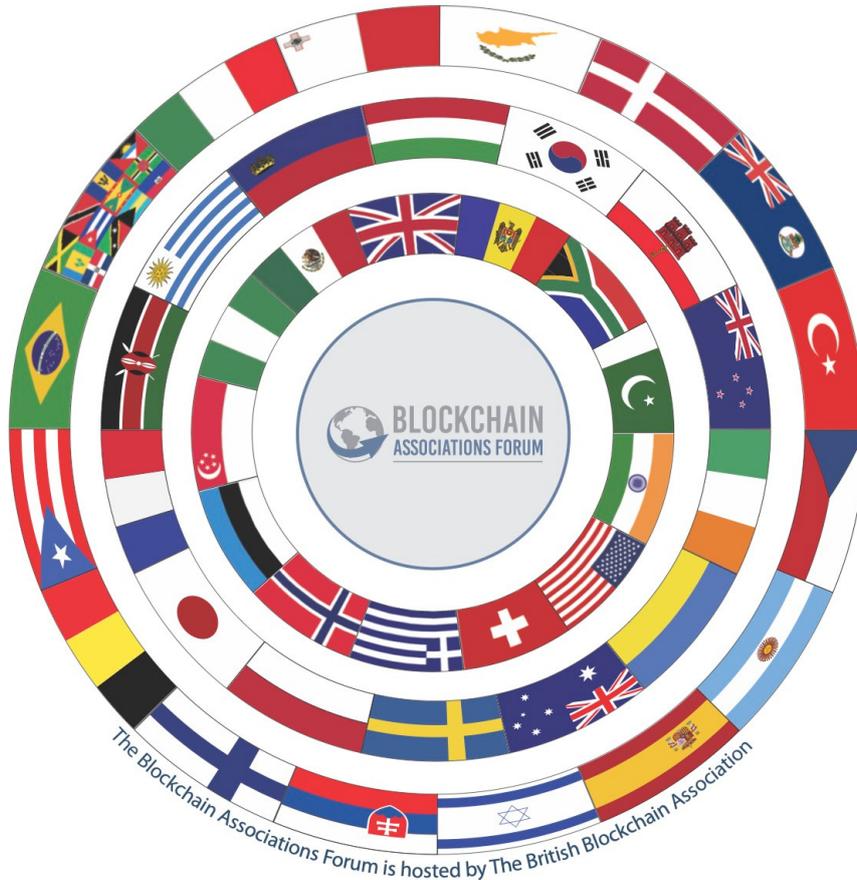


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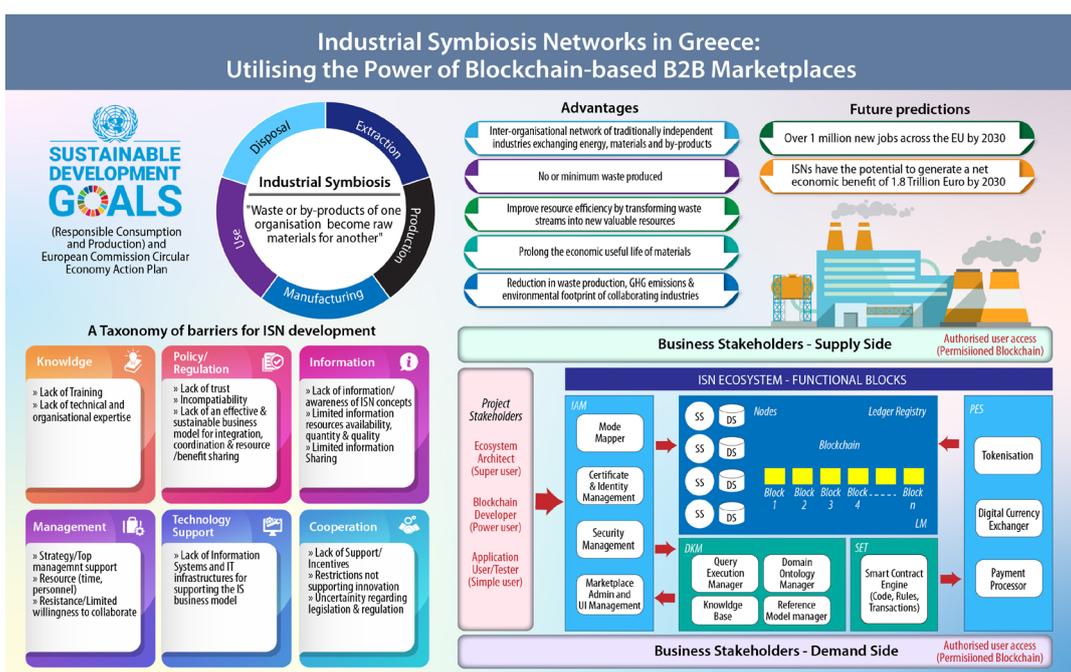
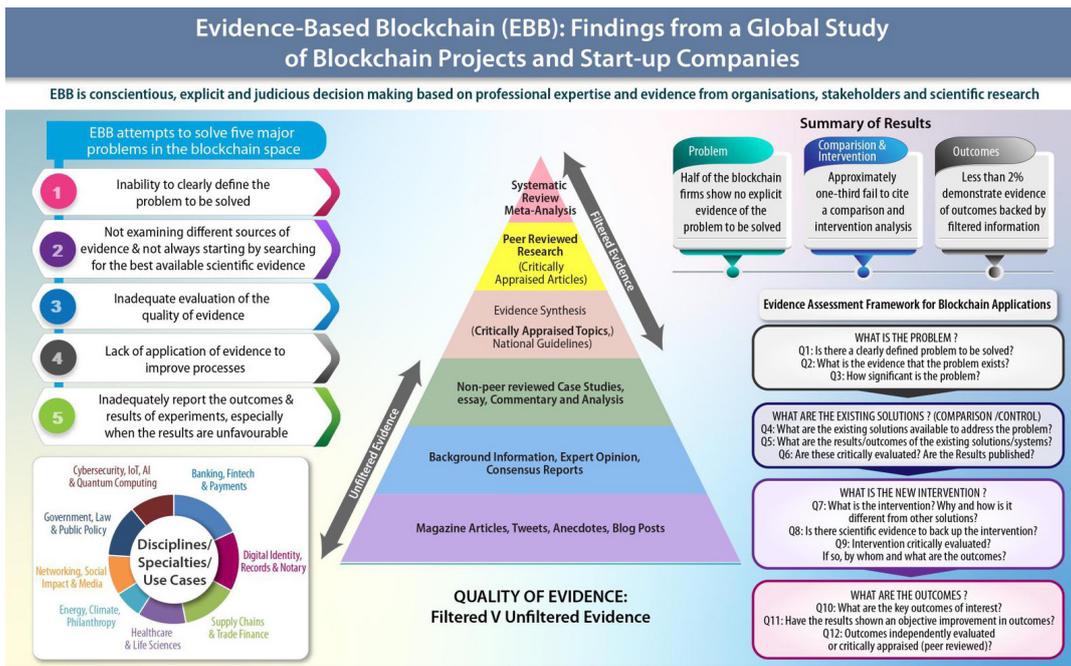
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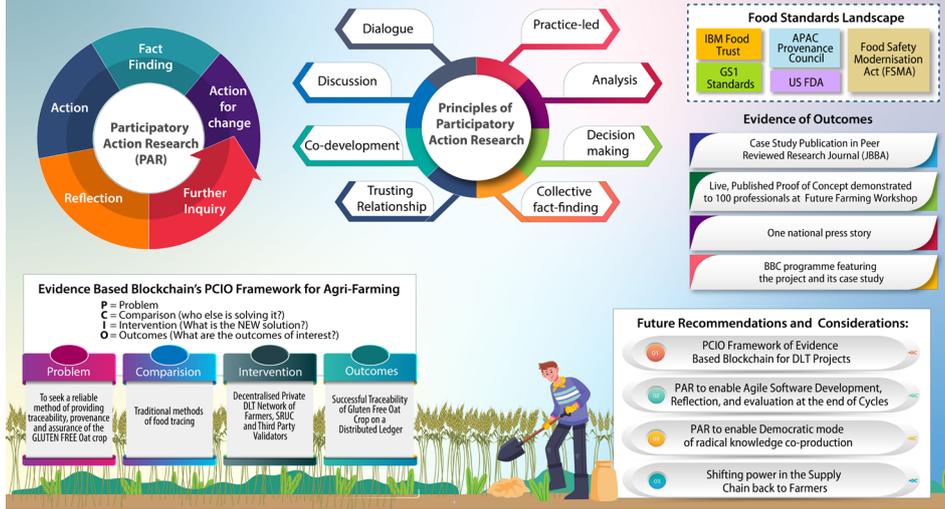
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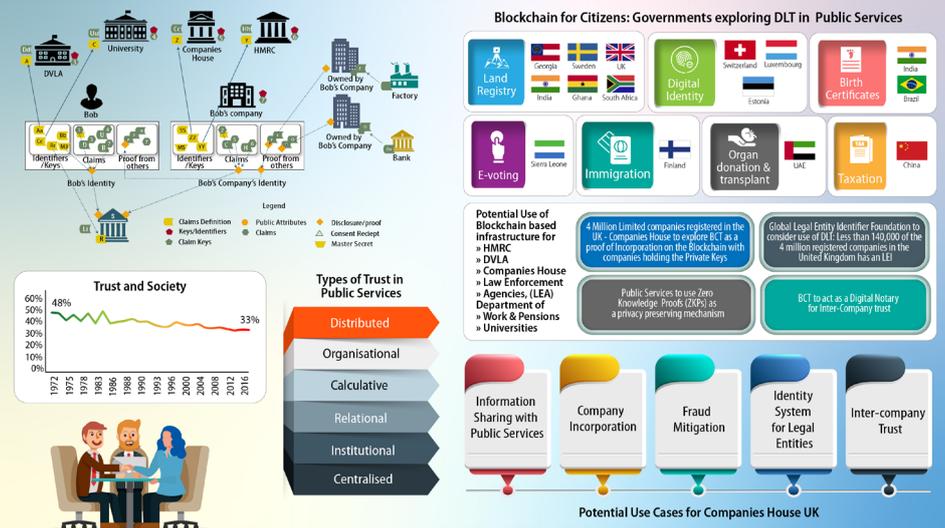
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Blockchain: A Panacea for Trust Challenges In Public Services? A Socio-Technical Perspective



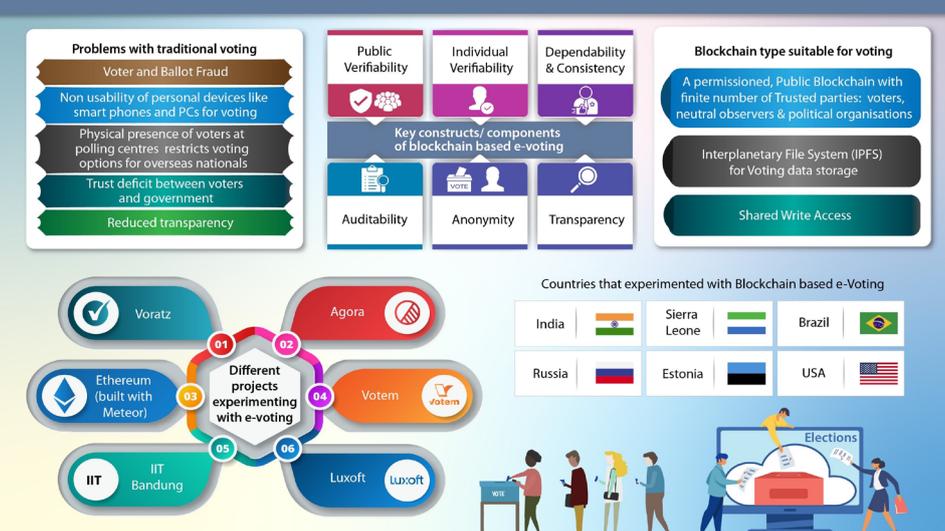
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E-Voting on the Blockchain



Kevin Curran
DOI: 10.31585/jbba-1-2-(3)2018

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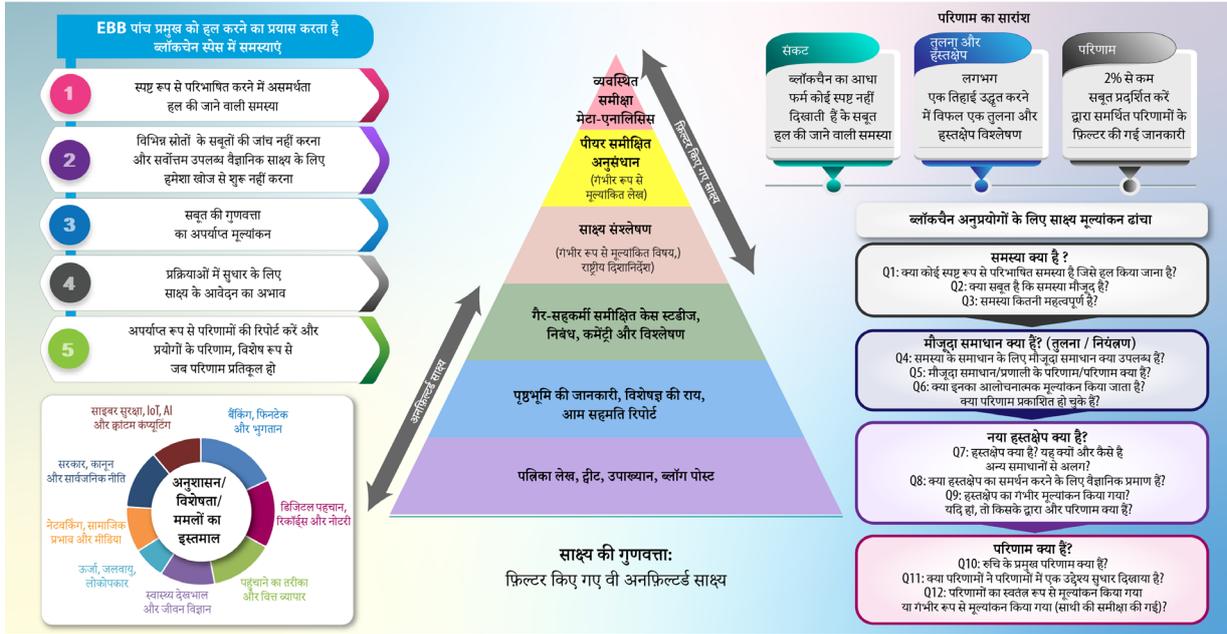


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HINDI

साक्ष्य-आधारित ब्लॉकचैन (EBB): ब्लॉकचैन परियोजनाओं और स्टार्ट-अप कंपनियों का एक वैश्विक अध्ययन से निष्कर्ष

EBB पेरोवर विशेषज्ञता और संगठनों, हितधारकों और वैज्ञानिक अनुसंधान के साक्ष्य के आधार पर कर्तव्यनिष्ठ, स्पष्ट और विवेकपूर्ण निर्णय लेने वाला है।



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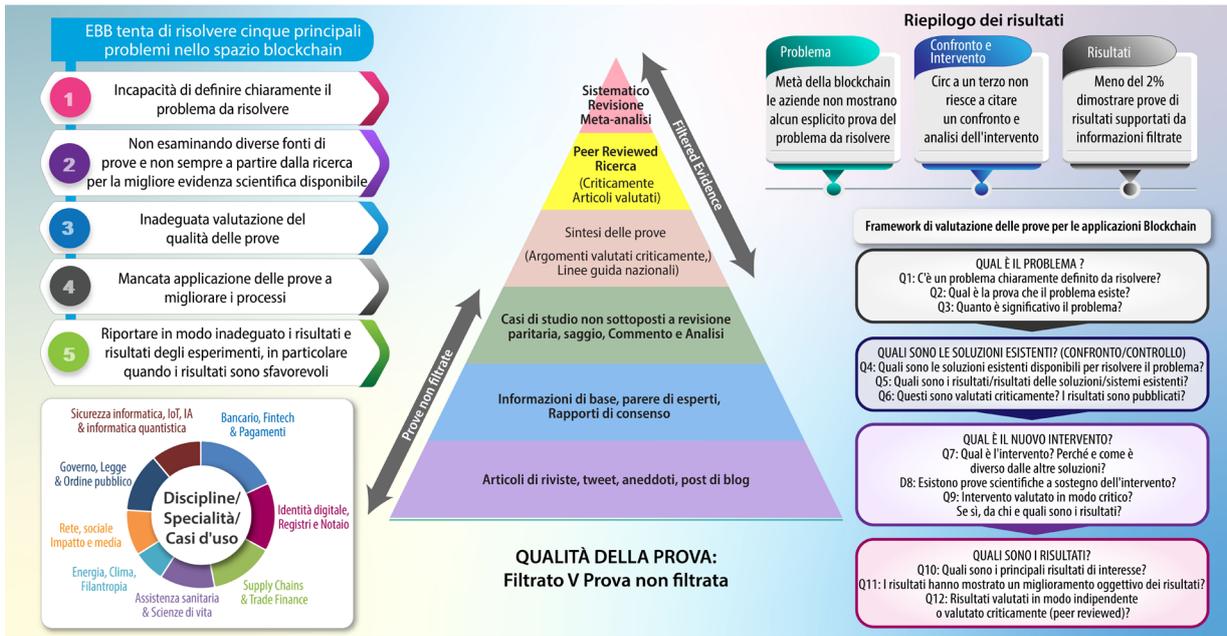
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अस्वीकरण: छवि के उपयोग को वैश्विक या अनुसंधान उद्देश्यों के लिए प्रकाशित करने के लिए उपयुक्त विधेया के साथ अनुमति है। मूल स्रोत के रूप में लेख। व्यावसायिक उपयोग के लिए इलेक्ट्रॉनिक के पुनरुत्पादन के लिए जेकेबीए से अनुमति की आवश्यकता होती है।

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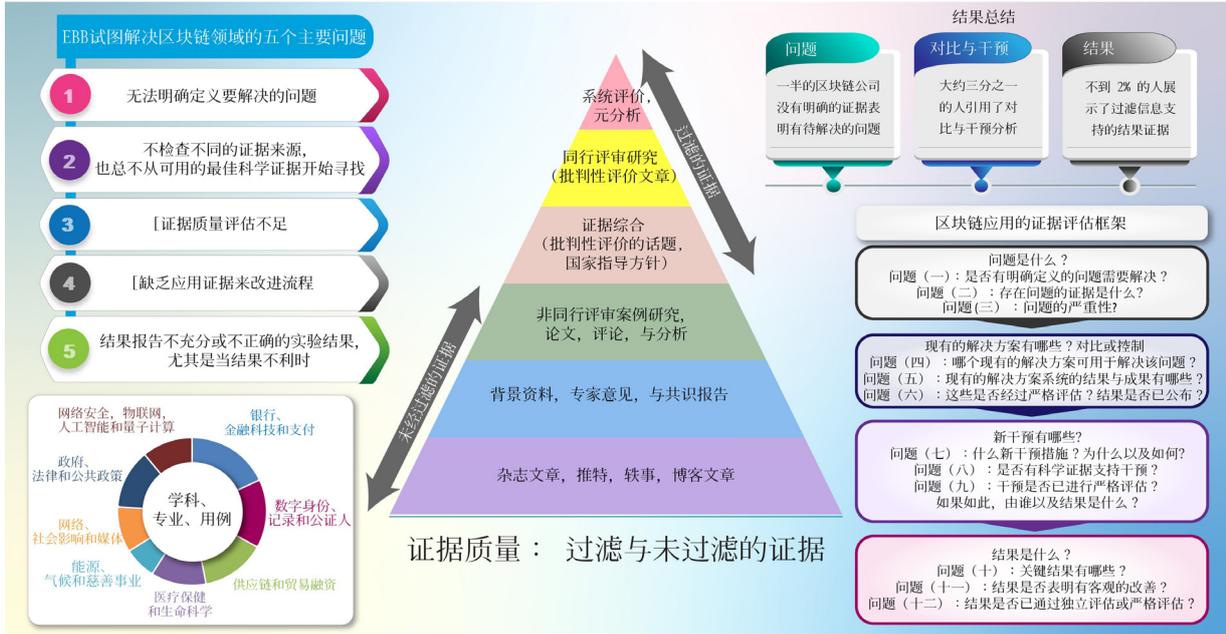
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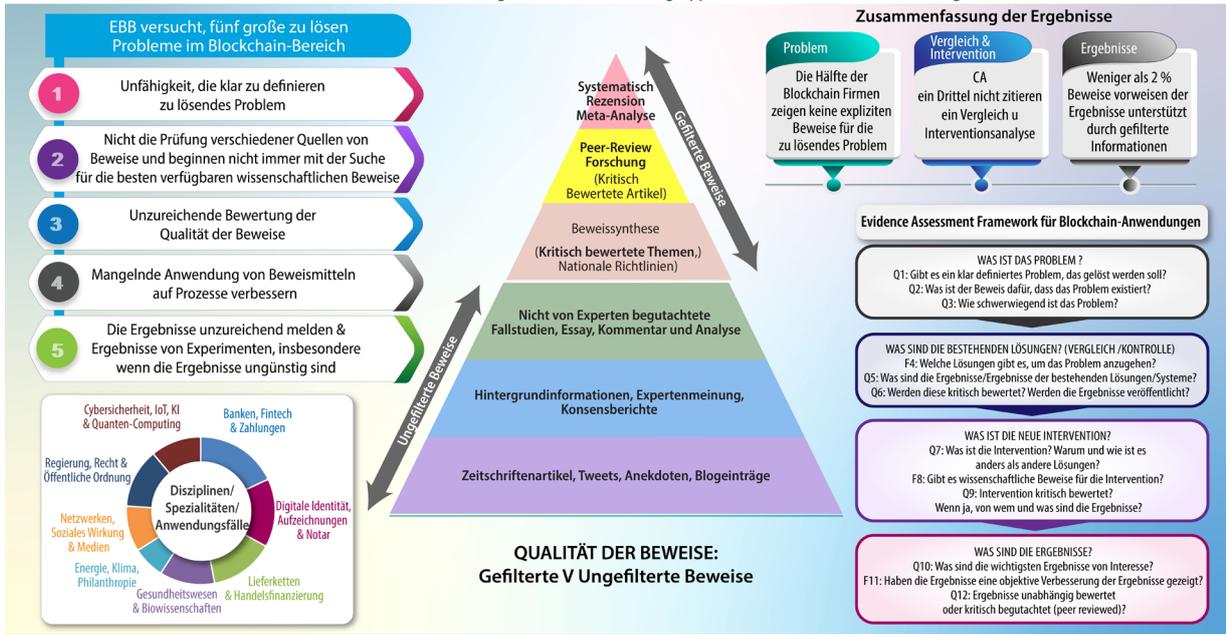
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Areas for future research:
Societal Impact, Sustainability
Quality of Life & Work, new opportunities

TECHNOLOGY

Hardware (VR), AR, AI,
Blockchain, Platforms,
Smart Contracts, DLT,
Bridges, Side-Chains



ACCESSIBLE VIA
DECENTRALISED
CRYPTOGRAPHIC ID

CONCURRENT &
CONVERGENT



INTEROPERABLE



PERSISTENT &
REAL TIME: 24/7



CORE ENABLERS

CREATORS

Artists, Developers,
Builders, Users, Coders,
Owners/ IP, Programmers
Networks, Communities



FINANCE

Crypto, NFT, Investing,
Rewards, Ownership,
DeFi, Trading, Gaming
Lending/ Borrowing

PERMISSIONLESS



OPEN SOURCE
AND SCALABLE



THE OPEN METAVERSE ECOSYSTEM

The Metaverse – What are the opportunities and challenges that lies ahead and how blockchain community could play an important role in this ecosystem?

Work has moved from conference rooms to video calls. The video games are replacing sports as a competitive activity and we spend most of our daily life looking at the screens – networking, socialising, e-commerce, education, and lot more - and no doubt covid has accelerated that shift, but metaverse takes these interactions to a whole new level – from a 2D experience to a 3D internet – where instead of looking at the screen, we are IN the place – a more immersive experience.

Metaverse is much more than just VR, crypto, gaming or avatars. It is a concept that ties these ideas together and seeks to explore how they interconnect and work in collaboration with each other. And while some of us think this is far away into the future, metaverse is already here.

So, what are the core enablers of Metaverse – without which metaverse simply could not exist:

Creators: Building a user centric, programmable virtual world where artists, coders, developers, builders, community, and programmers build a cohesive network.

Finance: An ideal Metaverse will have a fully functioning economy – NFTs, crypto, defi (trading, investing, buying, selling, gaming, borrowing and much more).

Technology: The hardware – VR, software – Blockchain, AR, AI, smart contracts, side chains, et al.

What are the **Key features** of an Open Metaverse?
Live, and Persistent – Real Time: no recorded sessions

Concurrent – and convergent – operating at the same time no cap on the users
Fully functioning economy

Interoperability – Users will be able to take their assets and rewards outside of one metaverse and use them in the other.

The Digital Avatars – *Self Sovereign Digital Identities*

Virtual Community Space: for example, virtual campuses where students can learn, work, and socialize both inside and outside the classroom - a metaverse where you can *build your own virtual worlds*, play games, explore NFT art museums, and attend live concerts using your Digital Avatars.

I believe we are very early in the world of Metaverse, and at this stage, we do not have all the answers so we should start by asking better questions: What will be the **societal impact** of metaverse on future generations? what are the **ethical** issues? Privacy, security, reputation, id theft. How to build **sustainable systems**? How about the concerns of energy consumption?

Open v closed systems – Facebooks Meta v fully open decentralised infrastructures?

Training and education of stakeholders – are we moving too fast? What's in it for the stakeholders? What are the **incentive mechanisms** for adoption of metaverse?

And finally, **will metaverse make our world a better place to live?**

I think it is worth exploring the possibilities, and the future looks exciting.

