Growing the Blockchain Information Infrastructure

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ABSTRACT
In this paper, we present ethnographic data that unpacks the everyday work of some of the many infrastructuring agents who contribute to creating, sustaining and growing the Blockchain information infrastructure. We argue that this infrastructuring work takes the form of *entrepreneurial actions*, which are self-initiated and primarily directed at sustaining or increasing the initiator's stake in the emerging information infrastructure. These entrepreneurial actions wrestle against the affordances of the installed base of the Blockchain infrastructure, and take the shape of *engaging* or *circumventing* activities. These activities purposefully aim at either influencing or working around the enablers and constraints afforded by the Blockchain information infrastructure, as its installed base is gaining inertia. This study contributes to our understanding of the purpose of infrastructuring, seen from the perspective of heterogeneous entrepreneurial agents. It supplements existing accounts of the "when" and "how" of infrastructure, with a lens for examining the "why" of infrastructure.

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INTRODUCTION
In 2008 a mysterious and anonymous character under the name Satoshi Nakamoto introduced Bitcoin to the world: An encrypted and decentralized protocol for peer-to-peer transactions of digital cash, based on a secure distributed transaction ledger known as the Blockchain [23]. This new technical protocol revealed a whole new way of organizing financial transaction in the early aftermath of the global financial crisis. Anyone can download a Bitcoin Core client and set up payments using Bitcoin transactions [1]. Bitcoin transactions are validated by "Bitcoin mining", which is performed by computer nodes on the network, and which also generates new Bitcoins as a reward to miners for making their processing power available to the network [34]. At its inception, the Bitcoin phenomenon triggered the imaginations of many: Libertarians wanting to free people from a corrupt and inefficient banking system; hackers wanting to oppose surveillance and install true anonymity in all kinds of transactions; as well as criminals seeing Bitcoin as an ideal vehicle for anonymous illicit transactions.

Over the past years, the emerging Blockchain infrastructure is no longer just restricted to underground movements of tech-savvy people with ideological aspirations, but has moved into the mainstream. A multitude of alternative Bitcoin-like protocols have emerged (altcoins or altchains) [39] and Silicon Valley investors are backing start-ups working with Blockchain technology. Large industrial corporations and financial institutions are taking in Blockchain technology, and Blockchain technology is increasingly being described as an emerging Internet-based protocol layer serving as ground for entrepreneurs to build new innovative services, which potentially may disrupt a large number of industries. While the Bitcoin protocol is clearly an interesting technical phenomenon [39] [34] [1] [12] [16] [6], it is also an emergent information infrastructure [31] [7] [26], which represents a great opportunity for research in CSCW and HCI. Blockchain technology is more than a protocol allowing for peer-to-peer transfer of digital cash, it is an emerging Information Infrastructure made up of layered and complex social and technical practices that are distributed globally in multiple sites, and dynamically transformed over time. Supporting our interest in the socio-technical aspects of the Blockchain infrastructure, we explore: *What characterizes the infrastructuring activities that contribute to sustaining and growing the Blockchain infrastructure?*

In this paper, we draw upon empirical work conducted over the last 12 months, where we follow and explore the Blockchain information infrastructure as it is manifested in various socio-technical activities. We follow the physical activities done by entrepreneurs working out of incubators, the financial consultant advising banks, and the CEO of a small hardware company specializing in Bitcoin ATM machines (BTMs) – as they are all involved in making the Blockchain information infrastructure. We study the activities taking place online such as in the open-source Blockchain communities and on Reddit threads, as well as

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offline activities where we observe physical gathering such as Blockchain meetups.

Through our investigation, we find that the Blockchain information infrastructure is shaped by *entrepreneurial actions* which are self-initiated and primarily directed at sustaining or increasing the individual stakes in the emerging information infrastructure. These entrepreneurial actions wrestle with the enablers and constraints afforded by the installed base of the Blockchain infrastructure, and take the shape of *engaging* or *circumventing* activities. These activities purposefully aim at either influencing or working around the technological, economic, governance, and legal affordances which emerge as the Blockchain information infrastructure develops, and its installed base gains inertia.

This paper is structured as follows. Firstly, we introduce information infrastructures as part of CSCW and HCI research. Secondly, we present our method, data sources, and analytical approaches arriving from our multi-sited ethnography [19]. Thirdly, we introduce the basic functioning of bitcoin and Blockchain technology, and present our results. Fourthly, we discuss of our empirical findings related to the literature on information infrastructures. Finally, we conclude.

INFORMATION INFRASTRUCTURE

Information infrastructures have been of interest to CSCW and HCI research for a long time. Thus, when we are exploring how the Blockchain information infrastructure is expanding through infrastructuring activities, we already have existing concepts to guide our endeavor.

One of the important characteristics of information infrastructures is their *relational nature*, which challenges the view that an infrastructure is *"a substrate: something upon which something else "runs" or "operates", such as a system of railroad tracks on which rail cars run"* [30]. Instead, the information infrastructures approach recasts infrastructure as an expression of ongoing dynamic and constantly changing socio-technical relationships. The relational is put in the center in a process of "infrastructural inversion" [8]. Through this inversion substrate becomes substance [31]. Thus, information infrastructures do not exist in a vacuum, but are seen as embedded into other socio-technical structures and relational arrangements. They can simultaneously be embedded in technological networks, interpersonal networks, organizational networks, or community networks [3] [33]. This embeddedness both enables and constrains the development of the infrastructure. On the one hand, the inertia of the installed base enables the development of standards and conventions of use supporting the continuing existence of the infrastructure. On the other hand, these standards and conventions of use also limit the action space available for future development. Simultaneously, the embedded characteristic of an information infrastructure will allow for "network externalities" whereby the resources made available by an infrastructure can draw on the relational arrangements into which the infrastructure is embedded.

