electronics

MDPI

Article

Modeling Bitcoin plus Ethereum as an Open System of Systems of Public Blockchains to Improve Their Resilience against Intentional Risk

Alberto Partida [1,*], Saki Gerassis [2], Regino Criado [3], Miguel Romance [3], Eduardo Giráldez [4] and Javier Taboada [4]

[1] International Doctoral School, Móstoles Campus, Rey Juan Carlos University, 28933 Madrid, Spain
[2] GESSMin Research Group, Department of Natural Resources and Environmental Engineering, University of Vigo, Lagoas Marcosende, 36310 Vigo, Spain; sakis@uvigo.es
[3] Department of Applied Mathematics, Móstoles Campus, Rey Juan Carlos University, 28933 Madrid, Spain; regino.criado@urjc.es (R.C.); miguel.romance@urjc.es (M.R.)
[4] Department of Natural Resources and Environmental Engineering, University of Vigo, Lagoas Marcosende, 36310 Vigo, Spain; egiraldez@uvigo.es (E.G.); jtaboada@uvigo.es (J.T.)
* Correspondence: apartidar@gmail.com or a.partidar@alumnos.urjc.es

Citation: Partida, A.; Gerassis, S.; Criado, R.; Romance, M.; Giráldez, E.; Taboada, J. Modeling Bitcoin plus Ethereum as an Open System of Systems of Public Blockchains to Improve Their Resilience against Intentional Risk. *Electronics* **2022**, *11*, 241. https://doi.org/10.3390/electronics11020241

Academic Editors: Dongkyun Kim, Qinghe Du, Mehdi Sookhak, Lei Shu, Nurul I. Sarkar, Jemal H. Abawajy and Francisco Falcone

Received: 6 December 2021
Accepted: 5 January 2022
Published: 12 January 2022

Abstract: In this article, we model the two most market-capitalised public, open and permissionless blockchain implementations, Bitcoin (BTC) and Ethereum (ETH), as a System of Systems (SoS) of public blockchains. We study the concepts of blockchain, BTC, ETH, complex networks, SoS Engineering and intentional risk. We analyse BTC and ETH from an open SoS perspective through the main properties that seminal System of Systems Engineering (SoSE) references propose. This article demonstrates that these public blockchain implementations create networks that grow in complexity and connect with each other. We propose a methodology based on a complexity management lever such as SoSE to better understand public blockchains such as BTC and ETH and manage their evolution. Our ultimate objective is to improve the resilience of public blockchains against intentional risk: a key requirement for their mass adoption. We conclude with specific measures, based on this novel systems engineering approach, to effectively improve the resilience against intentional risk of the open SoS of public blockchains, composed of a non-inflationary money system, "sound money", such as BTC, and of a world financial computer system, "a financial conduit", such as ETH. The goal of this paper is to formulate a SoS that transfers digital value and aspires to position itself as a distributed alternative to the fiat currency-based financial system.

Keywords: blockchain; Bitcoin; Ethereum; System of Systems; System of Systems Engineering; complexity; complex networks; emergence; intentional risk

1. Introduction

1.1. Epigraph

The quest to manage complexity has been present in human beings since early days. Equally, the need to register value transfer and ownership. Throughout History, we have created and taken part in complex systems with non-linear relations between their components. First, we focus on public blockchains, a technology that creates a "supersystem", also called a "network of networks" or a "system of systems", that registers the transfer of digital value, even with a potential link to physical value. We use complex network analysis and Systems of Systems Engineering to "digest" its complexity. We identify how public blockchains, such as Bitcoin and Ethereum, complement each other and emerge as an alternative to the traditional fiat currencies. Second, we propose a set of multi-disciplinary measures that, based on recent advances in intentional risk management, hint at how to improve resilience in this System of Systems of public blockchains.

1.2. Blockchain

We first explain the concept of blockchain. A blockchain finds its roots in cryptography and distributed systems [1]. It has a simple motto, i.e., "the longest chain wins". It is a type of distributed database that stores records in a linked collection of blocks [2] showing 3 key properties. First, each block is unequivocally linked to the following block by hash-function cryptography [2]. A hash is a mathematical function that provides data integrity by transforming an input into a unique encrypted output of a fixed length, i.e., validated blocks cannot be tampered with. Second, all transactions in a blockchain are accessible, i.e., they can be read by all users. In every transaction, a participant uses a unique private key to sign it. Third, the complete register of blocks is kept in all connected full nodes. This provides a high degree of availability. Sections 1.3 and 1.4 present the two most market-capitalised, public, open and permissionless blockchain implementations, Bitcoin (BTC) and Ethereum (ETH) [3].

1.3. Bitcoin

Bitcoin (BTC) is the pioneer of the current public, open and permissionless blockchain implementations. It is a crypto-currency that was launched in January 2009 following the seminal paper by Satoshi Nakamoto [4]. This author, or group of authors, decided to remain anonymous. Nakamoto's nine-page seed paper talks about a "peer-to-peer electronic cash system" [4]. It is an open-source and distributed transaction system that acts as an electronic analogue of cash located in the online world [5]. Its main feature is decentralisation, since there is no central authority responsible for issuing bitcoins and it is not necessary to involve a third party to make online transfers. In blockchain terms, a node (or peer) refers to any machine connected to the blockchain that keeps a full copy of its distributed ledger. Slowly but surely, Bitcoin is becoming a global digital value reserve, initially outside the traditional financial system. However, a growing number of players belonging to the mainstream financial system have started to accept BTC and include it in their investment portfolio. This digital store of value could replace the gold standard and become, in the future, the global digital reserve currency [6].

1.4. Ethereum

Ethereum (ETH) is an example of a public blockchain implementation that was created after BTC. ETH is a public, open and permissionless blockchain platform that runs code, i.e., smart contracts [7]. It is a shared global infrastructure that transports digital value. Ether is its native crypto-currency. The project started in 2014. Vitalik Buterim was one of its creators [8]. The ETH blockchain provides a decentralised Turing-complete virtual machine, called the "world computer", with more advanced scripting functionality than the pioneer BTC. Programming languages that use conditional branching and arbitrary memory-stored variables are Turing-complete. ETH and BTC do not compete with each other. They have different purposes and applications. While BTC plays the role of a digital reserve asset, ETH acts as the blockchain engine for an ample ecosystem of business cases. All of them benefit from the properties of a public blockchain with Turing-complete computing power. Examples are decentralised finance (DeFi), as mentioned in Section 4, Internet of Things (IoT)-related tokens [9,10] and an extensive variety of other fungible and non-fungible tokens (NFTs). Fungible tokens are exchangeable, i.e., similar to traditional coins, while non-fungible tokens are unique and distinguishable.

These complementary use cases for BTC and ETH lead us to research scientific methods that can jointly study their complexity. We use complex network theory and SoSE to understand how we can improve their resilience against intentional risk. Keeping BTC and ETH secure is pivotal for their mass adoption. We assume that these public blockchains will continue growing: BTC as a global digital store of value and ETH as an engine for decentralised applications. After introducing the blockchain technology and two of their most relevant public implementations, we move our focus, in Sections 1.5 and 1.6, to the tools we use to "digest" the complexity that we find in public blockchains.

1.5. Complex Networks

Complex networks is a field of study at the crossroad between mathematics, statistics, physics and sociology. It focuses on networks: systems composed of many interconnected dynamical units. Networks are composed of nodes, also called vertices (not to confuse this meaning of node with the one related to a computer that holds a copy of a blockchain, as explained in Section 4.2), and edges, also called links and arches. Network theory aims to capture the global properties of such systems by modeling them as graphs whose nodes represent the dynamical units, and whose links show the interactions between them [11]. Anchored in graph theory, it uses statistical analysis to describe networks with many nodes and edges between them. It is especially useful to describe systems with non-linear relations. The degree of a node is the number of edges connected to it. Complex network theory studies statistical properties of large-scale graphs such as degree distributions to model the structure and behaviour of these networks [12]. We study the complex networks that BTC and ETH spawn to understand their behaviour. We consider each of these complex networks a system within the "supersystem of public blockchains". This provides us with the opportunity to use SoSE as a novel approach to model public blockchains such as BTC and ETH.

1.6. System of Systems Engineering

The meta-definition of SoS used by [13] is a "supersystem" comprised of components that themselves are independent complex operational systems and interact with each other to achieve a common goal. Jamshidi specifies the following characteristics for SoS [13]: they are large-scale integrated systems; heterogeneous systems that can operate independently; they are networked together for a common goal. Typical real-life examples of Systems of Systems are the health care SoS, the communication and navigation SoS and the US Department of Defence SoS [13]. A very common way for these systems to interact and exchange information is through a network [13]. Notably, if these networks of networks are interdependent, they become significantly more vulnerable to random failures and targeted attacks than single networks. Single networks usually exhibit cascading failures that can rapidly provoke a system collapse. Understanding the system characteristics of BTC and ETH that could lead to a failure that propagates is a fundamental step in ensuring that public blockchains could be granted the level of trust required to effectively become widely recognised assets in the global economy [14]. Once we have identified how we study complexity in public blockchains, Section 1.7 presents intentional risk management with the objective of improving resilience in the System of Systems of public blockchains.

1.7. Intentional Risk Management

Risks proceed from accidental (non-intentional) and intentional sources. While non-intentional risks have been thoroughly studied [15] by traditional risk management methodologies, intentional risk management requires a different management approach as actuarial information does not provide sufficient insight on potential attacks. An attacker will target a specific asset depending on the value of the asset for the attacker, the risk they run to launch the attack and the cost they incur to execute it [16]. The most attractive assets to attack are those with a high value for the attacker. Among these, assets that are highly accessible for the attacker and tend to keep the attacker's anonymity will be the most targeted [16]. Both BTC and ETH fulfil these characteristics and are already becoming a prime target for cyber-attackers, in particular through crypto-currency exchanges [17]. Intentional risk managers need to identify which assets are the most coveted objectives for the attackers so that they can protect them more effectively. In this article, we apply the concept of intentional risk management to BTC and ETH to increase the resilience of this "supersystem".

1.8. Structure of the Paper

We have introduced the concepts upon which we anchor our hypothesis to model public blockchains such as BTC and ETH as complex networks that create a SoS of public blockchains to better understand and manage their complexity and, more specifically, their resilience against intentional risk. The rest of the article is organised as follows. Section 2 describes the state-of-the-art with regard first to blockchain, BTC and ETH as complex networks, second to SoSE and third to intentional risk management. Section 3 presents our methodology to model BTC and ETH as SoS. This section enumerates the SoS characteristics that we study in BTC and ETH. Section 4 describes the results of our analysis. Section 5 draws conclusions on the utility of SoSE to understand public blockchains and on how to improve resilience in a SoS devoted to transferring digital value and composed of BTC, a stable non-inflationary money, and ETH, a world financial computer system. Finally, Section 6 suggests future lines of work.

