Blockchain Assemblages

Whiteboxing Technology and Transforming Infrastructural Imaginaries

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ABSTRACT

In this paper we unpack empirical data from two domains within the Blockchain information infrastructure: The cryptocurrency trading domain, and the energy domain. Through these accounts we introduce the relational concepts of *Blockchain Assemblages* and *Whiteboxing*. Blockchain assemblages comprise configurations of digital and analogue artefacts that are entangled with imaginaries about the current and future state of the Blockchain information infrastructure. Rather than being a black box, Blockchain assemblages alternate between being dynamic and stable entities. We propose Whiteboxing as the sociomaterial process which drives blockchain assemblages in their dynamic state to be (re)configured, while related artefacts and imaginaries are simultaneously transformed, creating dynamic representations. Whiteboxing is triggered during disconfirming events when representations are discovered as problematic. Complementing existing historical accounts demonstrating technologies in the making, the contribution of this paper, proposes whiteboxing as an analytical concept which allows us to unpack how contemporary technologies are created through entrepreneurial activities.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in collaborative and social computing**; Human-centered computing → Collaborative and social computing theory, concepts and paradigms;

KEYWORDS

Information Infrastructures; Assemblages; Entrepreneurship; Embeddedness; Sociomaterial; Blockchain; Cryptocurrency; Renewable Energy

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1 INTRODUCTION

Blockchain is an emerging and rapidly growing information infrastructure [52] [21]. This infrastructure is evolving through the infrastructuring activities [38] of heterogeneous entrepreneurial actors who work at maintaining, extending and propagating the infrastructure. Infrastructuring in Blockchain is currently taking place as protocol extensions [21], which allow users to engage with the infrastructural kernel of cryptocurrencies such as Bitcoin. Point of Sales hardware (PoS), Bitcoin ATMs (BTMs), and online exchanges are examples of the gateway services that work at making the affordances of the Bitcoin kernel available to users [41]. Infrastructuring in Blockchain is also taking place as the technology permeates into already established information infrastructures through a process of infrastructural grind [22]. What started as a contained and purely digital protocol has now propagated to become a widespread technology that is carving out new markets (e.g. the cryptocurrency trading domain), or attempting to transform existing markets (e.g. the energy domain). Although Blockchain is often referred to as a monolithic entity, previous work in HCI has begun demonstrating the complexity of this multifaceted infrastructure [27] [45] [39] [21] [22.] While Blockchain can formally only be dated back less than a decade [36], it is clear that certain Blockchain sub-domains are more evolved and consolidated than others. Cryptocurrency trading was one of the first activities associated with the technology, and an infrastructure supporting this practice has been emerging for a number of years already. On the other hand, Blockchain in the Maritime [23] or Energy sectors [4], for instance, are much newer realms of application, and can therefore be considered at the very early stages of Blockchain infrastructuring.

Generally in the Blockchain information infrastructure, and particularly in the areas related to the permeation and appropriation of Blockchain into established domains, it is evident that there is a wholesale of imaginaries, claims, visons, and story-telling and yet very few real-life implementations that have gone beyond Proof-of-Concept. These stories, imaginaries, and associated artefacts are often evangelized by various entrepreneurial actors [21] who aim at further embedding [46] [48] the Blockchain information infrastructure into the fabric of pre-existing relational structures [47]. The facts, as well as the state of the projects that are being marketed through these entrepreneurial agents, are very often difficult to assess properly. How do we unpack a cacophony of narratives, stories, prototypes, whitepapers and blog posts making specific claims about ongoing Blockchain projects in new and pre-existing domains? This is particularly relevant because we have observed that these narratives and stories tend to transform as the entrepreneurial agents evangelizing them get further along in their infrastructuring process.

Taking a point of departure in the well-established notion that information infrastructures tend to only become visible upon breakdown [47], we will in this paper examine points of tension in the early stages of development of the Blockchain information infrastructure. More specifically, we will try to use these tensions and breakdowns to further unpack how these are tackled by entrepreneurial actors engaging in infrastructuring activities, which involve diverse digital and analogue artefacts, as well as evolving stories and narratives about their contribution to the overall development of blockchain technology. Our research question is as follows:

How are breakdowns at the early stages of Blockchain infrastructuring resolved?

In this paper we unpack empirical data collected over the past 36 months in multiple venues. We will show that at the early stages of Blockchain infrastructuring, it is impossible to distinguish between imaginaries pertaining to the infrastructure, and the infrastructure itself. They are socio-materially entangled. Similarly, the various artefacts and imaginaries that entrepreneurial actors engage with in their infrastructuring activities can be seen as sociomaterially entangled assemblages, which we will label Blockchain assemblages. At the early stages of infrastructural development, it is these Blockchain assemblages that tend to break down when they are exposed to disconfirming events, which question the nature of their representation. We found that these breakdowns in Blockchain assemblages are resolved through particular activities. We call these activities whiteboxing activities, as they are enacted by the heterogeneous entrepreneurial actors that have configured the assemblage in its current state. We complement current research on infrastructures within HCI by unpacking the early stage of infrastructuring technology in-the-making, long before they have become stable entities – long before technology turns into a black box [29] [6].

Our paper is structured as follows: First, we present the related literature that will help us build our argument, Second, we go through the method employed. Third, we unpack our empirical findings in two accounts each representing a particular venue in Blockchain, namely the cryptocurrency trading domain, and the energy domain. Fourth, we propose the concepts of blockchain assemblages and whiteboxing activities and finally, we conclude.