Large-scale information infrastructures are often characterized by ongoing development outside the initial scope of design, as a multitude of diverse actors continue to base their new activities on the existing infrastructure, and the affordances of its installed base. In example, gateway organizations [36] might develop new innovations that extend the functionality and range of the existing infrastructure [13]. This decentralized process means that such large-scale infrastructures can only to a certain extent be deliberately designed and built centrally. Instead they grow [10] organically within an everchanging environment.

Seeing "Infrastructur*ing"* as a transitive verb, brings about a conceptual shift in the focus of our analysis, which helps us better explain how ongoing infrastructural design activities as well as user appropriation activities contribute to bringing about and maintaining an information infrastructure [24]. Infrastructuring activities have also been explored as the *addressing* activities, which contribute to the ongoing trajectory of an information infrastructure [26], i.e. how these activities aim at sustaining the resources made available by the information infrastructure. Addressing activities are particularly related to the ways in which various tasks aid to *sustaining, renewing, adding*, or *shedding* features of the infrastructure Kernel.

So, what is it specifically that actors do, when they engage in infrastructuring at a practical operational level? *Synergizing* refers to the process of creating and maintaining productive socio-technical relationships [3]. Synergizing includes *aligning* stakeholders, and *leveraging* previous relationships, with the purpose of developing the information infrastructure. The processes of alignment and leveraging often draws on arrangements of relationships that originate in networks and webs into which the information infrastructure is embedded [3]. Simultaneously, these synergizing activities accumulate over time, and aggregate into further infrastructural embeddeness. Synergizing looks at the mundane everyday activities of heterogeneous, broadly-defined, *developers* who intentionally engage in aligning and leveraging activities with the goal of creating (cyber)infrastructure. In doing so, synergizing supplements the "when" of infrastructure [31], with an approach to understanding the "how" of infrastructure [33], as a dynamic relational process, and not an end goal. When we explore the infrastructuring activities taking place in the Blockchain infrastructure, we will investigate aspects related to embeddedness, synergizing, as well as intentionality.

METHOD

Due to the globally distributed and rapidly changing nature of Blockchain, uncovering the infrastructuring activities that contribute to creating, sustaining and growing this information infrastructure is a complex endeavor. This is particularly true because the Blockchain phenomenon is constituted by mobility, intersections, and flow, as well as connections, associations, and relationships across space and time. Thus, when we initiated our study in August 2015, we decided to engage in multi-sited ethnography [19], as a way to *trace the information infrastructure as an ethnographical phenomenon* [11].

Data collection: In our study, we followed, observed and interviewed companies and individuals involved with Blockchain technology in Denmark, and Ireland. Because of the relative novelty of Blockchain technology, these companies where mainly start-ups, which we identified through visits to incubators as well as by participating in events, such as Bitcoin meet-ups in Copenhagen. Examples of the types of start-ups that we engaged with are providers of Bitcoin ATM-machines, developers of digital Wallets, advisors to financial institutions on Blockchain technology, and Bitcoin security companies. More specifically we spent in excess of 80 hours observing the daily work of these companies, including regular operations, client meetings, business trips and social events. These observations, and ongoing meetings with our informants allowed for challenges, and tensions that we could not have foreseen to manifest themselves. Also, studying these sites allowed us to better understand the socio-technical aspects of the global Blockchain phenomenon through local activities.

Because of the distributed nature of the Blockchain information infrastructure, many connections between participating actors only takes place in digital fora. In these fora, be it Github, Reddit, BitcoinTalk, or Bitco.in, coordination between actors, as well as strategizing about the future of the technology takes place. We therefore saw it as important to supplement our various physical sites of investigation with ongoing examination of the digital traces left by the participants in relevant fora. Our informants were very helpful in directing us to the relevant corners of internet where activities influencing the operation, maintenance, and future plans for Blockchain technology are taking place.

Alternating between physical discussions with our informants and investigative work in digital fora created a synergy, whereby the data collected in either setting was enhanced and better understood as it was interpreted and corroborated by the other setting. Data was captured in field notes, documents, downloads of discussion fora, news articles, and audio-recorded interviews, which were later transcribed. Over the period, in excess of 180 hours were spent on collecting all the described forms of data.

Data analysis: Our data analysis began before data collection was finished. We iteratively worked through the data from observation notes, interview transcripts, article downloads, and so on, with the aim of finding categories and concepts that would help explain the characteristics of the socio-technical activities involved in the Blockchain information infrastructure. Initial proposed categories were organized by recurrent themes, and categorized in schemes, which were then transcribed into detailed write-ups of the data in an interpretative format. These write-ups were discussed with the informants, in order to assess the validity of the interpretation and selected categories and concepts. The write-ups were also the basis for preparing for ongoing field observations and interviews. As more data was collected, the initial categorizations several times needed re-sorting and re-analyzing, before finally solidifying into the interpretation presented in this paper.

Limitations: our local case was chosen because of the very tangible socio-material properties of Bitcoin ATMs, and our global bitcoin governance case on the other hand was picked with a focus on capturing moments of rupture in the infrastructure. At these moments of breakdown, infrastructures emerge and become available for scrutinizing, thus allowing us to explore the foundational entrepreneurial actions that contribute to sustaining the infrastructure. Obviously by making this choice we are omitting other socio-technical stories of entrepreneurial action in the Blockchain Information Infrastructure.