2. Related Works

2.1. Blockchain: When Technology Changes Society

Blockchain can be used, among many other use cases, to create a ledger, i.e., a chain of blocks with records representing financial transactions. Some digital ledgers are not based on chaining blocks but on directed acyclic graphs (DAG), Suciu et al. [18] compare both design options.

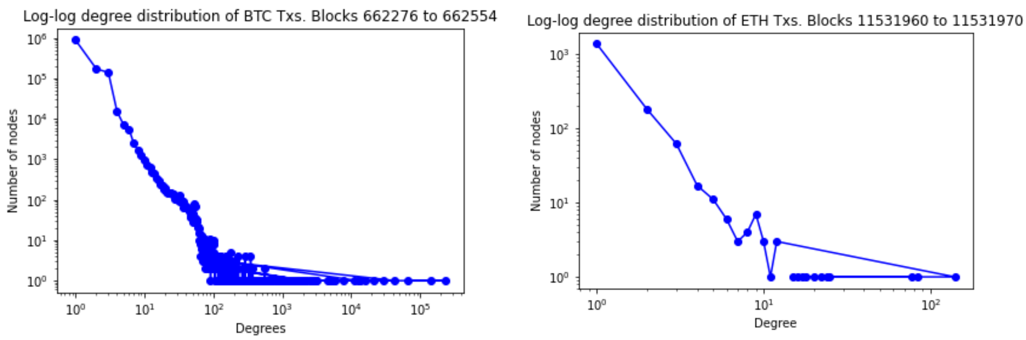
This is the case of IOTA, a public Internet of Things (IoT)-focused distributed ledger. Different digital ledgers can interact between each other, e.g., Thomas et al. [19] propose a protocol for interledger payments. Ripple uses the Interledger protocol (ILP) to connect bank systems across borders. The Ripple token (XRP) provides a standardised settlement layer across different digital asset ledgers [20]. The potential impact of blockchains in our society is immense. Blockchain is a politically non-neutral technology close to the social contract ideas of Hobbes and Rousseau [21]. There are many blockchain use cases in finance [22–25], governmental processes [2], supply chain management [26], identity management [9], legal contracts [27], health data [28], land registry [29], transport systems [30] and even cybercrime trading [31], among many others. Blockchains transcend the field of technology. Reijers et al. [21] mention that blockchain has implications on sociology and philosophy and Malone [32] introduces the idea of a potential end to central banking with the shift from fiat currencies to crypto-currencies. Understanding public blockchains better and explaining their potential in an unbiased manner to society would lead to broader adoption [33].

2.2. BTC and ETH: Public Blockchains as Complex Networks

In our quest to model BTC and ETH as a SoS, we first provide a collection of references that study both BTC and ETH using complex network theory to describe the behaviour of these networks. A comprehensive taxonomy is an optimal entry point for a systematic approach to blockchain implementations [34,35]. The existing literature on complex network theory addressing BTC is a valid sign of the complexity of the BTC network. One of the first complex network analyses of BTC transaction and user networks dates already from 2011 [5]. Reid and Harrigan [5] treat two networks, one in which BTC transactions are nodes and links are coin flows, and another one in which users, i.e., a collection of addresses, are nodes and links are coin flows as well. In the mentioned paper, the objective was to study anonymity in the BTC network. Later on, in 2014 and 2018, respectively, a new complex network analysis of BTC focused on preferential attachment confirmed that “the rich get richer” in BTC [36,37]. From a purely computational standpoint, a big data analysis framework facilitates the study of the BTC network [38]. The links of BTC with society in general and with financial markets in particular [39–41] indicate, as well, a degree of complexity that transcends traditional systems engineering.

In 2018, the degree distribution, degree assortativity, clustering coefficient and largest connected nodes in both BTC and ETH were both objects of study from a complex network viewpoint [42]. These network properties display evolutionary characteristics, i.e., they vary throughout time: their transaction networks are constantly changing with relatively low node and edge repetition ratios. According to [42], unlike typical growing networks, BTC and ETH networks do not always densify over time. This fact confirms the complexity of both BTC and ETH as systems. Complex networks analysis focused on ETH, similarly to those rotating around BTC, shows, as well, the system complexity that the ETH network entails. In 2018, Somin et al. [43] identify power law properties in both in and out degree distributions of the ETH transaction network. Guo et al. [44] reach similar conclusions in 2019. In 2020, Lin et al., Ferretti and D'Angelo and Somin et al. [45–47] continue this line of work regarding power law functions in degree distributions in both ETH and ERC20, i.e., ETH-based token networks. Collibus et al. [48] confirm this fact in 2021 and conclude that their transaction networks present super-linear preferential attachment.

A power law behaviour in a degree distribution reveals that there is a low number of nodes, in this case BTC and ETH addresses, receiving and starting a high number of edges, in this case BTC and ETH transactions, respectively, and a very high number of nodes with a very low number of edges. A typical "rich get richer" phenomenon. Figure 1a,b, inspired by [9] and produced with our own Python code [49], shows two examples of this degree distribution behaviour for BTC and ETH, present even in very short windows of time. Table 1, a simulation parameters table, shows the details of these time slots.



(**a**) (**b**)

Figure 1. Typical power-law transaction degree distributions. (**a**) BTC degree distribution. (**b**) ETH degree distribution.

Table 1. Simulation parameters related to BTC and ETH degree distributions.

Blockchain Name	Window Duration	Date	Number of Blocks	Average Number of Transactions per Block
BTC	48 h	21 December 2020	278	2000
ETH	2 min	26 December 2020	10	144

2.3. Approaching Systems Engineering: Open vs. Closed Systems

The study of complexity in Engineering has been a challenge for the last centuries. Already in 1956, Schlager [50] qualified The Bell Telephone Laboratories as the first organisation to use the term systems engineering: "when satisfactory components do not necessarily combine to produce a satisfactory system", systems engineering comes into play. In 2008, Jamshidi [13] edits a collection of articles focused on complex systems whose elements are complex as well. This new field is called System of Systems (SoS) and the discipline to design, integrate and manage these systems is System of Systems Engineering (SoSE).

Traditionally, Systems Engineering (SE) distinguishes between open and closed systems. SoSE follows a similar approach. We find the first SoS in Nature [51]. Natural SoS are continuously developing and evolving. They are self-organised and self-regulated and respond to evolving needs [51]. These properties are known as open systems characteristics. Examples of these are open interfaces, modular design principles and reconfigurable architectures. Closed immutable architecture strategies create SoS that are not available to outsiders or at a very high license cost [51]. Contrary to man-made SoS, there are no closed natural SoS. Open systems display self-governance principles such as self-control via "feedforward" and "feedback" mechanisms, self-regulation (homeostasis) to maintain their operation and self-organisation to allow for growth and complexity management [51]. Openness and evolution capacity are important anchors for our analysis as well.

2.4. Open Systems Principles

Entropy grows continuously in systems with closed interfaces. In contrast, open interfaces contribute to effectively handling complexity [51] and, consequently, entropy as well. Open systems use open interfaces to exchange energy, material and information with the outside world [51], i.e., they interact cooperatively (*synergy* principle) and they govern themselves (*self-government* principle). As a consequence, this self-organisation brings new structures, patterns and properties that do not exist in each of the components *per se* (*emergence* principle). One of these properties, paradoxically, can be a higher degree of freedom within the system. In addition, natural open systems aim to conserve energy by reducing waste as much as possible, blurring the line between waste and resources. Human-engineered systems still struggle with this *conservation* principle and with the *reconfiguration* principle as well, the latter being the possibility to adapt to changes in the environment. Finally, the *symbiosis* principle requires that all component systems, i.e., holons, benefit from participating in the system and the *modularity* principle focus on the boundaries of each component and on its level of specialisation, independence and variety of use. In an attempt to describe SoS based on their context, Gorod et al. [52] suggest using autonomy, belonging, connectivity, diversity and evolutive emergence. These properties facilitate the distinction between traditional systems and SoS [13].

2.5. Network-Centricity in Systems of Systems

Systems in a SoS interact with each other, exchanging information through a communications network. Network-centricity [13], or net-centricity [53], usually brings along the possibility for new holons to join the network and, hence, the SoS [13]. A service-oriented architecture (SOA) consisting of information service providers, service consumers and service registries is a typical design option for network-centric engineered SoS. The integrity and availability, and sometimes the confidentiality as well, of the information flows within and between network-centric SoS is paramount for their resilience [9]. At the time of writing, no published scientific study addresses the behaviour of complementary public blockchain implementations such as BTC and ETH from a network-centric SoS perspective. Federalism is an alternative way to analyse complex constructs through the political and managerial lens. Federations of systems usually present a strong sociopolitical dimension and a geographical dispersion [54].

2.6. Paradoxes in SoS Management

The existence of a paradox in a SoS is an expression of tension and complexity. SoS engineers see a paradox as a source of innovation rather than as a source of confusion [13]. We find paradoxes in the boundaries, the control and the characteristics of a SoS. In Section 4, we present a collection of paradoxes present in both BTC and ETH. They are clear expressions of tension and complexity but, ultimately, signs of innovation and new ways of thinking brought by these public open blockchain implementations.

2.7. Blockchain as a System of Systems

At the time of writing, few articles study a specific public blockchain implementation as a SoS; however, they do not suggest that a set of blockchain implementations could create a SoS. Roth [55], in 2015, performs a functional analysis of BTC as a SoS using the Systems Modeling Language (SysML) and considers BTC as a component system within the "traditional" financial SoS, as the current "sovereign money-based" financial system works as a SoS as well [55]. Reference to other potential blockchain-based holons is limited to how alternative coins could make that SoS more robust by adding redundancy to the SoS [55]. There is no mention of complementary use cases as we suggest it happens with BTC and ETH. More generally, Mylrea [56], in 2019, refers to how a blockchain-based distributed energy organisation can contribute to modernising, in an autonomous manner, a SoS such as the US power grid. The cases that Jamshidi presents as SoS [13], such as the airline industry, critical infrastructures, wireless sensors, service provision, space exploration, navigation and transportation networks, motivate our hypothesis to model public blockchains such as BTC and ETH as a SoS as well.

2.8. Intentional Risk

Given the current rise in public blockchain implementations, it becomes crucial to understand their characteristics and how we can better secure them, i.e., make them more resilient. Traditionally, information risk management has been based on an actuarial approach, using the typical impact vs. probability graphs. A specific risk was quantified as the product of the probability for that event to happen times the impact of that event happening [57], anchoring the probability on the frequency of past events. In 2015, a proposal to break down cybersecurity risks into intentional and non-intentional, the latter also named accidental, introduced an important element: the existence of ill-intentioned actors [57] who target information systems to extract value out of them, considering intentionality as the backbone for cyber-risk management [16].