2 RELATED LITERATURE

Blockchain has in the HCI literature been conceptualized as an emerging information infrastructure [21], which is yet in the making. Similarly to other large-scale infrastructures [52] [51], the Blockchain information infrastructure is sustained and expanded by the entrepreneurial actions [21] of heterogeneous actors, for instance gateway services. Through their infrastructuring [38] and synergizing activities [5], these actors act as protocol extensions to the infrastructural kernel [41] and thus shape the evolution of the information infrastructure. Viewing the evolution of Blockchain technology through this lens shifts focus away from infrastructure as a backdrop against which operations take place, to an approach emphasizing infrastructures as evolving socio-technical relationships [47] that are constantly in the process of being embedded, in pre-existing and overlapping structures and relational arrangements that can be technological, interpersonal, organizational, or communitarian [48] [46].

As the Blockchain information infrastructure evolves, its installed base will gain inertia over time as its kernel [41] consolidates, and its constituting socio-technical arrangements crystalize into standards and conventions of practice. Through this process, the complexities of the infrastructure will become opaque and the infrastructure itself will only become visible to the users upon breakdown [47], and otherwise remain black-boxed [29] [6] in everyday use.

Currently, the Blockchain information infrastructure is still in the process of achieving embeddedness [46], and slowly developing blackbox characteristics [29]. Latour frames Blackboxing as *"the way scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become"* (Latour, 1999, p. 304).

In the case of the Blockchain information infrastructure, not all sub-domains are equally evolved. While Bitcoin mining for example is a basic functioning of the protocol, and a domain that has emerged into a proper, industrial-scale operation, other sub-domains are still at the very early stage of infrastructural development. This could for instance be the case of Blockchain applications in industry domains (e.g. in maritime or energy). At its current stage of evolution, *cryptocurrency mining* (e.g. Bitcoin) is slowly gathering Blackbox characteristics, whereby the socio-technical practice of implementing a proof-of-work algorithm is increasingly standardized into an input-output process supported by complex assemblages of artefacts [34]. These assemblages, which can be seen as ways of ordering socio-technical entities into a state of symbiotic co-functioning [34], comprise heterogeneous multiplicities of code, hardware, practices, strategies and motivations. In other words, we can say that bitcoin mining is a sociomaterial [3] [8] working arrangement that includes Application-Specific Integrated Circuits, Mining "rigs", collaborative mining practices (mining pools), geographical clustering decisions, and specific business strategies. At the core of this process are large industry-scale mining farms that input an ever-increasing amount of electricity, and output a stable supply of new bitcoins and contribute to maintaining a secure network. In retrospect, looking back at the evolution of bitcoin mining, this blackboxed amalgamation of sociomaterial assemblages [34] can be opened up [29] and viewed as a social construction of technology [6] through which the assemblages of artefacts facilitating bitcoin mining have been continuously reshaped and redesigned by the various social groups involved in the practice [6]. Such an analysis would highlight the trajectory of mining equipment from relying on standard components in a computer (CPU and GPU) to the development of highly specialized integrated circuits created by rapidly professionalizing hobbyists [50] who managed to creatively fund, design, develop, and bring to market hardware components that were vastly more performant than what was available on the market. Each new round of technological advancement got inscribed [29] on top of the previous ones, and got combined with iterative improvements of the mining "business model", resulting in increased standardization and blackboxing.

The analytical process of opening up the Blackbox as proposed by the social construction of technology approach [6] has been examined successfully as an ex-post exercise. It allows to unpack with great details the historical sociomaterial complexities that have led to the current blackboxed state of an artefact assemblage. However, the approach has shortcomings when trying to understand the future trajectory of technology domains that are still at the early stages of infrastructural development. In such a context, Blackboxing would indeed tell us little about how the various complex practices and evolving artefacts that make up the Blockchain information infrastructure will shape in the future, particularly as the technology gets diffused beyond its first domain of application (cryptocurrency) and permeates [22] into other domains such as shipping and energy. This permeation of Blockchain into established industries is currently on its way, and the possibilities hypothetically seem broad. While Bitcoin and other cryptocurrencies are focused on the transaction of units of currency, Blockchains can indeed have many other uses (in principle), in the sense that virtually any form of relevant transaction data can be recorded in a shared ledger, such as for instance chain of custody records, identity documents, digital certificates [19], etc. Because of this, existing industries have started to look into relevant uses of Blockchain technology, resulting in a process of infrastructural grind [22] whereby blockchain technology is permeating into established domains at differential velocity [22]. Through this process of infrastructural grind, which is enacted differently at various point of intersection between infrastructures, standardization takes place resulting in increased consensus about technology interpretation, and flexibility of use and openness to further changes [20]. While Infrastructural grind is taking place between blockchain and various established domains, it is often still confined to technical proofs-of-concept. Currently the challenge in Blockchain domains that are at early stages of infrastructuring is how to move beyond these proofs-of-concept, which could be interpreted as imaginaries or design fictions [37] [7] [15].

In the context of blockchain domains that are at earlier stages of infrastructural development, an ex-ante approach to view the evolutionary trajectory of the technology is to unpack the imaginaries [37] [27] that shape the future visions of what the technology will become. Imaginaries about potential future use-cases for Blockchain technology, packaged as white papers, websites, public talks, slide deck, elevator pitches, and blog posts, make up a large part of the available data on Blockchain. These imaginaries can be seen as a medium for stakeholders to negotiate standards, practices and user bases of the infrastructure, which ultimately results in *crystallization* [37] – an agreement between negotiating parties. Kow and Lustig [27] develop this idea and unpack how the core stakeholders in bitcoin use imaginaries in their negotiations with each other aiming at achieving consensus and integrating with desired infrastructures. Imaginaries can furthermore be seen as co-created through communicative interaction between stakeholders who utilise material objects, gestures, and stories to iteratively imagine future scenarios [35]. This last approach to the creation of imaginaries will inspire our analysis of how sociomaterial Blockchain assemblages are dynamically created and used to open up the technology through *whiteboxing* activities.