RESULTS

Before presenting our empirical data, which looks at Blockchain from an information infrastructure perspective, we will briefly introduce the basic mechanics of how Bitcoin and its underlying Blockchain technology works. Bitcoin is fundamentally a technical protocol – the Bitcoin protocol - with hard-coded rules for monetary transactions between peers. Bitcoin is a distributed database that records all the transactions taking place on the network without the need for a trusted third party. Instead, Bitcoin relies on a network of communicating computer nodes running Bitcoin software. Bitcoin transactions use public-key cryptography to ensure security, thus each transaction must be signed with a private key giving access to spend the Bitcoin amount associated with a Bitcoin address. Each transaction is validated by the global Bitcoin network using the public key associated with that address. The Bitcoin protocol determines that every ten minutes, all the Bitcoin transactions of the last ten minutes are broadcast to the entire distributed network at the same time in one batch. Each batch is time stamped and locked into one block of transactions, which includes a cryptographic hash of the previous validated block, which in turn is connected to the previous one, and so on, all the way back to the first block, the so-called Genesis Block. The complete ledger of interchained transaction blocks, the 'Blockchain', is kept and updated every ten minutes on all computer nodes of the Bitcoin network. In order to ensure a fast propagation of the blocks to all the distributed nodes, the Bitcoin protocol sets a maximum size of one Megabyte (approx. 1700-1900 transactions) per block. A side effect of this maximum size is that it creates a limit to the scalability of the network as we will see in our empirical results. The process whereby the Bitcoin Blockchain is kept consistent, updated and immutable is called *Bitcoin mining.* Mining is the simultaneous process whereby transactions are validated and included in a block, and whereby new Bitcoins are created and given as a reward for putting processing power at the disposal of the network. Bitcoin mining, at its core, consists of computer hardware (nodes on the network) intensely utilizing their processor power in an attempt to solve an advanced cryptographic puzzle every ten minutes, in competition with all the other mining nodes on the global Bitcoin network. This is also referred to as "proof-of-work". Solving the puzzle gives the "winning" computer node the right to broadcast the finalized block to the rest of the network, and triggers a "block reward" consisting of freshly created Bitcoins. The puzzle is designed is such a way that it is impossible to solve by any other means than random trials. This means that the more processing power is thrown at the puzzle, the more hashes can be tried per second, and the greater the probability of solving the puzzle first. If there is an increase in the aggregate hashing power on the network, then the protocol will self-adjust making it more difficult to solve the puzzle. This prevents too many blocks, and Bitcoins as an extension of this, from being created too fast. The extreme amounts of processing power required to perform proof-of-work, and the chaining of blocks through cryptographic hashes, makes it virtually impossible to tamper with the Blockchain, as an attacker would have to change all subsequent blocks in order for changes made to one block to be accepted. Today, there are slightly over 16 million Bitcoins in circulation, with a market capitalization of 16.4 billion US Dollars. The protocol dictates that the block reward is halved every 4^{th} year (currently 12.5 Bitcoins), until all 21 million Bitcoins have been created which will happen approximately in the year 2140. Today, the total hashing power of the Bitcoin network has become greater than the world's 50 largest supercomputers combined, meaning that the odds of solving a puzzle on a personal laptop, for example, have become infinitely small. Bitcoin mining has thus become a large-scale industrial endeavor taking place in enormous data farms, which are located in geographies that have access to large quantities of cheap electricity.

Synergizing work in Bitcoin: the "blocksize" debate

Bitcoin was originally developed as a reaction to the financial crisis. Bitcoin was seen as an alternative to the excessive power held by large banks in the global economy. It was about shifting the power to the individual, and allowing anyone to have the right to hold onto and spend their own money freely. A totally decentralized peer-to-peer system for digital cash. However, as Bitcoin developed, so did the composition of its constituting communities. As the Bitcoin phenomenon became more known to a wider public, its underlying technology, Blockchain, became the object of scrutiny of new actors such as financial institutions and later industrial corporations. As these new actors joined the Bitcoin community they brought with them pre-existing arrangements of relationships such as connections to corporate interests, as well as specific methods for driving innovation processes. This can for example be seen in the emergence of so called Fintech Accelerators, where start-ups working with Bitcoin and Blockchain technology are brought in, and guided through their business development process, in return for an equity share. Our informant Brian, who runs a Blockchain start-up out of Dublin explains the advantage of Fintech Accelerators in these words: *"in each of the banks in Dublin we had one dedicated person to talk to. So, that's invaluable. If we have a question we ask them, if they don't know they will find somebody in the bank working on it all day just to try to help us".* By leveraging their pre-existing relationships and aligning with corporate interests, these new members of the Bitcoin community create synergies that push the infrastructure in the direction that suits their interest. While the inclusion of new actors into the Bitcoin information infrastructure allows for it to expand, it also accentuates disagreements and creates friction in its governance structure, as witnessed by the so-called "blocksize debate". In the following we will see how the synergizing activities of corporate players are an entangled part of the current inability of the Bitcoin network to scale considerably beyond its current size.

The governance principles in Bitcoin were not initiated at the inception of the cryptocurrency. Rather, they are developed and transformed over time based upon the community's capabilities to settle controversies. After the creator of Bitcoin, Satoshi Nakamoto, disappeared from public view, he handed over the keys to the core protocol to one of his remote collaborators Gavin Andresen (the myth is that the two of them never met physically). Gavin maintained control of the Bitcoin Core GitHub repository and was considered Bitcoin's lead developer until he stepped back in 2014. Before stepping down, Gavin and other main contributors to the Bitcoin core protocol, set up a governance system whereby a small handful for Bitcoin Maintainers have commit access to the protocol and the responsibility of reaching a consensus before implementing major changes to the code. Most of the core developers up until about a year ago, did not work full-time on the Bitcoin project, but were also employed in companies dealing with Bitcoin/Blockchain. As Brian puts it: *"They were here from the very beginning most of them, so they are really talented people, really good engineers… it's not their full-time job to be working on the network so they have access to the core of the network, but they are also working with Bitcoin start-ups that have a lot of money".* Today, to the best of our knowledge, this is still true for some core developers, while three of them, including Gavin Andresen, have been given independent employment at the Digital Currency Initiative at the MIT Media Lab. Here they are financed through an external fund raised by MIT.