Professor Naseem Naqvi FBBA
Chair, Centre for Evidence Based Blockchain

EDITORIAL

It gives me immense pleasure to author my second editorial in the history of the Journal of British Blockchain Association. My first one was written a few months before the outbreak of the Covid-19 pandemic. I feel that times have become more preoccupying and uncertain today with extremely serious rising concerns related to our health, our environmental sustainability and global security. Notwithstanding, I would like to stress how proud and honoured I am to present to you the **9th Issue of The JBBA** (May 2022), featuring ground-breaking research papers.

Following the pioneering Web 1.0 in the 1990s, Web 2.0 (that emerged around 2005-2006), the new web 3.0 umbrella term is heralded as a truly disruptive innovation propelling a new internet revolution that will redefine the way economic agents interact, and socio-economic systems are structured in the new economy. The building blocks of Web 3.0 directly stem from some of the latest developments in the distributed ledger technology space. To grasp this emerging reality that is literally pushing back the boundaries of what is possible in terms of human digital (technology) interaction, the relevant concepts have become tokenisation, non-fungible tokens (NFT), decentralised autonomous organizations (DAO), the Metaverse, et al.

Through the interplay and creation of both fungible and non-fungible tokens, tokenisation is a particularly significant trend today for it is redefining our individual and collective participation in the digitisation of the real world, but also the very content of the Internet itself, how the latter is owned, and by whom. The past eighteen months have seen how creative forces can be unleashed in a most spectacular fashion in today's platform-based digital economy. Thanks to the path-breaking concept of NFTs, works of art, photos, music, text, game objects, and even innovative ideas have been turned into unique bits of code stored on a blockchain.

Yet patience and critical thinking remain paramount. I believe that the contours of Web 3.0 still need further epistemological investigation and scientific refinement, to move away from the hype towards evidenced-based research breakthroughs. Let us not forget either the ethical dimension of our research endeavours and aspiration. We need to come to the collective realisation that innovation totally devoid of responsibility and concern for future generations is probably misguided.

Having said this, despite recurrent doubts and natural manifestations of impatience, DLT is already fulfilling its earlier promises although the latter technology has now become much more integrated into other emerging ones such as artificial intelligence, virtual reality, cloud storage, machine learning etc. These impressive technological developments are already foreshadowing the jobs of tomorrow. These professions of the future will range from the conductor less train designer, the remote surgeon and climate change specialist (drawing on blockchain technology, robotics, and virtual reality), the independent tokenisation and blockchain officers in (a-hierarchical) decentralised autonomous organisations, the metaverse engineers in small and medium sized enterprises, and so forth.

The articles in the present JBBA (Volume 5, Issue 1) represent fundamental steps in our overarching quest to understand the transformative forces at work in our economy and societies. I would like to list below the exceptional papers that JBBA has decided to publish after rigorous editorial screening, blind peer review, and resulting incremental improvements leading to final acceptance and publication:

- 1) *Non-Fungible Tokens as an Alternative Investment: Evidence from CryptoPunks*
- 2) *Creation of a Self-Sustaining Token Economy*

- 3) *Blockchain Adoption Factors, Enablers, and Barriers in Fisheries Supply Chain: Preliminary Findings from a Systematic Literature Review*

- 4) *Can Blockchain Take Smartphones Out of Contact Tracing?*

To conclude this editorial, let me thank again the authors for their excellent research papers, all the peer reviewers and my fellow editors for their relentless dedication. They have worked countless hours to improve the already outstanding quality of The JBBA and will continue to do so for years to come.

Marc Pilkington PhD FBBA

Associate Editor in Chief

THANK YOU REVIEWERS

The Editorial Board of The JBBA gratefully acknowledges and thanks the reviewers for their time and expertise. The following is the list of reviewers who contributed to the peer review process for the current Issue of The JBBA:

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TESTIMONIALS FROM AUTHORS AND READERS

“ The JBBA has an outstandingly streamlined submissions process, the reviewers comments have been constructive and valuable, and it is outstandingly well produced, presented and promulgated. It is in my opinion the leading journal for blockchain research and I expect it to maintain that distinction under the direction of its forward-looking leadership team.

Dr Brendan Markey-Towler PhD, University of Queensland, Australia

”

“ "I always enjoy reading the JBBA."

Professor Dr Emin Gun Sirer PhD, Cornell University, USA

”

“ It is really important for a future world to be built around peer-review and publishing in the JBBA is one good way of getting your view-points out there and to be shared by experts.

Professor Dr. Bill Buchanan OBE PhD, Edinburgh Napier University, Scotland

”

“ The JBBA has my appreciation and respect for having a technical understanding and the fortitude for publishing an article addressing a controversial and poorly understood topic. I say without hesitation that JBBA has no equal in the world of scientific Peer-Review Blockchain Research.

Professor Rob Campbell, Capitol Technology University, USA

”

“ I had a professional experience of publishing my work in The JBBA. The feedback from reviewers and editors certainly helped to turn my manuscript into a better publication. JBBA's cross-disciplinary publishing platform is crucial to enable the blockchain sector to flourish. The journal strongly advocates evidence-based outcomes, essential to differentiate sound research papers from those that are not.

Dr Joshua Ellul PhD, Chair, Malta Digital Innovation Authority

”

“ The opportunity to interact with JBBA's expert reviewers and their valuable feedback helped us greatly in our project. I feel honoured to have my paper featured in the JBBA. Peer reviewed research is the foundation to build best-in-class Web3 platforms.

Daniel Uribe MBA, Cofounder and CEO Genobank.io, USA

”

“ This is a very professionally presented journal.

Peter Robinson, Blockchain Researcher & Applied Cryptographer, PegaSys, ConsenSys

”

“ I would like to think of the JBBA as an engine of knowledge and innovation, supporting blockchain industry, innovation and stimulate debate.

Dr. Marcella Atzori PhD, EU Parliament & EU Commission Blockchain Expert, Italy

”

“ Very professional and efficient handling of the process, including a well-designed hard copy of the journal. Highly recommend its content to the new scientific field blockchain is creating as a combination of CS, Math and Law. Great work!

Simon Schwerin MSc, BigChain DB and Xain Foundation, Germany

”

“ Our group submitted a paper to ISC2021. The paper was reviewed, accepted and subsequently published in The JBBA. We were quite impressed by the speed of the review cycle and submission to publication time. JBBA has become an important journal in the field of Blockchain, given its efficient reviews and timeliness in the publication of research articles.

Professor Dr Sandeep Shukla, Indian Institute of Technology IIT Kanpur, India

”

“ I had the honour of being an author in the JBBA. It is one of the best efforts promoting serious blockchain research, worldwide. If you are a researcher, you should definitely consider submitting your blockchain research to the JBBA.

Dr. Stylianos Kampakis PhD, UCL Centre for Blockchain Technologies, UK

”

“ It has been a pleasure working with the JBBA's editorial team. The submission process was transparent and the reviews were accurate and meaningful, adding great value to the manuscript.

Professor Dr Stavros T. Ponis PhD, National Technical University of Athens, Greece

”

“ The articles in the JBBA explain how blockchain has the potential to help solve economic, social, cultural and humanitarian issues. If you want to be prepared for the digital age, you need to read the JBBA. Its articles allowed me to identify problems, find solutions and come up with opportunities regarding blockchain and smart contracts.

Professor Dr. Eric Vermeulen, Tilburg University, The Netherlands

”

“ The whole experience from submission, to conference, to revision, to copy-editing, to being published was extremely professional. The JBBA are setting a very high standard in the space. I am looking forward to working with them again in future

Dr Robin Renwick PhD, University college Cork, Ireland

”

“ The JBBA is an exciting peer-reviewed journal of a growing, global, scientific community around Blockchain and Distributed Ledger technologies. As an author, publishing in the JBBA was an honour and I hope to continue contributing to in in the future

Evandro Pioli Moro, Blockchain Researcher, British Telecommunication (BT) Applied Research

”

Non-fungible Tokens as an Alternative Investment: Evidence from CryptoPunks

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Abstract

The Non-fungible Token (NFT) market has experienced extraordinary growth since the beginning of 2021. This has attracted attention from investors who are seeking alternative investments. However, the investment performance of the NFT market has not been investigated yet. This paper explores NFTs as an alternative investment. More specifically, it investigates the NFT collection “CryptoPunks” as an investment option with the focus on evaluating the investment performance, assessing the variables that determine prices, calculating the portfolio diversification potential, and comparing the investment performance to other financial assets. Therefore, a quantitative study with secondary data is conducted using the hedonic regression method. Data on CryptoPunks and other asset types are retrieved from different public domains. The time frame that is observed is 1 June 2018 until 31 May 2021. The CryptoPunk data set includes 11,864 transactions with information on the collectible and the sale. The results indicate that CryptoPunks would have been the best investment over the past three years with an average monthly return of 34.19% and a standard deviation of 61.76%. Next to that, the Sharpe ratio indicates a good return-risk trade-off. One other main finding is that the rarity of the attributes and type of the CryptoPunk has a positive effect on prices. Besides that, CryptoPunks has portfolio diversification potential due to relatively low correlation with other asset classes. This paper provides one of the first statistical explorations of NFTs from an economic perspective. The paper also examines the potential of NFTs as an alternative investment asset. The paper concludes that (based on the period studied) NFT collectibles can be a viable investment, with good returns, and a diverse risk profile that is uncorrelated from other benchmark assets, such as art, treasury bills, and major cryptocurrencies.

Nothing in this paper can be considered to be financial advice.

Keywords: *Non-fungible Tokens, Alternative Investment, Hedonic Regression*

JEL Classifications: *G1*

1. Introduction

NFTs are an investment option that evolved in 2014 from the blockchain space. Digital assets are not new but the opportunity this system provides to allow personal ownership of unique digital property is a ground-breaking development made possible by the existence of the NFT. This market is still relatively new in comparison to the cryptocurrency market and has gained in popularity since the beginning of 2021. The market has shown a growth of 13,118% to a US\$2 billion market with “150,000 users in the first quarter of 2021” [1]. Users have shown interest in various categories of digital assets. That is why NFTs are usually divided into the categories “Collectible”, “Game”, “DeFi”, “Art”, “Utility”, “Music”, “Metaverse”, and “Sports”. Of these, the category yielding the highest sales volume is “Collectible”, while the highest average prices can be observed in the category “Metaverse” [2]. The most popular NFT platforms are displayed in Table 1. NBA Top Shot is the platform with the highest sales volume, most sales, and the most traders. The platform sells video highlights from the National Basketball Association (NBA). This shows that NFTs cannot only be leveraged as an investment but also used to strategically expand the digital business model of organisations or companies. But despite the success of the NFT market in past months, NFT investment is still new and therefore has opportunities as well as challenges ahead for it. This data shows that NFTs have high ROI potential and suggests that some investors classify them as new assets since the market shows similar

attributes to those of art and cryptocurrency. The main benefit of the art market is that this market has much higher transparency since all activities are publicly available.

Table 1: Top 10 NFT Projects Sorted by Total Sales Volume up until 1 June 2021 [3]

Project/ Marketplace	Category	Total Sales Volume (US\$)	Number of Traders	Total Sales
NBA Top Shot	Sports	581.59M	389,004	5,405,678
CryptoPunks	Collectible	350.56M	3,156	13,692
Rarible	All	108.08M	51,348	153,381
Sorare	Sports	77.38M	23,752	407,115
Meebits	Collectible	66.62M	2,329	3,910
Axie Infinity	Metaverse	62.64M	50,984	302,962
Hashmarks	Art	51.18M	4,634	11,730
Foundation	Art	42.89M	9,521	13,855
Decentraland	Metaverse	42.54M	4,493	14,295
Wafusion	Collectible	38.74M	2,515	37,066

The NFT market is driven by the following attributes:

- Heterogenous asset
- High market transparency
- NFTs are verifiable
- Availability of the market is 24/7
- Low liquidity
- Relatively high transaction cost
- Higher elasticity of supply than the physical art market
- Psychological factors of owning NFTs are different from owning traditional assets
- Price evaluation is not objective

Due to its newness, this market still needs to be explored and analysed. Specifically, pricing is an interesting topic that will help researchers to understand the market from an economic perspective and evaluate the extent to which NFTs are suitable for portfolio diversification and alternative investment. An important factor that is linked to pricing is measuring the financial performance of new assets. This paper will therefore explore NFT collectibles, from the project CryptoPunks, as an investment option; focusing on (i) creating a hedonic index, (ii) assessing the price impact of the hedonic variables, (iii) evaluating risk and return, and (iv) comparing it to other investment assets.

2. Literature Review

In general, research on NFTs is very new and therefore it is necessary to consider relevant literature from related fields of research regarding the financial performance of alternative investments. The following markets are reviewed as relevant to this study.

2.1. NFT Market Pricing

First, there is a lack of research into pricing and financial performance within the NFT market. Dowling [4] examined the NFT pricing of the metaverse Decentraland. While his study focuses mainly on market efficiency, Dowling's research shows that the average weekly returns on NFT investment between March 2019 and March 2021 were 2.14% with a standard deviation of 27.54% [4]. Nevertheless, Dowling [4] concludes that pricing remains inefficient despite a fast increase in value. This is primarily due to the fact that the NFT market is in its early stages. The main shortcoming of this study is that it is based on the assumption that all pieces of virtual land have equal value, which is not the case since they have different characteristics. This inequity in value has a measurable impact on pricing and, accordingly, an approach that is used in the physical real estate market would be more suitable. Another study by Dowling [5] assessed the extent to which NFT pricing is related to or influenced by cryptocurrency prices. The study concludes that there is low volatility transmission, suggesting that NFTs are a low-correlation asset class distinct from cryptocurrencies. However, a wavelet coherence analysis indicates that there is co-movement between the two markets. A study by Ante [6] also suggests that the Bitcoin and Ethereum markets impact the development of NFT markets. More specifically, a Bitcoin price shock initiates increased NFT sales. This is important since it helps to assess NFTs' suitability for portfolio diversification.

2.2. Art and Collectibles Market Pricing

It is important to look at the art and collectibles market since it also deals in homogenous assets that have characteristics similar to those of the NFT market, e.g., volatility, illiquidity, and irrationality [7]. To measure the financial performance of heterogeneous assets, different indexing methods are required from the ones that are used for homogenous assets.

In considering a range of literature from this market it becomes clear that the two main methods that have been used for this asset type are Repeat-

Sales Method (RSM) and Hedonic Regression (HR) [8]. RSM regulates quality by comparing transacted prices for the same asset over time [9]. The theory behind HR, on the other hand, states that an asset's overall price should equal the sum of its utility-generating qualities [10].

Burton and Jacobsen [11] purported that most research data within the collectibles market showed a positive financial return, albeit much lower than that of stocks and holding more risk. The real annual returns of collectibles can differ between -8.7% and 25.67% with high standard deviations. Furthermore, a meta-analysis showed that collectibles are negatively correlated to the stock market but their returns in bear markets are low and therefore do not seem to be a good investment option when stock prices fall. An important consideration when researching the art and collectibles market is that perceived psychological benefits are key drivers in buyer decision-making.

As well as its ROI, it is important to look at what drives and determines prices within this market. Koford and Tschoegl [12] and Hughes [13] investigated the impact of exclusivity on the price of rare objects and demonstrated that it impacts positively on it. Hughes [13] estimated that the prices of a collectible card game with a rare designation are up to 70–90 times higher than a common card game. Therefore, rarity is an important variable in an analysis of the CryptoPunks collection.

Last, one of the main studies within the art field by Worthington and Higgs [14] showed that the average annual returns of different art markets range from 1.90% to 4.22%. The researchers concluded that returns on art investment are less than returns on traditional assets, even though the risk is higher; therefore, they argue, art cannot be recommended as a profitable alternative financial investment. A later study by Renneboog and Spaenjers [15] supports Worthington and Higgs's [14] results. It demonstrated that art prices have increased by an average of 3.97% between 1957 and 2007, the SR being 0.2. This confirms the hypothesis that art does not have a good risk-adjusted return rate.

The appreciation at the upper end of the market has been higher than the average. Additionally, the hedonic regression analysis shows that "artist reputation, attribution, signs of authenticity, medium, size, topic, and the timing and location of the sale are significantly correlated with price levels" [15]. Interestingly, most sales are completed at the end of spring and fall. Besides timing, the demand for luxury goods and art market confidence are two other driving forces with regard to asset pricing. Even though there are some studies who support art as an alternative investment, the majority of the research suggests that art is not a good option as an alternative investment. The only time art outperforms the S&P 500 index, according to Zhukova et al. [16], is during periods of negative returns, which seems to make them a safe haven asset in times of crisis.

3. Data and Methodology

A quantitative study with secondary data was conducted. This primarily involves the hedonic regression analysis, including variables related to the collectible asset and monthly time dummies. The HR method is chosen because ROIs will be calculated based upon the analysis, with the influence of different variables being assessed. It is based upon those results that the most valuable CryptoPunks will be calculated. Following that calculation, risk and return will be compared to other asset types. Finally, an analysis of the correlation between the returns will give insight into the diversification potential of this NFT type.

3.1. Research Object

CryptoPunks was chosen as the main research object since it is one of the NFT marketplaces with the highest trading volume and therefore a suitable and representative research object for this study. Furthermore, CryptoPunks falls under the category "Collectible" which has the highest

sales volume among all categories.

According to Larva Labs [17], CryptoPunks is a collection of 10,000 uniquely generated characters with proof of ownership stored on the Ethereum blockchain. All CryptoPunks are 24x24 pixel art images that were inspired by cyberpunk. The Larva Labs project was also the inspiration for the ERC-721 standard. When the CryptoPunks collection was released, all characters could be claimed for free. Since all of them were claimed very quickly, they can now be traded via Larva Labs or OpenSeas. On both those marketplaces, it is possible to offer, bid on, and purchase punks.

The characters are based on a set of CryptoPunks types and attributes. Figure 1 shows the prevalence of each CryptoPunk type. More than half of the CryptoPunks are “Male.” There are nine “Alien” CryptoPunks. Furthermore, there is a total of 87 attributes (see Appendix 1). Some attributes are represented more often than others. The most common attribute is the “Earring” which is seen in 2,459 CryptoPunks. In contrast to that, only 44 CryptoPunks have a “Beanie” attribute. On average the 87 attributes are represented 316.54 times with a standard deviation of 288.15. More information on prevalence is provided on Table 10 in the appendix.

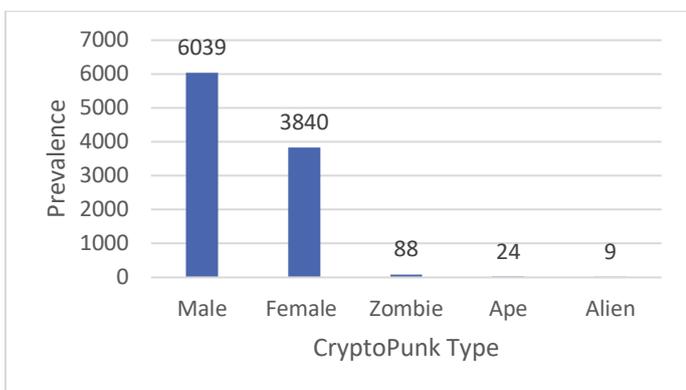


Figure 1: Prevalence of CryptoPunk Types

The number of attributes that a CryptoPunk has varies between zero and seven (see Figure 2). Only one CryptoPunk has seven attributes, making it the rarest CryptoPunk in terms of the number of assets it represents. A total of 4,501 CryptoPunks have three attributes making this attribute count the most common, making up almost half of all existing CryptoPunks. Shortly behind that is the prevalence of CryptoPunks with two attributes, totalling 3,560.

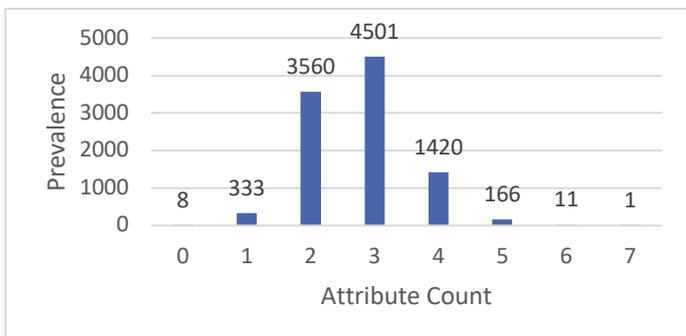


Figure 2: Prevalence of Number of Attributes

3.2. Data

Data on CryptoPunks and other asset types are retrieved from various public domains. The time frame observed for data retrieval is 1 June 2018 to 31 May 2021. Year One in the analysis will therefore be the period from June 2018 to May 2019. The same model will be applied to the subsequent

two years.

3.2.1 CryptoPunks

Historical trading data from all CryptoPunks sales transactions across the three years is retrieved from cryptoslam.io. All sales can be classified as secondary market sales since all CryptoPunks were given away for free for the primary sale before the observed period.

This data set comprises 11,864 transactions, each with information on the Seller and Buyer Addresses, CryptoPunk ID, CryptoPunk type, Ethereum price, USD price, and CryptoPunk attributes. Cryptoslam.io does not provide the exact transaction date in its transaction overview. Therefore, dates were entered manually by matching the transaction to the date listed in its corresponding “transaction data overview” on nonfungible.com. The prices that are listed are exclusive of the transaction cost. Additionally, this study will not include bidding prices.

Sales were conducted on 790 of possible 1,096 days. Most sales (320) were completed on 28 September 2020. Generally, the sales were fairly constant with occasional peaks. The sales hit the highest point in September 2020 but receded after that. Then they picked up again at the beginning of 2021. In total there were 923 sales in Year One, 1,773 in Year Two, and 9,168 in Year Three.

A total of 4,759 CryptoPunks were sold at least once during the three observed years. More specifically the number of sales a single CryptoPunk generated varied between 1 and 15 (see Figure 3). The CryptoPunks with the most resales are the CryptoPunks “9117” and “2937”, both with 15 resales. The majority of CryptoPunks (1,866) were sold just once during the observed time frame.

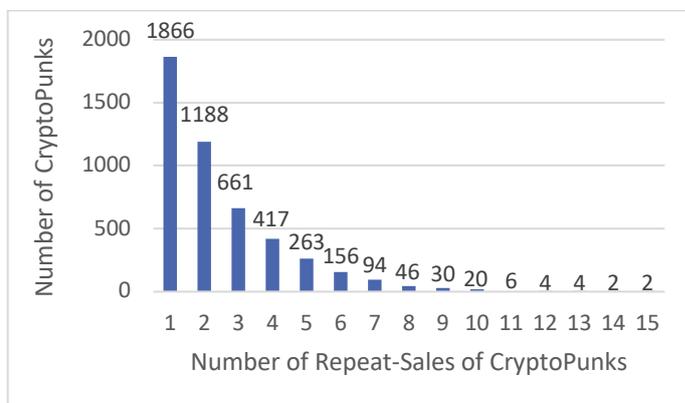


Figure 3: Repeat-Sales of CryptoPunks

The most expensive transactions in the time period observed are the sales of CryptoPunk “7804” and “3100” for 4,200 ETH or US\$ 7,676,397 on 11 March 2021. The average pricing varies significantly depending on the year observed (see Table 2). The average price increased 217% from the first to the second year and 13,353% from the second to the third year.

Table 2: Average Annual Sale Price and Sales Volume

	Year 1	Year 2	Year 3
Sale Price Mean	US\$88.32	US\$279.83	US\$37,645.82
Standard Deviation	224.40	927.54	128930.42
Total Sales Volume	US\$81,521.05	US\$496,129.90	US\$345,136,847.91

Other Assets

To be able to compare the returns and risks associated with NFTs, corresponding data from other assets need to be retrieved from different online sources. The US and World Equity market data is collected from

MSCI, the 10-Year US Government Bond Index is collected from investing.com, as is the Bitcoin and Ethereum Index, while the Real Estate Investment Trusts Index (NAREIT) is gathered from reit.com. Art market data could not be retrieved due to limited accessibility.

Furthermore, the monthly US T-Bill Risk-Free Rate is used as the risk-free rate retrieved from the Federal Reserve Economic Data database. The T-Bill is perceived as nearly risk-free since it is fully backed by the government. Hence it is often used by researchers and investors as the risk-free rate.

3.3. Method

3.3.1 Hedonic Regression of CryptoPunks

To index CryptoPunks, the hedonic regression method is chosen over the repeat-sales method since Ginsburgh et al. [8] demonstrated that HR outperforms RSR when the sample size is small. Furthermore, most CryptoPunks sales in the time period observed are not repeat-sales, making HR more suitable. One major benefit of this method is that it takes into account all information related to the transaction. This model regresses natural log returns to different time dummies while taking different hedonic characteristics into account.

The mathematical expression of the HR model for CryptoPunks is:

$$\ln [P_{ct}] = \alpha + \sum_v (\beta_v X_{vct}) + \sum_t (\gamma_t D_{ct}) + \varepsilon_{ct}$$

The price of the CryptoPunk c at the time t is P_{ct} . X_{vct} represents the value of the variable v of the CryptoPunk c at the time t . The coefficient β_v reflects the influence of variable v . The time dummy variable D_{ct} equals 1 if the CryptoPunk c is sold in period t . A monthly time period is chosen for the index and returns because there are too many days without sales to have reliable daily or weekly data.