3 METHOD

To explore breakdowns at the early stages of Blockchain infrastructuring, we report from two studies. Common for both studies is that they rely on approaches based on multi-sited ethnography [31], however this methodological approach is expressed differently in each of our empirical cases. When we study a phenomenon, which cannot be captured as existing only within one location and place, but instead take place and get produced across many sites and in multiple venues, we need to trace and follow the actors involved. Thus, part of our analyses becomes identifying the nature of the sites where the phenomenon takes place [9]. Studying breakdowns and complex configurations of artefacts, practices, and imaginaries as they take place in various domains within the blockchain information infrastructure is exactly such an elusive phenomenon, which cannot easily be captured by existing ethnographical methods, but requires us to critically identify where the sites of deployment are located. There are multiple roads by which we could start to explore breakdowns and assemblage creation and transformation within the Blockchain domain, but to be specific, we chose to explore it as it takes place in two different domains associated with the large-scale information infrastructures of Blockchain technology – namely within the cryptocurrency trading domain, and the energy domain. What makes these two domains interesting places to begin is that they represent two conceptually different ways in which the Blockchain information infrastructure is currently evolving. Firstly, we look into how multiple Blockchain artefacts and associated imaginaries contribute to creating and resolving breakdowns in a new infrastructure running in parallel to and inspired by an established domain (crypto-trading), and secondly, we look at how this takes place in connection with the proliferation and permeation of the technology underlying crypto-trading, Blockchain, into an already established domain (energy trading).

3.1 Data collection

Because of the different types of venues studied, our data collection strategies and sources also took different forms. Our data collection techniques comprised qualitative interviews, ethnographic observation, and involved interventionist participation over longer periods of time in relevant communities. Part of this work involved tech start-up communities, where the first-author was engaged and where he applied these various data collection approaches. More specifically, the first author has been involved with a Danish start-up called Blockchain Labs for Open Collaboration (BLOC) for the past 13 months. One of the projects that BLOC has been working on is a municipal initiative aiming at demonstrating the applicability of Blockchain technology for distributed solar energy production in an urban setting, specifically for creating a peer-to-peer marketplace for renewable energy produced by "prosumers" (Producer/consumers). The role of the first author in this case was participatory as well as analytic.

Over the past 9 months, we interviewed a total of 16 people whose insights and experience were particularly relevant for addressing our overall research question. Of them, 7 people were engaged in cryptocurrency trading either directly on their own, or through the intermediation of a fund, and 9 were relevant stakeholders in the energy sector, particularly solar, as well as at the intersection between blockchain and the energy domain. The interviews were recorded and transcribed

We also observed the development, over a period of 4 months, of a "friends and family" fund of around 1 million US dollars aimed at cryptocurrency trading. We followed the people involved in the project from initial planning, to preparation of the investment package, fundraising and closing of the funding round. This was done through ongoing one-on-one talks, calls, and participation in various internal meetings as well as investor events. A total in excess of 100 hours were spent on these activities. Furthermore, the first author engaged in participant observation at BLOC on an ongoing basis. During the past 16 months the first author spent on average 10 hours a week being part of the start-up's daily routines, hereunder joining in and participating in various business meetings, internal strategy meetings, speaking events at various conferences, and business trips in Denmark and abroad.

Table 1. Data collection overview

Type of intervention	Number of Organizations/companies	Accumulated hours of intervention
Interviews	9 stakeholders involved in Blockchain in the energy sector + 7 stakeholders involved in cryptocurrency trading	27 hours + transcription and analysis
Workshops and conferences	Participation in 3 conferences on Blockchain and energy (Austria, Denmark, USA)	45 hours
Participant observations	Blockchain Labs for Open Collaboration (BLOC) + A Danish cryptocurrency fund	580 hours, including documentation and transcription
Monitoring and participation in online fora	Reddit, BitcoinTalk, Telegram, Twitter, Ethereum community slack channel. (supplementary – not directly applied in this paper)	70 hours of data collection

Besides the above concrete activities, the first author has been involved and explored the Blockchain innovation communities for 36 months, exploring the information infrastructure of Blockchain in both maritime sectors, and well as the entrepreneurial practices of start-ups involved in various gateway services, hereunder bitcoin ATMs (BTMs). This empirical work includes in excess of 300 hours of participant observation and over 25 interviews. While these cases are not directly included in the empirical work presented in this paper, the larger insight into Blockchain as an information infrastructure does impact our approaches to explore how breakdowns are resolved at the early stages of Blockchain infrastructuring.

3.2 Data analysis

Analyzing the empirical data from the two venues of cryptocurrency trading, and renewable energy trading, we decided to let ourselves be guided by considerations related to the various roles of the examined artefacts, as well as the specific situated expressions of these roles in the venues that we have chosen. Specifically, this meant that we went over the sum of our extensive data with a particular focus on finding concepts and categories that would help us understand the unique characteristics of Blockchain assemblages as they are created and transformed within our two Blockchain venues. Practically, we started our data analysis simultaneously with ongoing data collection, and as specific categories and concepts pertaining to the roles and expressions of Blockchain assemblages starting gaining salience, we adapted further data collection in a more narrow and focused manner. We iteratively went through this process until settling on the categories presented in this paper.