Surrounding this core development team, there is an active community of contributors collaborating on websites such as GitHub and Reddit. In principle, any developer can influence the way in which Bitcoin technology evolves technically, since anyone can submit Bitcoin Implementation Proposals – so called BIPs. But when it comes to actually making changes to the protocol it is the Core Maintainers that have absolute power, assuming that they can agree amongst themselves. When the core developers decide to make changes to the protocol, a broader, community-wide consensus needs to follow. This is the process whereby the users of the network voluntarily upgrade to the newer version of the protocol. As the majority of users shift over, the rest will usually follow without any controversy. However, reaching consensus is not always easy, and the process can become entangled in vested interests as illustrated by the current "block-size" debate in Bitcoin. The Bitcoin blocksize debate is a dispute about the number of transactions that can be included in one block, meaning how many transactions per second the network is able to handle. Right now, the Bitcoin network can only handle around three transactions per second, which to put things in perspective is extremely little considering that VISA/Mastercard for instance handles over 2000 transactions per second on average. So, if Bitcoin is to properly scale into the mainstream public, blocksize is a bottleneck. Interestingly, the bottleneck can easily be resolved technically by making a few changes to the protocol. As Brian puts it: "*It's very, very easy to change. It's just one number in the code, it's not a technical limitation"*.

According to Brian, what drives the blocksize debate is only partly a matter of technical dilemmas regarding blocksize versus network security, but mostly a matter of vested financial interests of certain groups within the community. In Brian's own words: *"There is way too much money in play, because some venture capitalists have invested a lot of money into some companies trying to fix this problem. And there is a lot of lobbying of people trying to block the problem of Bitcoin just to get some companies taking off (…) It's just competition between companies and they are lobbying against Bitcoin."* What we see here is that corporate players, through their investments, fintech accelerators, and hires, are trying to influence the pending decision by the core developers regarding blocksize. A decision that can have direct consequences for start-ups building on Bitcoin technology. If the blocksize is kept as it is, it will allow for certain start-ups to develop so-called "side chains". Side chains are open tabs, where multiple transactions can be recorded outside the Bitcoin Blockchain, and then be re-consolidated with the Blockchain as one single transaction. Side chains allow for higher numbers of transactions without increasing the transaction cap that is built into the Bitcoin protocol. A prerequisite for the success of these start-ups strategically working on side chain technology, is that the Bitcoin blocksize remains unchanged, otherwise the core value proposition of the start-up will be greatly diminished. On the other hand, certain start-ups are in favor of increasing the blocksize because it would be an advantage for their specific business. At the time of writing this paper, the controversy over blocksize has come to a deadlock. No formal dispute settlement mechanisms have been put in place. The formal power to make changes to the protocol still lies with the Core Maintainers, who disagree on the future direction of Bitcoin. This technical dispute is bringing the growth of the Bitcoin infrastructure to a halt greatly impacting start-ups that have built their business model based on an expected scaling of Bitcoin.

Clearly, Bitcoin is not just a technical protocol, but instead a large information infrastructure shaped by the dynamically changing members of the Bitcoin community. The open nature of Bitcoin allows everyone to contribute code, and to participate in the development of start-ups building on the technology. What used to be a community grounded in cypherpunks, anarchists, and underground movements, has now become inflated by bankers, venture capitalist, and mainstream tech entrepreneurs, all trying to influence the development of the infrastructure. This is for instance done by aligning with the interests of mainstream industries and by pushing for the creation of more corporate-friendly business models. We have here shown that these synergizing activities, which aim at growing the Bitcoin infrastructure in a direction that is compatible with corporate interests, are entangled with the governance challenges in the Bitcoin community as witnessed by the blocksize debate.

Infrastructuring Bitcoin ATMs (BTMs): a labor-intensive endeavor

Shifting our focus to another site within the Bitcoin infrastructure, our empirical data shows us that the material properties of Bitcoin are embedded in the most basic and daily routines of Bitcoin entrepreneurs. We will look closer at a Danish start-up, Copencoin that specializes in setting up and operating Bitcoin ATMs (so-called BTMs) in different locations in Denmark. The company was founded by Daniel, who relocated to Denmark from his native New York. Daniel got involved with Bitcoin relatively early on, when mining was still an activity that could successfully be performed using a graphics card on a personal computer. His experience with the evolution of Bitcoin leads him to believe that the demand for Bitcoins will only grow in the future, which is why he sees himself as a bridge-builder between the abstract digital world of Bitcoin and the physical world into which the cryptocurrency is being manifested. Daniel sees his BTM machines as the embodiment of this bridge-building activity, which contributes to introducing Bitcoin to a mainstream public.

BTMs are "cash" machines, which allow users to exchange national currency for Bitcoin or vice-versa. BTMs are thus physical manifestations in the world of the material properties of the Bitcoin infrastructure. BTMs are often located in small kiosks or in bars and restaurants, precisely like regular ATMs. Establishments hosting a BTM do not necessarily know much about technology, as they mainly specialize in their own line of business such as purchasing beverages, serving drinks at a profit, and playing music. While BTM machines require a solid internet connection, setting up Internet is at best a peripheral endeavor to the hosts. Thus, prior to installing the BTM machine, Copencoin must upgrade the existing IT infrastructure of the host location. This work involves Daniel taking trips to the local electronics store in order to buy cables and routers, spending time with tools behind the counter and in the basement of the host establishment, setting up a Bitcoin payment solution, and giving adequate training to the staff about how to take Bitcoin payments. In so doing Daniel prepares the basic installed base of the BTM that connects the machine to the Bitcoin infrastructure. This work is highly practical and manual, and often missed in descriptions of work associated with Blockchain technology. Once the actual Bitcoin machine is installed, very tangible security issues arise. Here we are not talking about the security of the transactions taking place on the Bitcoin ledger, but about the physical safety of the BTM machine being left unattended in a given location. As Daniel explains it: "*The machine can be tampered with by the customers. It can be broken into by people who do not understand that the Bitcoins are actually not stored in the machine but on the Blockchain. Or sometimes the machine can be stolen…"*. Those are some very legitimate practical concerns that play an important role for Daniel's ability to sustain a viable business. Typically, the solution to this problem is to have security cameras installed that monitor the BTM machine at all times. In other words, yet another level of infrastructure needs to be added to the setup, which involves additional work.

