5-11-2023

Mindful Design and Operation for High Reliability Autonomous Systems

Jan Schwiderowski
IT University of Copenhagen, schw@itu.dk

Roman Beck
IT University of Copenhagen, romb@itu.dk

MINDFUL DESIGN AND OPERATION FOR HIGH RELIABILITY AUTONOMOUS SYSTEMS

Research Paper

Jan Schwiderowski, IT University of Copenhagen, Copenhagen, Denmark, schw@itu.dk

Roman Beck, IT University of Copenhagen, Copenhagen, Denmark, romb@itu.dk

Abstract

Autonomous systems (ATS) enabled by blockchain and artificial intelligence are hailed to revolutionize our lives and economy. However, ethical concerns and a lack of trust in machines making decisions on their own may explain why these systems are not yet embraced in large scale implementations. In blockchain-based ATSs, doubts have been fueled by failures of large crypto projects believed to be secure, such as the meltdown of the Terra/Luna algorithmic stablecoin (ASC). In this research, we analyze the failure of this ASC system through the lens of mindfulness using secondary data like the project's whitepaper and an interview with its chief executive officer. Hence, we make two contributions: First, we explore and argue for the possibility to mindfully design and operate ATSs as digital high reliability organizations. Second, we build a punctuated equilibrium model of mindfulness in systems. We thus extend the understanding of the design and management of ATSs.

Keywords: autonomous systems, mindfulness, high reliability organizations, blockchain.

1 Introduction

As next generation digitalization it is believed that there will be a move away from the mere automation of systems towards autonomously operating ones. An autonomous system (ATS) encompasses computer algorithms capable of making operational decisions related to prespecified tasks on their own for longer periods of time converting it into a techno-social system (Beck et al., 2022a). Examples are self-driving cars, virtual assistants, wearable augmented reality devices, or automatic portfolio managers (Baird and Maruping, 2021). Two big data-driven technologies play a huge role in ATSs: artificial intelligence and blockchain (e.g., Beck et al., 2022a; Berente et al., 2021). AI-based ATSs are often seen as black boxes with inherent risks where it is hard for users to explain their decisions (Asatiani et al., 2020; Meske et al., 2022). In contrast, blockchain-based smart contracts, executable code that enables trusted transactions and agreements to be conducted automatically, allow for the development of allegedly robust and transparent ATSs in a distributed way among decentralized parties (Beck et al., 2022a; Vacca et al., 2021). Despite being static and unable to self-adapt, smart contracts are the basis for building complex, composable applications, e.g., in decentralized finance (DeFi) (Katona, 2021). Possible advantages are disintermediation, lower transaction costs, and reduced error rates through replacing human with more reliable machine work (Beck et al., 2022b; Y. Chen and Bellavitis, 2020; Salovaara et al., 2019).

So far, ATSs have mainly been deployed to handle limited tasks. Reasons for this are ethical concerns regarding machines acting on their own, a lack of trust into machine agents, and a fear of uncontrollable consequences in case of failures (Beck et al., 2022b; Martin, 2019; Rai, 2020; Teodorescu et al., 2021). In the blockchain space, a lack of trust into such ATSs was reinforced by the collapse of "The DAO", a decentralized autonomous organization that broke down under a hacker attack carried out briefly after it started operating (Dupont, 2017). More recently, another notable blockchain-based ATS failed: the algorithmic stablecoin (ASC) system Terra/Luna (Briola et al., 2023). An ASC is a crypto token (i.e., a cryptographically secured digital token that is connected to a distributed ledger technology system such as a blockchain system) that by using algorithms ensures that its value is fixed to the value of a reference asset (Bullmann et al., 2019; Schwiderowski et al., 2023). In general, stablecoins are supposed to mitigate the huge price variations cryptocurrencies like Bitcoin entail (Jorgensen and Hays, 2022). Terra/Luna is based on the Terra blockchain and was one of the largest blockchain projects (Briola et al., 2023). However, in May 2022, its main stablecoin, TerraUSD, lost its peg to the US dollar and the system caved in within a week (Ruan, 2022). The Terra/Luna system is a highly relevant case to be analyzed in the context of ATSs for two reasons. First, the project's failure happened very unexpectedly and had massive consequences for the whole DeFi and crypto space. Second, despite the more controllable non-self-learning nature, distributed architecture, and alleged transparency of Terra/Luna, the system agglomerated huge risks over time that potentially contributed to its spectacular downfall.

In general, there is a need to find ways to improve the design and operation of ATSs to make them more reliable especially when they deal with tasks of high importance and value. Particular to ATSs is that humans can make more or less mindful strategic decisions on the design and re-design of these systems while the operational decisions are made less mindfully by machines which strictly follow implemented instructions (Salovaara et al., 2019). In information systems (IS) research, mindfulness has been found to be a prerequisite for more reliable information technology (IT) management, IT use and outcomes, and IS development (Dernbecher and Beck, 2017). Moreover, mindfulness is suggested to be an accelerator of individual and organizational reliability in the creation, management, and use of complex and imperfect systems (Butler and Gray, 2006). In this conceptual research, we thus explain how a mindful design and re-design can make ATSs more reliable by mitigating the problem that ATSs strictly operating as implemented are over time increasingly misaligned with their environment.

Based on the illustrative example of the Terra/Luna ASC, we identify and expand on indicators of more and less mindful decision making of Terraform Lab which maintains Terra/Luna. Hereby, we use secondary data which encompass Terra/Luna's whitepaper (Grobys et al., 2021), an interview with Terraform Lab's co-founder and chief executive officer Do Kwon (Guzman and Abrams, 2022), and other academic and non-academic sources. In this way, we make two theoretical contributions. First, using the lens of complex adaptive systems, we shed light on the possibility to mindfully design and operate an ATS as a digital high reliability organization (HRO) (Salovaara et al., 2019; Weick et al., 1999). We hence, extend the work of Salovaara et al. (2019) in three ways: We provide a complex adaptive systems view on digital HROs, discuss ATSs as digital HROs, and distinguish between mindful managerial decisions in the design and operation phase of ATSs. Second, we develop a punctuated equilibrium model of mindfulness in systems. Thereby, we enhance Dernbecher and Beck (2017)'s IS mindfulness theory by extending the concept of mindfulness to the system level and explaining the need of injections of mindfulness into a system to raise its long-term reliability in a dynamically changing environment. Thus, we answer the research question: *How can mindful design and operation turn ATSs into digital HROs?*

The remainder of this paper is organized as follows. First, we provide an overview of the theoretical and methodological background of this study. We then analyze indicators for rather more and less mindful decision making in Terra/Luna. Next, we discuss theoretical and practical implications of this analysis. We conclude this article by summarizing our main findings.

2 Theoretical Background

2.1 Digital High Reliability Organizations and IS Mindfulness

Originating from normal accident theory, HROs have been researched within different contexts as diverse as air traffic control, nuclear power plants, or hostage negotiations (Linnenluecke, 2017; Thatcher et al., 2018). By focusing on underlying social and organizational processes and interactions, HRO theory explains how safety and the prevention of accidents can be achieved in complex systems (Salovaara et al., 2019). HROs achieve reliability even in hazardous environments by enculturing five intertwined processes: deference to expertise, commitment to resilience, reluctance to simplify, preoccupation with failure, and operational sensitivity (Weick and Sutcliffe, 2006). With IT becoming ubiquitous, it is necessary to analyze HROs in digital contexts too. Digital HROs have been defined as organizations operated purely digitally without human involvement in operational decision making (Salovaara et al., 2019). Examples for digital HROs are certain information security companies (Salovaara et al., 2019).

Research on HROs is linked to research on mindfulness and especially organizational mindfulness (Vogus and Sutcliffe, 2012). Mindfulness in IS has been investigated on different levels (i.e., the individual, team, and organizational level) and with different application purposes (i.e., as prerequisite, accelerator, and implication) (Dernbecher and Beck, 2017). Organizational mindfulness has hereby been characterized as a top-down approach which creates the environment for thinking and action on the front line and as a relatively enduring property of an organization similar to a culture (Vogus and Sutcliffe, 2012). Mindfulness allows for extending environment scanning, generating more context relevant interpretations, and creating more discriminating decision behavior (Weick and Sutcliffe, 2006). Thus, it can be a key in making evidence-based rational decisions, e.g., by abstaining from blindly following routines and deferring decisions to the people most capable of making them (Butler and Gray, 2006; León and Mu, 2021; Sun et al., 2016; Weick et al., 1999). Mindful behavior has been characterized as a continuum ranging from more to less mindful where the latter, for instance, materializes in unreflectively and narrow-mindedly following procedures whilst ignoring the greater context and alternative solutions (Carlo et al., 2012; Levinthal and Rerup, 2006; Salovaara et al., 2019; Weick et al., 1999). An example for little mindful behavior is digital operations executed step by step as implemented by computer programs (Salovaara et al., 2019). Lastly, Dernbecher and Beck (2017) have initiated a multi-level theory of IS mindfulness based on the idea of a dual structure. In this theory, mindfulness shapes IT artifacts (e.g., using mindfulness when designing a system) and IT artifacts facilitate mindfulness (e.g., drawing on mindful characteristics which the system internalized when it was designed).