3.3 Limitations

In this paper, we explicitly emphasize empirical data from two specific cases that emerged in our work, namely a cryptocurrency trading case, and a Blockchain-in-energy case. We chose these cases because they illustrate well how blockchain assemblages comes into being. The data material, which is quantified in this section serves as background for our analysis of the two cases. In example, it is only because of the long-term engagement at BLOC that we were able to get close and follow the Blockchain-in-energy case, both through participant observation as well as through interviews and document analysis. Thus, other data material was relevant for our analytical process, even though it is not accounted for in a manner that explicitly, through citations, illustrates the conceptual findings of our broader data analysis.

4 RESULTS

4.1 Creating Blockchain assemblages in the cryptocurrency trading domain

The information infrastructure of cryptocurrency trading is still in its infancy. With the inception and growth of bitcoin and other derived altcoins, a whole range of gateway services acting as protocol extensions have started to emerge. Among others these comprise bitcoin ATMs (BTMs) providing easy access points to buy and sell bitcoins, Point of Sales systems (PoS) that seamlessly integrate cryptocurrency payments with existing payment infrastructures, and online exchanges where users can both access cryptocurrencies, and speculatively trade them against each other or against traditional fiat currencies. While exchanges primarily offer a digital service, BTMs and PoS systems involve hardware as well as software, which has been developed along a trajectory from hobbyist tinkering to more established industrial production.

The emergent nature of these gateway services and their hobbyist non-industrial origins make them less robust than the socio-technical kernel(s) that they are interfacing with. The kernel of the bitcoin infrastructure, i.e. the protocol and its derived mining and maintenance practices, has indeed withstood the test of time and proven to be very secure and robust to hacking, the same cannot be said about these gateway services. Numerous exchanges have indeed been hacked (e.g. MtGox), coins have gone missing, and the ethical practices of these companies have sometimes been quite doubtful (e.g. not investing in cybersecurity in order to keep profits high, or purposefully stalling the process whereby customers can get their money out of the exchange). This is not a criticism of gateway services, but rather an acknowledgement that they are still emerging and that in the process of professionalization of their business, the practices of their users have to adjust to the risk element inherent to engaging with the information infrastructure in its current state. This adjustment is done through tinkering activities that compensate for the lack of user-friendliness, and the real or perceived risks involved in engaging with cryptocurrencies.

Part of our empirical work includes following one amateur crypto-trader, going by the alias "SteelDuck" (SD). Below, we will show how he actively creates and tinkers with assemblages of digital and analogue artefacts, as well as imaginaries, which allow him to counter the perceived trading risks associated with a sociotechnical infrastructure that is still unstructured and emerging.

SD got into cryptocurrency trading because he became convinced of the ability of cryptocurrencies, and bitcoin in particular, to act as a hedging mechanism against what he sees as an imminent new financial crisis. SD is indeed generally pessimistic about the future of the global (non-crypto) economy, and he sees his activities as an exercise in safeguarding himself against future uncertainty, and financial instability. In his own words:

"In my opinion, almost everything else than bitcoin (and other cryptocurrencies) will go to zero when the next financial crisis hits. But I believe in bitcoin. I still believe it has a value, right. It has the value proposition of being digital gold. So, I don't think that that is going to go to zero. It will of course depreciate, but I would rather be in bitcoin when the financial crisis hits".

As a non-financially trained lay person, SDs journey into cryptocurrency trading has been one characterized by learning-by-doing and trial and error. In fact, his initial imaginary surrounding the affordances of bitcoin and cryptocurrencies, as a safeguard against a potential financial crisis, guided him to experiment with buying cryptocurrency on various online exchanges, and led him to try out various ways of building his portfolio strategy. This imaginary, that was primarily based on the potential opportunities and benefits of cryptocurrency trading, however got challenged as SD gained more knowledge and experience in the domain. Through his online research and in his exchanges with other amateur traders, he became increasingly aware of the weaknesses of online exchanges described earlier, and of the fragility of the emerging cryptocurrency trading infrastructure. In other words, his imaginary got exposed to a series of disconfirming events leading him to reconfigure it, so to speak, and to construct a new assemblage of Blockchain hardware and software practices, that would align with his new imaginary. This involved purpose designed hardware for cold storage of cryptocurrency combined with analogue security protocols embodied in physical artefacts. Below we will expand on this.

As an active cryptocurrency trader, SD is directly contributing to the growing and consolidation of the blockchain information infrastructure. His entrepreneurial actions aimed at implementing the trading strategy, directly impact the gateway operators that he engages with, as well as the manufactures of hardware that he relies on for his trading. Through these actions, he is, as all other entrepreneurs and users engaged in the Blockchain ecosystem an active infrastructuring agent. In his particular case, he enacts his role as infrastructuring agent through the active use and remix of various blockchain artefacts, which allow him to implement his trading strategy in the absence of strong regulation setting standards for crypto-exchanges. Crypto trading is indeed still largely unregulated, and many of the protections that investors find on for instance Forex exchanges, such as segregated bank accounts, and deposit insurance are largely missing in current cryptocurrency exchanges. To compensate for this, SD leans on various digital and analogue artefacts and combines them in a way that enacts a sort of analogue "end-to-end trading system" which affords him acceptable levels of risk-taking.

Practically, this means implementing an intricate system of digital and analogue practices based on software, hardware, and analogue props such as laminated paper sheets containing the "seed codes" needed to regenerate a coin portfolio. As we will see this is a paradoxically clear illustration that while blockchain, as a protocol, is secure, self-executing, and tamper-proof, it is very much not the case for activities taking place at the gateway level of the information infrastructure. Here security vastly depends on human factors, and analogue practices diligently executed by the infrastructuring agents in question. In the case of SD, this means that he makes sure to keep most of his coins (bitcoin as well as altcoins) in so-called "cold storage" on secure hardware wallets. These wallets, which roughly resemble USB flash drives, can be plugged into SD's computer, and from the display on the device he can enter his codes and accept transactions. None of this is done on a browser screen on the laptop. As SD explains:

"No one has been able to hack these wallets yet. Hacks usually occur at the user interface level in the browser. Small scripts get downloaded onto the browser leading you to think that you are sending money to one address, but actually the transaction goes to another address. But if you avoid the browser and verify everything on the actual device, then it should be as secure as possible."