After the basic IT infrastructure is in place, and the BTM machines are installed and monitored by security cameras, then the focus turns to attracting customers to the new location. In Daniel's own words: *"*A *machine is not worth much if people do not know where to find it"*. So now Daniel's activities turn to social media and other means of making people aware of the new BTM location. In all locations where Daniel has placed a BTM, he has upgraded the location from either poor, or no wifi, or wifi demanding a password, to newer high-speed routers with social media logins, which have benefitted the online presence of the host location while simultaneously informing customers of the presence of a BTM. For the more seasoned Bitcoin traders, Daniel has listed his machines on a location website (CoinATMRadar.com) which also has an app allowing people to find BTM locations. Daniel is also a founding member and co-organizer of the Bitcoin meetups in Denmark since their inception in 2013. Daniel makes sure to host the meetups in locations that host a BTM, thus benefiting both the venue, as well as contributing to growing the base of Bitcoin users that could potentially use Copencoin's BTMs.

Like with the physical activities that go into installing the BTMs, the activities promoting the locations are often overseen as important work for the Blockchain infrastructure, however they are critical for manifesting the cryptocurrency in material ways. Finally, operating BTMs also involves managing the available cash flow in the machines on an ongoing basis, as well as general repair and maintenance. At this stage, BTMs are not as sturdy as their industrial counterparts that dispense fiat currency, which results in more frequent breakdowns and a bigger need for frequent maintenance. Breakdowns can occur at any time, requiring Daniel to go to fix the problem so that the machine can be back online as quickly as possible to avoid losing transactions.

Unlike some of the start-ups referred to in the previous section, who aim at further appropriating the Bitcoin protocol for new uses, such as smart contracts or micropayments, Daniel's company is less affected by the blockchain debate, and less in need for an immediate increase in the size limit of the blocks. His business is not about further extending the use of Blockchain technology to other domains, but rather making the basic core functionalities of Bitcoin available to users. If his dream scenario of large scale market adoption of Bitcoin materializes however, then transaction confirmation on his BTMs will become jeopardized due to blocksize constraints. As it stands now, Daniel does not do anything to actively try to influence the blocksize debate, and is instead focused on operational activities that grow his BTM company.

These empirical observations demonstrate that the Bitcoin infrastructure extends beyond the digital protocol. For the Bitcoin infrastructure to exist in the real world, it needs to be embedded within the daily physical activities of people like Daniel, who work at making the affordances of the technology available to potential users. Doing so is a very practical and physical endeavor, including time spent on enabling the infrastructure at the host of the BTM through setting up Internet, communicating to potential customer about the location, and in repairing the machines when they break down.

Socio-technical decisions about BTM location

The material properties of the Blockchain infrastructure extend beyond operation and maintenance to the choices made by Copencoin related to location, hosts, financial limits, compliance and so called KYC/AML (Know your customer, Anti-money laundering) requirements for BTMs. Daniel explains: *"Bitcoin and Blockchain technology is indeed a new and disruptive technology, but it does not exist in a vacuum. We are still as a company subject to the same laws, rules, regulations and expectations that all normal business operations must face."* At its core, the purpose of Copencoin's business is to create connections between the digital world of the Bitcoin infrastructure and the physical material world. It is about making the payment mechanism afforded by Bitcoin technology available to a mainstream public, who can buy or sell bitcoins for cash in an easy and convenient way. In order to achieve this, considerations about identifying the right hosts and supporting new and existing users of BTM machines matters. Since the Bitcoin infrastructure supports anonymous transactions, finding ways to avoid the "wrong" and potentially illegal use of the Bitcoin infrastructure is a critical consideration. Daniel is very much aware of this, and explains that when he began his BTM adventure, he sought legal counsel and approached financial regulatory bodies for approval in writing. *"I was very open about my intentions and activities from the beginning. I received guidance and confirmed permissions* *for operation and have followed the guidelines I received ever since".* Despite of this, banks are inherently suspicious of Bitcoin start-ups in part due to previous scandals that have connected Bitcoin to criminal networks, money laundering, and drug trafficking. It is in the very nature of the Bitcoin infrastructure that all the transactions are public, but that the identity of the users is unknown unless registered by operators (BTMs or online exchanges). This makes it very difficult for banks to do proper AML/KYC as mandated by law, and creates a general atmosphere of distrust towards start-ups working with Bitcoin. This is corroborated by our informant Søren, who is an advisor to the financial sector in Denmark on matters related to compliance in the domain of Bitcoin and Blockchain. He states: *"(if you work with Bitcoin) you cannot get a bank account if you do not have any compliance tools. Because the banks do not send money out into a big Bitcoin hole, or receive money from anonymous Bitcoin addresses. It is not going to happen. You might think this is good or bad, but that does not matter one bit."* This lack of trust affects the ways in which BTM companies need to navigate. In Daniel's case, the main concern is making sure that the company's compliance policies are up to date and aligned with current and changing requirements

In Copenhagen, one of the potential locations for a BTM machine is Christiania, a central part of the city. The Freetown Christiania, is a self-proclaimed autonomous neighborhood in Copenhagen founded in the 1970s on the grounds of old military barracks and parts of the city ramparts of Copenhagen. Christiania has a vibrant art scene, interesting architecture, but is also surrounded by controversy due to the fact that the neighborhood hosts a large part of Denmark's illegal cannabis trade. Attracting one million visitors a year, Christiania might be an excellent place to set up a BTM machine. There are many people with cash in hand, and a potential need for the services provided by a BTM. However, setting up a BTM in Christiania, although perfectly legal, might also amount to encouraging illicit actions, which will not reflect positively on Copencoin as a company. So far, Daniel has steered clear of Christiania as a potential site for his BTM machines, despite of the location being a potentially good business opportunity. The opportunity is in his mind not worth the risk that government, banks, and police might associate his company with illicit drug trading. In fact, Daniel sees this as a blatant double standard: banks can have their most lucrative ATMs located right next to Christiania, but if a Bitcoin company moves in, then it would be held to a higher standard than regular banks. Daniel expresses his choice to steer clear of Christiania in these words: *"Copencoin prefers to take the high road, doing our best not to tarnish our image"*