2.2 Complex Adaptive Systems and Punctuated Equilibrium Models

Both theories on complex adaptive systems and on punctuated equilibria have originated in the natural sciences and been adopted by IS and organizational scholars to analyze various phenomena. An example is the explanation of change like organizational (e.g., Dooley, 1997) and IS change processes (e.g., Lyytinen and Newman, 2008). Another example is alignment processes such as IS-organization alignment (e.g., Sabherwal et al., 2001) and business-IS alignment (e.g., Merali et al., 2012). Complex adaptive systems are systems of interacting agents located in a changing environment. They can be characterized by concepts such as co-evolution, emergence, self-organization, fitness landscape, edge of chaos, dynamism, non-linearity, as well as adaptation (e.g., Onik et al., 2017).

Punctuated equilibrium models, in turn, are used to describe system states in the form of dynamic phase models. A system (e.g., the Terra/Luna ASC system) acting in line with punctuated equilibria is characterized by long periods of stability (equilibrium periods) in which only minor changes to the system's internal (e.g., the Terra ecosystem) or external environment (e.g., the wider socio-technical environment) occur. However, there are also revolutionary periods in which the system adjusts to acute and often unexpected environmental changes. These periods are triggered by so called punctuations which are events to which the system is unable to incrementally adapt with (Street and Denford, 2012).

2.3 Autonomous Systems and Algorithmic Decision Making

The design (i.e., planning, development, and implementation) and operation (i.e., running or execution) of socio-technical systems has always been one of the core elements of the IS discipline (Sarker et al., 2019). In recent years, the focus has increasingly shifted to automatic systems and even ATSs in which humans and machines interact in a symbiotic manner (Beck et al., 2022b; Jain et al., 2018). ATSs are characterized by that machines have at least some form of agency, that means the capacity to perform actions on their own for example through computation (i.e., algorithm-based agency) over longer periods of time (Baird and Maruping, 2021; Beck et al., 2022b, 2022a; Zhang et al., 2021). IT-based artifacts like virtual assistants, bots, autonomous vehicles, or blockchain-based smart contracts are usually designed to make rational and autonomous decisions and can be considered agents within these systems (Baird and Maruping, 2021; Lauslahti et al., 2017; Scholz, 2017). Algorithms governing stablecoins are able to make autonomous decisions through automatic execution and can thus be seen as prescriptive agents (Baird and Maruping, 2021). Algorithm here means a "set of encoded procedures for transforming input data into a desired output, based on specified calculations" (Gillespie, 2014, p. 1). These procedures include both the naming of a problem and the steps to solve it (Gillespie, 2014). Algorithms are static and meaningless machines unless they are connected to a database such as a blockchain (Gillespie, 2014). Once algorithm-based agents operate, they interact with other human and machine agents to complete pre-specified tasks (Lazer, 2015; Shaikh and Vaast, 2022). However, there is an ongoing debate about to which degree such agents can in fact operate autonomously (Shaikh and Vaast, 2022). In general, the cooperation between humans and machines in system design- and operation-related decision making can occur either by humans supporting machines or machines supporting humans (i.e., augmentation) (Berente et al., 2021; Teodorescu et al., 2021). As they have different capabilities, it is critical which tasks are best delegated to humans and which to machines (Agrawal et al., 2018; Fügener et al., 2022). In workplaces like some online labor platforms where algorithms serve as employers for humans, this can require sincere ethical considerations (Möhlmann et al., 2021; Teodorescu et al., 2021). Algorithms and computational agents act in the way they are implemented and hence little mindfully; only humans can make mindful decisions of which they need to be aware (Salovaara et al., 2019).

2.4 Algorithmic Stablecoins

Stablecoins are blockchain-based digital currencies intended to mitigate problems of centralized fiat currencies (e.g., high intermediation costs) and to be a more stable alternative to cryptocurrencies such as Bitcoin (Jorgensen and Hays, 2022; Lyons and Viswanath-Natraj, 2020). Stability in the context of stablecoins often means that the stablecoin token keeps a pre-defined peg to another asset which mostly is the US dollar (Grobys et al., 2021). First studies indicate that at least some stablecoins might indeed be relatively stable compared to Bitcoin but considerably less stable than centralized fiat currencies (Hoang and Baur, 2021). There are several design dimensions which affect the monetary stability of stablecoins (Jorgensen and Hays, 2022). In general, two features are of relevance when it comes to the stability of a currency. The first one is stable underlying and collateral assets such as gold or foreign reserves as backings. The other one is a central controlling authority like a central bank for national currencies which can intervene if the price of a currency leaves a desired range (Grobys et al., 2021).

Depending on their collateralization (i.e., securitization with other assets), three pure types of stablecoins can be distinguished. Fiat-collateralized (off-chain) stablecoins are backed by a national currency. Crypto-collateralized (on-chain) stablecoins use cryptocurrencies as backings. ASCs are ruled by hard-coded smart contracts which maintain prices stable and are often under- or not collateralized at all (Bullmann et al., 2019; Grobys et al., 2021). They are frequently issued in exchange for on-chain assets which the smart contract then holds as reserve. The smart contract contains rules on the issuance of ASC units and thus how the supply stays in balance with the demand so that the stablecoin's value maintains parity with its reference asset (Bullmann et al., 2019). For this, the smart contract needs information regarding the demand for and supply of the stablecoin which are often delivered by smart contracts called oracles that keep up-to-date order books at relevant marketplaces (Bullmann et al., 2019; Caldarelli, 2020). Smart contracts are also supposed to re-establish the peg between a stablecoin and its reference currency in case of a deviation, usually by adjusting the stablecoin's supply (Bullmann et al., 2019).

Lastly, three forms of ASCs can be distinguished. Rebase-type ASCs manage price-elastic ERC20 tokens. Their total supply is variable and regularly adjusted depending on changes in the tokens' price. Seignorage-type ASCs are usually based on two forms of cryptocurrencies, stablecoins (tokens) and seigniorage ownership (shares) and use a mint-burn process. Minting here refers to the creation of new tokens and burning to the removal of existing ones. When the stablecoins' price exceeds the intended peg, shares are used to bring up their supply. Seigniorage-type stablecoins also often issue a redeemable bond to incentivize buyers when the price drops below the peg. Partial-collateral-type or fractionalized ASCs blend features of collateralized and algorithmic ones. Other than collateralized ones, they avoid over-collateralization and reduce custodial risks. Contrary to algorithmic ones, they keep a tight peg with the reference currency (Ante et al., 2023; Zhao et al., 2021).

3 Research Method and Case Description

This conceptual research uses the illustrative example of the break-down of the Terra/Luna ASC system to discuss mindfulness in the design and operation of ATSs. Given that this collapse only happened in May 2022, published academic articles and background information on the case are still rare. To find relevant information for this study, we therefore conducted a broad search for related academic articles, news articles, and grey literature such as reports and whitepapers on Google and Google Scholar using the search string "'terra' AND 'luna' AND 'blockchain' AND 'stablecoin'". We read the found sources, identified relevant, and sorted out redundant ones. The main information sources we finally used in this study are Terra/Luna's whitepaper (Kereiakes et al., 2019), a peer-reviewed journal article analyzing the system's collapse (Briola et al., 2023), a news article summarizing events likely contributing to Terra/Luna's breakdown (Sandor and Genç, 2022), and a recent interview with Terraform Lab's co-founder and chief executive officer Do Kwon (Guzman and Abrams, 2022).

Terraform Lab released the Terra blockchain and payment platform in July 2019. The Terra blockchain, a delegated proof of stake blockchain (Saleh, 2021), was governed by a community. However, this community was strongly dominated by few individuals and especially Do Kwon and Terraform Lab when it came to system design and re-design decisions. Terra was mainly used for pegging ASCs to different currencies (Kereiakes et al., 2019). Its most popular stablecoin was TerraUSD which was pegged to the US dollar. Together with Terra's native Luna token, which is normally used for staking on governance votes, TerraUSD formed a two-coin seignorage ASC system (i.e., Terra/Luna). Hereby, at all times one Luna token could be swapped (i.e., exchanged) for one TerraUSD and vice versa using Terra's algorithmic market module smart contract (Kereiakes et al., 2019). This design was supposed to allow Luna to absorb TerraUSD's volatility so that it could keep its peg. Specific conditions needed to be met for Terra/Luna to work. First, independent actors with market-based incentives were needed to engage in price stabilizing activities. Terraform Lab intended to achieve this by designing arbitrage incentives into their system. Whenever TerraUSD's price exceeded one US dollar, arbitrageurs could profit by swapping Luna for TerraUSD through the market nodule (i.e., TerraUSD is minted and Luna is burnt) thus increasing the supply for TerraUSD which was supposed to lower TerraUSD's price. In the contrary case, arbitrageurs were incentivized to swap TerraUSD for Luna (i.e., Luna is minted and TerraUSD is burnt) which was intended to reduce the supply of TerraUSD hence raising its price (Briola et al., 2023; Kereiakes et al., 2019). Second, for the system to operate stably, a sufficient level of demand was needed. This was encouraged by later adding a savings protocol called Anchor to the Terra ecosystem allowing for lending and borrowing TerraUSD. Another protocol later added is Mirror which creates synthesized assets that can track the performance of certain US securities hence facilitating investments on Terra (Sandor and Genç, 2022). Lastly, reliable price information was required. As this information is exogeneous to the blockchain, it was included via decentralized miner oracles (Kereiakes et al., 2019).