When asked about the manufacturing of these devices, SD shared with us that the hardware wallets generally are the result of hobbyist tinkering, which has developed into a specific product, that in turn has resulted in the creation of a start-up company addressing this specific need. These products are typically sold on the company's website, and SD clearly advises us not to attempt to buy them anywhere else:

"You don't want to buy it on Amazon… (laughs out loud) … then you will get one that has been tampered with in order to extract your seed codes!"

Interestingly, SD uses hardware devices initially created by hobbyists in order to implement his trading strategy in a secure manner. What is particularly interesting here, is that these hardware artefacts, once introduced "into the wild" and used actively by traders like SD, can become part of a higher-level tinkering and remixing activity. In this case the artefacts central to the practice are supplemented by other artefacts and associated imaginaries to create a more intricate Blockchain assemblage for achieving infrastructural goals. Indeed, using the hardware wallet correctly, and thus avoiding the risk of malware in the web browser, is only part of the assemblage put in place by SD. Even more importantly, he has implemented an analogue security protocol around the physical storage of the hardware wallets and associated seed codes.

"The key that generates your account on the hardware wallet is a string of 24 words called a seed. This seed you of course need to keep in a different location than the actual device. And if you are smart you will inverse two of the words in a way that only you can remember. That way even the seed will be useless to a robber."

SD continues:

"AND you must store a copy of this seed with another person that you trust. So, if it burns here, you will have the seed there, and if the seed gets stolen over there, then you have it here… Moreover, you should preferably laminate your seeds and store them in fire-proof bags, and so on."

A final component of SD's implementation of his trading strategy pertains to the part of his capital, which is not kept in cold storage but stored on online exchanges for fast deployment. Here he explains:

"I would never have, let's say…(silence)… more than around 20% of my coins on online exchanges. And I would never have those 20% on the same exchange. It's about spreading your risk. So, you have for example 5% on Bittrex, 10% on Binance, 3% on Cryptopia, and 2% on something else… so you spread your working capital on exchanges that have a good track record and reputation. So, if an exchange cracks it will not be 20% of your holdings that you lose but let's say 5%... But that is the price you pay for being able to trade fast."

Asked to reflect about the sheer amount of menial and mundane activities going into upkeeping this protocol and underlying trading practice, SD states that if it weren't for hardware wallets like the ones he is using, then he would not find it worthwhile to trade at all. He would stick with buying bitcoin as a long-term investment and skip trading in altcoins altogether.

4.2 Tackling breakdowns, and reconfiguring Blockchain assemblages in the energy domain

Unlike bitcoin and other cryptocurrencies, which are entirely digital and only connected to the physical world through mining and some of the gateway services described earlier, Blockchain applications in established industries, e.g. the energy sector, are much more complex to manifest in the world. This is because they require an ongoing connection with pre-established industries. They need to permeate into these industries through a process of infrastructural grind whereby the infrastructural and technological properties of the converging infrastructures reflexively rub off on each other, ultimately resulting in embeddedness. Here the infrastructural properties of the energy sector will create both enablers, and most certainly constraints, for the permeation of Blockchain technology. Technologically, the proposed blockchain solution will have to be interoperable with pre-existing legacy systems, and legally it will have to be compliant with existing regulations in the domain, which for certain proposed applications can be a challenge.

In the case of the energy sector, the most reported potential application of Blockchain relates to distributed energy production, and related peer-to-peer marketplaces. An instance of this could be residential solar installation systems producing for the needs of the household and allowing for the transaction of excess production with neighbors via a Blockchain system. The Brooklyn Microgrid (BMG), operated by LO3 Energy, is an example of the technical feasibility of such a system. In 2015, the company did a *"sandbox experiment enabling three residents on President Street in Park Slope to participate in the first ever peer-to-peer energy transactions"*. The company is currently trying to expand on this experiment but is encountering legal constraints in the fact that *"the only option available to prosumers is net metering - counting electricity sent back to the grid as a credit against your own consumption"*. In other words, it is illegal in New York to sell electricity directly to neighbors without the intermediation of the existing grid, and the application of current rates and taxes. Waiting for possible legislative change, which might be under way in the state, the focus of BMG is now community building, and creating a demand for the solution at neighborhood level. This is done through community workshops, and engagement with local business owners in order to get them interested in buying locally produced electricity, once it becomes legal.

The start-up company Blockchain Labs for Open Collaboration (BLOC) in Copenhagen, has a similar experience in the Danish context. Here, the Copenhagen Solutions Lab (CSL), a municipal initiative, which works with *"intelligent technologies to create data-driven solutions that suit the city and its citizens"* has developed three so-called urban laboratories, one of which focuses on testing sustainable solutions for decentralized energy using Blockchain technology. This laboratory, named EnergyBlock, is a site in the north-west neighborhood of the city comprised of 3 adjacent buildings that have been chosen to become a testbed for the use of renewable energy in an urban setting, supported by Blockchain and other new technologies. Together with researchers from the Technical University of Denmark (DTU), BLOC was chosen as a partner for the implementation of the project. As it turned out the project team encountered problems on two levels: (i) legal constraints somewhat similar to the ones encountered by the Brooklyn Microgrid, and (ii) technical constraints related to the existing metering infrastructure in the buildings.