When installing a BTM machine, operators can choose to switch on a functionality on the machine that makes it mandatory to validate users' identity through an ID scan before each transaction. By so doing, Copencoin would ensure that only registered users can purchase or sell Bitcoins on the machines and that potential illicit actions are deterred. Turning on the identity functionality is mandatory in Sweden, but so far not so in Denmark unless a transaction exceeds the equivalent of 1000 Euro. However, adding the identity procedure adds several steps to the transaction, maybe to the point where users no longer consider it convenient. Particularly since the actual feeding and dispensing of bills on BTMs takes longer than on regular ATMs. Additionally, many Bitcoin users would strongly object to being registered on grounds of principles, regardless if what they are doing is completely legitimate. It would in their perspective run completely counter to the libertarian idea on which Bitcoin was founded. Therefore, from Daniel's perspective, it makes more sense to comply with the local legislation in Denmark, and keep the identity functionality on the ATM machines reserved for transactions exceeding the legal threshold. In his own words: *"We choose to be like Johnny Cash and walk the line by, on the one hand, being compliant with each jurisdiction, and also respecting customer privacy to a high degree. If we weren't, we would be promptly shut down by authorities".*

These empirical observations have shown us that the material properties of the Blockchain infrastructure are expressed in the strategic business choices made by Blockchain start-ups. Working with BTM machines, Daniel is obliged to deal with the constraints and affordances stipulated by this choice. Working with Bitcoin is far from a purely digital technological exercise. It is an exercise that has strong material properties and that enacts physical as well as ethnical constraints. Getting the right kind of customers that refrain from illicit activities, is not just an ethical consideration. It is also grounded in the AML/KYC requirement for companies operating BTM machines. Daniel must make balanced decisions without compromising his integrity about location, user base and impressions of his machines, while insuring absolute compliance with legal requirements.

Alignment work: the physicality of Bitcoin hardware

The two-way BTMs that Daniel operates require a constant balance between Danish currency and Bitcoins. This balance is prone to get skewed as buying Bitcoins is more in demand with users than selling Bitcoins. So, over time the machines need to get replenished with Bitcoins, and the cash needs to be removed and put in the bank. As the company grows, so does the size and volume of these transactions, making it important for Daniel to take risk factors into account, such as the fluctuating price of Bitcoins available for purchase on online exchanges. In order to mitigate this risk, Daniel has re-designed his company's business model to include Bitcoin mining. Implementing this plan involves physically buying large containers of bitcoin mining equipment in the Middle East, shipping the containers half way across the globe to Norway, where Daniel has set up a new start-up, connecting the equipment to a hydroelectric power plant, and transferring the created Bitcoins to his already existing BTM hardware infrastructure in Denmark. Specifically, this means that Daniel will invest the cash collected from the BTM machines into purchasing mining hardware, which will be running day and night solving the cryptographic puzzles that are required to propagate new Bitcoin blocks to the network, and that are a prerequisite for triggering block rewards. The block rewards collected will be freshly created Bitcoins that can then be transferred to the Bitcoin addresses of the specific BTM machines. This business model will give the company the economic benefit of not having to buy Bitcoins at a given daily spot price in order to replenish its BTMs, thus reducing the financial risk of sourcing the input for the BTMs. As Daniel puts it: *"At the end of the day we are going to need a guaranteed supply coming in faster so that we can meet the rush. (...) if you can own the whole process, you control it. There is less that can go wrong."* For a mining operation to be viable, scale is important. This means that Daniel had to invest in a substantial number of mining chips. Since the electricity in Norway is very cheap, Daniel and his new partner decided that it would make most sense to get slightly used equipment at a cheap price. This equipment would still be able to generate a profit when the energy cost is kept low. Through common acquaintances Daniel and his partner located second-hand mining equipment that was up for sale. The mining containers are shipping containers that have been retrofitted with powerful ASIC (Application Specific Integrated Circuits) mining rigs from floor to ceiling. The containers were located in the Middle East, and needed to be shipped to Norway. Daniel explains: *"The mining rigs are placed inside mining containers. We got some containers second hand. We bought them from the Middle East, where they were not of big use. The electricity is very cheap over there, but the chips would heat up like crazy in the hot desert weather. I guess you can't beat physics! So, we bought them cheap."*

The material properties of the Bitcoin infrastructure are far from digital only – they include physical containers and considerations about heat and electricity. The Bitcoin infrastructure extends the digital protocol through Bitcoin mining, which is vital to validating the transactions taking place on the Bitcoin network and which simultaneously creates new Bitcoins. This process is very much subject to the basic laws of physics. The mining chips might be the most performant on the market, but implemented in the wrong physical environment they become completely useless, as illustrated by the desert heat in the Arabian Peninsula. Also, the mining equipment is mobile, transportable, and subject to the same pathways as any other tradable physical good or commodity. Its physical embodiment in an actual shipping container emphasizes this materiality. The equipment is loaded, shipped, handled, subjected to custom procedures and duties as were it any other physical object. Handling this materiality requires real-world work, be it negotiation skills, trust between parties, time constraints, credit terms, and so on. Daniel's work in trying to solve his cash flow and sourcing issue is much more a material physical endeavor than an abstract digital one. Once the equipment arrives in Norway this physical work continues: *"We need to get a transformer so that we can turn them (the mining containers) all on and connect them to the Hydroelectric dam, and then we get a daily Bitcoin production. We will get our investment back by the third month. Three and a half months in theory if we get them all running. So now we are going to max out the power of that dam. We will literally be consuming everything that dam produces. And then after that we will have to buy it from the grid."*. When asked about what will happen if their plan to scale up production materializes, Daniel interrupts: "*then we have to buy a dam!"*