Intentional risk can be static or dynamic, depending on whether the attacker has authorised access to the target system or not [16]. Static risk-based attackers make use of authorised paths to access their objective and dynamic risk-based attackers make use of any possible but unauthorised path to carry out their plan. The three parameters that Chapela et al. [16] use in their model to manage intentional risk are value, accessibility and anonymity. They propose a model to manage intentional risk in non-linear systems based on complex network analysis [16]. Using network theory, introduced in Section 1.5, the more connected a node is, i.e., the more accessibility a computer system has, the greater the risk is for it to be compromised. The study of identity management resilience against intentional risk in blockchain-based Internet of Things (IoT) platforms is an example of this [9]. Typical intentional risks against blockchain are the 51% vulnerability, double spending, private key compromises and smart contract exploitation [58].

Table 2 summarises our research on the current state of art: the description of the blockchain technology, the complex network analysis of BTC and ETH, the concepts of SE and SoSE and intentional risk management. Our contribution focuses on modelling public blockchain implementations as a SoS to better manage their resilience against intentional risk.

Table 2. The role that related works play to build our contribution.

Topic	Study	Main Takeaway	References
Blockchain technology	Many use cases	A driver for change	[18–21]
		Impacting many sectors	[21–25,28–33]
Key implementations: BTC & ETH	As complex networks	Power law degrees	[5,34–41]
		"Rich get richer"	[9,42–48]
Systems Engineering	Complexity	Open vs. close systems	[51]
SoSE	Supersystems	5 SoS properties	[13,52]
	Network-centricity	Info exchange	[9,13,53]
Blockchain as SoS	Only focus on BTC	No complementary roles	[13,55,56]
Intentional risk	Attacks	Static vs. dynamic risk	[16,57,58]
	Parameters	Value, accessibility and anonymity	[16,57]
Our contribution			
Public blockchains	Modelled as a SoS	To improve resilience against intentional risk	[55,56]

3. Methodology and Implementation

3.1. Research Methodology

Our research question focuses on how to model BTC and ETH as an open SoS of public blockchains in which they are component systems. This is a novel approach, hardly explored so far, with the objective of better understanding the role that public blockchains play and will play in society and how they can be protected from ill-intentioned attacks, i.e., their resilience against intentional risk.

Generally speaking, we propose a five-step methodology to model a set of systems as an open SoS. In this particular case, we introduce the hypothesis that the two most market-capitalised crypto-currencies by the end of 2021 [3], BTC and ETH, can be modelled as components of an open SoS.

First, following the definition of SoS used in Section 1.6, we identify a common goal for the SoS of public blockchains. Second, we confirm that BTC and ETH are open systems with growing complexity. Third, we study net-centricity in BTC and ETH. Fourth, we use the characteristics proposed by Gorod et al. [52], i.e., autonomy, belonging, connectivity, diversity and emergence, to model BTC and ETH as a SoS and analyse them based in the balance panel proposed in [13]. Fifth, out of a vulnerability and threat analysis, we propose ways to improve the resilience of this particular SoS case study against intentional risk based on the parameters of value, accessibility and anonymity proposed by Chapela et al. [16]. Table 3 depicts our methodology.

Table 3. SoSE-based methodology to manage complex "supersystems".

Step	Label	Description	Why?
1	Common goal	Component systems share an ultimate goal	Definition of SoS
2	Open & Complex	Open systems with growing complexity?	Continuous evolution
3	Network-centric	Components use networks to communicate	Information exchange
4	Characteristics	Autonomy, Belonging Connectivity, Diversity Evolutive emergence	SoS Balance panel
5	Risk analysis	Vulnerabilities and threats Resilience against intentional risk	Future evolution

3.2. Methodological Implementation

- Step 1: Identification of a SoS.
  A System of Systems (SoS) exists when its components are independent complex systems that interact with each other to accomplish a common goal [13]. We postulate

that BTC and ETH are the two most prominent components of the SoS of public blockchains. They are two different systems, both with the goal of offering a digital distributed network of value;

- Step 2: Open systems with growing complexity.
  Once we identify a SoS of public blockchains, our second step is to determine whether BTC and ETH are open systems. As we have seen in Section 2.4, openness facilitates the inclusion of new components into a SoS. Under these premises, Section 4.2 analyses BTC and ETH as open systems with growing complexity;
- Step 3: Network centricity.
  The rapid development of information networks such as the Internet has facilitated interactions among SoS via network services up to the point that we talk about net-centric SoS. The existence of a service-oriented arquitecture (SOA) on top of a data network is a key characteristic for net-centric or network-centric SoS, also named net-centric enterprise systems [53]. Section 4.3 explores a service-oriented architecture (SOA) in BTC and ETH. More holistically, elements such as people, organisations, cultures, activities and interrelationships enable both systems to interact [13];
- Step 4: SoS characteristics.
  We characterise a SoS based on its properties as a more optimal way to comprehend its complexity instead of just framing it with a definition [52]. Chapter eight in [13] presents the SoS context based on five characteristics: autonomy, belonging, connectivity, diversity and evolutive emergence. In Section 4, we analyse these five characteristics for both BTC and ETH, and use the balance panel for each of them:

  (a) Autonomy.
  Autonomous systems operate independently [13]. We analyse BTC and ETH governance models, based on informal consensus. They are both independent. We describe key stakeholders such as their development and support communities and how they reach design decisions and try to avoid software forks while maintaining project legitimacy;

  (b) Belonging.
  The property of belonging to a system relates to its vision [13]. We explore BTC and ETH visions and identify opt in and opt out possibilities within the system and the balance that they strike between centralisation and decentralisation in mining power, community support, number of users and contributing developers;

  (c) Connectivity.
  We study how BTC and ETH interact between one another [13], especially in a scripted manner, and determine their common underlying technical foundation. We also determine whether the identified network-centricity is growing and examine the price correlation that both currencies show. From the platform viewpoint, we focus on their mining reward and supply models;

  (d) Diversity.
  A SoS achieves diversity if its holons are different to each other. We refer to leadership structure, range of business cases to answer, appetite for change and potential reasons to join these networks as proxies to understand the diversity present in this SoS;

  (e) Emergence.
  A pivotal feature of any SoS is the appearance of both intended and unintended properties that are not detectable in the specific component systems, i.e., holons. Emergence concentrates the added value of using SoSE. We compare the initial vision of the SoS of public blockchains [4,8] with its current use in two different levels, i.e., SoS-wide and holon-specific, and we identify properties that emerge from considering BTC and ETH as part of a more comprehensive system. We analyse the geopolitical consequences of this new financial SoS;

- Step 5: Vulnerabilities and threats. Resilience against intentional risk.
  We complete this analysis with the vulnerabilities we identify in the SoS and the threats it is exposed to. We use one of the identified threats, related to intentional risk, to come up with a series of security measures that would increase resilience against intentional risk. For this, we use the parameters proposed by Chapela et al. [16], i.e., value, accessibility and anonymity.

4. Analysis and Results

4.1. The System of Systems of Public Blockchains

We apply the methodology proposed in this article to understand and better manage the complexity of public blockchains. We consider that BTC and ETH are the two most prominent components of the SoS of public blockchains. They are two different open-source code implementations. They attract a very diverse community of users and proponents, however, they both share the common goal of transferring digital value. Figure 2 explains, step by step, how we conduct our methodology with keywords focused on purpose (first column), brief explanation (second column), main elements analysed (third column) and eventual conclusions (fourth column). We also add a fifth column to list the main tools that we use for our analysis. With regard to our complex network analysis code, implemented in Python, we make it available via github [49].

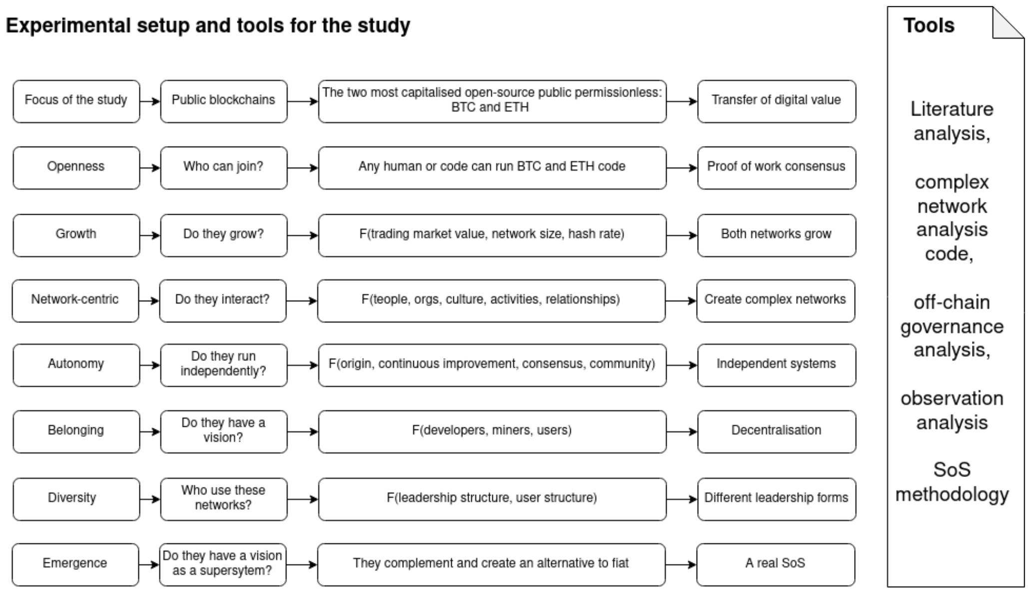


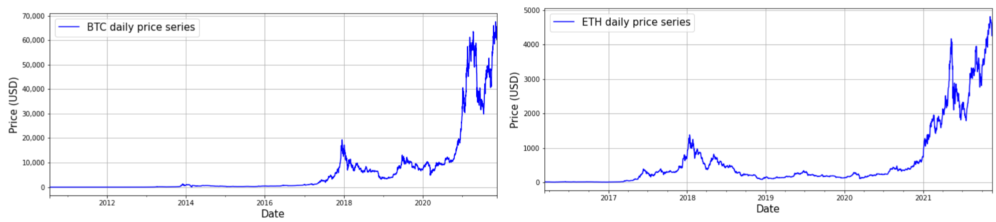
Figure 2. Experimental setup and tools for the study.