One of the partners on the project expressed it in the following words:

"In Denmark, freedom to transact energy resources is only allowed "behind the meter" and is restricted to transactions on the same building lot. This means that engaging in selling excess renewable energy generated by a solar rooftop installation can only be done within the same building. Selling it to the adjacent building would be illegal. Here you would have to feed the energy back into the grid, and the adjacent building would then be able to buy from the grid at retail price that includes taxes to the government"

Because of these laws, there is no incentive for building or house owners to generate more renewable energy than they can consume, since excess energy is essentially given away for free to the grid. The projections of a specific solar rooftop installation in Denmark therefore tends to be under-scaled in order to minimize the feedback into the grid, referred to as "leakage". These legal constraints meant that the scope of the EnergyBlock project immediately became more limited. Whatever the outcome of the project, it would mainly serve as a demonstration of technical feasibility but would not immediately be scalable to broader commercial use under current rules. Instead the project could be conceptualized as an exercise in creating awareness about the possibilities of distributed energy generation, potentially with the purpose of influencing law makers in a direction more open to peer-to-peer energy trading.

From the perspective of BLOC, who were invited in to work on the actual Blockchain technology, the aim of the project quickly moved from being an actual scalable market-ready solution, to becoming a constructed imaginary supported by basic technological features. Since the objective, for legal reasons, could not be to scale up peer-to-peer energy trading in Copenhagen and beyond, it became a matter of designing a simple showcase solution that would be a physical manifestation of a potential future scenario. In an internal brainstorming session, the founder of BLOC emphasized the importance of creating a simple and cheap solution that would generate publicity and focus on the issues pertaining to peer-to-peer energy trading. In this connection the founder of BLOC asked the first author of this paper to re-appropriate a hardware artefact called OpenBlock, which the first author of this paper had initially created for teaching and learning purposes – OpenBlock is essentially a private Ethereum Blockchain running on Intel Edison chips on Arduino micro-controlers:

"Why don't we re-use your teaching devices (the OpenBlock hardware) and actually connect them to the smart meters in the building? That could work… It is a fully fledged live Ethereum network, right? The scale of the transactions that

we will record is low, so we really don't need a fancy system… It should do the trick. It could be a quick win for all parties"

At the formal project launch workshop, there seemed to be a consensus among project partners for an approach aiming at a smaller scale technical prototype, and for the need to showcase something that would make the regulators inclined to push for change. As the project coordinator from CSL put it:

"We just want to show that it can be done technically, and that it could be an alternative to the existing centralized system."

When the practicalities of building a prototype were discussed, however, it became clear that some of the assumptions that BLOC had about the current state of the electric infrastructure of the buildings were inconsistent with reality. While smart meters were assumed, it turned out that the selected building was of older date, and that the current electricity meters were revolving disc meters rather than smart meters. These types of meters are based on a mechanical metal disk that rotates and incrementally updates an analogue display. Connecting such a meter to a Blockchain would not be possible unless it is done as a work-around solution whereby one could add a small adhesive optic sensor on the casing of the meter. This sensor would count the revolutions made by the disc and display the consumption electronically at given time intervals. This could then be connected to one of our hardware devices (OpenBlock) that could send consumption data to the Blockchain ledger. Similarly, it was assumed that there would be proper space on the roof of the building for a solar installation, but it turned out that large parts of the roof were being allocated for an urban greenhouse project. So, in the absence of a full-scale solar installation, other ways of simulating the full solar production potential needed to be devised. A solution that was discussed involved setting up a solar irradiation sensor on the roof, which would show the real time solar irradiation per square meter. In a simple database, the irradiation measurement could then be multiplied by a scaling-up factor based on a professional projection on the roof's capacity. This production output data would then be connected to the same blockchain that would be hosting the metering data.

When going through the details of the project, it becomes clear that what started out as a lofty and potentially transformative endeavor, became a whole different kind of exercise once it was unbundled and expressed in terms of hacks, tinkering, and workarounds needed for the project to deliver the desired infrastructural narrative. The various artefacts, whether it is the OpenBlock hardware, or the optic and irradiation sensors, were used as conceptual tools in order to investigate design possibilities for future solutions carrying the desired infrastructural imaginary. Interestingly, in this case the infrastructural imaginary is not the result of a specific technological implementation, but rather it became the whole focus of the exercise. The project is not about producing a working solution, it is about producing a desired infrastructural imaginary, that can serve the ongoing interests of the involved parties, and at the same time contribute to the infrastructural trajectory of the overall blockchain infrastructure. Likewise, the assemblages of artefacts employed in the conceptualization of this infrastructural imaginary are not so much components in a remix of applied artefacts, as in the crypto-trading case, but rather they are components in the ongoing articulation of the desired imaginary. In fact, the Blockchain artefacts are entangled with the imaginary through the act of discussing potential implementation options. Even if the options end up not being implemented in the world, they will have made an impact on the imaginary through which the objectives and visions of the project are articulated. This ended up being the case with EnergyBlock. At the time of writing this paper, the options that had been discussed had indeed still not been implemented, for a complex set of reasons that fall outside the scope of this paper. The co-creative exercise of discussing implementation option, however, has influenced the imaginary that CSL uses in talking about the project, namely that it's about showing technological feasibility and having a place for experimenting with devices and connectivity (not about creating a scalable solution). Likewise, the process has influenced the pathway that BLOC has decided to pursue when it comes to Blockchain in energy. The company's CEO puts it in these words:

"If you want to have a transformative impact in the sector, it makes more sense to avoid electron-based blockchain projects. Here the road to impact is too long. Rather you should look into Blockchain applications that are non-electron, or electron-derivative. Projects that do not directly deal with the transacting of energy between peers… at least not in a European setting where regulation is so constraining."