As during transportation, the Bitcoin mining equipment that Daniel bought cannot escape its material nature during installation and operation. It needs to be manually connected to the electrical infrastructure that will be powering the equipment, and it is subjected to the physical limitations of the electricity infrastructure. The equipment will only be able to produce as many Bitcoins as the electrical infrastructure allows. In so doing the electricity from the Norwegian dam will be channeled into running the mining equipment at the detriment of alternative uses. This will have a physical effect not just on Daniel's mining operation but also on the other activities taking place in that geographic location in Norway. Households for instance might have less access to electricity, and shortages might occur. Any subsequent decision to scale the Bitcoin mining operation will mean physically acquiring a whole dam, or having to rethink the business model so that it can support the added electricity cost incurred when connecting the equipment to the national electrical grid (e.g. replacing the chips with the newest on the market). In order to address his cash flow and sourcing problem, Daniel will have to make material decisions based on very tangible physical constraints

DISCUSSION

In our empirical material, we have seen that infrastructuring activities in the Blockchain infrastructure include installing cables and Wi-Fi, buying and shipping mining containers, as well as pursuing strategic business opportunities through lobbying. All these diverse activities make the resources and services afforded by the Blockchain protocol available in various ways while continuously extending and transforming the information infrastructure both digitally and materially. What characterizes the particular subset of infrastructuring activities that we have studied, is that they are carried out in a purposeful self-initiated fashion with the primary objective of sustaining and potentially growing the initiator's stake in the emerging infrastructure, be it measured in terms of revenue, influence, or control. This can be seen in Daniel's actions when attempting to manage the economic challenges of running 2-way BTMs that require ongoing replenishment with both Bitcoins and fiat currency. Handling the cash flow in the machines comes with a financial risk, since planning for their replenishment requires buying Bitcoins on online exchanges at fluctuating daily prices, which might tear into the profits made by the machines. In order to address this challenge, Daniel engages with his economic constraint through entrepreneurial actions. By integrating his business model backwards into the supply chain, i.e. purchasing mining containers in the Middle East, shipping them to Norway, and connecting them to a dam, Daniel is leveraging the enabling properties of the technology, which allows for self-initiated material extensions of the infrastructure by anyone able to do so. He is, in other words, circumventing his existing supply chain by expanding his business model to include Bitcoin mining. This entrepreneurial endeavor, involving setting up a new company with his Norwegian partner, as well as all the infrastructuring work described in the results section, is initiated for the purpose of solving an emergent challenge related to cash flow and financial risk mitigation. It is a company specific business concern that motivates the actions, rather than an overall concern for the development of the Blockchain information infrastructure. The primary driver of entrepreneurial activities in Blockchain is not directly to develop the emerging information infrastructure, but instead based upon economic interests. These economic interests are manifestations of the built-in economic rationale, which is encapsulated within the Bitcoin protocol. It is this economic rationale that incentivizes the entrepreneurial actions, which keep the blockchain infrastructure afloat. The protocol features an encoded model for how to earn money based upon mining activities, as well as derived incentives to capitalize on the extension of the protocol into the physical world. The explicitly encoded and transparent rules embedded in the design of the protocol is what creates the cohesiveness of the infrastructure. Development and consolidation of the blockchain infrastructure is a side-effect of the economic rationale inherent to the protocol, which incentivizes growing one's own business. The economic rationale is not directly pertinent in studies of e-science infrastructures [29], and less in focus in organizational studies of infrastructure [24], since the cohesiveness in these cases are based upon inter-organizational rationality [36], or the interest in finding ways to share data across diverse organizations [17]. As Bitcoin mining and Bitcoin dispensing through BTMs begins to take place through an integrated infrastructure, economic efficiencies will be created for the operators adopting this business model. Interestingly however, is that what is initiated as a purely economic strategy also creates enablers for further embedding [31] the Blockchain information infrastructure into mainstream financial infrastructures. One could indeed argue that by implementing an integrated business model, Daniel also opens up for the opportunity of leveraging the "fresh" nature of the Bitcoins in his BTMs, and the "green" source of energy used to mine them. This could be quite relevant when further developing the company's compliance and corporate responsibility policies, which would ensure a convergence with the institutions of the mainstream financial infrastructure, while simultaneously consolidating the blockchain infrastructure.

Research on cyberinfrastructures shows that agency is given to a *developer*, whose primary task is to technically design the emerging information infrastructure, while taking into account a range of considerations such as temporality [27], scale [28], and control [37]. Because of the difference between technically design-driven interests and business-driven interests, the actors shaping the blockchain infrastructures are not developers in the conventional sense, but rather entrepreneurs, who also do development activities that contribute to the emerging infrastructure. Thus, we argue that the infrastructuring activities shaping the Blockchain infrastructure are *entrepreneurial actions*. In other words, we view the process of infrastructuring in Blockchain as inherently entangled with the pursuit of entrepreneurial activities driven by heterogeneous individual concerns and goals. While these individual concerns and goals become manifested in specific start-ups, reflecting the demands of various user segments, our concept of entrepreneurial actions does not as such explicitly look at the specifics of user appropriation of various protocol extensions [24]. Rather it keeps a focus on the strategic motives behind specific infrastructuring activities. Because of this entanglement between infrastructuring and entrepreneurial actions, it is therefore impossible for us to, for instance, separate Daniel the entrepreneur from Daniel the infrastructuring agent. He is both at once.