On its peak, the Terra blockchain was one of the biggest blockchain ecosystems. In April 2022, the Luna token achieved its all-time high with a price of 120 US dollars per token and a market capitalization of 40 billion US dollars (CoinMarketCap, 2022). Terra was even seen as a frontrunner in interlinking the cryptocurrency and the real economy through its consumer payment app Chai which allowed to pay vendors in Terra stablecoins (Howe, 2021). Even shortly before its crash, TerraUSD was the fourth largest stablecoin by market capitalization (Briola et al., 2023). However, between May 7th and May 13th, 2022, an unrecoverable de-peg of TerraUSD from the US dollar took place. Two suggested causes for this were a huge short-sale of Bitcoin and a simultaneous attack on the Curve3pool liquidity pool (i.e., a smart contract-based pool of crypto tokens) used by Terra/Luna (Briola et al., 2023). At this time, the pool was weakened due to Terraform Lab transferring funds to another liquidity pool, Curve4pool. It is yet unclear if these events were a coordinated attack on the Terra ecosystem or the undeliberate result of unrelated actions (Briola et al., 2023). Although Luna Foundation Guard, an association founded in early 2022 to support the Terra ecosystem by managing reserves, counteracted immediately, the trend could not be reverted. Many users lost their trust and left Terra/Luna in a fashion compared to a bank run (Briola et al., 2023). Ultimately, this led to the decision to abandon the system and conduct a hard fork on the Terra blockchain. This effectively split the Terra system into the old one now called

TerraClassic around which a new community has formed and a new one called Terra 2.0 (Briola et al., 2023; Sandor and Genç, 2022). Both systems are running at the time of writing but are much smaller than the old system at its peak. The major events of the Terra/Luna system are summarized in Figure 1.

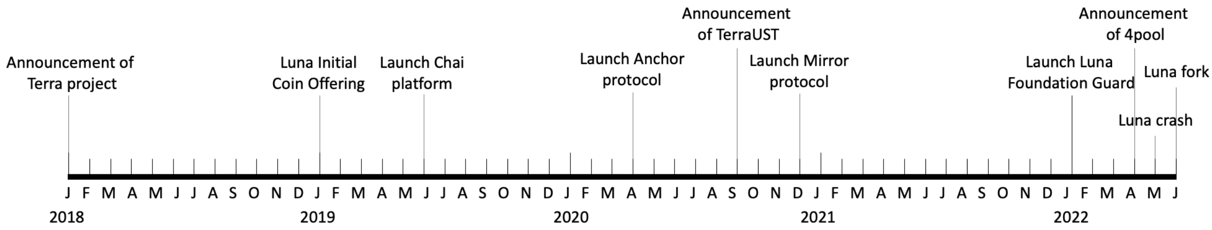

Figure 1. Timeline of major events (punctuations) in the Terra/Luna ASC system.

4 Analysis

In this section, for each of the five cognitive processes of HROs presented by Weick et al. (1999), we first explain what this process means. We then sequentially discuss for each of them indicators for more or less mindful decision making first in the design and then the operation (including re-designs) phase of ATSs by drawing on the example of Terra/Luna. Our main findings are summarized in Table 1.

4.1 Deference to Expertise

Deference to expertise is the process of being willing to delegate decision making to the people best able to focus on and deal with the situation at hand (Vogus and Sutcliffe, 2012). This behavior of mindful organizations is contrary to blindly following procedures and handing off responsibility within a hierarchy which is often found in less mindful organizations. However, in algorithm-based organizations, it is not only about delegating decision making to the most capable human agent but also to algorithms where they are most suitable to making the decision. As algorithms and humans have different strengths and capabilities it is therefore critical for the overall performance, which tasks are performed by which of these agents and how they collaborate (Fügener et al., 2022; Haesevoets et al., 2021).

This has implications for the design and operation of ATSs. In the design phase of an ATS, humans supported by technology search for information relevant to define the problem the algorithms are to solve and specify the steps how the algorithms solve the problem (Gillespie, 2014). It is humans who make the design decisions and who need to be mindful to incorporate all important information. This is because, once an ATS is running, it runs in accordance with the pre-specified procedures. If the problem formulation or the procedures to solve it are flawed, the system is probably to act in an undesired way. However, humans have bounded rationality and it is hence likely that they do not foresee all relevant scenarios when defining an algorithm (Salovaara et al., 2019). Human agents and especially system designers need to be mindful of this frame problem and price it in when designing an algorithmic system. Taking the example of Terra/Luna, the system designers considered this by allowing interventions (or punctuations) into the ATS. The possibility for interventions of central authorities into currency systems especially in crisis situations is regarded as an important risk mitigation and stability measure for example in national currency systems and hence indicates rather mindful reasoning (Grobys et al., 2021).

In the operations phase, an ATS runs and makes decisions with low mindfulness in line with the procedures defined in its algorithms (Salovaara et al., 2019). In ASC systems, algorithms decide if tokens need to be minted or burnt. It is possible for developers and designers though to intervene into the system. This happened several times in the Terra/Luna project. One example is the introduction of a liquidity pool called Curve4pool in collaboration with DeFi projects. The purpose was to increase the utility of Terra's stablecoins (Briola et al., 2023). However, moving funds from the hitherto used Curve3pool caused a transitory situation that weakened the liquidity basis of the system (Briola et al., 2023). This punctuation turned out to be one of the likely causes of Terra/Luna's downfall. Thus, it points to a little mindful decision that insufficiently considered the risk induced into the system by the liquidity pool transition. The riskiness of this move was even still underestimated when Curve3pool was already under attack. This is illustrated by Terraform Lab's Do Kwon stating:

"And my first reaction is, you know, this has happened before." (Guzman and Abrams, 2022).

4.2 Commitment to Resilience

Commitment to resilience is the process of detecting, containing, and eventually bouncing back from inevitable errors to a dynamically stable state. It means that highly mindful organizations are able to continuously manage fluctuations. Resilience can be increased through anticipation and improvisation (Rerup, 2001). Anticipation means the ability of an organization to forecast future states which helps it finding possibilities to survive and thrive. Improvisation is an organization's ability to deliberately merge the design and execution of a novel production (Cunha et al., 2017; Miner et al., 2001). It allows an organization to react in near real-time to triggers like problems, opportunities or experiential enrichment and come up with adequate responses (Ciuchta et al., 2021).

In the design phase of an ATS, it is hence important to anticipate future states of the system. Humans design the system in a way that it can handle all task-relevant foreseeable internal and external environmental events. This can be facilitated by a high degree of mindfulness of what is and could be happening within the system and its environment. In case of the Terra/Luna system, there were for instance early warning signals that the system and ASCs in general might be susceptible to certain types of attacks (e.g., Soros attacks) that could break the peg of TerraUSD to the US dollar (e.g., Hileman, 2019; Sandor and Genç, 2022). Do Kwon constantly rejected the possibility of such attacks succeeding in taking down the Terra/Luna system (Guzman and Abrams, 2022). Even though it is unclear if Terra/Luna fell victim to a coordinated attack (Briola et al., 2023), the categorical ruling out of the possibility of Terra/Luna collapsing hints towards a lack of mindful strategic thinking (Steptoe-Warren et al., 2011).

In the operations phase, the system needs to be able to deal with all kinds of situations which especially includes unforeseen and thus unplanned for developments. However, algorithmic systems are not capable of dealing with situations they are not designed for (Salovaara et al., 2019). In addition, system developers might not be prepared and are thus unable to fall back on established procedures and routines to cope with the emergent issue. Hence, to handle such a situation requires the ability to improvise in the form of mindful human interventions into the system to adjust it so that it becomes able to function as desired in this type of situation too. In the case of blockchain-based systems, this can for instance happen through either backward-compatible soft or backward-incompatible hard forks of the underlying blockchain protocol (Andersen and Ingram Bogusz, 2019). This is what happened in the Terra/Luna system as well after the Terra ecosystem, to the surprise of the system's management, collapsed, in an attempt to save the Luna token. A hard fork was conducted splitting the system into an old chain called TerraClassic and a new chain called Terra 2.0 (Kim et al., 2022).

4.3 Reluctance to Simplify

Reluctance to simplify interpretations is the process of taking into consideration that simplifications might lead to overlooking potentially unexpected positive or negative consequences (i.e., opportunities and threats) (Vogus and Sutcliffe, 2012). Therefore, more mindful organizations limit assumptions, improve the sensing capabilities of their employees, choose new employees with varying prior experience, enable job rotation, and stimulate skepticism (Weick et al., 1999). They focus on what they have overlooked while less mindful organizations tend to ignore this (Pearson and Mitroff, 1993).