The coefficient γ_t is used to create the price index I_t using antilogs. In the time period t the value of the hedonic index is:

$$I_t = \exp(\gamma_t) \times 100$$

The estimated return in the time period t can be calculated by setting the time dummy coefficient to 0 for the first time period. The return of the period t can then be calculated based on the following:

$$r_t = \frac{I_t}{I_{t-1}} - 1$$

The price impact PI_v of the hedonic variables is calculated using the coefficient β_v of each variable. Therefore, the price impact of variable v is:

$$PI_v = \exp(\beta_v) - 1$$

Based on this the most valuable CryptoPunk MVP_c can be estimated in order to evaluate which are the most valuable CryptoPunks.

$$MVP_c = PI_{v_{pt}} + PI_{v_{noa}} + \left(\frac{1}{\text{Number of Attributes}} * \sum_{a=1}^a PI_{v_a} \right)$$

The most valuable CryptoPunks are calculated by adding the price impact of the CryptoPunk type $PI_{v_{pt}}$ to the price impact of the number of attributes $PI_{v_{noa}}$ which the CryptoPunk exhibits and the average price impact of the CryptoPunk's attributes PI_{v_a} . The average of the CryptoPunk's attributes PI_{v_a} is taken to not duplicate the impact of $PI_{v_{noa}}$. If the CryptoPunk has zero attributes, then the following applies:

$$MVP_c = PI_{v_{pt}} + PI_{v_{noa}}$$

3.3.2 Hedonic Variables

HR analysis includes different variables relating to the collectible. In terms of collectible-related characteristics, all differentiating variables are included. With regard to sales characteristics, seasonality is a relevant variable. But it will not be included in this study since the time dummies are monthly periods. Including general monthly variables and monthly time dummies would only lead to distorted regression results and therefore they are excluded. However, the monthly time dummies will be used to check for seasonality. The point of sale is also excluded since more than 99% of all sales were conducted through Larva Lab's marketplace. The descriptive statistic is presented in Table 3. The variables are all dummy variables and therefore equal 1 if the variable is exhibited in the CryptoPunk and 0 if it is not.

CryptoPunk Type. The five different types of CryptoPunks have different prevalences and therefore some are rarer than others. As posited in the literature review, rarity has an effect on the pricing of physical collectibles. The sales share of each CryptoPunk type is related to the prevalence of each type. More than half of the total sales recorded during the three years were "Male" CryptoPunks, while "Alien" CryptoPunks were sold only three times.

Attributes. Next to the CryptoPunk type, the 87 attributes determine the visual appearance of the CryptoPunk. Rarity has an impact here too. CryptoPunks with the "Earring" attribute accounted for 26.13% of the sales, which is the most common of the 87. Conversely, the "Pilot Helmet" attribute is the least exhibited, only featuring in 26 of total sales.

Number of Attributes. The sales breakdown for this variable would appear from the data to be linked to the prevalence of the number of attributes in the set of CryptoPunks. Almost half of the CryptoPunks that were sold had three attributes. In contrast, only two transactions of CryptoPunks with seven attributes were observed.

Table 3: Descriptive Statistics of the Hedonic Variables of CryptoPunks with N = 11,864

	Mean	SD	0	1
CryptoPunk Type				
Male	0.6931	0.4612	3641	8223
Female	0.3003	0.4584	8301	3563
Zombie	0.0052	0.0721	11802	62
Ape	0.0011	0.0331	11851	13
Alien	0.0003	0.0159	11861	3
Number of Attributes				
Zero Attributes	0.0005	0.0225	11858	6
One Attribute	0.0115	0.1068	11727	137
Two Attributes	0.3449	0.4753	7772	4092
Three Attributes	0.4898	0.4999	6053	5811
Four Attributes	0.1386	0.3455	10220	1644
Five Attributes	0.0136	0.1157	11703	161
Six Attributes	0.0009	0.0304	11853	11
Seven Attributes	0.0002	0.0130	11862	2
Attributes				
Beanie	0.0058	0.0760	11795	69
Choker	0.0038	0.0615	11819	45
Pilot Helmet	0.0023	0.0477	11837	27
Tiara	0.0024	0.0485	11836	28
Orange Side	0.0040	0.0628	11817	47
Buck Teeth	0.0048	0.0691	11807	57
Welding Goggles	0.0051	0.0715	11803	61
Pigtails	0.0063	0.0793	11789	75
Pink with Hat	0.0070	0.0833	11781	83
Top Hat	0.0083	0.0910	11765	99
Spots	0.0126	0.1114	11715	149

	Mean	SD	0	1
Rosy Cheeks	0.0129	0.1128	11711	153
Blonde Short	0.0078	0.0877	11772	92
Wild White Hair	0.0089	0.0937	11759	105
Cowboy Hat	0.0113	0.1057	11730	134
Straight Hair Blonde	0.0107	0.1029	11737	127
Wild Blonde	0.0058	0.0760	11795	69
Big Beard	0.0122	0.1099	11719	145
Red Mohawk	0.0095	0.0971	11751	113
Vampire Hair	0.0239	0.1529	11580	284
Blonde Bob	0.0079	0.0887	11770	94
Half Shaved	0.0114	0.1061	11729	135
Straight Hair Dark	0.0132	0.1143	11707	157
Clown Hair Green	0.0136	0.1157	11703	161
Straight Hair	0.0126	0.1117	11714	150
Silver Chain	0.0212	0.1439	11613	251
Dark Hair	0.0146	0.1199	11691	173
Purple Hair	0.0150	0.1216	11686	178
Gold Chain	0.0113	0.1057	11730	134
Medical Mask	0.0151	0.1219	11685	179
Tassle Hat	0.0114	0.1061	11729	135
Fedora	0.0244	0.1542	11575	289
Police Cap	0.0163	0.1265	11671	193
Clown Nose	0.0204	0.1414	11622	242
Smile	0.0197	0.1390	11630	234
Cap Forward	0.0287	0.1668	11524	340
Hoodie	0.0184	0.1343	11646	218
Front Beard Dark	0.0384	0.1920	11409	455
Frown	0.0346	0.1827	11454	410
Purple Eye Shadow	0.0260	0.1590	11556	308
Handlebars	0.0346	0.1829	11453	411
Blue Eye Shadow	0.0230	0.1499	11591	273
Green Eye Shadow	0.0187	0.1355	11642	222
Vape	0.0197	0.1390	11630	234
Front Beard	0.0330	0.1787	11472	392
Chinstrap	0.0382	0.1916	11411	453
Luxurious Beard	0.0196	0.1385	11632	232
3D Glasses	0.0190	0.1364	11639	225
Mustache	0.0374	0.1898	11420	444
Normal Beard Black	0.0265	0.1605	11550	314
Normal Beard	0.0370	0.1888	11425	439
Eye Mask	0.0308	0.1729	11498	366
Goat	0.0371	0.1890	11424	440
Do-rag	0.0413	0.1990	11374	490
Shaved Head	0.0455	0.2084	11324	540
Peak Spike	0.0288	0.1673	11522	342
Mutton Chops	0.0403	0.1966	11386	478
Pipe	0.0295	0.1692	11514	350
VR	0.0292	0.1685	11517	347
Cap	0.1283	0.3344	10342	1522
Small Shades	0.0472	0.2121	11304	560
Clown Eyes Green	0.0384	0.1920	11409	455
Clown Eyes Blue	0.0358	0.1858	11439	425
Headband	0.0435	0.2040	11348	516
Crazy Hair	0.0314	0.1745	11491	373
Knitted Cap	0.0479	0.2135	11296	568
Mohawk Dark	0.0453	0.2079	11327	537
Mohawk	0.1542	0.3612	10034	1830
Mohawk Thin	0.0528	0.2236	11238	626
Frumpy Hair	0.0481	0.2140	11293	571
Wild Hair	0.0418	0.2001	11368	496
Messy Hair	0.0463	0.2101	11315	549
Eye Patch	0.0523	0.2225	11244	620
Stringy Hair	0.0637	0.2443	11108	756
Bandana	0.0609	0.2392	11141	723
Classic Shades	0.0591	0.2358	11163	701

	Mean	SD	0	1
Shadow Beard	0.0596	0.2367	11157	707
Regular Shades	0.0562	0.2303	11197	667
Big Shades	0.0535	0.2251	11229	635
Horned Rim Glasses	0.0538	0.2256	11226	638
Nerd Glasses	0.0577	0.2332	11179	685
Black Lipstick	0.0541	0.2262	11222	642
Mole	0.0802	0.2717	10912	952
Purple Lipstick	0.0498	0.2176	11273	591
Hot Lipstick	0.0545	0.2269	11218	646
Cigarette	0.0936	0.2913	10753	1111
Earring	0.2613	0.4393	8764	3100

Despite the month of sale being excluded as a hedonic variable, the descriptive statistics of the time dummy variables reveal that most CryptoPunk sales happened in February and September closely followed by March, April, and May (see Table 4). Seasonality often has an effect on sales and pricing. This has already been mentioned with regard to the art market

Table 4: Descriptive Statistics of the Month of Sale of CryptoPunks with N = 11,864

Month of Sale	Mean	SD	0	1
January	0.0801	0.2714	10914	950
February	0.1870	0.3899	9645	2219
March	0.1309	0.3373	10311	1553
April	0.1184	0.3231	10459	1405
May	0.1290	0.3352	10334	1530
June	0.0298	0.1699	11511	353
July	0.0125	0.1110	11716	148
August	0.0171	0.1297	11661	203
September	0.1909	0.3930	9599	2265
October	0.0485	0.2147	11289	575
November	0.0201	0.1402	11626	238
December	0.0358	0.1858	11439	425

3.3.3 Comparison of Investment Performances and Correlation of Assets

In order to assess the performance, the return and risk rates of the different assets are calculated and evaluated. The return rate r_t will be calculated in order to compare the returns. In evaluating risk, the Sharpe ratio (SR) is used. Finally, the correlation of the returns is assessed in order to get an understanding of whether NFTs are suitable for portfolio diversification.

4. Hedonic Regression

The data set of the 11,864 observed transactions has complete information on all variables that are listed in the previous section. Three of the hedonic variables and a time dummy variable could not be defined because of singularities. The R^2 shows that 97.18% of the variance of $\ln P_{it}$ is explained by the independent variables as specified. The p-value is < 0.001 for the overall regression analysis and therefore highly significant. Generally, the regression analysis shows very good fit which is supported by the actual vs. fitted and fitted vs. predicted plots (see Appendix 2 – figures 5 and 6).

Table 5 shows the coefficient, standard deviation, significance level, and calculated price impact of each hedonic variable. The analysis shows that CryptoPunks are on average priced 307.10% higher if they belong to the CryptoPunk type “Alien.” All other CryptoPunk types are priced lower on average. The same appears true for the number of attributes. CryptoPunks with zero attributes are, on average, priced 329.56% higher

while the price drops more than 30% for CryptoPunks with attributes. The specific attribute a CryptoPunk has also influences price. Most attributes have a positive effect on pricing. The “Beanie” attribute stands out since CryptoPunks with this attribute have on average 563.92% higher prices. Besides that, the attributes “Pilot Helmet,” “Orange Side,” “Choker,” “Welding Goggles,” “Buck Teeth,” “Pink with Hat,” “Pigtails,” and “Hoodie” increase the price by an average of over 100%. Unfortunately, the coefficient of the most common attribute “Earring” could not be calculated because of singularities.

Generally, it can be observed that rarity plays a role when it comes to CryptoPunk pricing. This can be deduced from the data showing that 9 of the 10 rarest attributes are also within the top 10 attributes having the highest price impact. Additionally, the type “Alien” belongs to one of the rarest types too. The same pattern is seen in impact of the number of attributes. CryptoPunks with seven and zero attributes are very rare. Although the impact of seven attributes could not be calculated, data shows that having zero attributes impacts the most highly on a CryptoPunk’s price.

This study’s findings regarding the price impact of certain hedonic variables can only be used for the CryptoPunk collection. This accords with the findings of Koford and Tschögl [12] and Hughes [13] who found that rarity has a positive effect on pricing in the case of physical collectibles

Table 5: Hedonic Variables Regression Results (Signif. codes: 0 ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1)**

Variables	Coefficient β_v	SD	Significance	Price impact PI_v in %
CryptoPunk Type				
Alien	1.403881	0.281659	***	307.10%
Zombie	-0.979351	0.136118	***	-62.44%
Female	-3.18772	0.125224	***	-95.87%
Male	-3.26573	0.124781	***	-96.18%
Ape	NA	NA	NA	NA
Number of Attributes				
Zero Attributes	1.457601	0.375266	***	329.56%
Six Attributes	-0.413039	0.34953		-33.84%
One Attribute	-1.6052	0.329017	***	-79.92%
Five Attributes	-1.881472	0.3246	***	-84.76%
Two Attributes	-2.331351	0.324847	***	-90.28%
Four Attributes	-2.350086	0.323409	***	-90.46%
Three Attributes	-2.364675	0.324001	***	-90.60%
Seven Attributes	NA	NA	NA	NA
Attributes				
Beanie	1.892993	0.063087	***	563.92%
Tiara	1.558338	0.090508	***	375.09%
Pilot Helmet	1.531511	0.092246	***	362.52%
Orange Side	1.252443	0.073339	***	249.89%
Choker	0.967288	0.067152	***	163.08%
Welding Goggles	0.925417	0.058118	***	152.29%
Buck Teeth	0.86351	0.060478	***	137.15%
Pink with Hat	0.799198	0.05987	***	122.38%
Pigtails	0.783312	0.061867	***	118.87%
Hoodie	0.696302	0.045317	***	100.63%
Wild Blonde	0.656021	0.063774	***	92.71%
Top Hat	0.655967	0.056337	***	92.70%
3D Glasses	0.594291	0.031657	***	81.17%
Wild White Hair	0.474065	0.055683	***	60.65%
Big Beard	0.466777	0.038891	***	59.48%
Gold Chain	0.462519	0.03968	***	58.81%
Medical Mask	0.45622	0.034913	***	57.81%
Cowboy Hat	0.413984	0.051086	***	51.28%
Blonde Bob	0.403481	0.057649	***	49.70%
Straight Hair Blonde	0.399676	0.052702	***	49.13%

Variables	Coefficient β_v	SD	Significance	Price impact PI_v in %
VR	0.35474	0.026392	***	42.58%
Rosy Cheeks	0.287597	0.037385	***	33.32%
Clown Hair Green	0.285134	0.048601	***	32.99%
Tassel Hat	0.259975	0.052336	***	29.69%
Smile	0.205879	0.031021	***	22.86%
Blonde Short	0.202156	0.05835	***	22.40%
Big Shades	0.193163	0.020822	***	21.31%
Luxurious Beard	0.192994	0.031449	***	21.29%
Spots	0.185761	0.037871	***	20.41%
Red Mohawk	0.183916	0.046209	***	20.19%
Purple Hair	0.17873	0.047586	***	19.57%
Clown Nose	0.171243	0.030182	***	18.68%
Silver Chain	0.156089	0.029679	***	16.89%
Police Cap	0.15109	0.038733	***	16.31%
Blue Eye Shadow	0.150178	0.029928	***	16.20%
Pipe	0.129869	0.025815	***	13.87%
Vape	0.109658	0.030802	***	11.59%
Half Shaved	0.102164	0.051757	*	10.76%
Nerd Glasses	0.092235	0.020369	***	9.66%
Classic Shades	0.089568	0.020136	***	9.37%
Green Eye Shadow	0.073256	0.032783	*	7.60%
Crazy Hair	0.0716	0.041269	.	7.42%
Cigarette	0.067177	0.016705	***	6.95%
Purple Lipstick	0.058551	0.023351	*	6.03%
Straight Hair	0.053493	0.050298		5.49%
Clown Eyes Blue	0.052906	0.024333	*	5.43%
Regular Shades	0.048207	0.020254	*	4.94%
Eye Mask	0.047955	0.025687	.	4.91%
Horned Rim Glasses	0.043736	0.020699	*	4.47%
Small Shades	0.043611	0.021675	*	4.46%
Vampire Hair	0.043547	0.04278		4.45%
Purple Eye Shadow	0.041206	0.028767		4.21%
Eye Patch	0.04074	0.020871	.	4.16%
Straight Hair Dark	0.03957	0.049933		4.04%
Cap Forward	0.036269	0.032242		3.69%
Normal Beard Black	0.025393	0.027857		2.57%
Fedora	0.022607	0.043143		2.29%
Frown	0.022101	0.024602		2.23%
Hot Lipstick	0.021415	0.022641		2.16%
Shadow Beard	0.021083	0.020546		2.13%
Dark Hair	0.015447	0.048713		1.56%
Goat	0.007871	0.024173		0.79%
Mohawk Thin	0.005869	0.025899		0.59%
Handlebars	0.005391	0.02491		0.54%
Moustache	0.003744	0.024163		0.38%
Chinstrap	-0.003858	0.024062		-0.39%
Front Beard	-0.007551	0.025611		-0.75%
Normal Beard	-0.012703	0.024316		-1.26%
Front Beard Dark	-0.015006	0.023931		-1.49%
Clown Eyes Green	-0.015894	0.023886		-1.58%
Mohawk Dark	-0.019095	0.026795		-1.89%
Black Lipstick	-0.019939	0.022715		-1.97%
Mutton Chops	-0.023133	0.023287		-2.29%
Mole	-0.031284	0.017641	.	-3.08%
Cap	-0.034099	0.040557		-3.35%
Messy Hair	-0.049069	0.039029		-4.79%
Wild Hair	-0.050631	0.039528		-4.94%
Shaved Head	-0.057036	0.039351		-5.54%
Peak Spike	-0.074237	0.041745	.	-7.15%
Mohawk	-0.082596	0.039002	*	-7.93%
Headband	-0.090165	0.039518	*	-8.62%
Knitted Cap	-0.09312	0.028428	**	-8.89%
Bandana	-0.094574	0.037951	*	-9.02%
Do-rag	-0.096638	0.039451	*	-9.21%
Frumpy Hair	-0.097809	0.03877	*	-9.32%
Stringy Hair	-0.121214	0.037733	**	-11.42%
Earring	NA	NA	NA	NA

Based on the coefficients of the time dummy variables the CryptoPunk index was calculated. The results are presented in Table 6 where the prices are standardised to June 2018 levels. The index is highly significant since most coefficients show p-values below 0.001. The index clearly shows a heavy increase from the end of 2020. It reaches its highest point of 161226.61 at the end of the observed period, in May 2021. On the other hand, the index dropped to its lowest point of 63.15 in December 2018.

Generally, strong variations in return rates can be observed. The highest return rate can be identified at 285.92% between January and February 2021, while the highest negative return occurred between February and March 2020 at -44.14%. The average monthly return is 34.19% with a standard deviation of 61.76%. Dowling studied the pricing of a different NFT category (see [4]) and a comparison of studies shows that the behaviour of the returns of Decentraland and CryptoPunks is fairly similar. The actual Decentraland returns are, however, less than CryptoPunks', since the average monthly return of the former category is around 9%.

Another remarkable observation is that the performance of CryptoPunks basically exploded during the global pandemic, despite a global recession. This might reflect that investments in art and cryptocurrency seem a safe haven in times of financial crises [18, 16]. Logic thereby follows that diversifying portfolios with such assets limits risk during uncertain times. Unfortunately, the NFT market is currently too new to make a sound examination on this topic.

Table 6: CryptoPunk Index and Returns (Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1)**

Month	Coefficient γ_t	SD	Significance	Index I_t	Return r_t in %
Jun 18	NA	NA	NA	100	
Jul 18	0.032459	0.122024		103.30	3.30%
Aug 18	-0.064528	0.080106		93.75	-9.24%
Sep 18	-0.213795	0.082091	**	80.75	-13.87%
Oct 18	-0.176217	0.067063	**	83.84	3.83%
Nov 18	-0.458275	0.068871	***	63.24	-24.58%
Dec 18	-0.459655	0.060253	***	63.15	-0.14%
Jan 19	-0.007222	0.066795		99.28	57.21%
Feb 19	0.113468	0.078309		112.02	12.83%
Mar 19	0.344017	0.068457	***	141.06	25.93%
Apr 19	0.466177	0.066497	***	159.39	12.99%
May 19	0.728302	0.055673	***	207.16	29.97%
Jun 19	0.996758	0.057316	***	270.95	30.79%
Jul 19	0.564781	0.074765	***	175.91	-35.08%
Aug 19	0.54873	0.074905	***	173.11	-1.59%
Sep 19	0.097304	0.057792	.	110.22	-36.33%
Oct 19	0.364021	0.098988	***	143.91	30.57%
Nov 19	0.102881	0.067063		110.84	-22.98%
Dec 19	0.21907	0.063273	***	124.49	12.32%
Jan 20	0.850521	0.050397	***	234.09	88.03%
Feb 20	1.429165	0.067135	***	417.52	78.36%
Mar 20	0.846884	0.081427	***	233.24	-44.14%
Apr 20	1.162363	0.063677	***	319.75	37.09%
May 20	1.784155	0.048357	***	595.45	86.23%
Jun 20	2.020327	0.062477	***	754.08	26.64%
Jul 20	2.004889	0.066848	***	742.53	-1.53%
Aug 20	2.22519	0.062185	***	925.52	24.65%
Sep 20	3.217701	0.045925	***	2497.06	169.80%
Oct 20	3.700141	0.049086	***	4045.30	62.00%
Nov 20	3.755422	0.064714	***	4275.23	5.68%
Dec 21	4.216632	0.054256	***	6780.47	58.60%
Jan 21	4.983607	0.048944	***	14600.01	115.32%
Feb 21	6.334063	0.045827	***	56344.12	285.92%
Mar 21	6.817502	0.046304	***	91369.97	62.16%
Apr 21	7.074851	0.046541	***	118186.74	29.35%
May 21	7.385396	0.047584	***	161226.61	36.42%

5. Most Valuable CryptoPunks

The most valuable CryptoPunks are displayed in Table 7. The CryptoPunk type "Ape," the CryptoPunk with seven attributes, and CryptoPunks with "Earrings" are excluded since the coefficient and therefore price impact could not be calculated. "Male" CryptoPunks with the "Beanie" attribute are the most valuable ones based on the calculation of MVP_c . Similarly, "Female" and "Male" CryptoPunks with zero attributes are highly valuable. All CryptoPunk types with the attribute "Beanie" belong to the top 20 most expensive CryptoPunks. Lastly, the CryptoPunk type "Alien", regardless of attribute numbers and attributes, has a high value.

In contrast to that, the least expensive CryptoPunks are "Male" and "Female" assets with the two attributes "Stringy Hair" and "Mole." Interestingly, only 8 out of the 20 have been sold in the observed time period. The CryptoPunks that have not been sold are CryptoPunk numbers 1903, 641, 1050, 2204, 281, 741, 5822, 635, 5905, and 198. If an investor could buy one of the CryptoPunks that have not been sold during the past three years at a low price point, the resale could have been highly profitable.

Table 7: Most Valuable CryptoPunks

ID	CryptoPunk Type	No. of Attributes	Attributes	Total Price Impact MVP_c
344	Male	1	Beanie	4.878228572
1903	Male	1	Beanie	4.878228572
2964	Male	1	Beanie	4.878228572
641	Female	0		2.336907762
1050	Female	0		2.336907762
2204	Female	0		2.336907762
6487	Female	0		2.336907762
281	Male	0		2.333810974
510	Male	0		2.333810974
741	Male	0		2.333810974
3307	Male	0		2.333810974
2890	Alien	1	Cap	2.27181816
7804	Alien	3	Cap Forward, Pipe, Small Shades	2.23834525
3100	Alien	1	Headband	2.18559856
5822	Alien	1	Bandana	2.18157857
635	Alien	2	Bandana, Regular Shades	2.1477073
5905	Alien	2	Do-rag, Small Shades	2.14436344
7846	Male	2	Beanie, 3D Glasses	1.8608115
89	Female	1	Choker	1.74099552
198	Male	2	Beanie, Luxurious Beard	1.56137627

Figure 4 shows eight of the 20 most valuable CryptoPunks and makes clear that the visual appearance of the CryptoPunks are quite distinct. It can be observed that the "Male" and "Alien" types predominate.

6. Comparison to Other Assets

In order to compare the investment performance of CryptoPunks with other assets, four different time frames are observed: the overall three-year time frame plus breakdowns into Years One, Two, and Three (see Table 8). Over the complete time frame, the CryptoPunk index outperforms all other assets. The CryptoPunk index has appreciated on average 34.19% each month over the three years observed. Besides that, the Sharpe ratio is the highest among all assets at 0.5338. This shows that even though the



Figure 4: A Sample of Some of the Top 20 Most Valuable CryptoPunks [17]

studies, the art market has shown annual returns of between 3.97% and 40% with high standard deviations depending on the geographical location [19, 15]. The collectibles market, meanwhile, has shown annual returns of between -8.7% and 25.67 [11]. However, it is important to keep in mind that the “return” does not include transaction costs involved in the buying of NFTs. The fees incurred when buying an NFT, referred to as “gas fees,” and the fees when you buy Ethereum cannot be underestimated.

If one is only considering its ROI, the NFT market seems more appealing than any comparable investment. But when analysed in the light of the standard deviation it becomes clear that this market is also highly volatile. Even though its SR shows a good return-risk trade-off, the risks inherent in a new irrational and highly volatile market cannot be underestimated. If one is looking to decide whether to invest in physical or digital heterogeneous goods, the results of this paper suggest that NFTs can be a better investment in comparison to, for example, investments in the physical art market. While both are risky investments, the risk-return trade-off is much better for the NFT market. Despite its return rates currently being higher, the market is also more accessible and transparent; and transactions can be effected much quicker. Also, investors do not need

Table 8: Comparison of Investment Performance

	CryptoPunks	T-Bill	10-Year US Bond	World Equity	US Equity	Bitcoin	Ethereum	US Real Estate REIT
All-Time (06/2018 – 05/2021)								
Monthly Return Mean	34.19%	1.22%	-0.40%	1.16%	1.45%	7.61%	9.40%	1.02%
Standard Deviation	61.76%	1.00%	15.54%	5.27%	5.45%	22.80%	30.22%	5.48%
Sharpe Ratio	0.5338		-0.1041	-0.0113	0.0428	0.2806	0.2709	-0.0361
Year 1 (06/2018 – 05/2019)								
Monthly Return Mean	8.93%	2.25%	-2.38%	-0.08%	0.24%	5.37%	-0.54%	1.05%
Standard Deviation	21.76%	0.20%	6.95%	4.69%	5.16%	24.24%	29.29%	4.64%
Sharpe Ratio	0.3070		-0.6661	-0.4960	-0.3897	0.1288	-0.0954	-0.2597
Year 2 (06/2019 – 05/2020)								
Monthly Return Mean	18.61%	1.41%	-7.88%	0.60%	1.10%	2.49%	2.15%	-0.54%
Standard Deviation	46.20%	0.74%	15.70%	6.20%	6.42%	18.70%	26.38%	7.03%
Sharpe Ratio	0.3721		-0.5920	-0.1309	-0.0487	0.0576	0.0278	-0.2781
Year 3 (06/2020 – 05/2021)								
Monthly Return Mean	72.92%	0.07%	8.89%	2.84%	2.90%	14.79%	25.77%	2.55%
Standard Deviation	78.93%	0.04%	16.37%	4.21%	4.16%	23.35%	27.75%	3.70%
Sharpe Ratio	0.9230		0.5388	0.6576	0.6819	0.6304	0.9262	0.6707

standard deviation is very high with a rate of more than 60%, this would still be the best investment to choose according to the risk-adjusted return. Over the same time period, the cryptocurrencies Bitcoin and Ethereum are shown outperforming the more traditional assets but still not performing as well as CryptoPunks.