Our empirical data has shown that the emerging Blockchain information infrastructure is embedded, or *sunk into*, other infrastructures, networks, processes and relationship practices [31]. This embeddedness is both the result of the *entrepreneurial actions* taking place when integrating the blockchain infrastructure with the material world, as well as a resource for the ongoing infrastructuring process [3]. Embeddedness into multiple infrastructures shapes how the installed base [7] of the emerging Blockchain information infrastructure grows, and ultimately takes on its own inertia [31]. As this happens, technological, economic, legal and governance considerations arise and present themselves as affordances of the emerging installed base. These affordances can be seen as either enablers or constraints for infrastructural development. The entrepreneurial activities contribute to sustaining and growing the Blockchain information infrastructure dynamically wrestling with the enablers and constraints afforded by the installed base.

We introduce *circumventing* and *engaging*, as core components of the entrepreneurial actions taking place in the Blockchain information infrastructure. These concepts offer new perspective on the process of infrastructure creation, namely a perspective rooted in purpose, seen from the perspective of the people who are creating the infrastructure. In other words, the "why" of infrastructure. This is an extension of the current literature on information infrastructures that has thoroughly examined the "when" of infrastructure [31], and the "how" of infrastructure [3] [33]. Circumventing and engaging are complementary to synergizing and its sub-components of leveraging and aligning [3]. Synergizing looks at the processes that *"entail the incremental alignment and realignment of people, processes and tools"*, while not looking into the characteristics of concrete synergies being made. Synergizing is all about process, not typologies or drivers. *Circumventing* and *engaging* are concepts that are dynamically connected with the enablers and constraints afforded by the installed base of the Blockchain information infrastructure. Circumventing and engaging provides a lens to examine the characteristics of the activities driving the Blockchain information infrastructure forward. We argue that circumventing and engaging are characteristics of the infrastructuring activities taking place in Blockchain, and important drivers for agency. So rather than the infrastructure being driven by tension typologies [28], the Blockchain infrastructure is driven by the activities of circumventing and engaging.

As Bitcoin evolved from an underground movement, multiple new communities joined the emerging Blockchain infrastructure, thus cypherpunks, anarchists, bankers, and venture capitalists all wrestle with the installed base of the blockchain information infrastructure through entrepreneurial actions. The malleability of the installed base has allowed for the growing communities to influence the governance process. This is done through *engaging* activities ranging from submitting implementation proposals (BIPs) to contributing code on GitHub, and hiring core developers to work on start-ups with vested interests. These engaging activities are largely made possible by the governance enablers of the installed base at this early stage of infrastructural development: an evolving governance process, and an open participation by all community members. While these enablers in principle incite participation and infrastructural growth, engaging with them can also create constraints for oneself and others, as illustrated by the deadlock on the issue of blocksize. It is the very open nature of Bitcoin governance that, through engaging activities, by heterogeneous groups has caused the current blocksize constraint. This constraint is in turn either engaged with through lobbying and investing as we saw in the results section, or worked around as witnessed by the emergence of alterative Blockchains (sidechains and altchains, such as Etherium, Rootstock or Counterparty). Through this optic, this emergence of alternative Blockchains is the result of *circumventing activities* by various groups and individuals. The deadlock on blocksize seems to drag on, and the interests of certain entrepreneurs and companies are not met in the current status-quo, so they set out to leverage the very open nature of the Bitcoin installed base with the purpose of working around the blocksize constraint. Open-endedness of infrastructures can be counter-productive, and can lead to reverse synergy [17]. In the Blockchain information infrastructure, the open-endedness is productively supporting propagation beyond the Bitcoin Blockchain, since it consequently opens the infrastructure up for larger audiences, and in so doing unlocks new enablers for others to engage with, e.g. smart contracts and other industry applications. Enablers, constraints, circumventing, and engaging are thus entangled in a dynamic and recursive way. *Circumventing* and *engaging* activities are directed entrepreneurial actions aiming at dealing with the technological, economic, legal or governance affordances expressed by the installed base of the Blockchain information infrastructure. While *circumventing* activities specifically leverage the resources of the installed base with the purpose of working around constraints, *engaging* activities leverage these same resources in order to push for the minimizing and/or removal of the imposed constraints Often circumventing and engaging activities are carried out simultaneously. The two concepts can be seen as a dualism, rather than a duality, in the sense that one does not exclude the other.

CONCLUSION

In our investigation of the infrastructuring activities that contribute to developing and expanding the Blockchain information infrastructure, we uncovered three main characteristics. Firstly, we found that the Blockchain infrastructure is shaped by *entrepreneurial actions*, which are purposeful and self-initiated, aiming at sustaining or increasing one's own stake in the emerging information infrastructure. Secondly, we saw how these entrepreneurial actions wrestle against the emerging enablers and constraints afforded by the installed base of the infrastructure as it develops and gains its own inertia. These enablers and constraints can be of a technological, economic, governance and legal nature. Finally, our investigation showed that the purposefulness of the entrepreneurial actions shaping and growing the Blockchain information infrastructure can be captured by the concepts of *engaging* and *circumventing* activities. Engaging and circumventing are two types of entrepreneurial actions that leverage the affordances of the installed base of the Blockchain information infrastructure, and either aim at minimizing or eliminating afforded constraints, or at working around these constraints in creative ways. Viewing the evolution of the Blockchain information infrastructure through the lens of engaging and circumventing activities supplements current approaches to infrastructuring. It does so by emphasizing a sense of purpose from the perspective of the heterogeneous groups of infrastructuring agents pushing the Blockchain infrastructure forward: the *why* of infrastructure.

The growth of the Blockchain information infrastructure will be very interesting to keep updated on, particularly since its expansion into other domains is still only at a nascent state. While we have seen how the infrastructure has grown beyond monetary transactions, through the involvement of new member communities, and through entrepreneurial actions that circumvent perceived deadlocks or constraints, it will be interesting for future research to keep an eye on how the infrastructure further propagates into new domains.

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