For the design of an ATS, this underlines the need of a detailed consideration of the system's environment. Complex IS such as ASCs are at the risk that events occur that cause a misalignment either within the system or between the system and its environment. This could potentially lead to irreversible dynamics and chaos which endanger the system's existence (Benbya et al., 2020). A mindful and proactive scanning of the system and its environment, already during the design phase is thus important to reduce the likelihood of uncontrollable death spirals. In Terra/Luna's initial set up, the designers abstained from including a reserve base in the system despite adequate and stable reserves being known survival mechanisms of currencies (Grobys et al., 2021). This suggests that the system designers simplistically assumed the algorithm itself to be able to keep the system in balance. Hence, this points to them being rather less mindful of the risks of a complex ASC system.

However, not only during the design phase but also while an ATS operates, it is vital to pro- and reactively sense the system and its environment for strong and weak signals of potential threats and opportunities (Pinsonneault and Choi, 2022). An earlier detection of a threat improves the chances to contain it and protect the system. Thus, a mindful control and monitoring of an ATS is important. This can also be done automatically like on some online labor platforms (Möhlmann et al., 2021), which, in turn, requires the mindful design of automatic monitoring and control mechanisms. In January 2022, the Luna Foundation Guard was created to accumulate and manage reserves that could help stabilizing Terra/Luna if the US dollar peg got under pressure (Briola et al., 2023; Sandor and Genç, 2022). This move reflects mindfulness of the risk that the peg could be lost. It thus represents a deviation from the initial design principle which based the system's stability almost entirely on its incentive mechanisms to induce a sufficiently large adoption of TerraUSD and Luna (Kereiakes et al., 2019). Nonetheless, an irreversible dynamic sending Terra/Luna into a death spiral occurred despite Luna Foundation Guard immediately buying back large amounts of TerraUSD using its reserves (Briola et al., 2023; Sandor and Genç, 2022). One reason for this could be that Bitcoin was used as main collateral in the Terra/Luna system which itself is an unstable currency (Osterrieder and Lorenz, 2017; Sandor and Genç, 2022). The decision for using Bitcoins as main reserve asset instead of more stable alternatives such as fiat currencies is another indicator for a low degree of mindfulness of the complexity and risks of ASC systems.

4.4 Preoccupation with Failure

Preoccupation with failure is the process of actively considering the possibility of failure that uses any failure or close call as an indicator of potentially larger problems (Sutcliffe et al., 2016). More mindful organizations treat failures and near misses as opportunities for reflecting of the system status from which they can learn and gain experiences (Weick et al., 1999). Hence, mindfulness allows organizations to sense both threats and opportunities (Gärtner, 2011). This is contrary to less mindful organizations which tend to focus on localizing failures instead of learning from them (Weick et al., 1999).

When designing an ATS mindfully, system designers and developers are aware of errors that they have committed previously. They also consider failures made on similar projects. For example, they learn from failures in the design of other autonomous blockchain projects such as "The DAO" (Dupont, 2017). Besides, they comprehend that there can be future situations they are currently unable to foresee in the design of the system. Ideally, they design the system so that it leaves them actionable digital or real options for later system re-design to react to these situations when they arise (Sambamurthy et al., 2003; Sandberg et al., 2014; Trigeorgis and Reuer, 2017). As is the case in the design of digital platforms, options allow for better balancing commitment and flexibility in the architecture and governance of an ATS and can be exercised during its operation when a threat or opportunity arises (Tiwana et al., 2010; Trigeorgis and Reuer, 2017). However, the design of actionable digital or real options into a system usually requires an up-front investment (Sandberg et al., 2014) of which designers need to be mindful too. In Terra/Luna, one option enabled by the flexible design of the Terra blockchain, was to later add other smart contract-based decentralized applications to the ecosystem (Briola et al., 2023; Sandor and Genç, 2022). In DeFi, this flexible design feature is referred to as composability (e.g., Katona, 2021).

Also, during the operations phase, mindful system designers keep in mind that failures can occur or even have already occurred but not yet materialized. They check and control the autonomously running system constantly to detect potential failures early on and ideally correct them quickly. One way to react to strong or weak signals of failure, is to exercise adequate options built into the system in the design phase. In Terra/Luna, the system designers intervened into the system by exercising the option to add the consumer payment app Chai on top of the Terra blockchain (Howe, 2021). Chai used stablecoins minted on the Terra blockchain for paying vendors of which many users due to the resemblance of the app with non-blockchain-based applications were unaware. Hence, despite initially only being used in South Korea, the app supported the adoption of TerraUSD. Terraform Lab's decision to integrate Chai into the

Terra ecosystem and using Terra stablecoins in the background therefore indicates a mindful consideration of the need for a high adoption rate of Terra/Luna to keep the system stable. However, it also further increased the complexity of the Terra ecosystem. This might have contributed to Terraform Lab missing a critical early warning signal of problems with Terra/Luna when they did not notice that Chai at the end of 2021 ceased to use Terra as stated by Terraform Lab's Do Kwon:

"By that point, other things in Terra were so large that I just wasn't paying attention to Chai very much. But that's definitely one of those things that we should have picked up on." (Guzman and Abrams, 2022).

4.5 Operational Sensitivity

Sensitivity to operations is the process of creating and maintaining an up-to-date and integrated big picture of the operational level. This implies that a mindful organization is attentive to and situational aware of its operations. Hence, errors can be identified early and the probability of surprises be reduced (Vogus and Sutcliffe, 2012; Weick et al., 1999). The operational decisions in ATSs are made by algorithms and thus little mindfully to which mindful organizations pay attention (Salovaara et al., 2019).

Blockchain-based systems such as ASCs induce their own economies (Beck et al., 2018). An important aspect in the design of such an ATS is their governance structure which shapes the systems' automatic and hence little mindful operational level. In blockchain systems, implicit and explicit rules are hard-encoded in protocols and smart contracts (De Filippi and Wright, 2018; Reijers et al., 2021). Hereby, three different elements of blockchain governance can be distinguished: decision rights, accountability, and incentives (Beck et al., 2018; Weill, 2004). Especially incentive mechanisms play a crucial role in the operations of ASCs. This is because they enable regulating and modifying user behavior in a desired way in algorithmic governance systems (Beck et al., 2018; Katzenbach and Ulbricht, 2019). The stability of ASC systems heavily depends upon a high rate of adoption. At Terra/Luna, the initial idea was to drive adoption almost exclusively via an efficient fiscal policy enabling arbitrage opportunities and network effects (Kereiakes et al., 2019). This purely algorithmic governance was very risky as mechanisms to react to a possible de-peg were limited.

Once designed, a blockchain-based ATS runs according to the hard-coded rules in its governing protocol (Beck and Jain, 2023). However, while in principle possible, its governance structure is often not completely algorithmic but entangled in the social and material space (Zook and Blankenship, 2018). Thus, from a systems thinking view (Arnold and Wade, 2015), blockchain systems can be seen as hard systems embedded in soft systems (Beck and Jain, 2023). For example, Terra/Luna was built on the Terra blockchain which allows for integrating additional protocols. Two protocols added to Terra's ecosystem are the synthetic asset protocol Mirror and the savings protocol Anchor which strongly affected Terra/Luna's operations. Mirror provided real world price data (e.g., from US stocks). However, the protocol was vulnerable to different attacks of which Terraform Lab only learned with a delay and thus reacted slowly to (Newar, 2022). Anchor allowed users to lend and borrow capital using bonded assets as collaterals. It promised investors a 20 percent annual percentage rate. Especially Anchor was probably one of the main incentives driving Terra/Luna's rapid adoption (Briola et al., 2023). The protocols' integration hence showed concern for the stability of the system which was strengthened by higher adoption rates and stronger network effects. However, it also made Terra more vulnerable to attacks and exposed it to extreme market conditions as constant cash injections were needed to meet the promised annual percentage rates (Briola et al., 2023). This suggests a lack of mindful system's thinking with respect to the effects of changes to the system's governance on its operational level (Arnold and Wade, 2015). This is underlined by Do Kwon saying about Anchor's annual percentage rate:

"This was still when DeFi yields were in full bloom, and there were tons of DeFi launches that were targeting stablecoin deposits, offering several hundred percent APRs [annual percentage rates], several thousand percent APRs." (Guzman and Abrams, 2022).

Mindfulness Process	**Theoretical Perspective**	**Example from Terra/Luna**	**Mindful Design of ATSs**	**Mindful Operation & Re-Design of ATSs**

deference to expertise	human-machine delegation	Curve4pool transition	enabling (central) interventions	(central) intervening in line with system goal
commitment to resilience	organizational resilience	Terra protocol fork	anticipating future system states	improvising system interventions
reluctance to simplify	signal and complexity theory, sensemaking	Luna Foundation Guard	considering system's environment	sensing of/ reacting to environmental signals
preoccupation with failure	digital and financial options theory	Chai payment app	integrating digital and financial options	exercising digital and financial options
operational sensitivity	IT and algorithmic governance	Anchor protocol integration	building holistic governance system	adapting holistic governance system

Table 1. Summary of findings for mindful design and re-design of ATSs.

5 Discussion

From our elaborations on mindful decision making in Terra/Luna, several insights can be taken. We first discuss implications for ATSs as digital HROs using the lens of complex adaptive systems (Benbya et al., 2020; Holland, 1992; Salovaara et al., 2019). We then develop a punctuated equilibrium model of system mindfulness (e.g., Sabherwal et al., 2001) in the design and operation of ATSs thus extending Dernbecher and Beck (2017)'s theory of IS mindfulness. We end this section by discussing practical implications, expanding on limitations of this study, and providing guidance for future research.