Here she refers to engaging with projects that either focus on financing or crowdfunding of renewable energy assets, as well as projects aiming at creating carbon-based economies. In both those cases, the regulatory constraints that would limit a project's feasibility and scalability are circumvented, in the sense that it aims at strengthening the renewable energy sector without actually addressing the physical electricity being produced and transacted between peers. In this case, this new company strategy had slowly manifested as a result of the infrastructural imaginary that was crystalized when discussing implementation options on the EnergyBlock project, using tinkering and remixing scenarios involving assemblages of Blockchain artefacts. The infrastructural imaginary designed through tinkering with implementation ideas, has in fact rubbed off on the self-perception of BLOC, and influenced the strategic trajectory of the company within the energy space. We could argue that the piecemeal approach to combining various re-appropriated artefacts with the intent of creating a bare bones technical demonstration, and associated imaginary about feasibility and regulatory constraints, did indeed accelerate the company's learning about the workings of the industry, and nudged them in the direction of new use-cases within the sector. Through designing an imaginary for EnergyBlock, the company also refined their own imaginary and associated strategy.

5 DISCUSSION

Our two empirical accounts from the cryptocurrency trading domain and the energy domain, demonstrate how breakdowns in the early stages of blockchain infrastructures are resolved in similar yet different ways.

Firstly, in both cases it became evident that it was impossible to distinguish between the imaginaries [37] [27] related to the infrastructure, and the infrastructure itself in the very early stages of the evolving blockchain information infrastructure. Moreover, in the energy case, where Blockchain permeates into an established industry through infrastructural grind [22], very few established blockchain solutions exist beyond proof-of-concept. This means that the associated imaginaries about future technological possibilities (e.g. peer-to-peer energy trading) are a core driver for the infrastructure, simultaneously as the technological artefacts emerge as potential solutions themselves. When breakdowns occur in these very early stages of the infrastructural development, they are as much breakdowns of proposed imaginaries as breakdowns of the technical infrastructure itself, often even more so. This became apparent in the EnergyBlock case, where a breakdown of the initial imaginary surrounding peer-to-peer energy trading supported by Blockchain resulted in a major repositioning attempt by the involved start-up. The Blockchain information infrastructure includes multiple imaginaries, which are entangled with the sociomaterial [3] technology infrastructure. In such situations a question emerges about the nature and material matter of breakdowns at these very early stages of infrastructural development. Our data suggest that we must consider the infrastructural breakdowns as cuts into dynamic sociomaterial assemblages [34] mutually enacted by artefacts and imaginaries [37] [35]. We refer to these assemblages as *blockchain assemblages,* Emphasizing the relational attributes [48]. Blockchain assemblages comprise configurations of digital and analogue artefacts that are sociomaterially entangled [3] with imaginaries [37] [27] about the current and future state of the Blockchain information infrastructure [21]. These configurations are case- and domain-specific (cryptocurrency and energy produced different types of blockchain assemblages) and rely on a multiplicity of digital and analogue artefacts and practices.

Our data point to the fact that the blockchain assemblages break down when exposed to disconfirming events. Disconfirming events take different forms. Disconfirming events can result in abrupt and fundamental breakdowns, like when the basic assumption behind the EnergyBlock project was invalidated in the project launch meeting. But disconfirming events can also manifest in less dramatic breakdowns, as when our crypto-investor informant became aware of the risks associated with storing his crypto-keys on online exchanges. In the case of crypto-trading, it was evident that our informant first went from online storage of his crypto keys, to relying on a secure hardware wallet (the Ledger device), and then adding his own analogue security protocol embodied in laminated seed codes and distributed storage of these codes in fireproof bags. His evolving blockchain assemblage was dynamically entangled [3] [34] with an underlying imaginary [37] about cryptocurrency value, trading strategies, infrastructural practices and perceived risks.

So, disconfirming events can cause Blockchain assemblages to break down in early stage information infrastructures, but what are then the ways in which these breakdowns are resolved by the involved infrastructural agents? Examining our data, we notice that the involved practices to resolve breakdowns in the blockchain assemblages centered around the same kind of activity in both cases. We propose to refer to this activity as *whiteboxing*. Whiteboxing is the activity whereby blockchain assemblages are unpacked and unconcealed. It is the activity where the black box of infrastructures is opened for examination and re-organization. Whiteboxing is when the cogwheels, wires, and narratives which make up the blockchain assemblages are revealed and examined. The technology and the imaginaries which together form blockchain assemblages unfold as an artefactual multiplicity [10]. Whiteboxing allows for excavation of the bits and pieces which form the blockchain assemblages, and thus spurs activities of reconfigurations, whereby artefacts and imaginaries are simultaneously transformed. Complementing existing work on information infrastructures [41] [5] [33], the activity of whiteboxing requires detailed knowledge beyond the polished façade of narratives told about blockchain technology in a certain domain. Whiteboxing is the activity were the paths through programming code, technology, domain, and imaginaries are exercised and where the nitty-gritty details of the infrastructure is revealed. Through whiteboxing, the infrastructures of blockchain become visible and available for scrutiny. But its only possible because of the disconfirming events pushing for breakdown [47]. Whiteboxing is a response to breakdowns that implies opening up blockchain assemblage making their inner constituting parts visible [46] [6] and available for reconfiguration. Reconfiguration of blockchain assemblage involves re-aligning its multiple digital and analogue artefacts, and articulating new imaginaries that express an updated perspective. Through this process a new iteration of blockchain assemblage is produced, which the entrepreneurial agents can once more attempt to propagate to their stakeholders. We are not proposing whiteboxing as an alternative to the notion of "point of infrastructuring" introduced by Pipek & Wulf (2009), but rather we see whiteboxing as a particular manifestation of infrastructuring in the context of Blockchain assemblages. Whereas points of infrastructure are created by breakdowns that originate from the "technology side" or the "work side" [38], our blockchain assemblage approach has an entangled focus on multiple constituting parts, among others technology, artefacts, practices, and not the least imaginaries. In this context, the breakdown of a blockchain assemblage through disconfirming events is very similar to what Pipek & Wulf describe, however it relies heavily on imaginaries. Since established work practices related to Blockchain in the domains we describe are yet to exist, breakdowns can be disconnected from any such work practice. Therefore, whiteboxing does not contradict Pipek & Wulf's infrastructuring, rather it illustrates a type of infrastructuring as it takes place in early-stage infrastructures and has a high reliance on imaginaries.