The yearly performance of the CryptoPunk index also demonstrates that it outperforms all other assets. In Year Three CryptoPunks showed the best performance with an average monthly return of 72.92% and an SR of 0.9230. This is the best return performance among all years and assets. Bitcoin and Ethereum did not match this performance, but gave better returns than the other assets in Years One and Two. Similar to CryptoPunks, their performance significantly increased in Year Three. Ethereum’s performance in Year Three shows an average monthly return rate of 27.55% and an SR of 0.9262 close to CryptoPunks’ performance. In comparison to the results from other research within the art and collectibles market, the return rates of CryptoPunks are also favourable. In previous

to worry about the oncosts of storage space and transportation since everything is digital. Obviously, this statement assumes that the historical patterns observed during this research will continue to hold in the future, something which cannot be guaranteed.

Table 9 displays the correlation matrix of returns of all assets. The correlation between CryptoPunks and the T-Bill, the 10-year US Bond, Bitcoin and Ethereum are ± 0.25 or higher, which indicates some co-movements between those markets. This supports Dowling’s (2021b) findings that suggest that NFTs are a low-correlation asset class that show some co-movement with different cryptocurrencies. It is noteworthy that the T-Bill and CryptoPunks have a negative correlation of -0.44. Therefore, the low T-Bill interest rates seem to encourage investors to look for assets such as NFTs in the form of CryptoPunks. Furthermore, the correlation between both cryptocurrencies can be explained by the dependency of NFTs on cryptocurrencies. The correlation with Bitcoin is higher than with Ethereum which might provide an area for further research since CryptoPunks are paid with Ethereum. Generally, the results

suggest that CryptoPunks are suitable for use in portfolio diversification.

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[2] NonFungible, 2021, Market Overview, [Online]. Available: <https://nonfungible.com/market/history>

Table 9: Correlation of Returns

	Crypto-Punks	T-Bill	10-Year US Bond	World Equity	US Equity	Bitcoin	Ethereum	US Real Estate REIT
CryptoPunks	1.00							
T-Bill	-0.44	1.00						
10-Year US Bond	0.36	-0.27	1.00					
World Equity	0.04	-0.21	0.40	1.00				
US Equity	0.02	-0.21	0.38	0.99	1.00			
Bitcoin	0.36	-0.18	0.22	0.32	0.31	1.00		
Ethereum	0.26	-0.37	0.12	0.29	0.26	0.69	1.00	
US Real Estate REIT	0.13	-0.06	0.30	0.83	0.82	0.31	0.30	1.00

7. Conclusion

The rapid growth of the NFT market is seen as a new opportunity by many investors, but the economics of NFTs are not well yet understood, due to the novelty of the field. It is important, therefore, to measure the financial performance of this new asset class. In order to do so, this paper used hedonic regression (HR) to investigate the NFT collection named CryptoPunks using a data set of more than 11,000 transactions. More specifically, this paper focused on evaluating the investment performance, assessing the variables that determine prices within the CryptoPunks collection, investigating its portfolio diversification potential, and comparing the investment performance to other financial assets. The hedonic index indicates that the CryptoPunk prices have on average increased monthly by 34.19% with a standard deviation of 61.76% over the past three years. This return rate is higher than any other investment type that formed part of this paper's research. Next to that, the Sharpe ratio (SR) indicates a good return-risk trade-off. One main finding based on the HR analysis is that the rarity of the attributes of the CryptoPunks has a positive effect on prices. This is consistent with research findings in the physical collectibles market. Moreover, CryptoPunks is a suitable investment for diversification since the correlation with other assets is relatively low.

Another major factor for consideration when deciding to invest in a new asset is whether it has the potential to grow. This seems to be the case for NFTs given that there are application cases specifically in the gaming, sport, and art industries. Next to that, once major challenges like usability and the lack of a legal form of ownership of NFTs are overcome, the market will reach a broader audience and thus the market will grow still further. However, despite the many positive aspects to NFT collectible investment, the high volatility, illiquidity, and irrationality of this market cannot be underestimated.

This paper aims to provide the first exploration of NFTs from an economic perspective. Its results suggest that, in comparison to other studies that have investigated the art market as providing alternative assets, the NFT market has the potential to offer a more profitable ROI. Its findings also accord with previous studies that investigated the impact of the rarity of a collectible on its value.

The main limitations of this paper are the small data set and the relatively short time period that is observed. In order to achieve a more precise overview of the entire NFT market, it is important to keep exploring this new asset class. Nothing in this paper can be considered to be financial advice.

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Appendices

Appendix 1 - CryptoPunk Attributes and Their Prevalence

Table 10: Prevalence of CryptoPunk Attributes

Attribute	Prevalence	
	Total	%
Beanie	44	0.44
Choker	48	0.48
Pilot Helmet	54	0.54
Tiara	55	0.55
Orange Side	68	0.68
Buck Teeth	78	0.78
Welding Goggles	86	0.86
Pigtails	94	0.94
Pink with Hat	95	0.95
Top Hat	115	1.15
Spots	124	1.24
Rosy Cheeks	128	1.28
Blonde Short	129	1.29
Wild White Hair	136	1.36
Cowboy Hat	142	1.42
Wild Blonde	144	1.44
Straight Hair Blonde	144	1.44
Big Beard	146	1.46
Half Shaved	147	1.47
Vampire Hair	147	1.47
Red Mohawk	147	1.47
Blonde Bob	147	1.47
Clown Hair Green	148	1.48
Straight Hair Dark	148	1.48
Straight Hair	151	1.51
Silver Chain	156	1.56
Dark Hair	157	1.57
Purple Hair	165	1.65
Gold Chain	169	1.69
Medical Mask	175	1.75
Tassel Hat	178	1.78
Fedora	186	1.86
Police Cap	203	2.03
Clown Nose	212	2.12
Smile	238	2.38
Cap Forward	254	2.54
Hoodie	259	2.59
Front Beard Dark	260	2.60
Frown	261	2.61
Purple Eye Shadow	262	2.62
Handlebars	263	2.63
Blue Eye Shadow	266	2.66
Green Eye Shadow	271	2.71
Vape	272	2.72
Front Beard	273	2.73
Chinstrap	282	2.82
3D Glasses	286	2.86
Luxurious Beard	286	2.86
Moustache	288	2.88
Normal Beard Black	289	2.89
Normal Beard	292	2.92
Eye Mask	293	2.93
Goat	295	2.95
Shaved Head	300	3.00

Attribute	Prevalence	
	Total	%
Do-rag	300	3.00
Peak Spike	303	3.03
Mutton Chops	303	3.03
Pipe	317	3.17
VR	332	3.32
Cap	351	3.51
Small Shades	378	3.78
Clown Eyes Green	382	3.82
Clown Eyes Blue	384	3.84
Headband	406	4.06
Crazy Hair	414	4.14
Knitted Cap	419	4.19
Mohawk Dark	429	4.29
Mohawk Thin	441	4.41
Mohawk	441	4.41
Frumpy Hair	442	4.42
Wild Hair	447	4.47
Messy Hair	460	4.60
Eye Patch	461	4.61
Stringy Hair	463	4.63
Bandana	481	4.81
Classic Shades	502	5.02
Shadow Beard	526	5.26
Regular Shades	527	5.27
Big Shades	535	5.35
Horned Rim Glasses	535	5.35
Nerd Glasses	572	5.72
Black Lipstick	617	6.17
Mole	644	6.44
Purple Lipstick	655	6.55
Hot Lipstick	696	6.96
Cigarette	961	9.61
Earring	2459	24.59

Appendix 2 - Goodness-of-Fit Plots

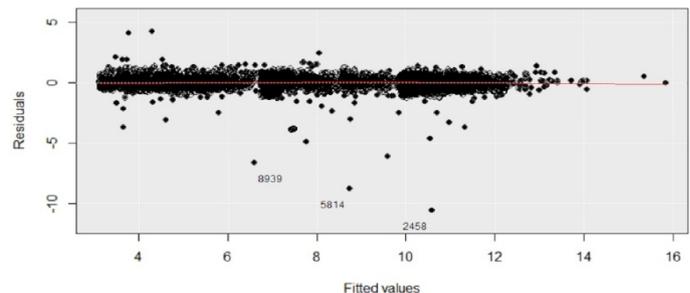


Figure 5: Residuals vs. Fitted Values Plot

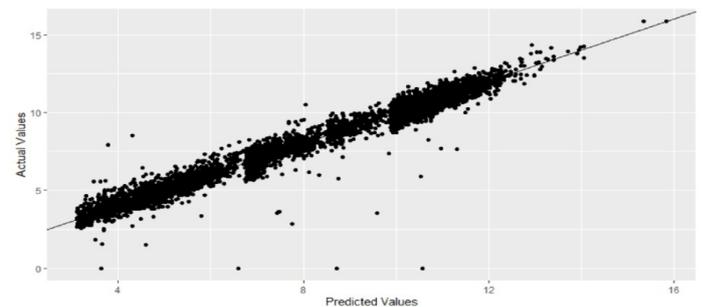


Figure 6: Actual vs. Predicted Values Plot

Blockchain Adoption Factors, Enablers and Barriers in Fisheries Supply Chain: Preliminary Findings from a Systematic Literature Review

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Abstract

Technological adoption has become a key goal of digital transformation within firms, affecting many facets of an organisation, such as attaining competitive advantage, increased revenue, reduction of operational costs, and improving operational efficiency. Blockchain as a decentralised peer-to-peer technology appears uniquely suited to being deployed within complex food supply chains such as the fisheries industry, which is the focus of this study. In this context, blockchain technology can be used for a variety of purposes, such as provenance authentication, handling and storage, transparency, counterfeit prevention, food forensics, and enhanced supply chain resilience. The purpose of this study is to synthesise existing research on the interrelationship between blockchain technology and the factors that determine adoption, as well as identifying the enablers and barriers. This preliminary work identified key themes emerging from the blockchain literature, suggesting that adoption factors are wide ranging, encompassing aspects including organisational readiness, security, complexity, partnerships, competition, governmental influence, and transparency. The thematic analysis of enablers and barriers to blockchain adoption identified the broad theme of resources as the key enabler and integration as the key barrier. These preliminary findings add to the growing body of research, including increased understanding of the current state of academic research in the areas of blockchain adoption factors, blockchain adoption in supply chains, blockchain adoption in the fisheries industry, and the enablers and barriers to adoption. This study is the initial step in a large-scale study with the next phase comprising case studies of specific fishery supply chain stakeholders.

Keywords: *Blockchain, Distributed Ledger Technology, Supply Chain, Fisheries.*

JEL Classifications: *L14, L21, L22, L23, L24, L66, L91, O33, Q22.*

1. Introduction

Blockchain has been gaining a lot of attention in recent years by both academics and practitioners spanning multiple industries [1]. Gartner predicts that blockchain will generate \$3.1 trillion in new business value by 2030 with wider-scale adoption coming on stream in 2023 [2]. Further data claim that blockchain spending will reach \$17.4 billion in 2024 [3]. This signifies increased interest in the realm of distributed ledger technology. Blockchain as a decentralised peer-to-peer platform appears uniquely suited to adoption within complex food supply chains. In contrast to other industries, food production operates in more vulnerable value chains that require increased attention to handling and storage. In addition, transport and temperature can affect food quality and freshness [4]. In the fisheries industry, blockchain technology can be used to record the readings of specialised IoT devices like intelligent sensors. Blockchain can store values from the point of capture all the way to the shipment delivered to the end customer. In this scenario, readings from sensors represent data about the status of the condition of the product (temperature) being transported. The blockchain can be used for the purpose of transportation, handling and storage, tamper-proof checks, and product history among others [5].

In the remainder of this article, we review the extant literature on blockchain adoption, supply chains, and fisheries. Although recent academic literature has begun to address blockchain adoption along supply chains in greater numbers, there still exists a paucity of research examining blockchain adoption in fisheries supply chain. To address this, we conducted a systematic literature review of recent literature examining blockchain adoption in supply chains. Various theories have been forwarded in the

past to elucidate the factors that drive information technology adoption [6]. We chose to utilise the technology, organisation, and environment (TOE) model first developed in 1990 by [7]. It pinpoints three distinct areas of an organisation's context that affect the process of adoption and implementation of a technological innovation: the technological context, the organisational context, and the environmental context [8]. This framework is extremely well suited to an industry that is characterised by its complexity at the organisational level. Ireland's fisheries industry is distinguished by its diversity of vessel types and fishing techniques. Further complexity is added through market segmentation, firm-level organisational structures, types of aquaculture production, and geographic locations [9]. This process enabled the identification of a number of adoption factors, enablers, and barriers to blockchain adoption. We believe the identification of these factors adds to the existing body of knowledge in the blockchain adoption sphere. These factors can be further used to identify enablers and barriers, specifically within the fisheries industry.

2. Literature Review

A systematic literature review was chosen as the most appropriate approach for this review. Emanating primarily from the sphere of medical research, this method is considered as 'a way to synthesize research findings in a systematic, transparent, and reproducible way and have been referred to as the gold standard among reviews' [10, p. 334]. The goal of this systematic review was to gather and analyse a large selection of sources in order to examine a comprehensive range of blockchain literature spanning supply chains, fisheries, and adoption. There exists a number of explanatory articles that offer a range of guidelines and approaches regarding the authoring

of a systematic literature review [10]–[17]. As the focus of the review was primarily the determination of the factors that enable the adoption of blockchain in the fisheries industry through the lens of the TOE model, the following keywords and strings were selected: blockchain and adoption AND fisheries, blockchain AND adoption AND TOE, blockchain AND supply chain AND adoption. The next stage involved the literature search. Given the multidisciplinary nature of the topics under examination, the keywords were entered into renowned academic databases such as Web of Science, Scopus, PubMed, Business Source Complete, Jstor, and ProQuest. The databases were searched for citations while limiting the search of the keywords to titles and abstracts only. Where there was any ambiguity pertaining to the article’s title, the abstract was examined to determine the relevance of the study. The resulting articles that were considered appropriate for inclusion were imported into the Mendeley reference management software package. The next stage concerned analysing the titles and abstracts against pre-determined inclusion and exclusion criteria. The inclusion criteria were determined as empirical, theoretical, and grey literature in a desire to be thorough. In an effort to be inclusive and garner an expansive result, concluding sections of articles were reviewed when the abstract lacked the information required [15, pp. 105–6]. Exclusion criteria were determined as duplicate citations, studies unrelated to the research question, i.e. occurrences of articles where the keywords appeared in the title but were not the focus of the article. Snowballing was then performed to elicit further references. This resulted in the retrieval of 272 articles. Of these 272 articles, 40 focused specifically on fisheries supply chains.

3. Blockchain and Supply Chains

A supply chain can be defined as a complex adaptive system network that traverses multiple stages, relationships, geographical locations, various financial systems, and multiple entities encapsulated by differing time-based pressures depending on the type of product and market [18], [19]. Supply chains are typified by the inclusion of multiple partners. These may include but are not limited to manufacturing factories, distribution centres, suppliers, couriers, and ancillary logistic services [20]. As such, supply chains are increasingly becoming more complex. A number of factors have contributed to this: the search for sustainability, increasing globalisation, trade liberalisation, reduction in trade costs, and the application of new technologies. In addition, the management of supply chain networks is a crucial factor in preserving organisational competitiveness [18], [21]. Blockchain’s role within supply chain has gained increasing attention from researchers and practitioners in recent times. A number of purported benefits have been listed, including smart contracts, product traceability, enforcement tracking, stock control, transaction and settlement, and information immutability [6]. Extant literature has identified a number of areas and applications within supply chain and supply chain management. Table 1 collates prior research and identifies the area of supply chain that will be affected by blockchain and its application to this area.

4. Blockchain Fisheries Adoption

The pace of technological innovation and change has necessitated the speedy adoption of information communication technologies as a crucial goal for firms. The fisheries industry can be characterised by its complexity, primarily because of the number of products, processes, individuals, and organisations that constitutes its make-up [35]. For example, Ireland’s fishing fleet is segmented around five key areas: refrigerated seawater pelagic segment, e.g. herring and mackerel, beam trawler segment, e.g. sole and plaice, polyvalent segment, e.g. whitefish and molluscs, specific segment, e.g. bivalve molluscs and aquaculture species, and aquaculture segment, e.g. collection of spat from wild mussel stocks for aquaculture installations [9, p. 408]. Irish aquaculture production is dominated by salmon farms. Additionally, fish processing comprises 160 companies, with 85 of these enjoying a revenue of more than €1 million [36]. The industry is primarily made-up of whitefish, pelagic, and shellfish operators, with whitefish, shellfish, and smoked salmon processors dominating [37, p. 119]. This complexity has been driven by the globalisation, distribution, and consumption patterns of food production [35], [38]. To address supply chain complexity, a number of solutions have been proposed, e.g. vigilant information systems and blockchain [5], [39]. Various theories have been forwarded in the past to elucidate the factors that drive information technology adoption. Many of these examine the motivation behind user behaviour like the technology acceptance model (TAM), the task-technology fit (ITF) theory, the diffusion of innovation (DOI) theory, the theory of reasoned action (TRA), the theory of planned behaviour (TPB), the unified theory of acceptance and use of technology (UTUAT), and social cognitive theory (SCT) [6]. Other theories espoused include the perceived e-readiness model and assimilation theory [40]. The TOE model was first developed in 1990 by [7]. It pinpoints three distinct areas of an organisation’s context that affects the process of adoption and implementation of a technological innovation: the technological context, organisational context, and environmental context [8]. The technological context refers to both the internal and the external technologies pertinent to the firm. From a more granular perspective, the technological context incorporates factors such as complexity, relative advantage, privacy, security, and compatibility. These factors have been shown previously to effect existing or potential information technology adoptions [8], [40], [41]. An abstract view of the organisational context describes the firm by examining its scope, size, and managerial structure. More specific considerations include top management support, prior IT experience, innovativeness, information intensity, and organisational readiness [8], [40], [42]. The environmental context refers to the wider area in which a company operates

Table 1. Supply Chain Area and Blockchain Application

Supply Chain Area and Blockchain Application		
Operations	Recording, tracking, and sharing information with greater speed and precision	[20], [22]
	Reduced paperwork and cost reduction	[20], [23], [24]
	Information management – immutability, error reduction, and increased trust	[18], [25]–[29]
Supply Chain Management	Governance structure	[1]
	Visibility, optimisation, and demand forecasting	[26], [30]
	Disintermediation – cost savings and efficiency	[25], [28], [31]
	Collaboration	[24], [32]
	Automation – smart contracts	[22], [24]
Auditing	Transparency	[23], [29]
	Traceability	[22]–[24], [30]
Activity Control	Increased trust and efficiency	[18]
Fraud Detection	Cost savings	[33]
	Asset ownership	[29]
	Information asymmetry	[26], [34]
Competitiveness	(Lack of) Transparency	[18]
Logistics	Customer value	[31]

its business, i.e. the industry, its competitors, and relationships with the government, including regulations [8], [40]. This research will incorporate an adapted framework proposed by [40], which incorporates the individual and task-related contexts in addition to the technology, organisational and environmental. The individual context considers social influence and hedonistic drives incorporating expectations, how privacy is perceived, as well as trust and non-utilitarian motives. The task-related context refers to the task and technology characteristics that have to be matched to allow a task-technology fit leading to positive performance and IT utilisation [40]. The TOE framework has been used extensively both across a wide variety of industries and in a number of different contexts [43]–[49]. Table 2 presents an overview of the articles reviewed that address blockchain adoption. It does so by delineating the TOE factors that drove adoption. Table 3 presents an overview of the articles reviewed that consider the individual and task-related factors that drive adoption. Table 4 lists the enablers and barriers identified.

Table 2. Summary of Blockchain Adoption Factors

Technological Factors		Organisational Factors		Environmental Factors	
Security	14	Organisational Readiness	13	Policy and Regulations	14
Complexity	9	Top Management Support	12	Competitive Pressure	10
Privacy	7	Technological Readiness	7	Collaboration Efforts	4
Integration	4	Innovativeness	4	Government Support	4
Technology Costs	4	Business Model Readiness	2	Transparency	4
Relative Advantage	4	Facilitating Conditions	1	Market Dynamics	3
Compatibility	3	Information Intensity	1		
Technological Immaturity	2				
Scalability	2				
Interoperability	2				
Perceived Benefits	2				
Disintermediation	2				
Traceability	2				

Table 3. Summary of Individual and Task Adoption Factors

Individual Factors		Task-Related Factors	
Trust	8	Task-Technology Fit	5
Expectations	3	Performance	2
Privacy	1	Complexity	1
Social Influence	1	Standards	1
		Usability	1
		Legal	1

Table 4. Enablers and Barriers to Blockchain Adoption

Enablers		Barriers	
Collaboration	6	Policy and Regulations	11
Management Support	5	Cost	10
Government Regulations	5	Lack of expertise	7
Organisational Infrastructure	4	Interoperability	7
Training and Education	4	Stakeholders	6
Perceived Benefits	4	Organisational Culture	6
Technological Infrastructure	3	Scalability	6

Support	3	Legal Concerns	6
Integration	3	Complexity	5
Partnerships	3	Market Barriers	4
Complexity Reduction	3	Awareness	4
Financial Resources	2	Privacy Issues	3
Job Opportunities	1	Security	3
		Uncertainty	2
		Infrastructure	2
		Hype	2

5. Thematic Analysis

Thematic analysis has become a widely used method for analysing qualitative data. This type of analysis can be performed within numerous ontological frameworks, which is in turn linked to the epistemological approaches to data [50]. There are two key approaches to thematic analysis in qualitative research. The first is the deductive approach, which utilises existing theories to build themes, then uses them as a guide in the coding process. This approach is rooted in the scientific method as the process moves from theory to hypothesis to hypothesis testing. The second approach is the inductive approach, which attempts to build themes through the examination of available information. The process followed begins with coding the contents of the data examined and then developing and completing themes during and after the coding process [50], [51]. This study employed a mixed approach to examine the literature. Firstly, the deductive approach was employed by using the TOE framework to build initial themes related to blockchain adoption that were then used to guide the coding process. Following that stage, the process moved onto utilising the Leximancer tool <https://www.leximancer.com/>. Leximancer is a text analytics tool frequently used by researchers to analyse the contents of textual documents to display the extracted data visually.

5.1. Blockchain Adoption Factors

Top management support emerged as the key outcome of the thematic analysis of the blockchain adoption factors. The theme of support can be broadly broken down into two broad concepts of top management support and organisational readiness. In this scenario, top management is a broad concept encompassing CEO level to senior management. This is context specific to the organisation. The second theme identified by thematic analysis is that of security. This theme can be broken into the key concepts of complexity, privacy, and transparency. The next theme to emerge is that of partners. In this context, the concepts related to partners include vision, cultural differences, financial factors, and policies. Complexity is the next key theme to emerge. This includes concepts such as technological novelty, security, technological immaturity, complexity perception, disintermediation, and compatibility. Government is the next theme to emerge. This incorporates government support, policy, and regulations. The theme of competitors refers primarily to the environmental adoption factor and the pressure exerted on organisations to adopt blockchain. Finally, the theme of transparency refers to concepts such as the enhancement of transparency through blockchain adoption, traceability, immutability, sustainable practices, and data disclosure for clients

5.1.1 Enablers

The outcome of the analysis of the data collated regarding the enablers to blockchain adoption identified six key themes.

Resources - The most heavily weighted theme to arise is resources. This is a broad theme that threw up a number of concepts encompassing availability of resources, technological and organisational infrastructure, network and human support, training and education, research funding, financial resources, and commitment to technological infrastructure and innovativeness.

Government - This theme was narrower and more focused on concepts around collaboration between government and industry, development of government guidelines, policy and frameworks, and regulations. The remaining themes emerged with lower weighting but still threw up some interesting data.

Support - The support theme contains the concepts of degree of managerial support, vendor support, and human support.

Visibility - The visibility theme refers to the concepts of transparency, tracking, improved communication, cargo visibility, and documentation transparency.

Business - The business theme refers to concepts such as choice of business partner as an adoption enabler, simplification of business processes, transaction cost reduction, knowledge sharing, and new business models.

Management - Finally, the management theme encompasses the concepts of management involvement in platform selection and the hiring of consultants.

5.1.2 Barriers

The thematic analysis of the barriers to blockchain adoption produced some very interesting results. In contrast to the enablers, where six key themes emerged, double the number of themes were produced for barriers.

Integration - Integration was the central theme to emerge in barriers to adoption. It is inextricably linked to a number of other barriers and encompasses concepts like acceptance by partners, uncertainty about benefits, costs and return on investment, scalability, existing infrastructure, standards, and lack of knowledge.

Regulatory - The regulatory theme encompassed the concepts of regulatory clarity and uncertainty pertaining to regulatory developments.

Costs - The costs' theme refers to general costs, high sustainability costs, and implementation costs.