5.1 Autonomous Systems as Digital High Reliability Organizations

In learning (e.g., self-driving vehicles) and non-learning (e.g., decentralized exchanges) ATSs, human and machine agents interact in the design, operation, and use of these systems. Humans (e.g., managers, designers) are responsible for making strategic decisions on the design and specify both the systems' purpose and the procedure to achieve it. This is usually done by setting up machines such as computer programs and algorithms (e.g., smart contracts) with which the operational decision power resides. On the user side, it is also humans (e.g., crypto investors, riders in self-driving cars) and machines (e.g., self-driving cars, smart contracts trading crypto tokens) who through their interrelated actions form the system. Machines hereby take over a dual role by being the system itself and agents within the system (Baird and Maruping, 2021). Smart contract-rooted ATSs even represent new forms of machinery intermediaries that take over tasks of established intermediaries (Feulner et al., 2022). Similar to digital platforms (e.g., Tiwana et al., 2010), such ATSs consist of an architectural core, a hard system operating them, as well as a governance structure, a soft system defining how they operate (Beck and Jain, 2023).

However, ATSs are not only hard systems embedded in soft systems but also part of a wider socio-technical environment with which they interact (Beck and Jain, 2023; H. Chen et al., 2021). For example, a self-driving car operates on physical roads with other machines (e.g., other self-driving cars) and humans (e.g., pedestrians). The diversity of agents in an ATS (e.g., different machines and humans), the connectedness and mutual dependency of these agents and the system itself to its environment (e.g., the need of a self-driving car for roads to drive on), as well as the ability of the system to adapt to environmental changes, make ATSs complex adaptive systems (Benbya et al., 2020). The point of adaptation is worth a deeper look. ATSs operate in line with prespecified procedures. While learning ATSs can adapt to a certain extent by adjusting based on feedback they receive on their actions (Stein et al., 2018), non-learning ATSs strictly convert the same inputs into the same outputs. However, the environment of ATSs is constantly evolving. Over time there is an expanding gap between the environment for which an ATS was designed to operate in and the actual environment it does operate in and with which it would need to co-evolve to stay stable and not drift into a state of chaos (Benbya et al., 2020). There is controversy around to which extent ATSs are able to self-manage this co-evolvement (Baird and Maruping, 2021; Shaikh and Vaast, 2022) fueled by prominent failures like "The DAO" or Terra/Luna. Terra/Luna faced a sudden discontinuity (non-linearity) and drifted into chaos when the value of TerraUSD, designed to be at one US dollar (attractor), dropped to almost zero (new attractor) (Benbya et al., 2020).

From this discussion of ATSs as complex adaptive systems, several insights for the mindful design and operation of ATSs as digital HROs can be drawn. As ATSs operate with little mindfulness (Salovaara et al., 2019), it is vital that designers develop them so that they cannot only excel in the current but also future environment states. Capturing all relevant aspects for the design of these complex systems requires designers to be reluctant to simplify and aware of the interconnectedness of an ATS's different components and its environment. Of particular importance is the design of an adequate governance that reflects technical and social aspects of an ATS and its environment as the ATS will operate abiding by the rules defined here. This requires a mindful scenario analysis of possible future system and environmental states to make the system more resilient. It can also help designers to raise their awareness that they will never be able to anticipate every future scenario in which the system has to operate (frame problem) (Salovaara et al., 2019). This shows a preoccupation with failure which is needed to avoid and learn from errors. One way to prepare for this is to build options into the system that allow upon later exercise to deal with environmental changes (Sandberg et al., 2014). However, no matter how mindful an ATS's design (e.g., by mindful work coordination between and among machine and human agents), environmental changes will ultimately lead to the system struggling to fulfil its purpose. A re-design of the system is then needed. Such interventions can happen proactively after the early recognition of strong or weak signals of opportunities for or threats to the system, or reactively after an opportunity or threat has materialized. An intervention that adequately considers the pre- and post-intervention state of an ATS reflects sensitivity for its operations on the part of the designers. One way to intervene into an ATS is to exercise purposefully designed options into which already has been invested (i.e., real and actionable digital options). The system's resilience can also be raised by improvising and exercising shadow or available digital options that were not purposefully designed into the system or have previously not even been recognized (Sandberg et al., 2014). The timely sensing of relevant strong and weak environmental signals can be facilitated by mindfully monitoring and controlling the operation of the system.

A final remark: A mindful system designer is not a "homo mindful" in the sense of an unboundedly rational person with unlimited (cognitive) resources who can always predict the future and has perfect knowledge of the world. Even the most mindfully designed system will break eventually. That means, even if Terra/Luna for instance were designed more mindfully, the structural weaknesses of ASC systems (e.g., the need for high adoption rates) might be such inherent flaws that every such system is bound to fail (e.g., Clements, 2021). However, we argue that the mindful design and operation of ATSs, as has been shown in digital and other HROs before, can help achieving higher reliability in ATSs too.

5.2 Punctuated Equilibrium Model of System Mindfulness

The design and operation of an ATS as a digital HRO, similar to other forms of organizations, can be seen as a process of organizational change or transformation that can be explained by a punctuated equilibrium model (e.g., Romanelli and Tushman, 1994; Sabherwal et al., 2001). The punctuations in this model are the interventions (i.e., re-design decisions) into the otherwise self-operating system and can be conducted in a more or less mindful way. The practice of mindfulness comes at a cost and thus needs to be carefully weighed against potential frame problems resulting from a less mindful design (Hales et al., 2012; Salovaara et al., 2019). However, as an ATS operates little mindfully, it seems important that the system is designed in a mindful way so that it internalizes mindful characteristics which in turn facilitate mindfulness when the system is adopted or integrated (Dernbecher and Beck, 2017). A system's degree of mindfulness tends to decrease naturally over time due to changes in the system's environment which reduce the system's alignment with this environment. To account for this increasing misalignment, mindful punctuations in the form of decisions that reflect and induce deference to expertise, commitment to resilience, reluctance to simplify, preoccupation with failure, and sensitivity to operations are required. However, while more mindful design or re-design decisions increase the extent of mindfulness of the system again hence facilitating the system's alignment with its environment, less mindful decisions tend to further decrease it making a consequential misalignment more likely. The need for a mindful design and re-design might be higher for non-learning ATSs like ASCs because these systems are more limited in their ability to self-adapt to environmental changes than learning ATSs.

Taking again the example of Terra/Luna and a closer look at Figure 1, we can see several punctuations strategically intervening into this otherwise autonomously operating ASC system. The most significant interventions were the introduction of Chai, Anchor, Mirror, curve4pool, and Luna Foundation Guard. All these punctuations were conducted in a somewhat mindful way to support the Terra/Luna system. The first three were carried out to increase the ASC's adoption rate which reflects mindfulness of the fact that an ASC requires a high adoption rate to be stable. Many other DeFi projects have never caught traction and failed due to insufficient adoption which is one of the security cornerstones of many blockchain solutions. In fact, as pointed out by Do Kwon, Terra/Luna's design was rather on the conservative side (e.g., with their annual percentage return promise) compared to other DeFi projects but apparently still overoptimistic. The latter two interventions were conducted being mindful of the importance of keeping the stablecoin always close to its one dollar peg to reduce the risk of market panic and bank-run-like behaviors. As a side effect, they decreased the dependency on the token supply-adjusting algorithm which previously had been the only implemented system mechanism for ensuring the peg. This reduced the system's autonomy in favor of additional security mechanisms designed to increase the general resilience of the system and provided more options to react in case the system would still get under pressure. Without these strategic punctuations, Terra/Luna might never have grown as quickly and big as it ultimately did and as a consequence broken down much earlier.

However, all these punctuations still also had characteristics of little mindful decisions either in the way they were made (e.g., using the rather unstable Bitcoin as Luna Foundation Guard's reserve currency) or because they introduced probably underestimated additional risks and complexity into the system (e.g., the system's vulnerability during the curve4pool transition). Whether these punctuations hence increased or decreased the degree of mindfulness in the Terra/Luna system and thus the system's co-evolvement with its dynamically changing environment is difficult to assess in the individual case. A more or less mindful decision occurs at a particular point in time under specific circumstances as a result of a collective, dialectic process of becoming mindful (Carlo et al., 2012; Levinthal and Rerup, 2006; Thatcher et al., 2018). The extent of mindfulness depends on which and how information are, and realistically could have been, included in the decision making process. However, these more or less mindful punctuations must not only be considered in isolation as it is especially their interplay that raised the level of complexity of Terra/Luna significantly. There were more than 100 projects built around Terra/Luna in total (Uhlig, 2022). Hence, Terraform Lab's struggles regarding the need to have a constant overview of these projects and their complex interplay (Guzman and Abrams, 2022), which were insinuated by Do Kwon in the context of Chai, have possibly contributed to the system's breakdown. This also raises concerns with respect to blockchain and especially DeFi systems in general because the potentially systemic risk-inducing (e.g., via contagion) composability of different decentralized applications is one of their defining features (Allen and Carletti, 2013; Katona, 2021).