4.2. Openness and Growth

BTC and ETH are two independent public blockchain implementations. Public blockchain implementations are permissionless, i.e., they pose no obstacle to joining their network and sending transactions as a user or validating them as a node. Any code-based artifact using BTC or ETH open-source code, driven by a human being or by a script, with access to a private cryptographic key, does not require any third-party approval to participate in the network. In other words, any individual or human-made device with the possibility of running a BTC or ETH wallet or node can join these networks and perform transactions. Equally, they can also join the mining community and create new bitcoins or ether, their corresponding crypto-currencies, while verifying transactions, as long as they commit to "demonstrate commitment to the system" using proof of work-based consensus. Alternatively, some blockchain implementations propose the use of proof of stake [7]. In addition, BTC and ETH show a distinctive feature of open systems: they exchange energy and information with the outside world [51]. They exchange information with social, financial and human environments, and they display mechanisms to adapt to those environments and evolve accordingly. We use three dimensions to confirm this point: their trading market, the network size and their hash rate:

(a) Trading market: It is possible to buy and sell BTC and ETH coins. Both BTC and ETH are two public blockchain implementations that have attracted growing attention in the financial markets. Although their daily market price and their hash rate fluctuate considerably, both dimensions, price and total hash rate, have grown relentlessly for the last five years.
Figure 3a depicts the daily BTC market price since its start. The upward trend is patent. BTC market capitalisation as a cryptoasset is growing. Equally, Figure 3b depicts the daily ETH market price since its start. An upward trend is patent as well. These steep climbing prices attract new users, both retail and institutional, generating more transactions. In July 2020, BTC market capitalisation reached USD 170 B; less than a year later, in April 2021, the figure topped USD 1099 B, going up to USD 1142 B in November 2021 [3], paving the way for an incessant growth during this decade. The Ethereum cryptoasset had a market capitalisation of USD 26 B in July 2020. In April 2021, this figure was of USD 222 B. In November 2021, the market value of ETH led to a capitalisation of USD 505 B [3];

(b) Network size: As price and network size are positively correlated in both BTC [59] and ETH [48], their networks grow. According to bitnodes [60], there were around 10,540 full active BTC nodes in July 2020 while, surprisingly, there were around 9610 nodes in April 2021. A node is a BTC server that keeps a copy of the entire blockchain and validates transactions. A miner node is a node that validates blocks. In November 2021, the number of active BTC nodes reached 13,898. The trend in ETH is the opposite: according to ethernodes [61], there were close to 7900 active ETH nodes in July 2020 and over 4250 in April 2021. In November 2021, ref. [62] counted 3238 nodes. Table 4 summarises the BTC and ETH figures mentioned.



(**a**) (**b**)

Figure 3. Daily market price (source: investing.com, accessed on 16 November 2021). (**a**) Bitcoin (BTC). (**b**) Ethereum (ETH).

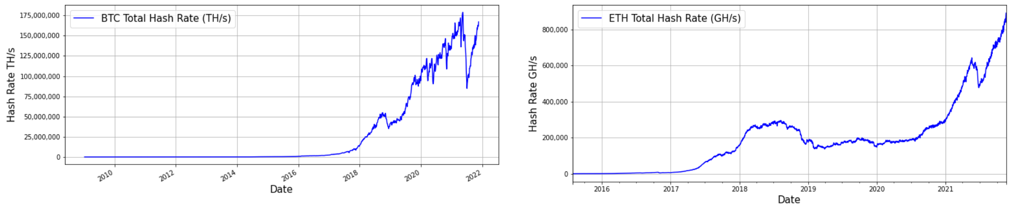
Table 4. Key Bitcoin and Ethereum figures.

Blockchain Name	Start Date	Active Nodes			Market Cap (USD B)		
		7/2020	4/2021	11/2021	7/2020	4/2021	11/2021
BTC	2009	10,540	9610	13,898	170	1099	1142
ETH	2014	7900	4250	3238	26	222	505

Network growth is visible in the address space. A node in each of these networks is an address (see Section 2.2). By design, based on the recommendation not to re-use addresses in transactions, address spaces continue growing in BTC and ETH since their inception. This continuous growth contributes to their distributed nature and to their complexity as addresses do not expire. Equally, block validation, i.e., mining, generates new coins as well, bitcoins and ether, respectively, increasing the number of coins circulating in the systems;

(c) Hash rate: Third, hash rate measures the computing power, i.e., calculation complexity, required to mine BTC and ETH blocks. Figure 4a,b shows how, especially since

2020, hash rates also increase. Both dimensions, market price and hash rate, indicate that the complexity of these systems, consequently, grow with time. They find themselves in a *causality dilemma*, and this is an inherent signal of complexity [63].



(**a**) (**b**)

Figure 4. Total Hash Rate. (**a**) Bitcoin (TH/s) (source: blockchain.com, accessed on 18 November 2021). (**b**) Ethereum (GH/s) (source: etherscan.io, accessed on 18 November 2021).

We can broaden our focus and infer that a SoS of public blockchains is therefore an open system that can potentially grow in complexity.

4.3. Network Centricity

BTC and ETH are network-based protocols. Network participants exchange information via open-source application programming interfaces (APIs). Typical actions are, e.g., creating an address, sending an amount to an address, validating a transaction and requesting information on a transaction or on a block. Examples of these APIs are the BTC remote procedure call (RPC) and the ETH javascript (js) APIs [64,65]. Functionality is then bundled into services provided by nodes and consumed by clients. These APIs are examples of a basic distributed service-oriented architecture (SOA). They confirm the network-centricity of BTC and ETH. Table 5 summarises the network-centricity of the SoS itself using the elements suggested by Jamshidi [13] together with a forecast on how their relevance will change in the near future:

Table 5. Network-centricity in public blockchain SoS.

Interaction via	Description	Relevance
People	Holders of crypto keep BTC and ETH in their portfolio	Increasing
Organisations	Crypto exchanges offer swaps between BTC and ETH and other coins	Increasing
Culture	BTC and ETH share decentralised principles	Stable
Activities	Coin wrapping, e.g., WBTC: an ERC20 token in ETH	Increasing
Relationships	Both subject to additional financial regulation	Increasing

We find similar interactions between other public blockchains running on their own platforms, i.e., mainnets, present in this SoS. Solana (SOL) and Algorand (ALGO) are two examples, the 5th and 20th most capitalised crypto-currencies in November 2021 [3]. In general, they interact with each other via common users, crypto-exchanges, basic design principles and wrapping techniques. Coin wrapping enables cryptoassets to be used on another blockchain, different to the native one. For example, wrapped BTC (WBTC) is an ERC20 (ETH-based) token that represents BTC 1:1 in the ETH network. Finally, as all of them are public blockchains, they are subject to any financial regulation that might potentially impact all public blockchain implementations.

4.4. Autonomy

BTC and ETH operate independently. They both run a separate off-chain governance model based on informal consensus. The role of Lead System Integrator [66] is crowd-sourced to a reduced number of developers supported by a large community. The seminal BTC paper by Nakamoto [4] defines, at a high level, the first BTC design decisions. The first open-source BTC client was made public on 9 January 2009. Once Nakamoto left the project in 2011, the so-called "Bitcoin core developers", Gavin Andresen, Pieter Wuille, Wladimir van der Laan, Gregory Maxwell and Jeff Garzik, took over the BTC protocol development and software maintenance. The number of developers able to commit code to "Bitcoin core" remains stable: 37 in April 2021 and 39 in November 2021 [67]. Changes to BTC require ample consensus [68]. Anyone in the community can launch a BTC improvement proposal (BIP) [69]. The search for consensus among key stakeholders, i.e., developers, miners (node operators) and users, is a top priority. Their aim is to avoid the threat of forking the protocol [68], either in a soft or hard way. Soft forks guarantee backward compatibility and hard forks do not. A software fork introduces changes in the code from a specific point in time. Similarly, the ETH protocol [70] works with Ethereum Requests for Comments (ERC). They eventually translate into Ethereum Improvement Proposals (EIPs) that need to reach sufficient consensus [71]. The number of ETH developers who can commit code is growing slightly: from 69 in April 2021 to 81 in November 2021 [72], as Table 6 displays. On independence, every BTC and ETH stakeholder can decide independently from each other. Ultimately, anyone in BTC or ETH could fork the protocols and start a new project. It would be up to their ability to entice users to use the new forked code. A key concept in both BTC and ETH is legitimacy, or a pattern of higher-order acceptance [73]. Already, through the study of autonomy in public blockchains, we distinguish at least two of the three typical paradoxes identified in chapter eight of [13], i.e., control and team paradoxes. There is tension present regarding where decision power resides and the balance between individuality or autonomy and team membership or belonging. Broadening our focus to a SoS of public blockchains, and based on these results, we infer that it consists of independent blockchain implementations.

4.5. Belonging

The original vision of BTC is the creation of a "purely peer-to-peer version of electronic cash" [4]. BTC and ETH are digital assets with no intrinsic value and no centralised issuer [8]. The vision of ETH is to build "a blockchain with a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralised applications where they can create their own arbitrary rules for ownership, transaction formats and state transition functions" [8]. In both blockchains, the three main related communities, i.e., developers, miners and users, can opt in and out of the SoS at any moment. This is a sign of an open system. The first paradox mentioned in chapter eight of [13], i.e. the boundary paradox, or the need to keep some things in the systems and some things out of the system simultaneously, is patent as well in public blockchains, e.g., in the on-chain vs. off-chain information storage dilemma.

On centralisation, the three main sources of critiques are: the very reduced number of developers with commit privileges in both blockchains, see Section 4.4, the location of most of the BTC mining power and the location of most of the BTC nodes. With regard to miners, China hosted over 65% of BTC mining power until October 2020. The main reason was the electricity oversupply and corresponding reduced prices of hydroelectricity in areas such as Sichuan. The price of electricity is a key driver for miners to interact [74]. After the nation-wide ban in July 2021, China abandoned BTC mining [75]. In November 2021, the USA (35.1%), Russia (11.9%) and Kazakhstan (13.8%) account for the top three mining countries. With regard to full active BTC nodes, the USA and Germany host close to 13% of them, although this figure is less than the 20% of nodes that each of these two countries had in April 2021 [60]. Regarding ETH, 34% of active nodes resided in the USA and 22% in Germany on April 2021, while, in November 2021, the US hosted 35% and Germany decreased to 15% [61]. See Table 6.

Regarding decentralisation, the Ethereum foundation ethereum.org (accessed on 1 December 2021) organises most of the support to the ETH community. A similar foundation project exists for BTC bitcoin.org (accessed on 1 December 2021). However, none of these foundations own the ETH or the BTC networks. Both networks are public like the Internet. With over 13,000 active BTC nodes and over 3200 active ETH nodes (see Table 4), the degree of active node decentralisation is higher in BTC than in ETH, where we identify that the number of active nodes is reducing. The decrease in ETH nodes is a worrying trend, particularly given the big drop in September 2021 [76]. Estimations in February 2021 set the number of BTC users over 71 million and the number of ETH users over 14 million, with 25% of them owning both crypto-currencies [77]. Both the BTC and ETH user communities are growing. Although the number of core developers for both BTC and ETH is rather limited, see Section 4.4, the number of active contributing developers has reached close to 500 members in BTC and more than 1000 in ETH [78]. Based on these figures, we still see more evidence tilting the *belonging* feature towards decentralisation than to centralisation in the SoS of public blockchains.