Stakeholder - The stakeholder theme contains concepts such as industry resistance, increased coordination demand, collaboration hesitation, external stakeholder involvement, and collaboration differences with partners.

Legal - The legal theme was conceptualised by issues like future legal implications and long-term uncertainty around legal developments.

Complexity - The complexity theme considers concepts like technological complexity, decreased operational efficiency, increased coordination demand, and required openness.

Scalability - The scalability theme incorporates concepts such as wasted resources, and intra-organisational implementation costs.

Uncertainty - Uncertainty as a theme contained broad concepts relating to legal, technological, and regulatory developments, as well as collaboration uncertainty.

Interoperability - The interoperability theme refers to the concepts of interoperability across jurisdictions and a reluctance to change current systems.

Technology - The technology theme incorporates concepts such as unfamiliarity and unclear benefits, lack of knowledge, and technology risks.

Infrastructure - The infrastructure theme contains the concepts of existing

technological infrastructure and needed infrastructure.

Expertise - The expertise theme refers to concepts such as existing knowledge and expertise

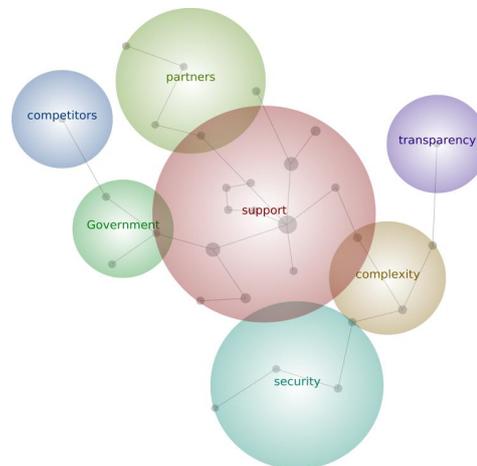


Figure 1: Blockchain Adoption Factors

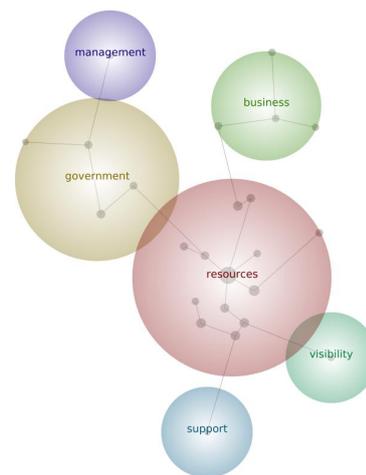


Figure 2: Enablers

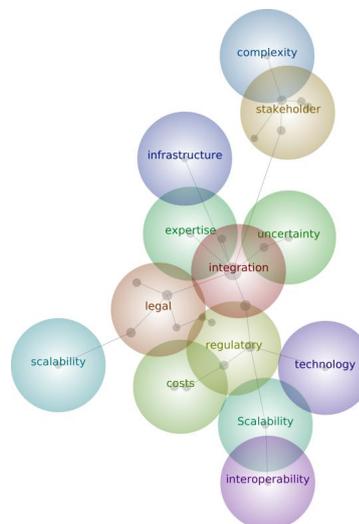


Figure 3: Barriers

6. Conclusion

Interest in blockchain utility in supply chain is garnering increasing interest. However, blockchain adoption in fisheries supply chain is a somewhat neglected sphere of research. To address this gap, this research presents the preliminary findings from ongoing research into blockchain adoption along fisheries supply chain. Through the performance of a structured literature review, we have identified key supply chain areas that are primed for the application of blockchain. A number of adoption factors have been identified and thematically analysed. Furthermore, enablers and barriers to blockchain adoption have been pinpointed and thematically analysed. The next step for this research is to empirically examine the enablers, barriers, and adoption factors through a series of interviews and focus groups. It is hoped that this will elicit further insight into these issues.

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None declared.

Ethical approval:

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Colin Callinan conducted the literature review and contributed to the writing and editing of the manuscript. Amaya Vega, Trevor Clobessy and Graham Heaslip supervised the project and contributed to the writing and editing of the manuscript.

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Can Blockchain Take Smartphones Out of Contact Tracing?

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Abstract

The global public health crisis caused by the emergence and spread of the coronavirus disease (COVID-19) has been devastating, prompting the need for immediate countermeasures to curb its spread, especially in the absence of any approved treatment shortly after its onset. This crisis has highlighted the gap in current contact tracing systems, which require massive public participation to be effective but lack a high degree of public acceptance. This low acceptance is mainly due to concerns regarding personal data privacy and guaranteed data protection, hindering the success of existing systems. We evaluate the use of blockchain to improve contact tracing and provide a solution to effectively track the spread of an epidemic, using COVID-19 as a relevant use case. The key requirements of the proposed system include protecting user data, maintaining full transparency using a decentralised system, and eliminating the need for global positioning system or personal data for contact tracing. A proof-of-concept system uses a private blockchain to secure and manage data collected at various locations using a mobile application or stored-value contactless smart cards. Contact tracing is performed via smart contracts over the blockchain using the collected data. We confirm the improvements provided by the proposed system for contact tracing.

Keywords: *blockchain, contact tracing, smart contract, Hyperledger Fabric*

JEL Classifications: *I100, Y800*

1. Introduction

Contact tracing allows us to identify persons who have been in close contact with others infected by diseases such as the coronavirus disease (COVID-19). Yap and Xie [1] highlighted the importance of collecting accurate epidemiological data via contact tracing. Such data are key for deploying preventive measures against outbreaks in a country and promoting situational awareness in the public. This has been evident throughout the COVID-19 pandemic and further emphasised in the COVID-19 report of the World Health Organization, which also lists various precautionary measures: ‘rapid diagnosis and immediate isolation of cases, rigorous tracking and precautionary self-isolation of close contacts’ [2]. The report also mentions the primary issue hindering the implementation of these measures: ‘an exceptionally high degree of population understanding, and acceptance of these measures are critical for countries to curb ongoing outbreaks’ [2].

The lack of any approved treatment during the early propagation of COVID-19 made prevention crucial, especially due to the unique properties of the virus including ‘non-specific features of the disease, infectivity even before the onset of symptoms in the incubation period, transmission from asymptomatic people, long incubation period, prolonged duration of the illness and transmission even after clinical recovery’ [3]. While the release of approved COVID-19 vaccines has put the end of the pandemic in sight, extensive measures will still be required to curb its spread and avoid new outbreaks as countries gradually reopen their borders for business and tourism.

The pandemic has exposed gaps in control of disease outbreaks and the urgency with which countermeasures should be adopted for potential outbreaks in the future. These aspects are important for potential outbreaks of diseases such as Ebola, severe acute respiratory syndrome, Zika, and variant strains worldwide, which can increase over time, as

shown in Figure 1. More frequent outbreaks can be attributed to various global trends. First, increased globalisation means that humans are more connected through travel and trade. Consequently, outbreaks can spread across the globe in a matter of days. Even within countries, increasing urbanisation, with 68% of the world population projected to live in urban areas by 2050 [5], and the concentration of people living in often unhygienic conditions can promote the spread of diseases.

Human displacement resulting from natural disasters, emergencies, poverty, or conflict has also led to large groups of people having to relocate outside their home countries. Under poor conditions, these people are often vulnerable to infectious diseases. Moreover, climate change directly impacts environmental health and can alter the transmission patterns of infectious diseases. In particular, water-borne diseases and zoonoses may have their transmission season lengthened and geographical ranges altered, as seen with Zika, malaria, and dengue [6].

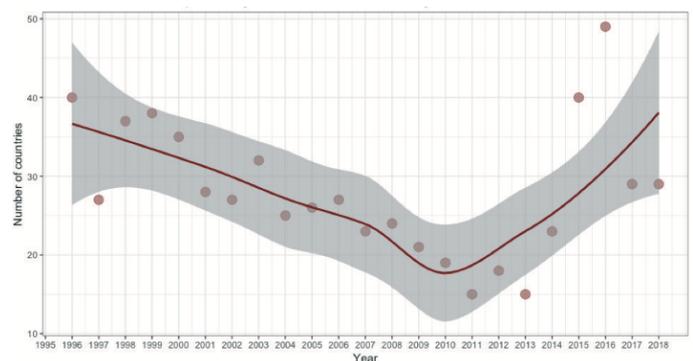


Figure 1: Number of countries experiencing disease outbreaks between 1995 and 2018 [4].

In June 2018, the abovementioned trends converged, and for the first time

ever, there were outbreaks of six out of the eight categories of diseases in the Priority Diseases list of the World Health Organization [7]. As each of these diseases has the potential to cause global disruption if allowed to spread [8], the development of effective countermeasures becomes imperative to prevent outbreaks and prepare for epidemics.

In the absence of digital contact tracing, patients reporting their symptoms to medical professionals are expected to collect and trace all their recent close contacts, being an unrealistic procedure in the modern world. On the other hand, digital contact tracing allows the use of smartphone data for health surveillance while protecting individual privacy and providing safeguards against data breaches [9]. Accordingly, we explore how blockchain can be integrated into an Internet-of-Things system to achieve contact tracing towards the development of a trustless system to tackle the continued spread of disease outbreaks.

2. Existing Contact Tracing Technologies

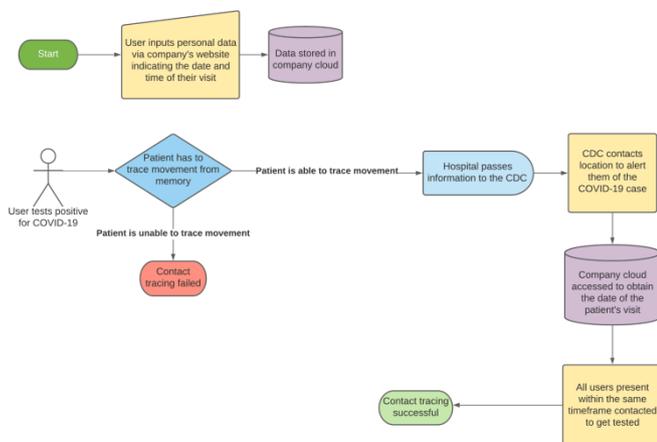


Figure 2: Workflow of typical contact tracing.

Current models for contact tracing should be analysed to devise potential improvements. Figure 2 shows the workflow of a typical contact tracing system. It shows the disconnection between users and hospitals as well as the delays in contact tracing due to the involvement of multiple intermediaries.

More modern systems include spatiotemporal reporting over networks and GPS (global positioning system) data to determine the locations for contact tracing [9]. Similar systems developed by Apple and Google [10] work with Bluetooth protocols and temporary keys in smartphones to preserve user privacy successfully. Thus, smartphones are inevitable in current digital contact tracing solutions.

However, these systems may cause concerns regarding individual data privacy and data protection, leading to low public acceptance. Most solutions are critically dependent on the number of participants, showing a low effectiveness if not widely used [11]. In addition, trust plays a major role along with preference, location, and jurisdiction in the multitude of available contact tracing apps (mobile applications), which further dilute the pool of participants.

We propose a solution considering COVID-19 as a use case. Although the epidemiology of COVID-19 was used as the basis for the model, it can be modified to fit different cases. To solve the problems of contact tracing, the proposed system is designed considering the following primary prerogatives:

- Must comply with the General Data Protection Regulation [12]
- Must secure user data
- Anonymous contact identification: Contact tracing must be

done without compromising user privacy

- User notification: Users must be notified of their exposure to a disease (e.g. COVID-19).

The complete list of requirements is provided in the Appendix, which covers the design requirements at various levels.

3. Methodology

Based on the contact tracing requirements, we conducted a survey of the available permissioned blockchain frameworks and selected Hyperledger to develop the proposed system. Hyperledger provides several frameworks for different implementations, as outlined in Table 1. The listed characteristics allowed us to narrow down the framework selection for the proposed system.

Considering the system specifications, Hyperledger Fabric was selected because it is a base framework that implements pluggable components, enabling system streamlining using only the necessary services.

4. Implementation

Figure 3 shows the workflow of the proposed solution with a blockchain streamline that automates contact tracing and removes intermediaries. A blockchain is primarily used for data management, taking advantage of its immutability and transparency, which creates trust among the public. Data are collected via nodes at different locations through a mobile application (app) or a stored-value contactless smart card, which possesses a unique ID serving as public key for the distributed ledger. The smart card removes the necessity of smartphones in contact tracing to improve accessibility. In addition, an algorithm implemented by smart contracts uses these data to highlight locations where users test positive for COVID-19 and automatically flag users who likely had contact with the infected patient.

Figure 4 shows the dataflow of the proposed system including acquisition, processing, and storage of user data to be used by smart contracts when addressed.

Full transparency is maintained in two stages. The first stage involves linking the user's private key to a national medical record or identity number for authentication according to the country of implementation. For this use case, in the event of a contagious disease outbreak such as COVID-19 in the United Kingdom, the National Health Service (NHS) could act as regulators of the client application, working with admin access. The NHS is the only party with complete access to the client application as NHS numbers are used for authentication and the NHS acts as a regulator of the client application. Hence, a seamless transition between hospitals identifying cases can be achieved as the hospitals already possess and manage NHS accounts. In the event of an emergency outbreak, the approach can be modified by using any national medical records or identity numbers for authentication according to the country of implementation. Second, the proposed system enables the backtracking of the IDs of COVID-19 patients at hospitals through their identity numbers upon hospitalisation. Allowing patients to be checked against the ledger can minimise human error and enables system redistribution of pings over predetermined exposures, improving the pinpointing accuracy.

Smart contracts simulate contact by using positive and negative transactions for entry and exit, respectively. These transactions are triggered by the input from users over nodes via the app or the stored-value contactless smart cards. Only the user ID and unique area code assigned to the node are timestamped in the ledger. Upon occurrence of a positive COVID-19 test, the smart contracts are triggered to query the ledger for the corresponding ID. Presence is then identified in the world state by users possessing the same positive key-value pair, who are automatically notified of their exposure via the app or email.

Table 1: Characteristics of Hyperledger Frameworks

Requirement	Fabric	Sawtooth	Iroha	Burrow	Besu	Indy	Grid
Permissioned Blockchain	✓	✓	✓	✓	✓	✓	✓
Modular Architecture	✓	✓	✓	✓			
Flexible smart contract deployment	✓	✓	✓	✓	✓		
Flexible coding language	✓	✓					
Adaptable Consensus Mechanism	✓	✓	✓		✓		
Mobile Application Synergy	✓		✓			✓	
Versatile	✓		✓				
Case-specific		✓			✓	✓	✓
Simple	✓			✓			

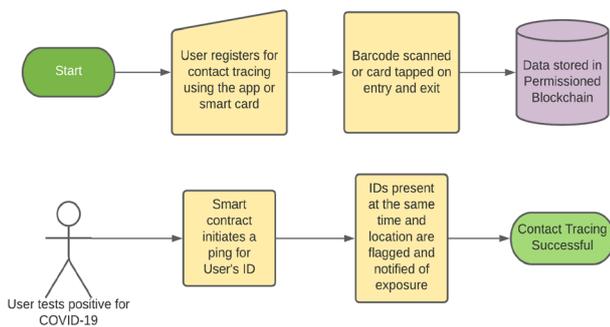


Figure 3: Workflow of proposed blockchain-based contact tracing.

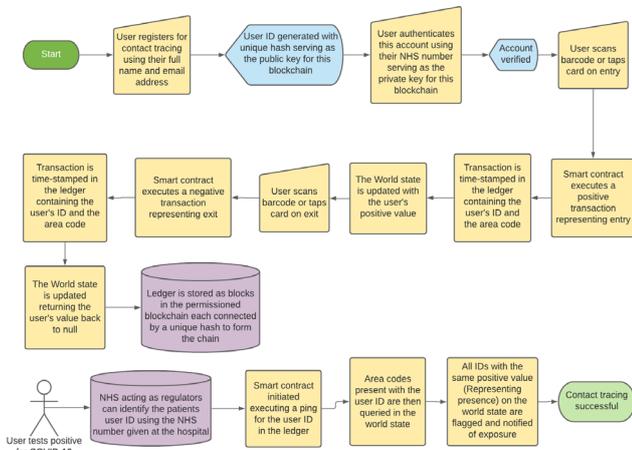


Figure 4: Blockchain contact tracing dataflow.

Considering human factors, in the events of no-scan, tailgating, or a probable miss-read of IDs, a two-layer stop gap is set to minimise errors due to missed binary actions. First, a 24-hour timer is incorporated into the chaincode for entry scans. Using a conditional statement, a negative exit transaction is automatically executed to set the value of the ID back to null. A large time value was chosen to accommodate errors; however, the time value requires optimisation in the testing phase to avoid wasted ping transactions. To address wasted ping transactions within that time range, the second layer extends the conditional statement on entry transactions to return a recurring positive ID value to null. This process is crucial to preventing errors due to 'omnipresence', forgoing the timer in the event of a missed exit transaction. These steps potentially mitigate human error, optimised during quality checks using several sample scenarios.

Contact tracing can create awareness and provide information on the spread and demographics of a disease. In addition, it provides analytical data anonymously by interpreting the network statistics obtained using

Hyperledger Caliper [13]. For example, the number of cases in an area can be determined by the number of smart contracts triggered, and the number of blocks generated per day allows us to understand traffic and exposure across a region. Thus, the proposed system provides an additional source of accurate and trusted epidemiological data, which are essential to curb the spread of a disease.

5. Adoption and Usage

Contact tracing as an emergency countermeasure depends heavily on user behaviour, and its effectiveness is determined by public acceptance. These features are the greatest barriers facing the implementation of contact tracing, especially in countries with a general distrust in the government. In a cross-country survey [14] conducted across France, Germany, Italy, the United Kingdom, and the United States, findings were consistent with the general notion that contact tracing solutions should be delegated to a transparent public health authority for positive public acceptance. Hence, we used national medical records independent of government IDs for authentication in this study.

Even with such delegation, the general mistrust in tracking solutions for contact tracing is still highly apparent. Thus, users are more likely to opt-out of downloading or disconnect their devices from use when contact tracing apps are mandated. Other sources of mistrust include a genuine discomfort with the use of sensitive data (e.g. geolocation data) and fear of data protection during and beyond the use of a smartphone app.

General public concern on these matters is based on genuine fear and mistrust. The focus of our solution to overcome this fear is creating an incentive based on trust itself.

First, contact tracing requires public consent at the onset but has been mostly limited to the use of smartphones. Our solution aims to tackle this by creating an option through contactless smart cards, which require no device and are not traceable. Removing the necessity of smartphones also makes the solution accessible to an entire population, thereby creating a larger pool of users.

Second, with contact tracing made autonomous by using smart contracts in blockchain, the system runs independent of human interference on the back end, and user and admin interactions only occur on the front end via a client application. Eliminating the possibility of human interference is another key selling point for adoption and favours creating a trusted source of epidemiological data using network statistics. This is vital because distrust in governments and public media causes people to mistrust the epidemiological data released, impacting their overall awareness.

Lastly, by taking advantage of decentralisation and the high-level encryption of blockchain, our solution does not require personal data. Authentication only occurs on the front end using national medical records that are currently handled by hospitals, avoiding any dissemination of personal data.

6. Technical Solution

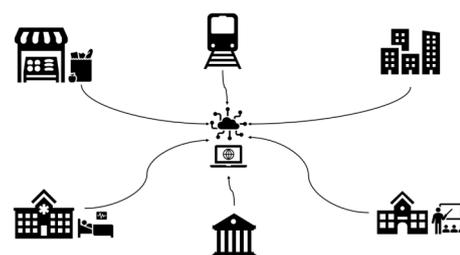


Figure 5: Grid diagram of implemented blockchain-based contact tracing.

We adopt a modular approach with a blockchain spanning a fixed geographical area to optimise storage and performance by minimising the traffic across the network. Figure 5 illustrates the implementation of this approach, where nodes are deployed across densely populated locations within an area interacting with the blockchain via the client application.

6.1. Blockchain Architecture

The private blockchain is a base ledger with a single organisation consisting of interoperable peer nodes and associated by their channels with each node represented by a unique area code.

As illustrated in Figure 6, client application A0 handles the proposal of smart contracts to be invoked by peers P_i–P_n, which are mediated by ordering node O through channel C1 to execute preconfigured smart contracts. A smart contract SC either updates ledger L1 with entry/exit transaction or queries the ledger for key–value pairs during a ping depending on the input from the client application. Configurations for organisation R0 and the channel are stored in certificate authority CA0 and channel configuration CC1, respectively, which are issued by the membership service provider during initialisation.

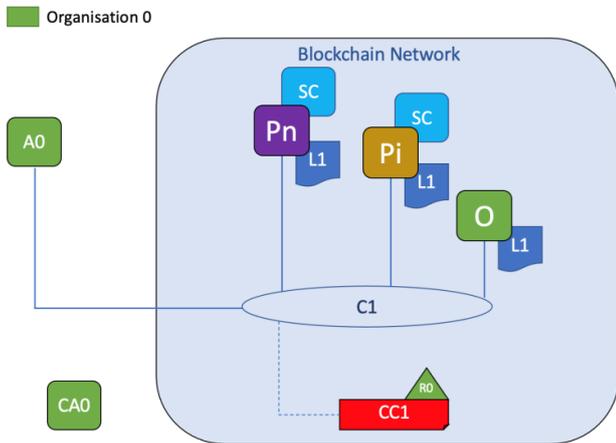


Figure 6: Blockchain architecture.

6.2. Storage Solution

To optimise storage, the proposed system minimises data collection by considering only timestamped user IDs and their respective area codes. Nevertheless, the defining limitation of blockchains is storage, and this use case requires storage to be on-chain. A key element to optimise storage is purging user data 20 days after a user reports infection with COVID-19. This is achieved by using the private data collection feature of Hyperledger Fabric [15, 16].

6.3. Private Data in Hyperledger Fabric

In Hyperledger Fabric, private data provide another layer of security in the permissioned blockchain. This framework grants access to a defined subset of organisations and peers to endorse, commit, or query sensitive data [16]. Hence, the NHS can be defined as a regulator, given exclusive access to read and write private data.

Data purging is performed in the collection policy configuration of the smart contract using property Blocktolive. This property determines the number of blocks for which private data are retained, removing data from consequent blocks but retaining their hash value to serve as immutable evidence [16]. In this case, purging is configured by estimating the number of blocks generated per day multiplied by 20 to satisfy the system requirements.

7. Proof of Concept

As a blockchain administration project, we evaluate the system design, structure, and implementation. Blockchain development on this scale requires a team of developers. Therefore, considering resource limitations, the key features of this specific solution are highlighted in a mock-up using the test network of Hyperledger Fabric [17].

Figure 7 shows the architecture of the blockchain for the test network. The architecture contains ordering organisation O and two peer organisations R1 and R2 with one peer node each (P1 and P2). The implemented architecture was run in a Linux Ubuntu terminal with chaincode written in JavaScript.

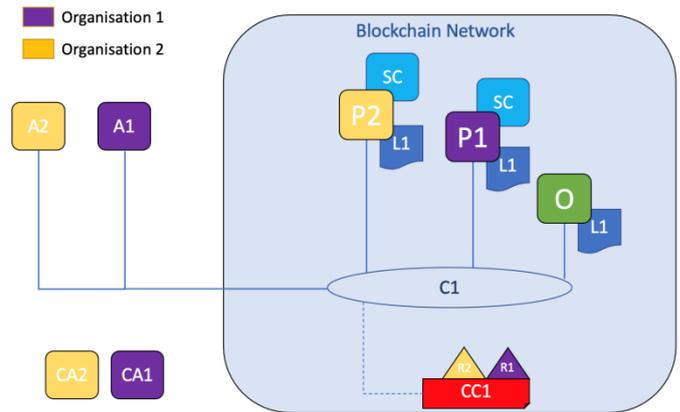


Figure 7: Test network of Hyperledger Fabric to implement blockchain architecture for proof of concept.

Figure 8 shows the network components in the Linux terminal that lists all the docker containers currently running. After the network is running, a channel is created to allow interactions via smart contracts. These contracts handle interactions between peers by querying the ledger or invoking functions included in the chaincode.