Lastly, it is worth noticing that in Terra/Luna all punctuations targeted the internal environment of the algorithmic core system, not the algorithm itself. While the initially uncollateralized ASC system transitioned into a partially collateralized one hence becoming a fractional algorithmic stablecoin (Ante et al., 2023), the algorithm responsible for adjusting the supply of TerraUSD remained the same. This again highlights the additional layers of complexity and their resulting risks added to Terra/Luna by building more and more systems on top of the existing one.

5.3 Practical Implications

ATSs are on the rise and come with many chances and risks. A better understanding of how to manage them is therefore needed. Our study has several implications relevant to practitioners engaged with ATSs and blockchain. In general, it seems important to consider ATSs as parts of a wider environment. ATSs create value through a complex interplay of human and machine agents to which managers and system designers should pay careful attention. In particular, an adequate monitoring and controlling as well as a holistic design of governance structures considering technical, social, and material aspects seem vital for building highly reliable ATSs. Our study indicates that using the lenses of mindfulness and HROs can be a promising path forward especially for ATSs where there is much at stake. Hence, training in mindfulness and strategic and systems thinking can help organizations creating more reliable ATSs. However, it is important to bear in mind that mindfulness practice and training come at a cost so that organizations are advised to make cost-benefit considerations before investing in mindfulness. We also find support for systemic fragility and riskiness of ASCs. Thus, investors into these types of assets are advised to be mindful of the complexity of ASC systems. Just because an ASC system has been running successfully for some time is no proof of its stability. For designers of ASCs, it seems recommendable to use collateralized over non-collateralized stablecoins. However, the choice of collateral matters too as the overly strong reliance on Bitcoin in Terra/Luna suggests. Lastly, for DeFi practitioners, the failure of Terra/Luna illustrates that although it is possible to build more and more applications on top of each other, the increasing risk due to the rising complexity of the system should be paid careful attention to.

5.4 Limitations and Future Research

This study has a couple of limitations. First, it is based on secondary data mainly from grey literature sources and only one illustrative case is considered. Given that ASC systems have inherent fragilities, it is likely that this played a major role in Terra/Luna's failure independent of how mindful managers and designers acted. Second, other examples of more and less mindful decisions from the Terra/Luna case could have been discussed. Third, we only report indicators for more and less mindful behavior using an outside perspective. However, some of the little mindfully-appearing actions taken by Terraform Lab could have also been taken strategically, if, as is not ruled out yet, malevolent actions on part of its management caused the project's failure. Lastly, we only consider a non-learning ATS in this study. While mitigating this by expanding upon aspects of learning ATSs in the discussion, an analysis of a learning ATS case in this study might have generated additional and more nuanced insights.

We have several recommendations for future research. First, other ATSs and especially learning ones could be analyzed to complement our study. Next, concepts for designing reliable systems from traditional systems engineering research could be applied to blockchain- and AI-based ATSs. Moreover, empirical research on mindfulness in ATSs is urgently needed. It would also be interesting to conduct more analyses of the failure of Terra/Luna as this could generate important insights into both ATSs and ASCs relevant for researchers and practitioners. Next, more research on mindfulness on the system and inter-organizational level is needed. A starting point could be a mathematical model and empirical analysis of our punctuated equilibrium model of system mindfulness. In general, we invite researchers to use the lens of complex adaptive system to analyze phenomena from the blockchain world more often. Lastly, research on new approaches to strategic decision making within blockchain and ATSs is needed.

6 Conclusion

ATSs based on data-heavy technologies like blockchain and artificial intelligence do not just automate tasks but operate largely on their own. They are at the forefront of the ongoing digitalization of our lives and economy. In this conceptual paper, we use the illustrative case of the collapse of the Terra/Luna ASC system to generate insights into how mindfulness in the design and operation of ATSs can help achieving high reliability. We suggest mindful work task coordination between humans and machines, mindful anticipation and improvisation to create resilience, mindful proactive and reactive internal and external environmental signal sensing, mindful consideration and exercise of financial and digital options, as well as a holistic and system-view-driven approach to mindful governance as cornerstones of highly reliable ATSs. We position mindfulness as a time-varying characteristic of systems which can be higher or lower depending on the design and re-design decisions taken against the background of an ATS's dynamically changing environment. Thus, we make two theoretical main contributions. First, we provide arguments for perceiving and managing ATSs as digital HROs. Second, we develop a punctuated equilibrium model of mindfulness in systems. Practitioners can benefit from our work by taking our insights into account when designing and operating ATSs or considering investing into them. While we do not know if Terra/Luna broke down due to a lack of mindful decision making by its designers, illegitimate activities of its management, or a massive, coordinated attack, we are convinced that mindful design and re-design decisions can tremendously contribute to making ATSs more reliable in the future.

References

Agrawal, A., Gans, J., Goldfarb, A. (2018). *Prediction Machines: The Simple Economics of Artificial Intelligence*. Harvard Business Press.

Allen, F., Carletti, E. (2013). What Is Systemic Risk? *Journal of Money, Credit and Banking*, *45*, 121–127. https://doi.org/10.1111/jmcb.12038

Andersen, J. V., Ingram Bogusz, C. (2019). Self-Organizing in Blockchain Infrastructures: Generativity Through Shifting Objectives and Forking. *Journal of the Association for Information Systems*, 1242–1273. https://doi.org/10.17705/1jais.00566

Ante, L., Fiedler, I., Willruth, J. M., Steinmetz, F. (2023). A Systematic Literature Review of Empirical Research on Stablecoins. *FinTech*, *2*(1), 34–47. https://doi.org/10.3390/fintech2010003

Arnold, R. D., Wade, J. P. (2015). A Definition of Systems Thinking: A Systems Approach. *Procedia Computer Science*, *44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Asatiani, A., Malo, P., Nagbøl, P. R., Penttinen, E., Rinta-Kahila, T., Salovaara, A. (2020). Challenges of Explaining the Behavior of Black-Box AI Systems. *MIS Quarterly Executive*, *19*(4), 259–278. https://doi.org/10.17705/2msqe.00037

Baird, A., Maruping, L. M. (2021). The Next Generation of Research on IS Use: A Theoretical Framework of Delegation to and from Agentic Is Artifacts. *MIS Quarterly*, *45*(1), 315–341. https://doi.org/10.25300/MISQ/2021/15882

Beck, R., Dibbern, J., Wiener, M. (2022a). A Multi-Perspective Framework for Research on (Sustainable) Autonomous Systems. *Business & Information Systems Engineering*, *64*(3), 265–273. https://doi.org/10.1007/s12599-022-00752-0

Beck, R., Dibbern, J., Wiener, M. (2022b). Interview with Peter Mertens and Wolfgang König: “From Reasonable Automation to (Sustainable) Autonomous Systems.” *Business & Information Systems Engineering*, *64*(3), 311–315. https://doi.org/10.1007/s12599-022-00753-z

Beck, R., Jain, G. (2023). DLT-based Regulatory System Dynamics. In *Proceedings of the Annual Hawaii International Conference on System Sciences*. Hawaii.

Beck, R., Müller-Bloch, C., King, J. L., University of Michigan. (2018). Governance in the Blockchain Economy: A Framework and Research Agenda. *Journal of the Association for Information Systems*, 1020–1034. https://doi.org/10.17705/1jais.00518

Benbya, H., Nan, N., Tanriverdi, H., Yoo, Y. (2020). Complexity and Information Systems Research in the emerging digital world. *MIS Quarterly*, *44*(1), 18. https://doi.org/10.25300/MISQ/2020/13304

Berente, N., Gu, B., Recker, J., Santhanam, R. (2021). Managing Artificial Intelligence. *MIS Quarterly*, *45*, 1433–1450. https://doi.org/10.25300/MISQ/2021/16274

Briola, A., Vidal-Tomás, D., Wang, Y., Aste, T. (2023). Anatomy of a Stablecoin’s failure: the Terra-Luna case. *Finance Research Letters*, *51*(103358). https://doi.org/10.1016/j.frl.2022.103358

Bullmann, D., Klemm, J., Pinna, A. (2019). *In search for stability in crypto-assets: are stablecoins the solution?* (ECB Occasional Paper No. 230). LU: European Central Bank. Retrieved from https://data.europa.eu/doi/10.2866/969389

Butler, B. S., Gray, P. H. (2006). Reliability, Mindfulness, and Information Systems. *MIS Quarterly*, *30*(2), 211–224. https://doi.org/10.2307/25148728

Caldarelli, G. (2020). Understanding the Blockchain Oracle Problem: A Call for Action. *Information*, *11*(11), 509. https://doi.org/10.3390/info11110509

Carlo, J. L., Lyytinen, K., Boland, R. J. (2012). Dialectics of Collective Minding: Contradictory Appropriations of Information Technology in a High-Risk Project. *MIS Quarterly*, *36*(4), 1081–1108. https://doi.org/10.2307/41703499

Chen, H., Wen, Y., Zhu, M., Huang, Y., Xiao, C., Wei, T., Hahn, A. (2021). From Automation System to Autonomous System: An Architecture Perspective. *Journal of Marine Science and Engineering*, *9*(6), 645. https://doi.org/10.3390/jmse9060645