An example of enacted whiteboxing as a result of a disconfirming event is our EnergyBlock case, where BLOC's initial imaginary about the future of energy trading via Blockchain got questioned. As the legal context turned out to be unfavorable to peer-to-peer energy trading, and as the team came to realize that the actual buildings were lacking the required, and assumed, electrical infrastructure to see the project through as intended, the focus of the start-up changed. It was now looking into repositioning its blockchain assemblage by tinkering with and remixing available artefacts and through creative collaboration with the project stakeholders [6]. Specifically, we saw that BLOC through their whiteboxing process attempted to recast a particular artefact as something different than what it was initially designed for. Rather than being a tool for teaching and learning, the OpenBlock artefact would become (hypothetically) a hardware component in a larger integrated socio-technical system comprised of sensors, meters, and blockchain hardware and software. These ideas never materialized, but they allowed for the creation of controversy frames and the repositioning of BLOC's Blockchain assemblage into a different trajectory aiming at a different infrastructural intersection [22], namely crowdfunding and carbon markets.

Whiteboxing supplements the view that the entrepreneurial actions [21] of heterogeneous actors in the Blockchain domain are self-directed and comprised of engaging and circumventing activities [21]. Indeed, whiteboxing can be seen as a more granular analytical concept for explaining how entrepreneurial agents circumvent the constraints encountered when the infrastructural kernel [41] pushes back on their actions. The act of circumventing infrastructural constraints can thus be seen as an effort that is mediated by a whiteboxing process that re-configures artefacts and entangled imaginaries into new representations that better reflect a current-state world view. Iteratively, whiteboxing activities thus contribute to infrastructural consolidation, and emerging standards [20], which in turn directly impact the overall growth [21] pathway of the Blockchain information infrastructure.

In both our cases, and most clearly in the energy case, the early stage of the infrastructure is predominately imaginary rather than factual, and what drives the infrastructure forward is the iterative trial-and-error of entrepreneurial actors attempting to materialize their current situated imaginaries. We therefore see the path to increased infrastructural embeddedness [48] and kernel consolidation [41] as one that is continuously interrupted by disconfirming events resulting in breakdowns that in turn are resolved through whiteboxing. We believe that the frequency of these breakdowns will decrease over time as proper use-cases get identified and larger scale systems get deployed and solidified. Theoretically this shows us that whiteboxing distinguishes itself by being future-oriented in the context of technological infrastructures that are still at an early stage of evolution and have not yet reached embedding [48] into the fabric of pre-existing relational structures.

6 CONCLUSION

In this paper we have examined two domains within Blockchain that are at an early stage of infrastructural development, namely the cryptocurrency trading domain and the energy domain. In order to direct our investigation, we have relied on multi-sited ethnographic approaches that have informed our focus in the respective domains. The aim of our investigation was to unpack particular points of tension and breakdown in the evolution of the Blockchain infrastructure, and to assess how these were resolved by the entrepreneurial agents involved in these particular domains. Our empirical data showed us that at the early stages of infrastructural development in Blockchain, there is a considerable reliance on imaginaries about future potentials of the technology. These imaginaries are sociomaterially entangled with a multiplicity of digital and analogue artefacts developed and utilized entrepreneurial agents, as well as with specific practices, and business models. This multiplicity is configured into dynamic *Blockchain assemblages* that drive the infrastructural work of the entrepreneurial agents in question. Interestingly, we have shown that these Blockchain assemblages are iteratively manifested as stable as well as dynamic entities interrupted by assemblage breakdowns caused by disconfirming events. As breakdowns occur through disconfirming events, *whiteboxing* activities are enacted in order to open up the Blockchain assemblage and sociomaterially reconfigure its entangled parts. As an analytical concept, we show that whiteboxing is a lens through which we can better understand the iterative reconfigurations of artefacts and imaginaries that take place in infrastructural development it its very early stages, before blackboxing and full embedding into pre-existing relational arrangements.

Going forward, the research presented in this paper adds to the slowly burgeoning literature on Blockchain in CHI, which until recently has primarily been focused on conceptual frameworks for Blockchain studies in HCI, or on select studies aiming at making this technology more user friendly. We argue that approaching Blockchain from an infrastructural perspective opens up many potential future avenues of research within CHI. Tracing infrastructuring activities, for instance, as they are being enacted by entrepreneurial actors, and finding their intersection with broader societal structures and norms could in principle give rise to important HCI research into how the state of entanglement between technology and societal structures is dynamically (re)negotiated with implications for both users and populations at large. This will be particularly relevant since the proliferation of Blockchain systems into established industry domains has only begun.

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