Figure 9 shows the creation of assets in the ledger by invoking the smart contract followed by the query of all assets from the ledger to illustrate the querying process. Assets from the ledger can be queried in multiple ways according to the use case. Figure 10 shows a simple asset query by ID from the ledger using smart contracts, demonstrating querying by the unique user ID after a positive COVID-19 test.

```

root@kali:~/VirtualBox/fabric-samples/test-network$ docker ps -a
CONTAINER ID   IMAGE                                COMMAND                  CREATED
STATUS        PORTS                               NAMES
a51bb52dfaf7  dev-peer0.org1.example.com-sc-orttsebaowlkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3  /bin/bash              5 minutes
279d18393f498864fc3  7e0d634291d69606d0b53b7304e796881f8c4d5f7b67dc487c8892ba75eb893  docker-entrypoint.sh   3 minutes
es_ago        Up 3 minutes                         dev-peer0.org1.example.com-sc-ortts
ebawolkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3
3fcef0a4560     dev-peer0.org2.example.com-sc-orttsebaowlkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3  /bin/bash              3 minutes
279d18393f498864fc3  32118ecc5b851c76bf8ca72041511f64341c7a1b7853cc939981d02a7a3  docker-entrypoint.sh   3 minutes
es_ago        Up 3 minutes                         dev-peer0.org2.example.com-sc-ortts
ebawolkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3
183df761844     hyperledger/fabric-tools:latest                                     /bin/bash              5 minutes
47617083f106    hyperledger/fabric-orderer:latest                                  cli                    5 minutes
409340353cfa    hyperledger/fabric-peer:latest                                    "orderer"             5 minutes
es_ago        Up 5 minutes                         0.0.0.0:7050->7050/tcp, 0.0.0.0:7053->7053/tcp  orderer.example.com
4882448ac69     hyperledger/fabric-peer:latest                                    "peer node start"     5 minutes
es_ago        Up 5 minutes                         0.0.0.0:7051->7051/tcp                               peer0.org1.example.com
c882448ac69     hyperledger/fabric-peer:latest                                    "peer node start"     5 minutes
es_ago        Up 5 minutes                         7051/tcp, 0.0.0.0:9051->9051/tcp                   peer0.org2.example.com
edfcc12983c0    hello-world                                                        /hello                 2 month
s_ago        Exited (0) 2 months ago                                           nervous_brattain

```

Figure 8: Test network components implemented in Hyperledger Fabric.

```

root@kali:~/VirtualBox/fabric-samples/test-network$ peer chaincode invoke -o localhost:7050 --ordererTLSHostnameOverride orderer.example.com --tls --cafile $(PWD)/organizations/ordererOrganizations/example.com/orderers/orderer.example.com/msp/tlsacerts/tlsca.example.com-cert.pem -c ch-orttsebaowlkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3 --peerAddresses localhost:7051 --tlsRootCertFiles $(PWD)/organizations/peerOrganizations/org1.example.com/peers/peer0.org1.examp
le.com/peers/peer0.org2.example.com/tls/ca.crt -c '{"function": "initLedger", "Args": []}'
021_04_12_22:02:12.351807 [chaincode] chaincodeInvokeQuery => INFO 001 Chaincode invoke successful. result: stat
us:200
root@kali:~/VirtualBox/fabric-samples/test-network$ peer chaincode query -c ch-orttsebaowlkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3 --peerAddresses localhost:7051 --tlsRootCertFiles $(PWD)/organizations/peerOrganizations/org1.example.com/peers/peer0.org1.example.com/tls/ca.crt --peerAddresses localhost:9051 --tlsRootCertFiles $(PWD)/organizations/peerOrganizations/org2.example.com/peers/peer0.org2.example.com/tls/ca.crt -c '{"function": "getAssets", "Args": []}'
021_04_12_22:02:12.351807 [chaincode] chaincodeInvokeQuery => INFO 001 Chaincode invoke successful. result: stat
us:200
root@kali:~/VirtualBox/fabric-samples/test-network$ peer chaincode query -c ch-orttsebaowlkpbpe-1834500_1.0-5773f4b29ef8ee1547f11d4ba04cfb46d9237b9aaa6279d18393f498864fc3 --peerAddresses localhost:7051 --tlsRootCertFiles $(PWD)/organizations/peerOrganizations/org1.example.com/peers/peer0.org1.example.com/tls/ca.crt --peerAddresses localhost:9051 --tlsRootCertFiles $(PWD)/organizations/peerOrganizations/org2.example.com/peers/peer0.org2.example.com/tls/ca.crt -c '{"function": "getAssets", "Args": []}'
021_04_12_22:02:12.351807 [chaincode] chaincodeInvokeQuery => INFO 001 Chaincode invoke successful. result: stat
us:200
root@kali:~/VirtualBox/fabric-samples/test-network$

```

Figure 9: Asset creation.

```

bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset1"]}'
{"ID":"asset1","Color":"Blue","Size":25,"Owner":"Tomoko","AppraisedValue":300,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset2"]}'
{"ID":"asset2","Color":"red","Size":15,"Owner":"Brad","AppraisedValue":400,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset3"]}'
{"ID":"asset3","Color":"green","Size":10,"Owner":"Jin Soo","AppraisedValue":500,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset4"]}'
{"ID":"asset4","Color":"yellow","Size":10,"Owner":"Max","AppraisedValue":600,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset5"]}'
{"ID":"asset5","Color":"Black","Size":15,"Owner":"Adriana","AppraisedValue":700,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["ReadAsset","asset6"]}'
{"ID":"asset6","Color":"white","Size":15,"Owner":"Michel","AppraisedValue":800,"docType":"asset"}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$

```

Figure 10: Basic query per user ID.

More complex functions can be implemented by smart contracts to query the ledger using key-value pairs [18]. The assets in the test network have five key-value pairs, excluding the asset ID. These pairs can be individually queried from the ledger using rich queries to pull all the assets with the same value. Figure 11 shows a rich query performed using key owner to pull all assets owned by an individual. This further demonstrates asset queries by their key-value pair to pull all users at a specific node using the area code and to determine their presence in the system.

```

bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["QueryAssets","({\"selector\":{\"docType\":\"asset\",\"owner\":{\"\"in Soo\"}},\"use_index\":{\"key\":\"asset\",\"record\":{\"appraisedValue\":200,\"assetID\":\"asset3\",\"color\":\"green\",\"docType\":\"asset\",\"owner\":{\"\"in Soo\"},\"size\":10}})\"}']}'
{"key":"asset3","record":{"appraisedValue":200,"assetID":"asset3","color":"green","docType":"asset","owner":{"in Soo","size":10}}}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["QueryAssets","({\"selector\":{\"docType\":\"asset\",\"owner\":{\"\"tom\"}},\"use_index\":{\"key\":\"asset7\",\"record\":{\"appraisedValue\":75,\"assetID\":\"asset7\",\"color\":\"red\",\"docType\":\"asset\",\"owner\":{\"\"tom\"},\"size\":10}})\"}']}'
{"key":"asset7","record":{"appraisedValue":75,"assetID":"asset7","color":"red","docType":"asset","owner":{"tom","size":10}}}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["QueryAssets","({\"selector\":{\"docType\":\"asset\",\"owner\":{\"\"michel\"}},\"use_index\":{\"key\":\"asset10\",\"record\":{\"appraisedValue\":35,\"assetID\":\"asset8\",\"color\":\"purple\",\"docType\":\"asset\",\"owner\":{\"\"michel\"},\"size\":15}})\"}']}'
{"key":"asset8","record":{"appraisedValue":35,"assetID":"asset8","color":"purple","docType":"asset","owner":{"michel","size":15}}}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$ peer chaincode query -C ch-ortisebawolkpobe-1834500 -n sc-ortisebawolkpobe-1834500 -c '{"Args":["QueryAssets","({\"selector\":{\"docType\":\"asset\",\"owner\":{\"\"michel\"}},\"use_index\":{\"key\":\"asset10\",\"record\":{\"appraisedValue\":250,\"assetID\":\"asset6\",\"color\":\"white\",\"docType\":\"asset\",\"owner\":{\"\"michel\"},\"size\":15}})\"}']}'
{"key":"asset6","record":{"appraisedValue":250,"assetID":"asset6","color":"white","docType":"asset","owner":{"michel","size":15}}}
bawo_1@bawo-VirtualBox:~/fabric-samples/test-network$

```

Figure 11: Rich query based on key-value pairs.

8. Conclusion

We propose a contact tracing system that meets various requirements for application to a use case considering COVID-19. The proposed system may contribute to combating epidemics, improving current contact tracing systems by providing trust to users. In fact, securing personal data and maintaining full transparency without requiring smartphones can increase public acceptance, which is essential for creating a sufficient pool of data for digital contact tracing. Incorporating the system into the NHS operations creates a seamless transition between testing and identification of disease cases, establishing a new trusted source of epidemiological data. As countries are looking forward to reopening their economies, effective contact tracing becomes essential to prevent new outbreaks of COVID-19. The proposed system may be applied in the current COVID-19 pandemic as well as other epidemics or pandemics in the future to support prevention and control.

This study was limited to blockchain administration owing to resource constraints and our current unavailability of manpower and expertise necessary to develop the blockchain solution at a practical scale. Such implementation would involve quality checks beyond the system's successful operation for ensuring speed, efficiency, and a low failure rate in tests against various sample scenarios. In future work, we intend to use a complete build to evaluate the scalability and enhanced data analysis across modules using available Hyperledger tools. In addition, the proposed solution may be extended by integrating the vaccination status into the IDs to anonymously gather data and accurately determine the immunisation efficacy across multiple regions.

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Appendix: Requirements of Proposed Blockchain-Based Contact Tracing System

Level	Requirement	Description
Stakeholder	Compliance with General Data Protection Regulation [11]	<p>Lawful basis of processing: consent</p> <ul style="list-style-type: none"> Participants provide valid consent through app/smartcard registration
	Securing data of participants	<p>Data secured by the blockchain immutability</p> <ul style="list-style-type: none"> Data stored on blockchain cannot be tampered with because each block contains the hash value of the previous block as its header
		<p>No personal data needed for contact tracing by leveraging blockchain anonymity</p> <ul style="list-style-type: none"> NHS number is only used for account authentication, locked to the private key NHS numbers are already handled by the NHS, avoiding data sharing
		<p>Data offloaded after 20 days following positive cases of COVID-19</p> <ul style="list-style-type: none"> Achieved using private data collection feature of Hyperledger Fabric Private data are purged after a number of blocks defined in the collection policy of smart contract An estimate can be set for the number of blocks created in a day multiplied by 20
User	Portability	Users interact with the system via app or stored-value contactless smart card
	Accessibility	Modular design allows for strategic deployment of nodes over a region
System		Contact tracing initiated by preconfigured smart contracts
	Contact identification	<p>System should identify contact anonymously:</p> <ol style="list-style-type: none"> User presence is registered at nodes using app or stored-value contactless smart card Smart contract is initiated on entry or exit, reflected in blockchain as a positive or negative transaction, respectively User ID or public key is timestamped to ledger with each transaction Ping smart contract initiated using ID of a user diagnosed with COVID-19 Smart contract acts by querying ID against world state Any other IDs present with the same positive value (representing presence) are flagged
	User notification	<p>All user IDs flagged by a ping are notified of exposure via app or email</p> <ul style="list-style-type: none"> Handled automatically by smart contract feeding back to client application
	Data management	<p>User IDs are unique, random-generated hashes used as public keys for blockchain</p> <p>NHS numbers are locked to private keys used for account authentication</p> <ul style="list-style-type: none"> Allows backtracking of user IDs at hospitals
		<p>Only IDs are timestamped in a block against area code assigned to node</p> <p>Ledger data are offloaded every 20 days</p>
		<p>System handles identification only by input after a positive COVID-19 test</p> <ul style="list-style-type: none"> Input serves as trigger for smart contract
Data analysis	<p>Anonymous data received from nodes should be intelligible for epidemiological analysis</p> <ul style="list-style-type: none"> Number of ping smart contracts initiated represent new COVID-19 cases New information available on spread and demographics of disease 	

Creation of a Self-Sustaining Token Economy

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Abstract

Creating a self-governing token economy is a challenge for any project seeking to create a product with a rational token run that provides motivation and profit. It is also important to maintain correct token liquidity after listing on an exchange. Developing an algorithm for tokenomics and manually planning initial coin-offering rounds is an extremely difficult task because the human mind cannot fully understand all the factors and probable scenarios of token behaviour during product operation and trading.

The safest and most effective way of building tokenomics is through formal methods. We offer algebraic modelling based on the theory of interactions between agents and environments. The behaviour of each agent, namely, the investor, product users, and traders on an exchange, and a smart contract, which controls the interaction, are defined by the set of actions presented in behaviour algebra. Symbolic modelling methods allow one to build the best scenarios for circulating tokens and maintain economic equilibrium over an extended period. Automatic proofs of statements in behaviour algebra make it possible to verify properties such as the impossibility of centralisation or the malicious actions of stakeholders who look to obtain illicit benefits.

We have developed an online automated web service called tokenomics constructor that makes it possible to build tokenomics with simulations of possible behavioural scenarios and provides proofs of properties of interest. The tokenomics constructor uses historical stock exchange data to model trade. The system is supported by an algebraic server that leverages algebraic behaviour methods and an automatic proof system.

Keywords: *token economy, behaviour algebra, formal methods, symbolic modelling*

JEL Classifications: *C51, C60*

1. Introduction

Today, the world is experiencing a boom in the adoption of blockchain. New projects and services evolve daily, creating a new ecosystem of crypto-related platforms and products that use cryptocurrencies and tokens.

Nevertheless, we are still in the very beginning of a blockchain-ruled world with only a few real benchmarks or examples of long-lasting, self-sustaining token economies. The main reason is that the creation of a self-governing token economy is a difficult task that requires considerable effort, knowledge, and provision.

It is easy to see that most creators, even if they have a profound white paper and seem to have a thoughtful token economy, intuitively build pyramid-like structures with a lack of real token utility and stakeholders' motivation to hold; most importantly, they use their tokens in daily activities within the platform. As a result, most projects never reach a system balance and become too dependent on the speculation of whale-investors.

Is there a simple and efficient way to help blockchain project creators avoid mistakes and create self-sustainable token economies right at the stage of white-paper and minimum viable product development?

The key to this is math and formal methods. Modelling is a mandatory activity that should be provided during tokenomics (token economy) creation. Algebraic modelling can help build and prove the economic equilibrium and analyse different undesirable properties, such as centralisation, or prevent malicious actions of unscrupulous stakeholders.

This study considers the technology and program systems that can be used

in token economy creation.

2. What is token economy in the scope of formal methods?

At first glance, the scenarios that occur in tokenomics are like a game between participants who want to gain their own preferences. On the one hand, it is a sales game in which participants hold, sell, or buy tokens according to changes in the liquidity or marketing information. On the other hand, tokenomics is built according to some service, which is built based on blockchain platforms. In many projects, the token is seen as a means of motivation, deliberately created to increase its effectiveness. Thus, in education systems, the token is used to encourage students to study diligently to reduce the fee for educational services. In other services, tokens are paid for reputation, number of services consumed, or installation of equipment. In general, the tokenomics of such services is built so that the more efficiently the consumers use the service and are rewarded with tokens, the more profit goes to the creators of the service.

For the most part, the ideas of such a game are offered by investors when compiling "white pages" and more often the rules of the game are more attractive at first glance and the business appears clear and transparent. However, even with very limited rules and factors that affect the token life cycle, the human brain does not always see all scenarios and always wants to believe that development will follow the best scenario. Even if calculations are made, they cannot cover the full range of possible events and only present some scenarios, generally the best ones.

Suppose we know the first steps in investing and the exact number of tokens in the exchange. The subsequent stages depend on many factors, and it is impossible to accurately compute the development of events with

specific values.

Tokenomics, as a science, includes several fundamental studies on the structure, environment, stakeholder motivation, token life cycle, and more. This is described in the works by Au and Power and Khamisa [1,2]. Some mathematical aspects of tokenomics are presented in the work by Tan [3] to explain key statements.

Experimental data on the functioning of tokenomics in various projects led to the so-called laws of tokenomics [4] developed by Fred Krueger of Stanford University. The laws were based on a large amount of data presented in cryptocurrency market analysis.

The study of self-governing tokenomics has led to the emergence of justifications and research in several areas.

1. Game theory underlies parties' motivations. If a blockchain-based platform embodies a service, the task of tokenomics encourages buyers and, which, profit sellers. With the help of tokenisation, such a task is considered successful if economic equilibrium is established over a period. This implies a stable change in the basic parameters of tokenomics, such as the token price.

2. Statistical methods underlying the prediction of token behaviour. Studying the probabilities of various events and historical data and using them for machine learning is useful for creating a model for predicting token behaviour.

3. Formal methods, mainly probabilistic methods, are used to analyse the resilience of malicious or dishonest actions, such as fake trading, centralisation, and collusion between stakeholders [5].

All these approaches can be useful, but the prediction accuracy is not always possible, provided that not all factors can be predicted in a token game.

From our viewpoint, it would be appropriate to use methods based on the algebraic approach, where instead of specific values of the parameters of tokenomics, we manipulate the formulas representing the set of possible values of the parameters.

This approach forms the basis of symbolic or algebraic modelling. When building a model, we assumed a set of actions that occur between participants in tokenomics and changed their parameters accordingly. Modelling makes it possible to observe the projected development of events over a certain period. But it must be understood that such a prediction is feasible if the maximum of the most influential factors is considered.

With a certain set of such data, it is possible to conduct a fairly accurate analysis of the properties of tokenomics. Such properties are primarily the tokenomics equilibrium or predicted fluctuations in the token price. In certain projects, stakeholders can influence development and invest heavily in stabilising or destabilising the tokenomics. Then, properties such as the possibility of centralisation or accumulation of manual control in the hands of two or three participants should also be analysed.

The factors that significantly affect the liquidity of a token cannot be determined unambiguously. An example is the price of Bitcoin, which significantly affects projects.

Here, it is possible to consider different scenarios with different possible behaviours of such factors.

Later in this study, we will consider the algebraic approach that we use to analyse and study tokenomics projects and will formalise and investigate one of the use cases. The compilation of tokenomics can be performed

on a simplified basis to try understanding its problems. To do this, we developed a program tokenomics constructor, which after entering the parameters builds some analytics with the appropriate charts and will show certain scenarios for developing a tokenomics project. This program is available and can be used [6].

3. Theory of agents and environments and the algebra of behaviours in formalising tokenomics

Previous work in which we considered tokenomics [7,8] contains an approach based on the theory of interactions between agents and environments.

In 1997, English scientist David Gilbert and Ukrainian professor Alexander Letichevsky Senior created this theory, which also actively uses the concept of algebra of behaviours.

Environments and agents evolve and exhibit observable behaviour. An agent can be inserted into the environment, interact with other agents, and change the behaviour of the environment and other agents. The change in the behaviour of an agent is determined by its atomic action.

The basics of this paradigm were set out in the literature [9,10].

Tokenomics determines a set of agents that interact with each other by performing atomic actions. Such agents include project stakeholders, investors, exchanges, and traders. An agent can bring together a group of individuals or represent a system that also changes the environment; for example, such an agent can be a smart contract.

Each agent can have a state determined by its attributes. As the attributes change, so does the agent's state. For example, attributes may be the number of tokens or fiat money from the agent. An agent can have a type defined by either a set of attributes or a common feature. For example, "Investor" may be defined as an agent with a specific number of tokens and fiat money. Agents of this type can be banks, people, or companies. In theory, agents have names.

At first glance, the concept of an agent is very close to the concept of a class in object-oriented languages. The difference is that a class is created to run a particular program and has many features to implement the execution – methods, interfaces, and other features. The formal definition of an agent is intended for the possibilities of algebraic modelling, which differs from the usual execution of a program by representing a set of scenarios of agent behaviour in an environment characterised by algebraic representation, such as formulas in the theories used here.

An example of a formal presentation of the agents' description is presented in the next section, where a specific case study is considered.

The interaction of agents in the environment is determined by some behaviour, which is also represented by formal specifications.

The algebra of behaviours was also developed by Gilbert and Letichevsky Sr. It is a two-sorted algebra over the actions of agents and behaviours. The main operations of algebra are prefixing and nondeterministic choices, which are extended by so-called compositions parallel and sequential.

Examples of behaviour equations include the following:

$$\begin{aligned} B0 &= a1.a2.B1 + a3.B2, \\ B1 &= a4.\Delta, \\ B2 &= \dots \end{aligned}$$

This implies that behaviour $B0$ can be interpreted as a sequence of actions $a1$ and $a2$, followed by behaviour $B1$, or as action $a3$, followed by behaviour

B2. Behaviour *B1* finishes after action *a4*, where Δ denotes the successful termination constant.

Tokenomics in behavioural equations is a tree of actions with possible cycles performed by the agents involved. They can act in parallel or sequentially, defining a set of tokenomics scenarios that consist of actions. Because an agent is an entity that has attributes, the set of attribute values determines the state of the agent, and the set of states of the agents determines the state of tokenomics.

The actions of agents themselves consist of a precondition that allows the agent to act in certain states and a postcondition that determines the change of its attributes and, accordingly, the change of state of the agent.

The peculiarity of the action, which is an algebraic entity, is that the state is determined by the formula over the attributes rather than specific values. The behaviour scenario of tokenomics agents may be a sequence of actions that changes the state of the agent represented in some theory, such as inequality in linear arithmetic. The predicates and operations in the formula depend on the type of agent attribute. Let us consider the formal representation of tokenomics in the algebra of behaviours using a specific example.

4. Tokenisation of the Internet of Things as an example of tokenomics

We consider the formalisation of tokenomics as an example of an abstract Internet of Things (IoT) project.

The essence of the project is to create a network of base points that provides data exchange with IoT devices, such as animal trackers, human health devices, car gadgets, and other sensors and mobile gadgets. Such base points are antennas that provide a certain coverage for users.

The following agents function throughout the tokenomics system.

Base point owners earn revenue from the data traffic and the number of users who have joined it. Owners of IoT devices buy devices from their respective vendors and pay for their ability to use the network.

A token operates as a system for online payments and rewards. Accordingly, base point owners receive rewards in tokens, and users pay for traffic or bandwidth services in tokens. The token is used in the system to make a profit and appears in the investments.

To buy a token, it must be registered on the exchange. In modern exchanges, a certain amount of the presented token must be supported by a stable currency, meaning that, in addition to the tokens, a certain amount of fiat money is loaded on the exchange, which forms the price of the token.

In connection with the beginning of the sale and purchase of a token on the stock exchange, a new type of agent is created that deals with trading, which depends on the increase or decrease in liquidity. These actions affect the price of the token and, accordingly, tokenomics as a whole. The exchange is also an agent in the tokenomics system.

The main agent is the one who represents the team of developers–entrepreneurs. An agent is also a product service or smart contract that defines the actions of a blockchain service. They collect tokens for transactions and direct some of the profits from the transactions to the team.

Finally, there is an agent that represents investors and can act as a trader, realising his or her tokens, which he or she collected in the first round of investment.

Figure 1 shows the relationship between the agents or the movement of the token between them.

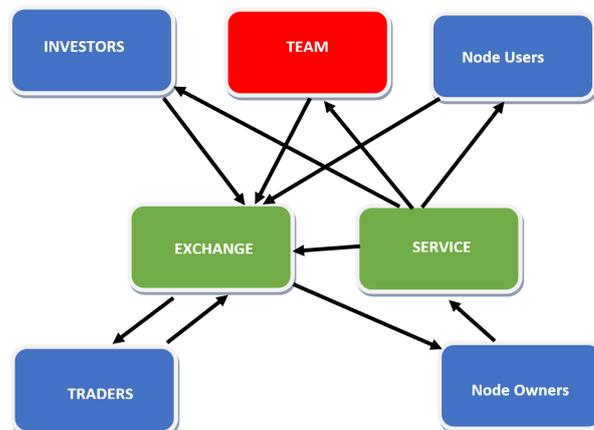


Figure 1. The token movement between agents

Next, we define a formal description of the tokenomics model in terms of the behavioural equations and actions of agents. Let us define the type of agent as the stakeholder of this token system, which has two attributes: *token*, the number of tokens, and *fiat*, the amount of fiat money. Let us mark the corresponding names of agents: *NodeOwners*, *NodeUsers*, *Team*, *Exchange*, *Traders*, *Investors*, and *Service Product*. We use the notation of the theory of agents and environments and determine access to their attributes by writing *AgentName.token*, such as *Investors.token* and *Exchange.fiat*.

The tokenomics of service comprises two parts. The first is investment. During the investment rounds, some of the tokens are sold privately, and afterwards, an open sale begins for everyone.

The second part concerns the service. Its launch starts with a certain token value on the stock exchange and certain results of the marketing group, which attracts network users to the service and owners of base points that expand the network.

Behavioural equation can be written as a sequential composition of two behaviours.

$$B0 = INVEST; SERVICE$$

Behaviour *INVEST* is a cycle of several rounds when tokens are sold and funds are raised.

$$INVEST = round.INVEST + empty$$

The round action determines the flow of tokens to investors according to the period determined by the allowed time predicate *time (Round, X)*. The general type of action is as follows:

$$round = Time (round, X) > SmartContract.token = SmartContract.token + TokenBudget (X);$$

$$Investors.token = Investors.token - TokenBudget (X)$$

The semantics of the record are as follows: if the predicate *Time* is true, namely, the time of the round has come or the time is equal to the corresponding month; for example, *Round = X*, then the service product or smart contract must perform the planned budget actions, namely, to add tokens to investors from the smart contract.

If the service has already started during the investment, then we use a parallel composition of two behaviours, and the beginning of the service

will be determined by the allowing predicate.

$$B0 = INVEST \parallel SERVICE$$

Here, if the token was registered during the investment, the behaviour of the exchange was also combined in parallel with it and the service.

$$B0 = INVEST \parallel SERVICE \parallel EXCHANGE$$

SERVICE behaviour is the periodic execution of monthly purchases of new basic antennas and payment of rewards to their owners, the implementation of the plan for the use of traffic, and the work of the marketing team responsible for increasing the number of service users.

$$SERVICE = nextMonth.addNewOwners.rewardToken.addNewUsers.deviceUsersToken.SERVICE$$

Here, it was convenient to consider a discrete model with respect to monthly intervals. We disregard the fact that the token price can change many times during the month. Therefore, a more accurate model was built when a one-day interval was used. The number of users involved per day also affects the course of events; however, this model is proposed as a general approach that can be transformed into different periods. This approach can also be used to predict the behaviour of the token, allowing an even distribution of values throughout the location, which allows for an accurate investigation of the properties of tokenomics.

Let us now consider the actions separated by the prefixing operation involved in the *SERVICE* behaviour.

addNewOwners – Adds the number of new antenna owners in the postcondition based on various factors. This can be historical data from open blockchain resources, which can be combined with marketing effectiveness, depending on the amount of money invested.

rewardToken – Distributes tokens for antenna owners from the smart contract balance.

addNewUsers – Adds new users to IoT devices. This action uses a marketing effectiveness feature, combined with historical data.

deviceUsersTokens – This action deals with the purchase of tokens on the exchange by users, payment for the use of the network, and the corresponding change in the price of the token, as the tokens were purchased. Some of the tokens used for using the network are considered profit for the team.

We disregard the description of actions, as it may contain factors that we have not described; however, we have not considered critical actions or the inability to perform them. Such situations can arise when the balance of a smart contract does not have sufficient tokens for payment, when there are no funds for marketing, or when the exchange lacks tokens for sale. All such actions must also be present in the behavioural equations. Given our understanding of the model and method, we abstract from such things.