Chen, Y., Bellavitis, C. (2020). Blockchain disruption and decentralized finance: The rise of decentralized business models. *Journal of Business Venturing Insights*, *13*, e00151. https://doi.org/10.1016/j.jbvi.2019.e00151

Ciuchta, M. P., O'Toole, J., Miner, A. S. (2021). The Organizational Improvisation Landscape: Taking Stock and Looking Forward. *Journal of Management*, *47*(1), 288–316. https://doi.org/10.1177/0149206320966987
Clements, R. (2021). Built to Fail: The Inherent Fragility of Algorithmic Stablecoins. *Wake Forest Law Review Online*, *11*, 131. https://doi.org/0.2139/ssrn.3952045
CoinMarketCap. (2022). Terra Classic price today, LUNC to USD live, marketcap and chart. Retrieved September 14, 2022, from https://coinmarketcap.com/currencies/terra-luna/historical-data/
Cunha, M. P. e, Miner, A. S., Antonacopoulou, E. (2017). Improvisation processes in organizations. In *The SAGE handbook of process organization studies* (pp. 559–573). London: SAGE.
De Filippi, P., Wright, A. (2018). Smart Contracts as Legal Contracts. In *Blockchain and the Law* (pp. 72–88). Harvard University Press. https://doi.org/10.4159/9780674985933-005
Dernbecher, S., Beck, R. (2017). The Concept of Mindfulness in Information Systems Research: A Multi-Dimensional Analysis. *European Journal of Information Systems*, *26*(2), 121–142. https://doi.org/10.1057/s41303-016-0032-z
Dooley, K. (1997). A Complex Adaptive Systems Model of Organization Change. *Nonlinear Dynamics Psychology and Life Sciences*, *1*, 69–97. https://doi.org/10.1023/A:1022375910940
Dupont, Q. (2017). Experiments in Algorithmic Governance: A history and ethnography of "The DAO," a failed Decentralized Autonomous Organization. In M. Campbell-Verduyn (Ed.), *Bitcoin and Beyond: Cryptocurrencies, Blockchains and Global Governance*. Routledge.
Feulner, S., Guggenberger, T., Stoetzer, J.-C., Urbach, N. (2022). Shedding Light on the Blockchain Disintermediation Mystery: A Review and Future Research Agenda. *ECIS 2022 Research Papers*. Retrieved from https://aisel.aisnet.org/ecis2022_rp/13
Fügener, A., Grahl, J., Gupta, A., Ketter, W. (2022). Cognitive Challenges in Human–Artificial Intelligence Collaboration: Investigating the Path Toward Productive Delegation. *Information Systems Research*, *33*(2), 678–696. https://doi.org/10.1287/isre.2021.1079
Gärtner, C. (2011). Putting new wine into old bottles. *Management Decision*, *49*(2), 253–269. https://doi.org/10.1108/00251741111109142
Gillespie, T. (2014). The Relevance of Algorithms. In T. Gillespie, P. J. Boczkowski, & K. A. Foot (Eds.), *Media Technologies: Essays on Communication, Materiality, and Society*. The MIT Press. https://doi.org/10.7551/mitpress/9780262525374.003.0009
Grobys, K., Junttila, J., Kolari, J. W., Sapkota, N. (2021). On the stability of stablecoins. *Journal of Empirical Finance*, *64*, 207–223. https://doi.org/10.1016/j.jempfin.2021.09.002
Guzman, Z., Abrams, Z. (2022). Inside Crypto's Largest Collapse with Terra's Do Kwon. Retrieved September 16, 2022, from https://www.coinage.media/
Haesevoets, T., de Cremer, D., Dierckx, K., Van Hiel, A. (2021). Human-machine collaboration in managerial decision making. *Computers in Human Behavior*, *119*(106730). https://doi.org/10.1016/j.chb.2021.106730
Hales, D. N., Kroes, J., Chen, Y., Kang, K. W. (2012). The cost of mindfulness: A case study. *Journal of Business Research*, *65*(4), 570–578. https://doi.org/10.1016/j.jbusres.2011.02.023
Hileman, G. (2019). State of Stablecoins (2019). SSRN Scholarly Paper, Rochester, NY. https://doi.org/10.2139/ssrn.3533143
Hoang, L. T., Baur, D. G. (2021). How stable are stablecoins? *The European Journal of Finance*, 1–17. https://doi.org/10.1080/1351847X.2021.1949369
Holland, J. H. (1992). Complex Adaptive Systems. *Daedalus*, *121*(1,), 17–30.
Howe, T. (2021). Chai is what it will look like when 'Non-Crypto-People' use crypto. Retrieved October 6, 2022, from https://medium.com/@tayneurnewdancer/chai-is-what-it-will-look-like-when-non-crypto-people-use-crypto-a475e97de67f
Jain, H., Padmanabhan, B., Pavlou, P. A., Santanam, R. T. (2018). Call for Papers—Special Issue of Information Systems Research—Humans, Algorithms, and Augmented Intelligence: The Future of Work, Organizations, and Society. *Information Systems Research*, *29*(1), 3–4. https://doi.org/10.1287/isre.2018.0784

Jorgensen, K. P., Hays, D. (2022). Options for Designing Stablecoins and Central Bank Digital Currencies. In *ECIS 2022 Research Papers* (p. 157). Timisoara, Romania: AIS Electronic Library. Retrieved from https://aisel.aisnet.org/ecis2022_rp/157

Katona, T. (2021). Decentralized Finance: The Possibilities of a Blockchain "Money Lego" System. *Financial and Economic Review*, *20*(1), 74–102. https://doi.org/10.33893/FER.20.1.74102

Katzenbach, C., Ulbricht, L. (2019). Algorithmic governance. *Internet Policy Review*, *8*(4). https://doi.org/10.14763/2019.4.1424

Kereiakes, E., Kwon, D., DiMaggio, M., Platias, N. (2019). Terra Money: Stability and Adoption. Retrieved from https://assets.website-files.com/611153e7af981472d8da199c/618b02d13e938ae1f8ad1e45_Terra_White_paper.pdf

Kim, E., Andersen, T., Marventus, E., A., Borges, P., Schmidt, D., Western, M. (2022). Emergency Management and Recovery of Luna Classic. arXiv. Retrieved from http://arxiv.org/abs/2207.01700

Lauslahti, K., Mattila, J., Seppala, T. (2017). Smart Contracts How Will Blockchain Technology Affect Contractual Practices? *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3154043

Lazer, D. (2015). The rise of the social algorithm. *Science*, *348*(6239), 1090–1091. https://doi.org/10.1126/science.aab1422

León, Y. L., Mu, E. (2021). Organizational Mindfulness Assessment and Its Impact on Rational Decision Making. *Mathematics*, *9*(16), 1851. https://doi.org/10.3390/math9161851

Levinthal, D., Rerup, C. (2006). Crossing an Apparent Chasm: Bridging Mindful and Less-Mindful Perspectives on Organizational Learning. *Organization Science*, *17*(4), 502–513. https://doi.org/10.1287/orsc.1060.0197

Linnenluecke, M. K. (2017). Resilience in Business and Management Research: A Review of Influential Publications and a Research Agenda. *International Journal of Management Reviews*, *19*(1), 4–30. https://doi.org/10.1111/ijmr.12076

Lyons, R. K., Viswanath-Natraj, G. (2020). What Keeps Stablecoins Stable? *NBER Working Paper Series*, *Working Paper 27136*, 63. https://doi.org/10.1016/j.jimonfin.2022.102777

Lyytinen, K., Newman, M. (2008). Explaining information systems change: A punctuated socio-technical change model. *European Journal of Information Systems*, *17*, 589–613. https://doi.org/10.1057/ejis.2008.50

Martin, K. (2019). Designing Ethical Algorithms. SSRN Scholarly Paper, Rochester, NY. https://doi.org/10.2139/ssrn.3056692

Merali, Y., Papadopoulos, T., Nadkarni, T. (2012). Information systems strategy: Past, present, future? *The Journal of Strategic Information Systems*, *21*(2), 125–153. https://doi.org/10.1016/j.jsis.2012.04.002

Meske, C., Bunde, E., Schneider, J., Gersch, M. (2022). Explainable Artificial Intelligence: Objectives, Stakeholders, and Future Research Opportunities. *Information Systems Management*, *39*(1), 53–63. https://doi.org/10.1080/10580530.2020.1849465

Miner, A. S., Bassof, P., Moorman, C. (2001). Organizational Improvisation and Learning: A Field Study. *Administrative Science Quarterly*, *46*(2), 304–337. https://doi.org/10.2307/2667089

Möhlmann, M., Zalmanson, L., Henfridsson, O., Gregory, R. W. (2021). Algorithmic Management of Work on Online Labor Platforms: When Matching Meets Control. *MIS Quarterly*, *45*(4), 1999–2022. https://doi.org/10.25300/MISQ/2021/15333

Newar, B. (2022). Luna Classic pricing error leads to Mirror Protocol exploit. Retrieved March 7, 2023, from https://cointelegraph.com/news/luna-classic-lunc-pricing-error-leads-to-mirror-protocol-exploit