Table 6. BTC and ETH autonomy and belonging related figures.

Blockchain Name	Users (M)	Contrib. Devs.	Core Developers		Active Node Location (%)	
			4/2021	11/2021	4/2021	11/2021
BTC	71	500	37	39	CN (65)	US (35), KZ (14), RU (12)
ETH	14	1000	69	81	US (34), DE (22)	US (35), DE (15)

4.6. Connectivity

All BTC and ETH active nodes and clients can enjoy the same power of connectivity. Both BTC and ETH networks are permissionless, i.e., provided that they run the corresponding committed open-source protocol, any compatible running code can join both networks. The study of the connectivity property confirms the network-centricity of the SoS of public blockchains [13,53]. BTC and ETH active nodes are connected to the BTC and ETH networks, respectively. Both networks run on top of the public Internet. Table 5 lists the means through which they are interconnected. We focus on the scripted interaction, i.e., coin wrapping. In November 2021, around 249,000 BTC [79], out of the 18.8 million BTC already mined by end November 2021, are tokenised in ETH via wrapped BTC (WBTC), an ERC20 token [80]. They are mostly deployed in ETH-based Decentralised Finance (DeFi) projects. This figure is growing. On July 2020, there were only 15,000 tokenised BTC [81] and, on April 2021, there were 141,000 BTC. In terms of price, BTC–ETH correlation has been permanently positive since 2018, close to 0.8 during 2019 and 2020. During November 2021, BTC–ETH price correlation was over 0.75 [82].

From the platform-centric viewpoint, BTC and ETH miners verify transactions and receive a reward for it. These transactions fill up a BTC block. Miners receive newly created bitcoins and ether, respectively, when they finalise a block, i.e., they "mine" a block. In the case of BTC, this block mining reward is halved after 210,000 blocks. The current reward of 6.25 BTC started on 11 May 2020. Those miners with a higher hash rate, i.e., computing power, enjoy a higher probability of mining a block. Once all 21 million BTCs are mined, and this will happen around the year 2140, the question of whether transaction verification income, based only on transaction fees, will be still profitable for miners remains open. Taproot, the latest BTC upgrade, performed in November 2021, aims to scale up the number of transactions that the network can cope with and to increase privacy by complicating the identification of participants in a transaction [83]. With regard to their monetary policy, while BTC supply is deflationary, i.e., limited to 21 million, ETH supply is inflationary, i.e., there is a maximum yearly new supply of 18 million ETH. Both networks show an increased connectivity. However, they have been criticised for demanding high transaction fees during times of heavy use and overall network growth. BTC aims to solve this challenge with BTC Lightning Network (BLN) and ETH with ETH 2.0. BLN collects transactions first off-chain and uses scripting to guarantee integrity [84]. ETH 2.0 promises scalability based on a multi-chain concept (sharding) [85].

In general, interledger communications such as Interledger Protocol (ILP) enable the possibility of connecting different public blockchain implementations through code-based connectors, between BTC and ETH as well. This means that a BTC transfer can end up as an ETH sum via an ILP connector in an ETH address.

4.7. Diversity

First, we identify basic differences between BTC and ETH that make them even more complementary: BTC appears as a leaderless public blockchain with a broad user population and decentralised governance. Although its degree distribution approximates a power law function [36,37], its control structure is highly decentralised. ETH degree distribution resembles a power law function [48] and its leadership structure is more precise. ETH attracts more experimentation and innovation and it is more multi-faceted than BTC. Second, we focus on the diversity existing in the three main stakeholder communities for BTC and ETH: miners, developers and users, to understand the current balance between homogeneity and heterogeneity. Mining pools are groups of miners that share computing power, i.e., hash rate. None of them reaches 51% of the total BTC hash rate [86]. Only if the five biggest BTC pools would collude, they could opt to attempt a 51% blockchain control attack to modify a transaction. A similar situation applies to ETH [87]. Regarding development, there is more activity in ETH than in BTC: there are more than 300 BIPs [69] but more than 3300 EIPs [88]. As mentioned in Section 4.4, the number of core developers in both networks is reduced, although ETH attracts more developers than BTC. From the user perspective, the increase in users is initially a good proxy for heterogeneity growth. Early adopters of BTC were libertarians and techno-anarchists [89]. In 2021, many other profiles join both networks, partially disgruntled by the highly expansionary monetary policies followed by key central banks.

4.8. Emergence

We first refer to the intended emergent properties and second to the unintended ones. Table 7 provides a summary of the emergent properties that we identify in this SoS and its components.

Table 7. Intended and unintended emergent properties.

Realm	Emergent Property	Intended
SoS	Decentralised network of digital value	Yes
SoS	Alternative to fiat-based financial system	No
BTC	Peer to peer electronic cash system	Yes
BTC	Digital global reserve asset (“digital gold”)	No
ETH	The world distributed computer	Yes
ETH	Main DeFi platform (“alternative financial conduit”)	No
ETH	Platform to transfer “unique” digital value	No

4.8.1. Intended Emergent Properties

The intended emergent property of the SoS of public blockchains is to provide a decentralised network to transfer value: in the case of BTC, via a digital asset that has no intrinsic value in itself. In the case of ETH, via a Turing-complete protocol able to implement decentralised applications. Public blockchain implementations use a digital asset with no intrinsic value. This digital asset represents digital private property in three different ways: as native crypto-currencies, such as bitcoin and ether, and, in the case of ETH, as fungible tokens (ERC20 tokens) and as non-fungible tokens (ERC721 and ERC1155 tokens). Public blockchains offer a channel through which to transfer digital private property, i.e., digital value.

4.8.2. High-Level Unintended Emergent Property

Considering our analysis of the SoS of public blockchains, we estimate that the high-level unintended emergent property of a SoS of public blockchains is to stand as an alternative to the financial system based on fiat currencies, established in 1971 with the cancellation of the direct convertibility of the USD into gold. We find two competing and distinct SoS, the traditional centralised financial SoS and the open SoS of public blockchains. Neither BTC nor ETH included this key property of aspiring to become an alternative financial system in their seminal white papers [4,8]. Figure 5 depicts the results of our SoS characteristics-based analysis [13].

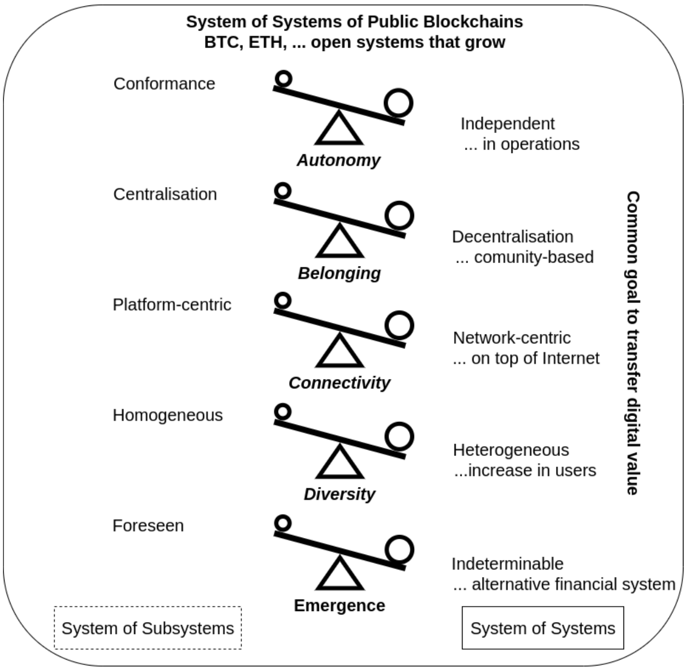


Figure 5. Public blockchains. SoS characteristics balance panel.

4.8.3. Holon-Specific Unintended Emergent Properties

More specifically, BTCs unintended emergent property is to become a global reserve asset, i.e., the "digital gold". The expanding fiat currency monetary policy since 2008, plus the performance difficulty for BTC to achieve high transaction speeds, in contrast to other blockchain implementations [90], transforms BTC into a digital value reserve more than into an instant peer to peer payment system. However, initiatives such as BLN [84] and the taproot upgrade [83] aim to increase transaction rate. An initially unintended emergent property of ETH is to act as main underlying blockchain implementation for Decentralised Finance (DeFi). DeFi translates, via smart contracts, most of the financial activities present in the traditional centralised financial system such as lending, borrowing, trading, using derivatives and depositing funds. We define it as the "alternative financial conduit" system. ETH's "distributed world computer" is the distributed platform in which an entire financial system, based on fungible tokens, is beginning to run. Stablecoins constitute the means of settlement in this distributed financial system. The total capitalisation of stablecoins in November 2021 is USD 145 B, from USD 60 B on April 2021 [91]. A stablecoin is a crypto-currency whose value is pegged to either a fiat currency, mostly the USD, or to a basket of assets.

Traditionally, the US dollar (USD) plays a dominant role in the world financial system [92]. The fundamental role that the USD plays in finance provides a geopolitical advantage to the US and leverage to apply economic sanctions to other non-allied countries. The arrival of the public blockchain-based SoS impacts this USD dominance. The fact that the most capitalised stablecoins are pegged to the USD [91] confirms the growing geopolitical importance of this new SoS. Other competing geopolitical powers such as China entered the digital coin scenario via their "digital yuan". Central banks around the globe are piloting central bank digital currencies (CBDCs) in an attempt to preserve the "status quo".

With regard to non-fungible tokens, the unintended emergent property of ETH is to act as a platform to transfer “unique” digital private property. NFTs offer a distributed and non-intermediated creativity market. Examples are “Cryptokitties” and “Mutant Apes” [93].

Additionally, a myriad of public permissionless blockchain implementations have launched their own networks, i.e., mainnets, to compete with ETH and to save ETH transaction fees. The appearance of multiple blockchain implementations to answer specific business cases [22] complements the roles of BTC and ETH within this overarching SoS of public blockchains. All these sidechains are also components, holons, in this SoS. Table 8 lists four of the top market capitalised projects in November 2021 according to coinmarketcap [3].

Table 8. Public blockchain projects within the SoS.

Project	Origin	Business Case	Market Cap (B USD)	Consensus
Binance Coin (BNB)	2017	Biggest crypto exchange’s blockchain	111	Proof of authority
Solana (SOL)	2020	DeFi solution with short processing times	61	Proof of history
Cardano (ADA)	2017	Decentralised app engine	54	Proof of stake
Polkadot (DOT)	2017	Multi-chain focused on cross-chain transfers	37	Nominated proof of stake

We have modelled BTC and ETH as holons of the open SoS of public blockchains and we have identified the emergent property that creates a new distributed "supersystem" of digital private property, i.e., digital value. We present now the result of a threat and vulnerability analysis. One of the threats we identify is precisely intentional risk.