When formalising human behaviour, questions arise, such as in what sequence and at what time will this or that human action occur? Behavioural algebra refers to the ability to synchronise actions and perform them in parallel or in a certain sequence. In the process of modelling actions that correspond to a certain behaviour, all possible scenarios of human behaviour are considered up to the equivalence. An important factor in the accuracy of modelling is the choice of the minimum period that corresponds to the duration of action.

The actions themselves correspond to all possible operations in the

tokenomics environment that are allowed by a smart contract or system. Some actions, such as user growth, depend on the external environment, namely, the success of marketing rather than tokenomics. When formalising such actions, historical data and different marketing scenarios should be considered. However, note that the algebraic method allows one to operate with a set of scenarios, including external factors.

EXCHANGE behaviour can significantly affect tokenomics scenarios. It includes actions that determine the behaviour of traders, namely, holding, selling, or buying tokens. This behaviour can be predicted using different algorithms combined with historical data on the purchase and sale of tokens on different exchanges. Of course, various factors affect the increase or decrease in stock exchange activity. Therefore, to assess the forecast of tokenomics, it is necessary to take different options for the behaviour of the exchange based on the historical data of token sales. The more diverse the behaviours we consider, the more accurately we can determine the properties of tokenomics. Appropriate functions of the desire to hold, sell, or buy tokens were built for modelling.

One of the levers of influence on tokenomics is emissions, such as throwing fiat money or tokens on the exchange to stabilise the token price. This action can be considered and included in the formalisation of the *SERVICE* behaviour.

Thus, having a formal description of the parallel composition of behaviours together with actions, we can analyse the properties of tokenomics, in particular, constructing charts of different behaviours or algebraic charts for arithmetic data.

Property analysis was performed using modelling, both concrete (or simulation) and symbolic. If we determine all the initial conditions and criteria of behaviours on the stock exchange and the marketing plan, it is possible to build a chart of the token price as an indicator of equilibrium. However, note that most of the data are subjective, and there are significant doubts about their accuracy. An example token chart of the simulation is shown in Figure 2.



Figure 2. Token price diagram

The graph shows that the token fluctuations are stable; however, if adjustments are made and the function of the desire to sell tokens is increased, the price will fall quickly, and the equilibrium may not be compensated by increasing the number of users.

Here, to eliminate subjective data, we considered possible ranges of values instead of specific values. We used algebraic modelling, which works with intervals or more complex constructions. Here, instead of a chart, we obtain a set of formulas for each month, which represents the state of the tokenomics environment and depends on the number of tokens for each agent – $x1, x2, \dots$ and the price of token t .

$$S1(t, x1, x2, \dots), S2(t, x1, x2, \dots), \dots, Sn(t, x1, x2, \dots), \dots$$

The equilibrium property of tokenomics can be expressed by an allowable interval for the token price, which is expressed by the arithmetic inequality. Note that the equilibrium formula can be more complex and contains other factors, such as the presence of sufficient tokens on the smart contract or the growing profit of the team.

In general, if we denote equilibrium formula as $R(t, x1, x2, \dots)$, then the conjunction of this formula and the state of tokenomics in month n would be

$$R(t, x1, x2, \dots) \wedge Sn(t, x1, x2, \dots)$$

We can prove the satisfiability of the formula. This proves that there are values at which the formula is true. Next, by performing inverse algebraic modelling, we can determine the intervals for the initial values that will lead to equilibrium. From these intervals, one can select the desired values to implement in tokenomics when starting the service or rounds.

Thus, the desired properties can be determined and the initial values of the attributes can be calculated. If most factors are determined by appropriate intervals or formulas, the prediction of tokenomics can be quite accurate.

5. Tokenomics constructor

A tokenomics constructor was developed for tokenomics creators who are beginners in this activity. This constructor assumes that the creator can enter specific data planned for the project – the total number of tokens, rewards for users, and marketing function – and define the functions of the exchange. Figure 4 illustrates a fragment of the tokenomics constructor site.

After entering the desired data, the algebraic server can be queried for the simulation. Because the data are specific, one can build a chart of the distribution of tokens by agents and calculate the price of the token depending on the time, such as a period of a month. Figure 3 provides an example of the distribution of tokens for different agents throughout the project and shows the relative balance. Other distribution charts and special properties can be specified during the query to the algebraic server.



Figure 3. Token distribution between agents

For more experienced users, it is possible to use the creator of insertion models in terms of the algebra of behaviours, agents, and environments. This system provides an interface for creating appropriate agents and environments and modelling the entire system with the output of graphs and corresponding scenarios in the form of message sequence chart traces. These traces contain a set of actions with the corresponding states of the agents, which, under certain initial conditions, lead to the violation of a certain property, for example, exceeding a certain threshold in the tokens for a particular agent. The model creator window is illustrated in Figure 5.

Finally, for studies with more serious properties – equilibrium, which is determined by certain parameters; centralisation; resistance to possible

attacks of fraud to gain illicit profits – the algebraic server or algebraic virtual machine is used. It contains a set of formal methods that work within the algebra of behaviours.

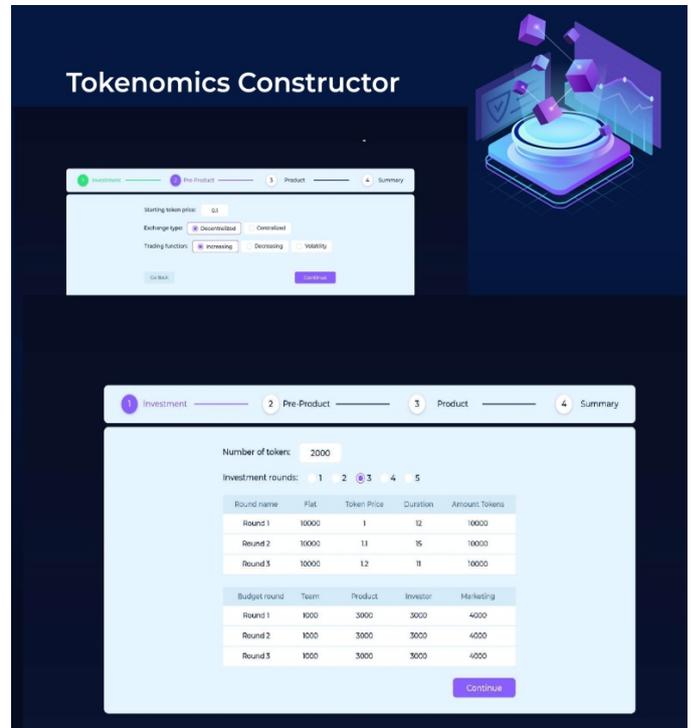


Figure 4. Tokenomics constructor site fragment

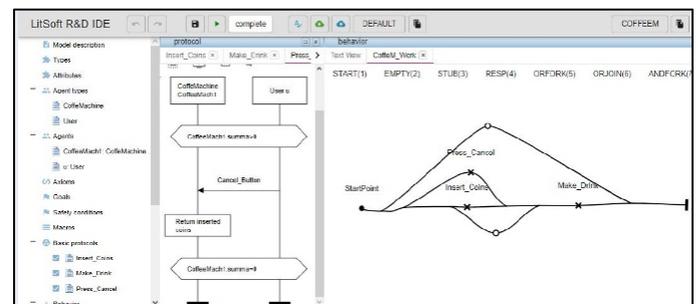


Figure 5. Model creator tools

6. Conclusion

This technology provides an opportunity to create self-sustaining tokenomics for projects that use tokenisation and blockchain technology for the deployment of network services in various subject areas. At first glance, the formalisation of tokenomics is a time-consuming process that requires serious mathematical education. However, the use of a tokenomics constructor is the first step in assessing the problems that may arise in the project. Also the original project created in the tokenomics constructor can be downloaded and extended in the model creator. The specification of a behavioural algebraic language slightly differs from the specifications of common programming languages, but any mid-level programmer can program a system.

Thus, the creation of formal specifications of tokenomics and modelling provides an opportunity to observe the problems in the project and

configure the actions of agents or smart contracts to maintain equilibrium or eliminate undesirable properties. On the other hand, the quality of system evaluation depends on the accuracy of formalisation and the completeness of the collection of all factors influencing tokenomics. This may depend on the interaction of experts, economists, and those experienced in blockchain projects with programmers who implement the tokenomics model. Additionally, there are unforeseen, unexpected, or force majeure circumstances that can significantly change the behaviour of the entire system, including natural disasters. This means that cryptocurrencies will experience significant fluctuations, which will be difficult to predict regardless of how perfect the service is.

Thus, it is inexpedient to completely ignore the modelling of tokenomics, and arguably doing so could be harmful. The human brain cannot assess all possible scenarios and abnormalities. Therefore, formal methods can be used to create more predictable and self-governing tokenomics.

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Decentralised Autonomous Organisations: A New Research Agenda for Labour Economics

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Abstract

Decentralised autonomous organisations (DAOs) are a new type of organisational structure and a new type of labour market. We review several theories from industrial and labour economics about contemporary post-industrial labour markets and assesses their applicability in emerging DAO labour markets. The review suggests a need for new theoretical frameworks to analyse the new forms of DAO employment, as well as a need for empirical research and new data collection methodologies fit for DAO digital labour economics.

Keywords: *decentralised autonomous organisation, labour market, labour economics, industrial economics, cryptoeconomics*

JEL Classifications: *J21, J22, J23, J24, J46, J49, E24, L00*

1. Introduction

Decentralised autonomous organisation (DAOs) is a new form of organisational structure offering an alternative to corporations [1–5]. A DAO is a digitally-native organisation that allows their members to govern themselves through smart contracts set on a public blockchain [6–10]. For workers, the critical difference is the horizontal structure, where there is little formal hierarchy and no bosses. Every member of a DAO is at the same time a co-owner, co-manager, and potential co-worker. The membership community governs a DAO as a mini democracy where everyone's vote counts. Members collectively decide on every matter and rules are executed according to the nexus of smart contracts that constitute the DAO.

DAOs offer a revolutionary new type of employment: a hybrid of ownership, traditional employment, freelancing, and volunteering. Every member is a boss and a worker (both paid and unpaid) and is free to contribute when and where they see fit. Members might contribute to a managerial or executive function (boss) by submitting and deciding on proposals for DAO activities, or act as employees or contractors (worker) by completing approved tasks themselves. Each member is free to choose how much time they want to spend working, voting, and participating in discussions. Members decide how much labour they are willing to supply to a DAO and under what conditions – from freelancing micro-work to a standard full-time working week, and beyond – provided there is DAO demand for their preferred employment contract. Moreover, one can be a member of multiple DAOs and choose how much time and effort they devote to each. According to DeepDAO, numerous top DAO contributors are members of dozens of DAOs at once, with the largest contributor currently part of over a hundred [11]. Employment in a DAO is flexible, discretionary, overlapping, and deregulated.

Labour economics is a branch of economics that has studied employment relations in conventional firms and markets [12] and industrial organisation is a field of institutional economics building on the theory of the firm by examining the structure and boundaries of firms and markets [13–16]. We review several theories from industrial and labour economics about contemporary post-industrial labour markets and assesses their applicability

for the new emerging DAO labour market relationship.

2. What is DAO labour?

The DAO has emerged as both a new type of organisational structure and a new type of labour market. DAOs blur the lines between traditional institutions of economic organisation (firm and market) and employment relations (owner and worker), offering new institutional innovations for studying theories of the firm, governance, management, and labour economics [5, 17].

DAO employment offers considerable worker flexibility – in terms of their overall supply of labour, working hours, and variety of tasks – due to the digital, remote, and asynchronous nature of DAO operations [18, 19]. Even today it is possible to earn a living working for a DAO or across multiple DAOs, with some earning an income as much as \$US 300,000 in 2021 [20]. A survey of 422 DAO members conducted by Gitcoin and Bankless showed that half of the respondent were able to earn a living from working in one or more DAOs [21]. However, the remuneration rarely comes as a traditional salary and is commonly paid in tokens. Furthermore, the moment one starts working for a DAO and gets paid can be two entirely different points in time.

How does this work? The moment one joins a DAO (usually by purchasing a token), they can start contributing by participating in a community forum (e.g., on Discord) and voting (e.g., on Snapshot). At this point, however, there is a slim chance of getting paid. As one's reputation grows, the DAO community may reward them based on discussion and participation KPIs (usually via airdrops). Once a member has familiarised themselves with the DAO and proved their reputation, they might start contributing to the core DAO project. At this stage, this usually happens in the form of completing a bounty – a small, disconnected task. Bounties are paid and lead to further accumulation of reputation and DAO specific skills [17–21].

The next step is to secure a part-time or full-time position within a DAO. While relatively rare and hard to get, these jobs are often well-paid. Longer-term or ongoing position such as these are usually associated with the core

operations of the DAO project: for example, a software developer role in a protocol DAO; or a graphic designer role in an NFT art production DAO. If one does not want to have a fixed arrangement, they can continue contributing when convenient, and the peer review process will decide how to remunerate the value they add to the DAO [17–21].

While displaying some characteristics of traditional employment (e.g., volunteering, gig economy, contracting), the distinguishing characteristics of DAOs require fundamentally new approaches to economic analysis and employment practices. For example, DAOs provide a new and different context to owner-worker labour dynamics by distributing ownership and control benefits to workers with their employment [21]. Employment itself is a dynamic concept in DAOs, where employment status is not a binary variable but a spectrum of arrangements (both within a DAO or across multiple DAOs or sub-DAOs) depending on development cycle timelines, investments in DAO-specific human capital and reputation, and labour market forces of competition for talent between DAOs. Moreover, in practice DAO employment is currently largely unregulated (i.e., due to DAO legal uncertainty), and could in principle become unregulatable (i.e., only governed by DAO member decisions and smart contracts) [8, 22].

3. Human capital investment in two-period schooling model

Traditional labour market models start with human capital theories. Consider a two-period model of schooling investment [24]. In the first period, the individual invests in education. In the second period, they get returns from employment. The longer the schooling investment period one, the greater the expenses and the greater the return in the second period, also referred to as the skill-wage premium. The model suggests that a greater skill-wage premium will encourage more years of education, and a higher interest rate will discourage studying for longer. The total present value of the skill-wage premium over the lifetime should be larger or equal to the expenditures on the education for a person choose to study. This model can be applied to a DAO labour market by assuming that period one (the cost) corresponds to the period of learning about the DAO, entering the community, and building trust and confidence. Period two (the benefits of the skill-wage premium) then corresponds to the access and ability to make proposals to the DAO for work. While there is often no formal education required to join the DAO, skills will be necessary later when completing bounties, especially when working on the core DAO projects, for example, as a software developer. Along with token costs, these opportunity costs associated with DAO apprenticeship are still upfront costs. An individual needs to spend considerable time and effort contributing to the DAO community by participating in discussions to get a reputation within each specific DAO.

4. Firm-specific human capital and bargaining power

The process of gaining reputation and skills within the DAO resembles another labour market model – firm-specific human capital. Becker's [24] model of human capital accumulation provides a detailed theoretical background to general and firm-specific training. Both will increase workers' marginal product of labour [25]. General training will increase the marginal productivity in a range of jobs, while firm-specific only at the current workplace. As a result, the general investment in human capital will increase the worker's wage across the industry. The same is not the case with firm-specific human capital. While the worker's productivity is higher, the firm has no incentive to increase the wage since the worker cannot get a better offer elsewhere.

Firm-specific capital accumulation process in a DAO is different. Firstly, a member of a DAO starts accumulating their DAO-specific capital after they join the DAO but before they get any paid work done, unlike in the traditional company, where paid work is the only source of specific capital accumulation. Moreover, DAO-specific capital is a prerequisite to getting paid tasks in a DAO. Even though firm-specific capital plays a more

significant role in hiring and maintaining paid work in a DAO, there is less room for withholding a skill-wage premium. Individuals can be active members of multiple DAOs simultaneously, hence accumulating the firm-specific capital at more than one DAO, unlike traditional firms where each worker is typically an employee of one firm. Members choose how many DAOs they want to be part of and how they allocate their time and effort between the DAOs. Therefore, DAO membership allows for more outside options.

Workers are imperfect substitutes within each experience group, even in the conventional labour market [26]. This stylised empirical observation is especially prominent in the DAO labour market as each DAO is uniquely designed, and the size of the DAO labour market is relatively small. Therefore, although individuals first accumulate firm-specific capital before completing paid tasks in the DAO, they still retain their bargaining power.

5. Asymmetric information and monitoring

The principal-agent problem in the labour market is concerned with how the principal (employer) can design a remuneration scheme to motivate the agent (employee) to act in their interests [27–31]. The problem stems from the fact that employer and employee interests are different. The employer wants to maximise their profits, and the employee maximises their utility by minimising their effort (moral hazard problem). The problem persists due to information asymmetry, where an employer cannot fully observe the employee's effort into their work [32].

The principal-agent problem between employer and employee in the traditional corporation stems from the asymmetry of information and hierarchical structure of the firm. In the DAO labour market, neither holds. Firstly, the governance structure of the DAO is flat all employees are also members and, hence, owners and decision-makers [6–9, 17, 18]. That eliminates the problem of the conflicting utility maximisation objectives. On the other hand, a DAO's existence on blockchain makes all transactions completely transparent [6–9, 17, 18]. That includes the contribution of the DAO members. Even the participation in forum discussions is tracked and shown as a KPI. The information on the completed tasks and effort is entirely transparent and, in most DAOs, is used as a basis for the distribution of remuneration for the work done. Hence, the design of DAOs works to minimise principal-agent problems.

6. Discrimination and inequality

Economic discrimination in labour markets occurs when two workers are paid different wages despite having the same abilities and therefore, adding the same value to the firm [33]. Gender wage gaps persist even in developed western countries even with substantial regulatory and social effort to eliminate them [34].

DAO membership is pseudonymous, meaning that a person is represented by a pseudonym and an avatar image that does not have to show their identity and hence does not communicate any of the characteristics that traditionally result in labour market discrimination [35]. Remuneration decisions are based only on observed productivity and contribution to the DAO.

Nevertheless, DAO employment could systematically disadvantage some groups of employee-members. DAO labour markets are highly deregulated, with no leave and other job security provisions. Therefore, those who must look after children, for example, can still be at risk of being disadvantaged because they might be taking time off more frequently. This is a possible explanation for gender imbalance within the DAO workforce, reported in the recent GitHub/Bankless survey showing almost seven times more males than females in the DAO member gender mix [21]. Conversely, the flexibility of the DAO working arrangements can attract caregivers to

being DAO contributors.

7. Conclusion

DAOs are an exciting new research area for labour economics, and we have briefly indicated here how some of the main theories that might apply. However, to advance this we need to gather more and better data. Most theories in labour economics are calibrated and tested using real-world data. Presently, the same cannot be done for the DAO labour market theoretical propositions because suitable data does not exist. To date, there is only one small survey conducted by Github and Bankless [21]. While providing valuable initial insight into the market, it has major methodological drawbacks. The sample is largely biased towards the members of the abovementioned DAOs that were funding the survey. Further, it was biased toward highly active members of the DAOs, which is not representative of the average DAO member experience.

The leading example of empirical work on labour relationships related to DAOs is Atherton et al. [36], which provides an interesting insight into blockchain skills demand and shortages using Burning Glass job listings data. However, this work examines all blockchain industry labour skills and did not discuss DAO skills. Existing job market data does not provide the capacity to single out skills needed to work for DAOs from broader blockchain industry related skills, however this could be achieved by applying a similar methodology specifically to DAO job listings. Tagaki [37] presents another interesting methodology for defining DAO-compatible occupations, by constructing an index measuring the suitability of skills for DAO work, using the US Department of Labor O*NET database. However, this work is based on the author's subjective interpretation of suitability for DAO employment and fails to measure the size of the labour markets with DAO-compatible occupations.

The limitations of the works and the need for reliable data justify the need for developing a robust DAO surveying and measurement methodology, as an input to an empirical DAO labour economics. Data on DAO employment is preliminary and not suitable for the academic economic analysis. Existing survey methodologies for labour market surveys cannot be directly applied to DAO surveys as sampling methods cannot be directly transferred to the DAO digital economy without some difficulty; for example, due to the still largely unregulated position of DAOs and the pseudonymous characteristic of DAO employment. Hence, we also suggest that future research should focus on developing survey and other data collection methodologies specific to the DAO economy. There is much work yet to be done here.

Further, to underpin future empirical economics analysis there need to be robust theoretical foundations. Even the brief attempt to apply the few fundamental labour economic theories revealed that they do not fully describe DAO labour market behaviours. We therefore suggest that DAO labour economics should be studied and developed as a new research frontier with potentially novel theoretical foundations – drawing on, testing, and modifying existing frameworks from labour economics. There are also important theoretical connections to be made with formative theories of industrial organisation [38–42], which could further inform practices of ownership, control, and management in DAO digital labour economics.

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How Blockchain Technology could support Democracy and E-Voting

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I have proposed amendments to the Elections Bill that would require the Government to research the benefits of blockchain for both electronic voting and improving the security of the electoral register.

The UK's National Blockchain Roadmap (NBR) published in July last year [1] made several recommendations to support the development of a British blockchain ecosystem. Building on recommendations from the Walport Report [2] and my own DLT for Public Good Report [3] the NBR recommended utilising the potential of blockchain for Government and Public Services. Governments around the world have successfully explored the potential of blockchain in areas such as land registration (Georgia, UK, Sweden, India, South Africa), digital identity management (Switzerland, Estonia, Luxembourg), birth certificates (Brazil), immigration (Finland), organ donation and transplant (UAE) and taxation (China) [4, 5]. An interesting potential use case for blockchain is in making electronic voting more secure, an approach that has been explored by a team at the London School of Economics [6].

There's a trust problem in our politics right now, both nationally and globally. Fake news and social media have led to a pandemic of mis- and dis-information as we found in our Lords Select Committee Report on Democracy and Digital Technologies, "Digital Technologies and the Resurrection of Trust" [7]. There is a trust issue with the very process of elections themselves, but we have the technology, to restore trust and improve engagement, security, accessibility, and inclusion. Blockchain, in tandem with the right mindset, leadership and collaboration could offer more than hope for an inclusive electoral experience for us all.

To this end, I have put down amendments to the Elections Bill [8], currently progressing through the House of Lords. My amendments would require the Government to research the benefits of blockchain for both electronic voting and improving the security of the electoral register. My amendments in full:

144 Insert the following new Clause— "Electronic voting Within 3 months of the passing of this Act the Secretary of State must commission research into the desirability of electronic voting, including— (a) lessons to be learnt from similar systems in other countries, (b) the accessibility and inclusion benefits which may result from such a system, and (c) the use of blockchain and distributed ledger technologies, with the aim of ensuring security and immutability of votes cast."

209 Insert the following new Clause— "Investigation of technological solutions to increase the security of the electoral register. Within 3 months of the passing of this Act, the Secretary of State must consult on how the UK electoral register could be established utilising immutable distributed ledger technologies, including how these technologies could increase the security of the electoral register."

So, the prize at stake: increased enfranchisement, an election system inclusive by design, secure, immutable, auditable. I urge the Government and Electoral Commission to consider this opportunity seriously and act to explore this important DLT use case for the benefit of citizen and state.

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CONFERENCE PROCEEDINGS

4th Blockchain International Scientific Conference 14 March 2022, ISC2022, UK

1. The role of Interdependencies in Blockchain adoption: the case of Maritime Trade

Melissa Appleyard and Kristi Yuthas
Portland State University, USA
Category: Oral Presentation

Abstract

Despite its many potential economic and organizational benefits, blockchain technology still has not been widely adopted by enterprises. Recent literature has identified a number of potential adoption barriers but has not been fully explored from the perspective of firm strategy. Theoretical and practical understanding of organizational collaboration and interorganizational information systems helps expand thinking about adoption. Building on this foundation, we argue that successful blockchain implementation requires and creates interdependencies, both among consortium partners and with stakeholders in the broader ecosystem. Beyond traditional forms of collaboration, interdependencies occur when organizations intentionally become reliant upon one another. Starting from factors identified in a systematic review of the literature on adoption and exploring these factors through the lens of strategic collaboration, we develop a new adoption framework. The framework describes two internal interdependencies—socio-technical and economic, and two ecosystem interdependencies—standards and legal/regulatory that affect blockchain adoption. We illustrate these interdependencies using the example of supply chains in maritime trade. The framework can be used as a diagnostic tool to identify critical factors at play at different stages of a project's evolution, and it can be used to identify points of leverage for adoption of blockchain technology.

Keywords: *Blockchain adoption, DLT adoption, blockchain consortia, organizational collaboration, organizational interdependencies, maritime trade*

2. NFTs, the Metaverse, and Environmental Benefits

Kristi Yuthas and Jesse Dillard
Portland State University, USA
Category: Oral Presentation

Abstract

NFTs and other tokens have been criticized because of the energy required to mine coins and maintain networks. Discussions about reducing environmental costs focus on consensus mechanisms and other platform features. Typically missing from these discussions are the extensive environmental benefits that can result from use of NFTs in metaverse contexts. By design, the metaverse replaces material objects and experiences with virtual ones, creating the potential for decarbonization and nonclimate benefits such as reduced land and water use. NFTs support virtualization through identity, provenance and tracking of virtual objects and digital twins and by enabling collaborative processes and simulations. This paper provides a first effort toward framing the potential benefits of NFTs in the metaverse. Starting with foundational principles of sustainability and key environmental indicators, we provide a set of categories through which to evaluate environmental impacts. Next, we explore academic and trade literature to group and describe current and potential NFT use cases in metaverse contexts. We then explore the potential benefits and costs of these use cases in the environmental impact categories. This new approach to thinking about environmental impacts contributes to our understanding of both blockchain and sustainability by providing systematic guidance for impact assessment. It enables NFT and metaverse designers to both improve the impacts of existing use cases and to develop use cases that provide environmental benefits in new and creative ways. For traditional organizations seeking to improve outcomes, it paves the way for exploring new blockchain-based approaches to achieving environmental goals.