Onik, M. F. A., Fielt, E., Gable, G. G. (2017). Complex Adaptive Systems Theory in Information Systems Research- A Systematic Literature Review. In *Proceedings PACIS 2017* (Vol. 271, pp. 1–14). AIS Electronic Library. Retrieved from http://aisel.aisnet.org/pacis2017

Osterrieder, J., Lorenz, J. (2017). A statistical risk assessment of Bitcoin and its extreme tail behaviour. *Annals of Financial Economics*, *12*(1), 13. https://doi.org/10.1142/S2010495217500038

Pearson, C. M., Mitroff, I. I. (1993). From crisis prone to crisis prepared: a framework for crisis management. *Academy of Management Perspectives*, *7*(1), 48–59. https://doi.org/10.5465/ame.1993.9409142058
Pinsonneault, A., Choi, I. (2022). Digital-enabled strategic agility: it's time we examine the sensing of weak signals. *European Journal of Information Systems*, *31*(6), 653–661. https://doi.org/10.1080/0960085X.2022.2027824
Rai, A. (2020). Explainable AI: from black box to glass box. *Journal of the Academy of Marketing Science*, *48*(1), 137–141. https://doi.org/10.1007/s11747-019-00710-5
Reijers, W., Wuisman, I., Mannan, M., De Filippi, P., Wray, C., Rae-Looi, V., … Orgad, L. (2021). Now the Code Runs Itself: On-Chain and Off-Chain Governance of Blockchain Technologies. *Topoi*, *40*(4), 821–831. https://doi.org/10.1007/s11245-018-9626-5
Rerup, C. (2001). 'Houston We Have a Problem': Anticipation and Improvisation as Sources of Organizational Resilience. *Comportamento Organizacional e Gestão*, *7*, 21–44.
Romanelli, E., Tushman, M. L. (1994). Organizational Transformation as Punctuated Equilibrium: An Empirical Test. *Academy of Management Journal*, *37*(5), 1141–1166. https://doi.org/10.5465/256669
Ruan, Q. (2022). Systemic Risks in Financial Networks Under Strategic Attacks. SSRN Scholarly Paper, Rochester, NY. https://doi.org/10.2139/ssrn.4180984
Sabherwal, R., Hirschheim, R., Goles, T. (2001). The Dynamics of Alignment: Insights from a Punctuated Equilibrium Model. *Organization Science*, *12*(2), 179–197. https://doi.org/10.1287/orsc.12.2.179.10113
Saleh, F. (2021). Blockchain without Waste: Proof-of-Stake. *Review of Financial Studies*, *34*(3), 1156–1190. https://doi.org/10.1093/rfs/hhaa075
Salovaara, A., Lyytinen, K., Penttinen, E. (2019). High Reliability in Digital Organizing: Mindlessness, the Frame Problem, and Digital Operations. *MIS Quarterly*, *43*(2), 555–578. https://doi.org/10.25300/MISQ/2019/14577
Sambamurthy, V., Bharadwaj, A., Grover, V. (2003). Shaping Agility through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms. *MIS Quarterly*, *27*(2), 237–263. https://doi.org/10.2307/30036530
Sandberg, J., Mathiassen, L., Napier, N. (2014). Digital Options Theory for IT Capability Investment. *Journal of the Association for Information Systems*, *15*, 422–453. https://doi.org/10.17705/1jais.00365
Sandor, K., Genç, E. (2022). The Fall of Terra: A Timeline of the Meteoric Rise and Crash of UST and LUNA. Retrieved September 27, 2022, from https://www.coindesk.com/learn/the-fall-of-terra-a-timeline-of-the-meteoric-rise-and-crash-of-ust-and-luna/
Sarker, S., Chatterjee, S., Xiao, X., Elbanna, A. (2019). The sociotechnical axis of cohesion for the IS discipline: its historical legacy and its continued relevance. *MIS Quarterly*, *43*(3), 695–720. https://doi.org/10.25300/MISQ/2019/13747
Scholz, L. H. (2017). Algorithmic Contracts. *Stan. Tech. L. Rev.*, *20*(128), 43.
Schwiderowski, J., Balle Pedersen, A., Beck, R. (2023). Crypto Tokens and Token Systems. *Information Systems Frontiers*, *Forthcoming*. https://doi.org/10.1007/s10796-023-10382-w
Shaikh, M., Vaast, E. (2022). Algorithmic Interactions in Open Source Work. *Information Systems Research*, isre.2022.1153. https://doi.org/10.1287/isre.2022.1153
Stein, A., Tomforde, S., Diaconescu, A., Hahner, J., Muller-Schloer, C. (2018). A Concept for Proactive Knowledge Construction in Self-Learning Autonomous Systems. In *2018 IEEE 3rd International Workshops on Foundations and Applications of Self* Systems (FAS*W)* (pp. 204–213). Trento: IEEE. https://doi.org/10.1109/FAS-W.2018.00048
Steptoe-Warren, G., Howat, D., Hume, I. (2011). Strategic thinking and decision making: literature review. *Journal of Strategy and Management*, *4*(3), 238–250. https://doi.org/10.1108/17554251111152261
Street, C. T., Denford, J. S. (2012). Punctuated Equilibrium Theory in IS Research. In Y. K. Dwivedi, M. R. Wade, & S. L. Schneberger (Eds.), *Information Systems Theory: Explaining and*

Predicting Our Digital Society, Vol. 1 (pp. 335–354). New York, NY: Springer. https://doi.org/10.1007/978-1-4419-6108-2_17

Sun, H., Fang, Y., Zou, H. (Melody). (2016). Choosing a Fit Technology: Understanding Mindfulness in Technology Adoption and Continuance. *Journal of the Association for Information Systems*, *17*(6), 377–412. https://doi.org/10.17705/1jais.00431

Sutcliffe, K. M., Vogus, T. J., Dane, E. (2016). Mindfulness in Organizations: A Cross-Level Review. *Annual Review of Organizational Psychology and Organizational Behavior*, *3*(1), 55–81. https://doi.org/10.1146/annurev-orgpsych-041015-062531

Teodorescu, M., Morse, L., Awwad, Y., Kane, G. (2021). Failures of Fairness in Automation Require a Deeper Understanding of Human-ML Augmentation. *MIS Quarterly*, *45*(3), 1483–1500. https://doi.org/10.25300/MISQ/2021/16535

Thatcher, J. B., Wright, R. T., Sun, H., Zagenczyk, T. J., Klein, R. (2018). Mindfulness in information technology use: definitions, distinctions, and a new measure. *MIS Quarterly*, *42*(3), 831–848. https://doi.org/10.25300/MISQ/2018/11881

Tiwana, A., Konsynski, B., Bush, A. (2010). Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics. *Information Systems Research*, *21*, 675–687. https://doi.org/10.1287/isre.1100.0323

Trigeorgis, L., Reuer, J. J. (2017). Real options theory in strategic management: Real Options Theory in Strategic Management. *Strategic Management Journal*, *38*(1), 42–63. https://doi.org/10.1002/smj.2593

Uhlig, H. (2022, July). A Luna-tic Stablecoin Crash. Working Paper, National Bureau of Economic Research. https://doi.org/10.3386/w30256

Vacca, A., Di Sorbo, A., Visaggio, C. A., Canfora, G. (2021). A systematic literature review of blockchain and smart contract development: Techniques, tools, and open challenges. *Journal of Systems and Software*, *174*, 110891. https://doi.org/10.1016/j.jss.2020.110891

Vogus, T. J., Sutcliffe, K. M. (2012). Organizational Mindfulness and Mindful Organizing: A Reconciliation and Path Forward. *Academy of Management Learning & Education*, *11*(4), 722–735. https://doi.org/10.5465/amle.2011.0002c

Weick, K. E., Sutcliffe, K. M. (2006). Mindfulness and the Quality of Organizational Attention. *Organization Science*, *17*(4), 514–524. https://doi.org/10.1287/orsc.1060.0196

Weick, K. E., Sutcliffe, K. M., Obstfeld, D. (1999). Organizing for high reliability: Processes of collective mindfulness. In R. I. Sutton & B. M. Staw (Eds.), *Research in organizational behavior* (Vol. 21, pp. 81–123). US: Elsevier Science/JAI Press.

Weill, P. D. (2004). Don't Just Lead, Govern: How Top-Performing Firms Govern IT. *MIS Quarterly Executive*, *3*(1), 1–17.

Zhang, Z., Yoo, Y., Lyytinen, K., Lindberg, A. (2021). The Unknowability of Autonomous Tools and the Liminal Experience of Their Use. *Information Systems Research*, *32*(4), 1192–1213. https://doi.org/10.1287/isre.2021.1022

Zhao, W., Li, H., Yuan, Y. (2021). Understand Volatility of Algorithmic Stablecoin: Modeling, Verification and Empirical Analysis. arXiv. Retrieved from http://arxiv.org/abs/2101.08423

Zook, M. A., Blankenship, J. (2018). New spaces of disruption? The failures of Bitcoin and the rhetorical power of algorithmic governance. *Geoforum*, *96*, 248–255. https://doi.org/10.1016/j.geoforum.2018.08.023