4.8.4. Vulnerabilities and Threats of the SoS of Public Blockchains

We complement the previous results with a vulnerability and threat analysis of the public blokchain SoS. We identify five vulnerabilities:

- Adoption requires understanding.
  The knowledge-based barrier to entry is considerable. Participants in this public blockchain-based SoS require understanding of the underlying mathematical, cryptographic and economic concepts upon which both BTC and ETH are built. There is hardly any abstraction layer between users and the internal complex functioning of these blockchains;
- Adoption requires hiding complexity. The user-friendliness of the software tools that interface with this SoS is still very low;
- Early stage of evolution. Even with high rates of adoption and rising market capitalisation, public blockchains are still at a very early development phase. The industry is flourishing and growing fast; however, it has not yet reached any consolidation phase;
- Signs of centralisation. Complex network theory-based literature identifies linear and super-linear preferential attachment in BTC and ETH in their transaction networks [36,37,48,59]. This reveals the higher degree of dependence on specific super-hub nodes in these networks. An additional sign of initial centralisation is the decrease in the number of active ETH nodes [76].
- Governance exclusively dependent on code. The smart exploitation of any programming error in the code that implements elements such as mining rewards, smart contracts and distributed autonomous organisations (DAO, a distributed governance engine) can siphon out funds and make any public blockchain project fail. A real example of this already happened in Ethereum in 2016 [94].

  Equally, we observe five threats:

- Regulation. The overall impact that financial regulation will have on the future of this SoS is still unknown. Taxation, legal jurisdiction, cross-border implications and know your customer requirements are just some examples of key regulatory aspects that are still not fully defined for the distributed SoS of public blockchains;

- Privacy vs. Traceability Trade off. One of the first business cases for the use of BTC was the online black market "Silk Road" [95]. Identities behind BTC addresses were not known. However, anonymity is not a design feature in BTC but, rather, pseudo-anonymity [5]. Ethereum does not offer transaction anonymity either. The lack of auditable and regulated know your customer procedures could hamper the mass growth of public blockchains;
- Future developments in encryption. Bitcoin uses SHA-256 as its hashing algorithm [96] and the Elliptic Curve Digital Signature Algorithm (ECDSA) with the elliptic curve secp256k1 to sign transactions [97]. The taproot BTC upgrade introduces Schnorr signatures [83]. Ethereum uses Keccak-256 [98] to hash transactions and ECDSA to sign them [99]. Future developments in quantum computing [100] could render current cryptographic algorithms used in public blockchains insecure. Should this happen, then the core development communities mentioned in Section 4.4 should react quickly with the corresponding cryptographic upgrade by proposing new key lengths or, alternatively, new algorithms;
- Missing co-operation. The permanent interaction between the SoS of traditional finance with the SoS of public blockchains is not yet defined. The governance frameworks in both systems need to find a common ground to allow for future-proof interactions between both financial proposals;
- Intentional risk. The economic value locked in the SoS of public blockchains is growing. Consequently, the interest of ill-intentioned actors to extract value out of it is also increasing [101]. The future of this SoS will depend on its resilience against intentional risk.

These vulnerabilities and threats pose the risk of impeding mass adoption of this SoS.

4.9. Resilience against Intentional Risk

We start from the definition of profitability associated to the attacker (PAR) proposed by Chapela et al. [16] to quantify intentional risk (Equation (1)). The level of intentional risk *IntRisk* to which a system *SoS* is exposed to corresponds to the maximum product of the <*value*, *accessibility*, *anonymity*/*k*> triplets of their *participant elements e*, being *k* a standard constant we name *legal robustness*, related to the legal consequences that an attacker could face. We propose to optimise as many factors as possible in Equation (1) to reduce the intentional risk that the SoS of public blockchains is exposed to. The reduction in the exposure to intentional risk increases the resilience of the system against it.

$$PAR = \max\left(value_e \cdot accessibility_e \cdot \left(\frac{anonymity_e}{k}\right)\right) \quad (1)$$

As *participant element* in Equation (1), we select the most fine-grained possible component of the open public blockchains we study, i.e., an address. An address in a public blockchain consists of a unique identifier that refers to a public–private cryptographic key pair involved in a transaction either as the origin or destination. We use complex network notation to mathematically state our analysis: for each of the blockchain implementations present in the SoS of public blockchains b_i, we consider a transaction network T_{b_i} in which every address N_{b_i} used is a node and every transaction between addresses is an edge T_{b_i} denoted by $T_{b_i} = (N_{b_i}, E_{b_i})$ being its nodes N_{b_i} and E_{b_i} its edges. We identify three attributes for each N_{b_i}:

- $Va(N_{b_i})$: the *value* as the quantity of cryptocurrency or fungible tokens held by the address N_{b_i}. By design, this is public information. As an example, in the case of NFTs, this attribute simply refers to the *value* assigned by the market to it;
- $Ac(N_{b_i})$: the *accessibility* of N_{b_i}. This is a function of the *accessibility* to its private cryptographic key. Having access to the private key gives the possibility to claim

ownership of $Va(N_{b_i})$. A high $Ac(N_{b_i})$ implies poor protection measures to keep the private key secure;

- $An(N_{b_i})$: the *anonymity* of N_{b_i}. This measures the degree of uncertainty to link N_{b_i} with a screened identity in the physical world. A high $An(N_{b_i})$ implies that N_{b_i} cannot be associated to a confirmed physical identity. Attackers of a public blockchain implementation b_i use a collection of N_{b_i} with a high $An(N_{b_i})$ as consecutive destinations of their fraudulent transactions to make tracking unfeasible.

Regarding the legal robustness k constant, its value indicates how dissuasive legal measures are for attackers to embark on plans to compromise public blockchains.

We increase the resilience of the SoS of public blockchains by minimising the intentional risk that each participating address runs as Equation (2) defines:

$$\forall\, b_i \in SoS, \quad IntRisk_{SoS} = \max\left(Va(N_{b_i}) \cdot Ac(N_{b_i}) \cdot \left(\frac{An(N_{b_i})}{k} \right) \right) \tag{2}$$

Table 9 lists our proposed security measures to increase this SoS's resilience against intentional risk. Their implementation requires a multidisciplinary, i.e., technical, procedural and cultural approach, especially during design, development and operations of the holons of this SoS. The scope of these proposals corresponds to the SoS of public blockchains. Only a SoS-overarching approach, or, at least, a specific focus on BTC and ETH as the two main public blockchain implementations, can increase the resilience of a SoS whose main emergent property is to become a real distributed alternative to the traditional finance system. If we would only focus on one holon, then, following Equation (1), the overall resilience of the SoS would not improve and its adoption would not increase.

Table 9. Measures to increase intentional risk resilience.

Action	Principle	Phase
Reduce asset value	Distribute value across many addresses	Design/Operations
	Avoid very rich hubs	Operations
Decrease accessibility	Maintain the use of strong crypto	Design
	Improve code security	Development
	Simplify interfaces	Development
	Improve private key security	Design/Dev/Operations
	Extend use of cold storage	Operations
	Enhance security awareness in users	Communications
Decrease anonymity	Improve identity management	Operations
	Link with physical identities	Governance
	Achieve global legal coverage	Governance
	Extend blockchain monitoring	Operations
Increase legal measures	Extend know your customer processes	Operations

5. Conclusions

We conclude that:

(a) Our proposed methodology, based on SoSE, is a valid and replicable tool to understand and to manage complex "supersystems" or "networks of networks".
We apply this methodology to the complexity present in public blockchains: we model BTC and ETH, two public open and permissionless blockchain implementations, as holons that complement each other within a SoS of public blockchains. Public blockchains enable the transfer of digital private property with a link, or not, to physical private property. Thanks to the use of SoSE, we identify that BTC aspires to become "sound money", i.e., stable non-inflationary money, a digital global reserve asset. ETH, the "distributed world computer", aims to become the "alternative financial conduit" system to run decentralised finance;

(b) The unintended emergent property of the SoS of public blockchains is to stand as an alternative to the traditional centralised financial system based on fiat currencies.

This emergent property only appears when we focus on BTC and ETH, and, more generally, on public blockchain implementations, as a unique "supersystem". This SoS transfers digital value and competes with the traditional financial system as a potentially future-proof and disruptive alternative to the way the world conducts finance, especially since the Nixon shock in 1971 [102] with the cancellation of the direct convertibility of the USD into gold;

(c) One of the threats to the future of the SoS of public blockchains is its exposure to intentional risk. The materialisation of this risk could impact its mass adoption;

(d) The parameters proposed by Chapela et al. [16] in their intentional risk equation, i.e., value, accessibility and anonymity, are useful to suggest a series of security measures that would increase the resilience against intentional risk of the SoS of public blockchains.
These measures apply to the governance, design, development, operation and communication phases present in the implementation of this SoS;

(e) The optimisation of these intentional risk parameters, i.e., value, accessibility and anonymity, in the SoS of public blockchains, will impact positively on the evolution of the emergent property of this SoS.

6. Future Work

We suggest four paths to further research on the use of SoSE in the study of public blockchains and to improve the resilience against intentional risk of the SoS of public blockchains:

(a) To analyse how the SoS of public blockchains links with the SoS of traditional centralised fiat currency-based finance;
(b) To explore whether the modeling of the Decentralised Finance (DeFi) ecosystem is a SoS in itself;
(c) To build a complete application programming interface (API) that would facilitate the implementation of security measures in public blockchains with the objective of increasing their resilience against intentional risk;
(d) To explore the potential applications of machine learning and artificial intelligence (ML/AI) techniques, as described by Xu et al. [103], in the prevention, detection and mitigation of intentional risks against public blockchains.

Author Contributions: Conceptualization, A.P. and S.G.; methodology, A.P. and S.G.; software, A.P.; validation, A.P., S.G., R.C., M.R., E.G. and J.T.; formal analysis, A.P. and S.G.; investigation, A.P. and S.G.; resources, A.P., S.G., R.C., M.R., E.G. and J.T.; data curation, A.P.; writing—original draft preparation, A.P. and S.G.; writing—review and editing, A.P., S.G., R.C., M.R., E.G. and J.T.; visualization, A.P.; supervision, R.C., M.R., E.G. and J.T.; project administration, A.P., S.G., R.C., M.R., E.G. and J.T.; funding acquisition, A.P., S.G., R.C., M.R., E.G. and J.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: We used BTC and ETH data from publicly available datasets provided by coinmarketcap.com, bitnodes.io, ethernodes.org, etherscan.io, stats.buybitcoinworldwide.com and coinmarketcap.com (all af them last accessed on 1 December 2021). We make our Python-based complex network analysis code available via github. The References Section provides details on each specific Internet address.