Keywords: *NFT, metaverse, sustainability, environmental impact, virtualization, energy*

3. Personal Genomes à la Carte: Multi-Omics End-to-End and BioNFT's

Gisele Waters¹ & Daniel Uribe²

Engineering Hearts^{®1}, USA and Genobank^{™2}, USA

Category: Oral Presentation

Abstract

Biosamples and their multi-omics data (genomics, proteomics, epigenomics, etc.) pass through a sequence of events, a supply chain, from preanalytical biosample collection to post analytical results interpretation, dissemination, and application to vendor commercialization. This article examines the sequence and delineates how stakeholders in this “biology à la carte” supply chain exist with asymmetries of power across end-to-end processes. The asymmetry of power between parties (from donors to controllers) and the multitude of touchpoints where our biosamples are accessed inevitably create opportunities for risks and benefits across stakeholders. The purpose of this article is to present a critical evaluation of the data architecture in the end-to-end journey with a detailed accounting of who, what, where, when, how and why multi-omics datasets are used. To better understand who benefits, who is at risk, and who decides on the biological assets (biosamples + biodata) governance and provenance, an ethical risk analysis was conducted. Selective data touchpoints and their unique contributions to multi-omics data processing, control, and use are also described. Lastly, we present the rationale and use case for promoting end-to-end transparency in the supply chain with the introduction of Biological Non-Fungible Tokens or BioNFTs that “resolve” in a public blockchain. We offer a description of how BioNFT, a decentralized biosample permission platform, could serve as a sentinel mechanism that mitigates risks and expands benefits to stakeholders. BioNFTs are proposed as a dynamic blockchain solution which provides liability coverage for the stakeholders at the top and a negotiation mechanism for data originators and donors at the bottom of the supply chain.

Keywords: *genomics, blockchain, non-fungible token, NFT, ERC721, ERC2477, ERC1155, DNA, RNA, microbiome, provenance, biosamples, biobanking, BioNFT, supply chain*

4. Blockchain Arbitration: A Forum For Improving Access to Justice for Small Claim Disputes?

Sara Hourani

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Category: Oral Presentation

Abstract

Smart contracts can be used in supply chain management, trade finance and insurance amongst many other transactions. In the context of these, it could be relevant to include a dispute resolution clause in the smart contract to prompt the parties to resolve their differences with regards to the performance of the contract. The main specificities of the inclusion of an ODR or arbitration clause in a smart contract is decentralisation and the automated enforcement of the process outcome or award. In light of these technological innovations, this paper focuses on an examination of the extent to which smart contract arbitration offers parties an ameliorated access to justice, especially in the context of small disputes. This paper therefore effectuates in the first instance a complete overview of how blockchain arbitration works. The paper then explores the advantages and limitations that this procedure offers with regards to the parties' possibility of access to justice in contrast to traditional types of dispute resolution such as traditional arbitration. In part 3, the paper uses this analysis to observe the extent that the parties' rights are protected by the current international and national legal framework for providing adequate access to justice to resolve their disputes. The paper aims at furthering the legal understanding of blockchain-based arbitration as a process and analyse its potential to enable access to justice for small claims in international arbitration disputes.

Keywords: *blockchain, smart contracts, arbitration, dispute resolution, international disputes, small claims.*

5. Digital Parfit: Non-branching Digital Beings

David R. Koepsell

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Category: Oral Presentation

Abstract

Derek Parfit's book *Personal Identity* describes a number of thought experiments relating to the question of what it means to be a person whose identity endures over time. In one such thought experiment Parfit suggests an analogy with an amoeba that could divide yielding qualitatively identical copies. Suppose a person could divide in this way? Which of the products of this division would retain the identity of the person who divided? What could serve, here, as some individuating factor?

There are some who hold that at some time in the future it will be possible to achieve what call 'digital immortality' by uploading the contents of a human brain into the cloud. This prospect is interesting not least because it provides us with a clear scenario under which the problems posed by Parfit's thought experiments about branching selves would be realized. I will examine some problems of branching, digital being and propose a solution for individuating digital singletons using the new technology of Non-Fungible Tokens, and describe what that would entail.

Specifically, because NFTs provide a computable medium while preventing duplication, NFTs could provide assurance for the singular identity of digital beings, a potentially important solution to a barrier to adoption for those wishing to endow digital beings with unique personal identities like humans, or even for the far-flung potentials of digital mind uploading.

Keywords: *blockchain, NFT, identity, artificial intelligence, digital beings, blockchain*

6. An Overview of Blockchain Technology and Security Risks: a layering perspective

Sepideh Mollajafari and Kamal Bechkoum

University of Gloucestershire, UK

Category: Oral Presentation

Abstract

Blockchain is an emerging technology that has received a pervasive attention in recent years for storing and transferring data via decentralised, peer to peer network. Since the beginning of cryptocurrency, researchers and developers believed that the blockchain technology could do more than simple digital transaction. From the initial foundation based on cryptocurrency to the development of smart contract, this advanced technology promises huge business benefits for various industry sectors.

Notwithstanding its known benefits for numerous business domains, and despite having some protective measures and security features such as digital signature, hashing, zero knowledge proof, consensus algorithms, this advanced technology still faces significant security challenges within its different abstract layers.

This paper, summarises the critical cybersecurity threats and vulnerabilities inherent to smart contracts based on our in-depth literature research and analysis. We firstly, introduce the architecture of blockchain. From the perspective of architectural layering, each layer of the blockchain has its own corresponding security issues. Secondly, various components of each layer of blockchain are described. We then present a taxonomy describing the inter-relationships between the vulnerabilities, attacks and consequences. The outcome of this research prompted concerns and a research direction around developing countermeasures to alleviate the security risks and vulnerabilities inherent to blockchain smart contracts.

Keywords: *Blockchain, Smart contract, Ethereum, Vulnerabilities, Attacks*

7. Impermanent Loss Conditions – An Analysis of Decentralized Exchange Platforms

Matthias Hafner

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Category: Oral Presentation

Abstract

Decentralized exchanges are widely used platforms for cryptocurrency traders. The most common types work with automated market makers (AMM) allowing traders to exchange cryptocurrencies without the need to find matching counterparties. Thereby, traders exchange against baskets of cryptocurrencies that are managed by liquidity pools using smart contracts. These cryptocurrencies are provided by liquidity providers in return for fees. Static analyses show that small permanent price increases in one of the cryptocurrencies in the liquidity pool can result in losses for liquidity providers. Thus, despite AMMs success, many researchers and practitioners claim that liquidity providers frequently suffer "impermanent losses". However, such static analyses do not consider dynamic effects between participants over time. We therefore investigate the "impermanent loss" problem in a dynamic setting using monte carlo simulations. More explicitly, we model Uniswap's smart contract, the behavior of different participants and assume various price developments to analyze the profits of liquidity providers. This agent-based modelling approach allows us to investigate under which conditions "impermanent losses" occur. We find that "impermanent losses" only happen if price increases are permanent and immediate. Moreover, our simulation indicates that shocks must be larger than 5%, otherwise accumulated fees compensate losses. Hence, under normal conditions, price changes do not negatively affect liquidity providers' profit significantly. We conclude that the "impermanent loss" problem is less severe than claimed and suggest that AMM developers should focus on price shocks rather than price changes in general.

Keywords: *DeFi, Decentralized Exchanges, Automated Market Makers, Platform Economics, Impermanent Loss, Uniswap, Liquidity Pools*

8. Model-driven Development of Blockchain-based Platforms in the Algebraic Virtual Machine Environment

Dr. Oleksandr Letychevskyi

LitSoft, Ukraine

Category: Oral Presentation

Abstract

The paper is dedicated to the analysis of blockchain-based platforms with the purpose of verification and for exploring their resistance to possible attacks during the development process. It uses the algebraic approach realized in the Algebraic Virtual Machine (AVM) created by our team that accepts blockchain system models on different levels of abstraction. The variety of algebraic methods allows the resolution of verification problems and the detection of vulnerabilities in blockchain-based systems by using symbolic modelling and algebraic matching of behaviours. The behaviour of blockchain systems can be presented as a model in behaviour algebra specifications. We can thus consider the algorithm of consensus, smart contract or some slice of the design of a blockchain-based platform, especially the token economy aspect. A blockchain is a distributed system, and the methods of resolving behavioural equations in the scope of theory of agents and environment interactions implemented in the AVM are applicable. This can resolve the problem of reachability of undesirable behaviour or possible attacks from the external environment.

Such practices could be used in the development of safety critical or reliable blockchain applications and be part of a development process. The use of models on different levels of abstraction could also be applied in testing activities for test suite generation and symbolic test execution. The first experiments with the AVM application were realized with attack resistance in POS consensus algorithms testing, Ethereum smart contract (Solidity) verification and token economy projects analysis.

Keywords: *algebraic modelling, symbolic execution, smart contracts, consensus algorithms, distributed systems, formal verification, model-based testing*

9. Legal Framework of the Non-Fungible Tokens (NFTs) and Opportunities of the Various Implementations

Bedrettin Gürcan

University of Szeged Faculty of Law and Political Science, Hungary

Category: Oral Presentation

Abstract

Blockchain is a distributed digital ledger, shared consensually with and synchronised across different participants on the database of different chains and use peer-to-peer networks, time stamping, asymmetric (public key) cryptography, and the proof of work consensus mechanism.

Blockchain has many promises to be used on several fields. Since technology has significant advance of keeping data safe, transparent and immutable, it has significant potential of the data security. Proof of ownership is the one of the most promising blockchain features to use under the intellectual property protection.

Popularity of NFTs (Non-Fungible Tokens) is rapidly increasing with covid pandemic. NFTs might represent a work of music, art, images, internet creations and transactions. Blockchain based NFTs claim that the intellectual /ownership rights of the any actual or virtual objects can be secured immutably and make easier to keep and transfer the ownership.

There has been an inconclusive debate about legal base of the NFTs in different jurisdictions and practices. Some countries have taken more soft steps compared with others' radical steps. As an example of radical steps, Thailand's Securities and Exchange Commission (SEC) has officially banned certain kinds of tokens, including non-fungible tokens (NFTs) to avoid the potential loss of the investors. Although there has been relatively little research on legal side of the NFTs, this study is an attempt to address the issue of the legal base of the NFTs in different jurisdictions to create better understanding of the NFTs.

Keywords: #nft #blockchain #cryptocurrency #law #intellectualproperty

10. Blockchain Adoption Factors, Enablers, and Barriers in Fisheries Supply Chain: Preliminary Findings

Colin Callinan, Amaya Vega, Trevor Clohessy & Graham Heaslip

Galway-Mayo Institute of Technology, Ireland

Category: Oral Presentation

Abstract

Technological adoption has become a key goal of digital transformation within firms, affecting many facets of an organisation such as attaining competitive advantage, increased revenue, reduction of operational costs, and improving operational efficiency. Blockchain as a decentralised peer to peer technology appears uniquely suited to being deployed within complex food supply chains such as the fisheries industry, which is the focus of this study. In this context, blockchain technology can be used for a variety of purposes such as provenance authentication, handling and storage, transparency, counterfeit prevention, food forensics, and enhanced supply chain resilience. The purpose of this study is to synthesize existing research on the interrelationship between Blockchain technology and the factors that determine adoption, as well as identifying the enablers and barriers. This preliminary work identified key themes emerging from the blockchain literature suggesting that adoption factors are wide ranging, encompassing aspects including organisational readiness, security, complexity, partnerships, competition, governmental influence, and transparency. The thematic analysis of enablers and barriers to blockchain adoption identified the broad theme of resources as the key enabler and integration as the key barrier. These preliminary findings add to the growing body of research including increased understanding of the current state of academic research in the areas of blockchain adoption factors, blockchain adoption in supply chains, blockchain adoption in the fisheries industry and the enablers and barriers to adoption. This study is the initial step in a large scale study with the next phase comprising case studies of specific fishery supply chain stakeholders.

Keywords: Blockchain – Distributed Ledger Technology – Supply Chain – Fisheries

11. A Review of Blockchain/Distributed Ledger Technologies Maturity in Europe, United Kingdom & Scandinavia: A Public Services Perspective

Dr Trevor Clohessy¹, Professor Joyce O'Connor², Mr Dominic Allen³

*Galway-Mayo Institute of Technology, Ireland*¹

*Blockchain Ireland*²

*Trinity College Dublin*³

Category: Oral Presentation

Abstract

This research focuses on a descriptive analysis of Blockchain/Distributed Ledger Technologies (DLT) developments in the public sector throughout the 27 European Union (EU) countries, the UK and Switzerland. The public sector is defined as government-led and funded, or partly government-led and funded, blockchain initiatives in public/private sector partnerships. Drawing on the EU Blockchain Strategy, it uses 4 criteria to evaluate each country, and from the findings, it creates a rating map based on the criteria used: national blockchain strategy, legal regulatory frameworks, exemplar use cases, and Blockchain/DLT courses.

It found that overall, the public sector blockchain ecosystem in the countries examined is at an embryonic stage. Only 3 of the 29 countries studied have national blockchain strategies. Although 16 countries have at least 1 exemplar use case of blockchain/DLT in the public sector, they are rare and cannot compare to the strides been taken in the private sector.

No countries have introduced blockchain/DLT specific legislation, however, 12 have introduced laws concerning the financial sector, fintech, and digital assets. The strongest area examined by the criteria used was blockchain/DLT courses throughout the countries examined with 23 of 29 countries offering courses from basic to master's level.

Currently, the private sector is leading the blockchain/DLT space, with the public sector trailing far behind. The main areas blockchain/DLT is being used for, and the focal point of the legislation, are fintech and digital assets.

The other beneficial uses of blockchain/DLT are severely underutilized at this current time, specifically in the public sector but also generally.

The standout countries according to the criteria used in this study are Austria, Germany, Italy, France, Malta, Spain, Switzerland, and the UK.

Keywords: *Blockchain, DLT, Public Services, Europe, United Kingdom, Scandinavia*

12. Stablecoins: Foundations for stability in a post-fiat world

James E. Ball

University of Aberdeen, Scotland

Category: Oral Presentation

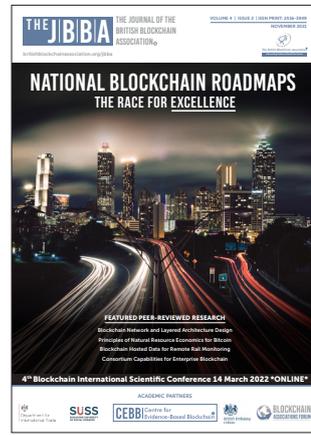
Abstract

The rapidly growing use and consumption of stablecoins has opened up new avenues for financial interaction between blockchain based digital currencies and the fiat money system. The introduction of stablecoins was a revolutionary concept in the digital asset world, as it provided a convenient method for the legacy financial system to interface with the new emergent Web3 economy. These first generation stablecoins focused on pegging their value to fiat currencies such as the USD or Euro. This concept guarantees relative stability and protection against the volatility of digital assets such as Bitcoin and Ethereum, however, this is not the case in economies impacted by inflation. With worries looming on the horizon for the US dollar which is widely considered to be the global reserve currency, there is a real threat that stablecoins will no-longer represent a truly stable store of value. This paper explores two key concepts; 1) What is 'stability' and 2) what would a truly 'stable' digital asset look like. Additionally, it introduces the concept of 'next generational' stablecoins which use methods such as inflation baskets as a means of creating a fixed exchange rate system with local or regional economic integration.

Keywords: *Stablecoins, Blockchain, Inflation, Fiat money, Fixed exchange rate systems*



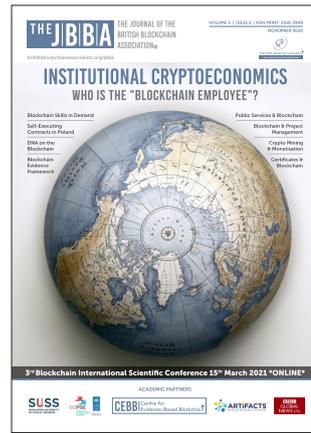
Volume 4 - Issue 1
May 2021



Volume 4 - Issue 2
November 2021



Volume 3 - Issue 1
May 2020



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Volume 2 - Issue 1
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Volume 2 - Issue 2
October 2019



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The British Blockchain Association
Advocating Evidence Based Blockchain

BBA FORUM | MARCH 2022

SUNDAY, 27 MARCH 2022 (5 PM BST)

Registration Link: <https://bit.ly/375Tsc2>

5:00 PM | Welcome
BBA Secretariat

JOURNAL CLUB

5:05 PM | Non Fungible Tokens & Crypto-Punks

Luisa Schaar, University of Law, UK

Author of the 2022 JBBA Paper:

NFT's as an Alternative Investment: Evidence from Crypto Punks

5:20 PM | Blockchain, Contact Tracing and Pandemics

Oritsebawo Paul Ikpobe, The University of Birmingham, UK

Author of the 2022 JBBA paper:

Can Blockchain Take Smartphones Out of Contact Tracing?

5:35 PM | Crypto Governance and Cryptocurrency Exchanges

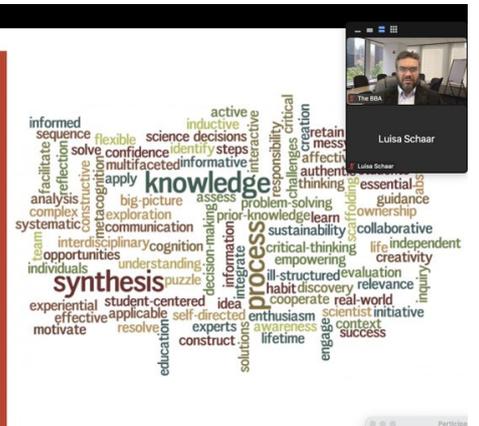
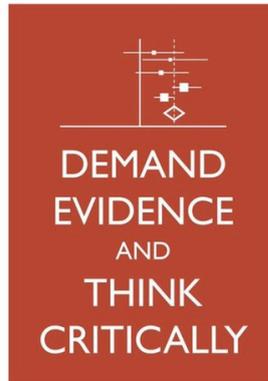
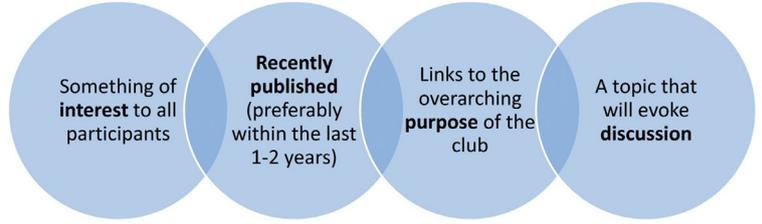
Sabino Correa, London Business School, UK

Author of the 2020 JBBA Paper:

Crypto Governance: Analysing Platforms for Crypto Assets Trading

5:50 PM - 6:00 PM: Open Forum AMA & Close

Blockchain and Crypto-assets Journal Club:



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The What & The Why

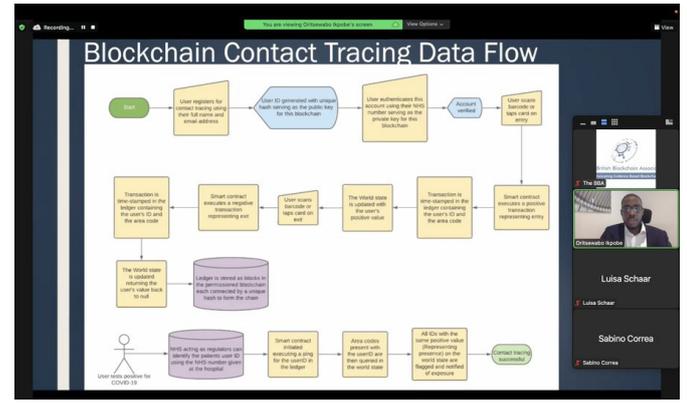
This research is about analysing the Crypto Trading environment under the fundamentals in terms of governance for any business:

Topic	Crypto Exchanges Governance Proposed Key Performance Indicators (KPI)	
	Minimum Points	Maximum Points
Legal Compliance		
Company name and Registry Identification	0	1
Key personnel and Management Identification	0	1
Directors and Investors Identification	0	1
Years of Activity		
Number of Years	0	3
Jurisdiction of Incorporation		
Clear Jurisdiction of Incorporation	0	1
Clarity about Controller Jurisdiction	0	1
Authority Regulation		
Clearly presents as Authority regulated	0	3
Number of Points	0	11

Table 2 - KPI Score Summary

- Sample** • Sample representing 99% of the daily trading volume as of 01-Jan-2020
- KPI** • 78 Exchanges assessed under the KPI
- Fees** • Analyse the fee structure of the group

Cross Results



Crypto Governance: Analysing and Comparing Crypto Assets Trading Platforms

Published at the Journal of the British Blockchain Association Volume 3 – May/2020

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London Business School

27.03.2022

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A BBA student chapter helps reinforce classroom and experiential learning. In addition to the learning that occurs during chapter meetings, the submission of research articles to the JBBA journal helps develop industry-specific skills, along with skills in project management, technical writing and interpersonal communications.

Chapter activities culminate at the annual scholars in Blockchain conference, where students interact with students from other chapters, BBA members and advisors and network with industry leaders, scientists, and researchers.

The BBA recognises that students are the future leaders of the industry, and treats them as such. Chapters instil future professionals with an understanding of the role that collaboration, research, development and networking plays in blockchain developments and industry progress.

REASONS TO START THE BBA STUDENT CHAPTER

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Foster dialogue about trends, issues, movements, opportunities impacting the blockchain industry

Connect to industry professionals and career opportunities

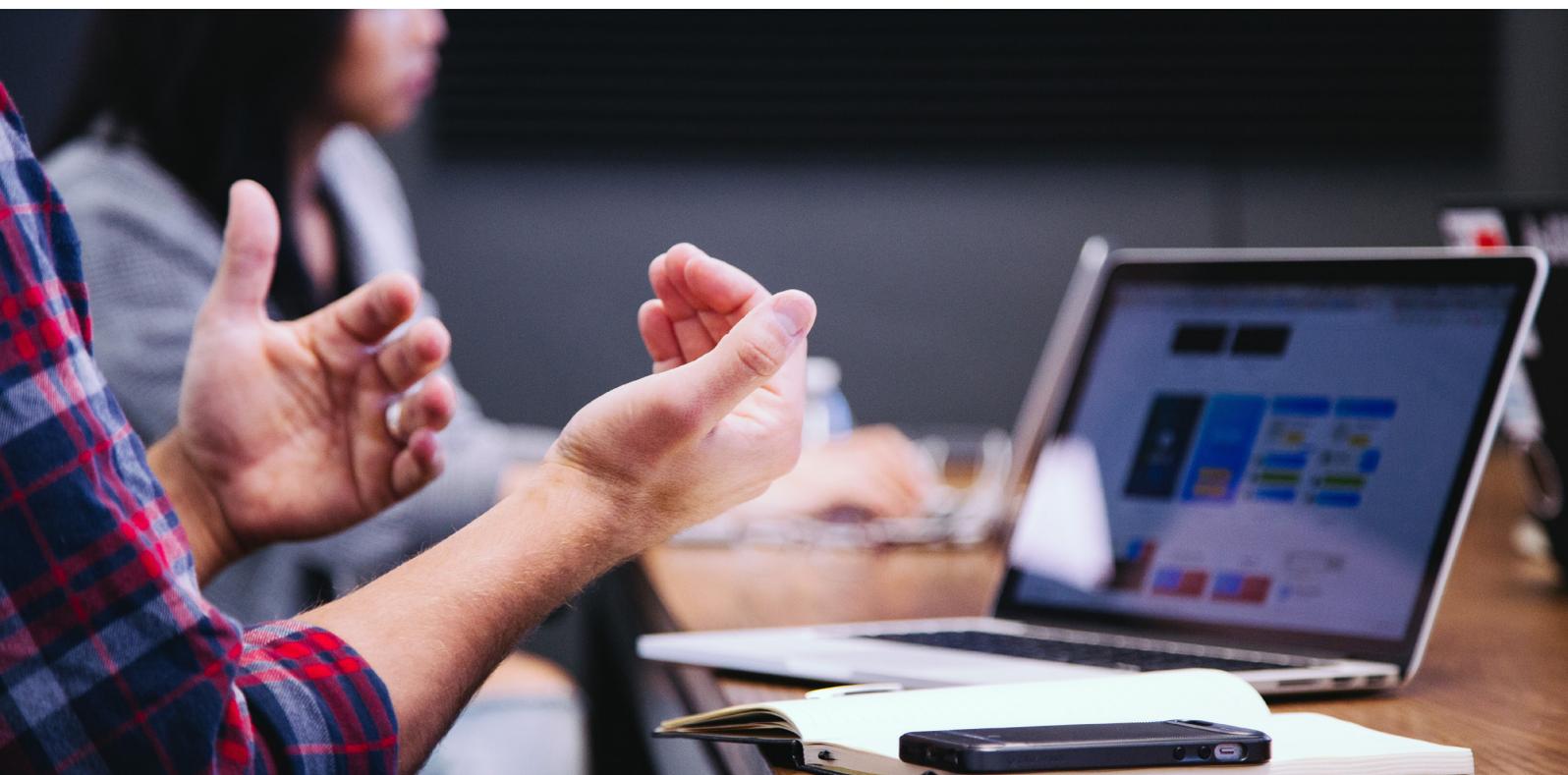
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Form student and professional relationships across the BBA including those with students from other chapters

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For more info, visit <https://britishblockchainassociation.org/starting-a-student-chapter>



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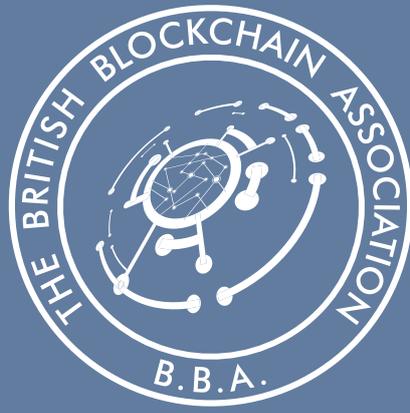
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