Acknowledgments: The authors would like to acknowledge Diego Andina. Head of Group for Automation in Signals and Communications. ETSIT. Universidad Politécnica de Madrid. He inspired A.P. to write this paper and provided initial guidance on System of Systems Engineering.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yli-Huumo, J.; Ko, D.; Choi, S.; Park, S.; Smolander, K. Where Is Current Research on Blockchain Technology? A Systematic Review. *PLoS ONE* **2016**, *11*, e0163477. [CrossRef]
2. Walport, M. Distributed Ledger Technology: Beyond Block Chain. UK Government Chief Scientific Adviser. 2015. Available online: https://bit.ly/3yzbq34 (accessed on 16 November 2021).
3. Coinmarketcap. Cryptocurrencies Market Capitalisation in Real Time. Available online: https://coinmarketcap.com/all/views/all/ (accessed on 25 November 2021).
4. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. Nakamotoinstitute.org, October 2008. Available online: https://bitcoin.org/bitcoin.pdf (accessed on 16 November 2021).
5. Reid, F.; Harrigan, M. An Analysis of Anonymity in the Bitcoin System. In Proceedings of the IEEE Third International Conference on Privacy, Security, Risk and Trust, Boston, MA, USA, 9–11 October 2011; pp. 1318–1326. [CrossRef]
6. Weber, W.E. A Bitcoin Standard: Lessons from the Gold Standard; No. 2016-14; Bank of Canada Staff Working Paper. 2016. Available online: http://hdl.handle.net/10419/148121 (accessed on 1 December 2021).
7. Ethereum. ETH Corporate Site. Available online: https://www.ethereum.org/ (accessed on 16 November 2021).
8. Ethereum.org. Ethereum Whitepaper. Available online: https://ethereum.org/en/whitepaper/ (accessed on 16 November 2021).
9. Partida, A.; Criado, R.; Romance, M. Identity and Access Management Resilience against Intentional Risk for Blockchain-Based IOT Platforms. *Electronics* **2021**, *10*, 378. [CrossRef]
10. Partida, A.; Criado, R.; Romance, M. Visibility Graph Analysis of IOTA and IoTeX Price Series: An Intentional Risk-Based Strategy to Use 5G for IoT. *Electronics* **2021**, *10*, 2282. [CrossRef]
11. Boccaletti, S.; Latora, V.; Moreno, Y.; Chavez, M.; Hwang, D.-U. Complex networks: Structure and dynamics. *Phys. Rep.* **2006**, *424*, 175–308. [CrossRef]
12. Newman, M.E.J. The structure and function of complex networks. *SIAM Rev.* **2003**, *45*, 167–256. [CrossRef]
13. Jamshidi, M. *System of Systems Engineering: Innovations for the 21st Century*; First Published: 21 April 2008; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2009; ISBN 9780470195901/9780470403501. [CrossRef]
14. Liu, X.; Peng, H.; Gao, J. Vulnerability and controllability of networks of networks. *Chaos Solitons Fractals* **2015**, *80*, 125–138. [CrossRef]
15. Partida, A. *Secure IT Up! Cyber Insurance Due Diligence*; CreateSpace Independent Publishing Platform: Scotts Valley, CA, USA, 2012; ISBN 9781478314752.
16. Chapela, V.; Criado, R.; Moral, S.; Romance, M. *Intentional Risk Management through Complex Networks Analysis*; Springer Briefs in Optimization; Springer: Berlin/Heidelberg, Germany, 2015.
17. Marella, V.; Kokabha, M.R.; Merikivi, J.; Tuunainen, V. Rebuilding Trust in Cryptocurrency Exchanges after Cyber-attacks. In Proceedings of the 54th Hawaii International Conference on System Sciences, Maui, HI, USA, 5–8 January 2021; pp. 5636–5646.
18. Suciu, G.; Nădrag, C.; Istrate, C.; Vulpe, A.; Ditu, M.; Subea, O. Comparative analysis of distributed ledger technologies. In Proceedings of the 2018 Global Wireless Summit (GWS), Chiang Rai, Thailand, 25–28 November 2018; IEEE: Piscataway, NJ, USA, 2018; pp. 370–373. [CrossRef]
19. Thomas, S.; Schwartz, E. A Protocol for Interledger Payments. Hyperledger Working Group. Interledger.org. 2016. Available online: https://interledger.org/interledger.pdf (accessed on 16 November 2021).
20. Frankenfield, J. Interledger Protocol. investopedia.com. Available online: https://www.investopedia.com/terms/i/interledger-protocol.asp (accessed on 19 November 2021).
21. Reijers, W.; O'Brolcháin, F.; Haynes, P. Governance in Blockchain Technologies & Social Contract Theories. *Ledger J.* **2016**, *1*, 134–151. [CrossRef]
22. Catalini, C.; Gans, J.S. *Some Simple Economics of the Blockchain*; Working Paper 22952; National Bureau of Economic Research: Cambridge, MA, USA, 2016. [CrossRef]
23. ECB. Distributed Ledger Technology. In Focus, Issue 1, European Central Bank. 2016. Available online: https://bit.ly/3fHcOYS (accessed on 16 November 2021).
24. ESMA. *The Distributed Ledger Technology Applied to Securities Markets*; Report ESMA50-1121423017-285, Discussion Paper; European Securities and Markets Authority: Paris, France, 2017. Available online: https://bit.ly/344omjI (accessed on 16 November 2021).
25. Pinna, A.; Ruttenberg, W. Distributed Ledger Technologies in Securities Post Trading: Revolution or Evolution. Available online: https://bit.ly/3oHEMaY (accessed on 16 November 2021).
26. Longo, F.; Nicoletti, L.; Padovano, A.; d'Atri, G.; Forte, M. Blockchain-enabled supply chain: An experimental study. *Comput. Ind. Eng.* **2019**, *136*, 57–69. [CrossRef]
27. Filippi, P.D.; Hassan, S. Blockchain technology as a regulatory technology: From code is law to law is code. *arXiv* **2018**, arXiv:1801.02507. [CrossRef]
28. Hölbl, M.; Kompara, M.; Kamišalić, A.; Zlatolas, L.N. A Systematic Review of the Use of Blockchain in Healthcare. *Symmetry* **2018**, *10*, 470. [CrossRef]
29. Peiró, N.N.; García, E.J.M. Blockchain and land registration systems. *Eur. Prop. Law J.* **2017**, *6*, 296–320. [CrossRef]
30. Vasiliy, E.; Spirkina, A.; Buinevich, M.; Vladyko, A. Technological Aspects of Blockchain Application for Vehicle-to-Network. *Information* **2020**, *11*, 465. [CrossRef]

31. Stroukal, D.; Nedvedova, B. Bitcoin and other cryptocurrencies as an instrument of crime in cyberspace. In Proceedings of the 4th Business & Management Conference, Istanbul (IISES), Istanbul, Turkey, 12–14 October 2016. Available online: https://bit.ly/3fgyNap (accessed on 16 November 2021).
32. Malone, J.A. *Bitcoin and Other Virtual Currencies for the 21st Century*; CreateSpace Independent Publishing Platform: Scotts Valley, CA, USA, 1861. Available online: https://amzn.to/3oFn73I (accessed on 16 November 2021).
33. Srivastava, G.; Dhar, S.; Dwivedi, A.D.; Crichigno, J. Blockchain education. In Proceedings of the 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), Edmonton, AB, Canada, 5 May 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 1–5. [CrossRef]
34. Tasca, P.; Tessone, C.J. A Taxonomy of Blockchain Technologies: Principles of Identification and Classification. *Ledger J.* **2019**, *4*. [CrossRef]
35. Dinh, T.T.A.; Liu, R.; Zhang, M.; Chen, G.; Ooi, B.C.; Wang, J. Untangling Blockchain: A Data Processing View of Blockchain Systems. *IEEE Trans. Knowl. Data Eng.* **2018**, *30*, 1366–1385. [CrossRef]
36. Kondor, D.; Pósfai, M.; Csabai, I.; Vattay, G. Do the Rich Get Richer? An Empirical Analysis of the Bitcoin Transaction Network. *PLoS ONE* **2014**, *9*, e86197. [CrossRef]
37. Maesa, D.D.F.; Marino, A.; Ricci, L. Data-driven analysis of Bitcoin properties: Exploiting the users graph. *Int. J. Data Sci. Anal. Nat. Res.* **2018**, *6*, 63–80. [CrossRef]
38. Sommer, D. Processing Bitcoin Blockchain Data Using a Big Data-Specific Framework. Available online: https://files.ifi.uzh.ch/CSG/staff/scheid/extern/theses/BA-D-Sommer.pdf (accessed on 16 November 2021).
39. Wheatley, S.; Sornette, D.; Huber, T.; Reppen, M.; Gantner, R.N. Are Bitcoin bubbles predictable? Combining a generalized Metcalfe's Law and the Log-Periodic Power Law Singularity model. *R. Soc. Open Sci.* **2019**, *6*, 180538. Available online: https://royalsocietypublishing.org/doi/abs/10.1098/rsos.180538 (accessed on 1 December 2021). [CrossRef]
40. Bovet, A.; Campajola, C.; Mottes, F.; Restocchi, V.; Vallarano, N.; Squartini, T.; Tessone, C.J. The evolving liaisons between the transaction networks of Bitcoin and its price dynamics. *arXiv* **2019**, arXiv:1907.03577.
41. Garcia, D.; Tessone, C.J.; Mavrodiev, P.; Perony, N. The digital traces of bubbles: Feedback cycles between socio-economic signals in the Bitcoin economy. *J. R. Soc. Interface* **2014**, *11*, 20140623. Available online: https://royalsocietypublishing.org/doi/abs/10.1098/rsif.2014.0623 (accessed on 1 December 2021). [CrossRef] [PubMed]
42. Liang, J.; Li, L.; Zeng, D. Evolutionary dynamics of cryptocurrency transaction networks: An empirical study. *PLoS ONE* **2018**, *13*, e0202202. [CrossRef]
43. Somin, S.; Gordon, G.; Altshule, Y. Social Signals in the Ethereum Trading Network. *arXiv* **2018**, arXiv:1805.12097.
44. Guo, D.; Dong, J.; Wang, K. Graph structure and statistical properties of Ethereum transaction relationships. *Inf. Sci.* **2019**, *492*, 58–71. [CrossRef]
45. Lin, D.; Wu, J.; Yuan, Q.; Zheng, Z. Modeling and Understanding Ethereum Transaction Records via a Complex Network Approach. *IEEE Trans. Circuits Syst. II Express Briefs* **2020**, *67*, 2737–2741. [CrossRef]
46. Ferretti, S.; D'Angelo, G. On the Ethereum blockchain structure: A complex networks theory perspective. *Concurr. Comput. Pract. Exp.* **2020**, *32*, e5493. [CrossRef]
47. Somin, S.; Gordon, G.; Pentland, A.; Shmueli, E.; Altshuler, Y. ERC20 Transactions over Ethereum Blockchain: Network Analysis and Predictions. *arXiv* **2020**, arXiv:2004.08201.
48. Collibus, F.M.D.; Partida, A.; Piškorec, M.; Tessone, C.J. Heterogeneous Preferential Attachment in Key Ethereum-Based Cryptoassets. *Front. Phys.* **2021**, 568. [CrossRef]
49. Github. Public Python Repository to Plot BTC and ETH Transactions Degree Distributions in Block Slices. Available online: https://github.com/acoxonante/sos (accessed on 26 December 2021).
50. Schlager, K.J. Systems engineering-key to modern development. *IRE Trans. Eng. Manag.* **1956**, *3*, 64–66. [CrossRef]
51. Azani, C.H. System of systems architecting via natural development principles. In Proceedings of the 2008 IEEE International Conference on System of Systems Engineering, Monterey, CA, USA, 2–4 June 2008; pp. 1–6. [CrossRef]
52. Gorod, A.; Sauser, B.; Boardman, J. System-of-Systems Engineering Management: A Review of Modern History and a Path Forward. *IEEE Syst. J.* **2008**, *2*, 484–499. [CrossRef]
53. Dahmann, J.; Baldwin, K.; Rebovich, G. Systems of Systems and Net-Centric Enterprise Systems. In Proceedings of the 7th Annual Conference on Systems Engineering Research (CSER 2009), Loughborough, UK, 20–23 April 2009. Available online: https://www.researchgate.net/publication/228990763_Systems_of_Systems_and_Net-Centric_Enterprise_Systems (accessed on 1 December 2021).
54. Handy, C. Balancing Corporate Power: A New Federalist Paper. Harvard Business Reviw, November–December 2009 Issue, Leadership. Available online: https://hbr.org/1992/11/balancing-corporate-power-a-new-federalist-paper (accessed on 1 December 2021).
55. Roth, N. An Architectural Assessment of Bitcoin: Using the Systems Modeling Language. *Procedia Comput. Sci.* **2015**, *44*, 527–536. [CrossRef]
56. Mylrea, M. Distributed Autonomous Energy Organizations: Next-Generation Blockchain Applications for Energy Infrastructure. In *Artificial Intelligence for the Internet of Everything*; Lawless, W., Mittu, R., Sofge, D., Moskowitz, I.S., Russell, S., Eds.; Chapter 12; Academic Press: Cambridge, MA, USA, 2019; pp. 217–239. ISBN 9780128176368. [CrossRef]

57. Andina, D.; Partida, A. *IT Security Management: IT Securiteers—Setting up an IT Security Function*; Lecture Notes in Electrical Engineering, Book 61; Springer: Berlin/Heidelberg, Germany, 2010; ISBN 9789048188819.
58. Li, X.; Jiang, P.; Chen, T.; Luo, X.; Wen, Q. A survey on the security of blockchain systems. *Future Gener. Comput. Syst.* **2020**, *107*, 841–853. [CrossRef]
59. Vallarano, N.; Tessone, C.J.; Squartini, T. Bitcoin Transaction Networks: An overview of recent results. *Front. Phys.* **2020**, *8*, 286. [CrossRef]
60. Bitcoin. BTC Reachable Nodes. Available online: https://bitnodes.earn.com/ (accessed on 16 December 2021).
61. Ethernodes Dashboard. Available online: https://www.ethernodes.org/network/1 (accessed on 21 November 2021).
62. Ethernodes Dashboard. Available online: https://etherscan.io/nodetracker (accessed on 16 November 2021).
63. Bitcoin Network Hashrate VS Price Explained. Available online: https://stats.buybitcoinworldwide.com/hashrate-vs-price/ (accessed on 3 December 2021).
64. Bitcoin Developer. Bitcoin API. RPC API Reference. Available online: https://developer.bitcoin.org/reference/rpc/index.html (accessed on 21 November 2021).
65. Ethereum API. Ethers.js Library. Available online: https://docs.ethers.io/v5/api/ (accessed on 21 November 2021).
66. Gansler, J.S.; Lucyshyn, W.; Spiers, A. The Role of Lead System Integrator. Available online: https://dair.nps.edu/handle/123456789/2424 (accessed on 1 December 2021).
67. Github. Bitcoin Core Contributors. Available online: https://github.com/bitcoin/bitcoin/blob/master/CONTRIBUTING.md (accessed on 16 November 2021).
68. Nabilou, H. Bitcoin Governance as a Decentralized Financial Market Infrastructure. SSRN. 16 March 2020. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3555042 (accessed on 1 December 2021).
69. Github. Bitcoin Improvement Proposal (BIP). Submission Workflow. Available online: https://github.com/bitcoin/bips#readme (accessed on 16 November 2021).
70. Github. Ethereum Project Management Repository. Available online: https://github.com/ethereum/pm (accessed on 16 November 2021).
71. Github. Ethereum Improvement Proposals. Available online: https://github.com/ethereum/eips/issues (accessed on 16 November 2021).
72. Github. Ethereum Code Repository. Available online: https://github.com/ethereum (accessed on 16 November 2021).
73. Buterin, V. The Most Important Scarce Resource is Legitimacy. March 2021. Available online: https://vitalik.ca/general/2021/03/23/legitimacy.html (accessed on 16 November 2021).
74. Singh, R.; Dwivedi, A.D.; Srivastava, G.; Wiszniewska-Matyszkiel, A.; Cheng, X. A game theoretic analysis of resource mining in blockchain. *Clust. Comput.* **2020**, *23*, 2035–2046. [CrossRef]
75. Cambridge Center for Alternative Finance. Bitcoin Mining Map. Evolution of Country Share. November 2021. Available online: https://ccaf.io/cbeci/mining_map (accessed on 23 November 2021).
76. Conway, L. Thestreet.com. Ethereum Has Lost over 6500 Nodes in the Last Two Weeks. 2021 . https://www.thestreet.com/crypto/ethereum/ethereum-is-still-missing-huge-amount-of-nodes-after-unintentional-hard-fork (accessed on 3 December 2021).
77. Crypto.com. Measuring Global Crypto Users. February 2021. Available online: https://bit.ly/2OujUq9 (accessed on 16 November 2021).
78. Electric Capital. Blockchain Developer Analysis Report. August 2019. Available online: https://bit.ly/328lcdT (accessed on 16 November 2021).
79. Coinmarketcap. Wrapped BTC Market Capitalisation in Real Time. Available online: https://coinmarketcap.com/currencies/wrapped-bitcoin/ (accessed on 16 November 2021).
80. Bitcoin.com. Side-Chaining $3 Billion in Value: There's More Than 141,000 Tokenized Bitcoins Issued on Ethereum. 2020. Available online: https://bit.ly/3rZ1iwe (accessed on 16 November 2021).
81. Binance.com. Tokenized Bitcoin on Ethereum Explained. April 2021. Available online: https://academy.binance.com/en/articles/tokenized-bitcoin-on-ethereum-explained (accessed on 16 November 2021).
82. Coinmetrics.com. BTC ETH Price Correlation. November 2021. Available online: https://charts.coinmetrics.io/correlations (accessed on 4 August 2021).
83. Investopedia.com. Bitcoin's Taproot Upgrade: What You Should Know. Available online: https://www.investopedia.com/bitcoin-taproot-upgrade-5210039 (accessed on 4 December 2021).
84. Bitcoin Lightning Network. Available online: https://lightning.network/ (accessed on 3 December 2021).
85. Ethereum 2.0. Available online: https://ethereum.org/en/eth2/ (accessed on 3 December 2021).
86. Blockchain.com. An Estimation of Hashrate Distribution amongst the Largest Mining Pools. April 2021. Available online: https://www.blockchain.com/charts/pools (accessed on 16 November 2021).
87. Blockchain.com. Top 25 Miners by Block. Available online: https://etherscan.io/stat/miner?range=7&blocktype=blocks (accessed on 16 November 2021).
88. Ethereum.org. Ethereum Improvement Proposals. Available online: https://eips.ethereum.org/all (accessed on 16 November 2021).
89. Oliver Wyman. Crypto-Assets: Their Future and Regulation. Available online: https://owy.mn/2OC6jgE (accessed on 16 November 2021).

90. Miyamae, T.; Honda, T.; Tamura, M.; Kawaba, M. Performance improvement of the consortium blockchain for financial business applications. *J. Digit. Bank.* **2018**, *2*, 369–378.
91. Coincodex.com. Stablecoins by Market Cap and Volume. Available online: https://coincodex.com/cryptocurrencies/sector/stablecoins/ (accessed on 16 November 2021).
92. Greenwald, M.B. The Future of the United States Dollar: Weaponizing the US Financial System. Available online: https://bit.ly/3fZwglF (accessed on 4 December 2021).
93. Finder.com. The Top 50 NFT Collections You Should Know about. Available online: https://www.finder.com/cryptocurrency/nft-collections (accessed on 4 December 2021).
94. Cryptopedia. Gemini.com. What Was the DAO? 2021. Available online: https://www.investopedia.com/tech/what-dao/ (accessed on 3 December 2021).
95. Christin, N. Traveling the Silk Road: A measurement analysis of a large anonymous online marketplace. In Proceedings of the 22nd International Conference on World Wide Web, Rio de Janeiro, Brazil, 13–17 May 2013; pp. 213–224. [CrossRef]
96. Bitcoin.it. Hash. Available online: https://en.bitcoinwiki.org/wiki/Hash (accessed on 4 December 2021).
97. Bitcoin.it. Elliptic Curve Digital Signature Algorithm. Available online: https://en.bitcoin.it/wiki/Elliptic_Curve_Digital_Signature_Algorithm (accessed on 4 December 2021).
98. Ethereum Wiki. Ethash. Available online: https://eth.wiki/en/concepts/ethash/ethash (accessed on 4 December 2021).
99. Github.com. Ethereum Cryptography. Available online: https://github.com/ethereum/js-ethereum-cryptography (accessed on 4 December 2021).
100. Gisin, N.; Ribordy, G.; Tittel, W.; Zbinden, H. Quantum cryptography. *Rev. Mod. Phys.* **2002**, *74*, 145. [CrossRef]
101. Damianou, A.; Khan, M.A.; Angelopoulos, C.M.; Katos, V. Threat Modelling of IoT Systems Using Distributed Ledger Technologies and IOTA. In Proceedings of the 2021 17th International Conference on Distributed Computing in Sensor Systems (DCOSS), Pafos, Cyprus, 14 July 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 404–413. [CrossRef]
102. Irwin, D.A. The Nixon shock after forty years: The import surcharge revisited. *World Trade Rev.* **2013**, 12, 29–56. [CrossRef]
103. Xu, Y.; Liu, X.; Cao, X.; Huang, C.; Liu, E.; Qian, S.; Liu, X.; Wu, Y.; Dong, F.; Qiu, C.-W.; et al. Artificial intelligence: A powerful paradigm for scientific research. *Innovation* **2021**, *2*, 100179. [CrossRef]