BBBlockchain: Blockchain-based Participation in Urban Development

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***Abstract*—Urban development processes often suffer from mistrust amongst different stakeholder groups. The lack of transparency within complex and long-term planning processes and the limited scope for co-creation and joint decision-making constitute a persistent problem for successful participation in urban planning. Civic technology has the potential to improve this predicament. With BBBlockchain, we propose a blockchain-based participation platform, which is able to address all layers of participation. In the development of the platform, we focus on two key aspects: How to increase transparency and how to introduce enhanced co-decision-making. To this end, we exploit the immutable nature of blockchains and effectively offer a platform that excludes monopolistic control over information. The decision-making process is governed by smart contracts implementing, for example, timestamping of planning documents, opinion polls, and the management of a participatory budget. Our architecture and prototypes show the operational capabilities of this approach in a series of use cases for urban development.**

***Index Terms*—blockchain, smart contract, participation, urban development, civic technology, empowerment**

I. Introduction

Civic participation is key to successful urban planning. Even more so, as the urban environment is facing rapid transformation induced by accelerating urbanization, demographic and climate change and the increasing digitalization of cities. Formal participation processes, as for example required by law for urban land use, are valuable but they often allow for participation on a minimum level only. They lack the necessary inclusiveness and hence representativeness. In particular, they often suffer from a level of mistrust in the permitting authorities or the political and private sector stakeholders decisively influencing the process. We therefore envisage a civic platform that is able to mediate between stakeholders and to overcome the underlying issues of deploying blockchain technology for this purpose.

In this paper, we introduce *BBBlockchain*, a blockchain-based participation platform. Our design goals are to achieve more transparency, trust, and participation in planning processes. The decentralized and immutable nature of blockchain technologies allow to exclude monopolistic control over information and processes. We identify, develop, and implement various use cases, which are supposed to augment currently conducted participation processes. The use cases comprise secure timestamping and document management, open discussion and social media integration, opinion polls and voting, and the use of tokens. With these use cases, we address the various layers of participation [1], [2], reaching from information and consultation up to democratic decision making and empowerment of citizens.

The pivot point of the BBBlockchain architecture is a set of smart contracts, deployed on the Ethereum blockchain. We opt for a permissionless design approach to make decision processes transparent and accountable. The deployed smart contracts instantiate our use cases and allow users to directly interact with its functions, for example, to submit a vote. For convenience and better user experience, we offer an application programming interface (API), which coordinates blockchain interactions. The API also enables the use of BBBlockchain on mobile devices and seeks to increase the inclusiveness of the platform.

While related approaches exist, most notably Adhocracy [3], Sovereign [4], and Social Coin [5], they still build upon a centrally-controlled architecture and therefore do not overcome trust and transparency issues. Accordingly, our main contributions can be summarized as follows:

- in this interdisciplinary research effort, we align two disciplines, urban development and computer science, to jointly solve so far insuperable challenges in urban participation
- we identify and develop use cases that augment participation processes in urban development projects and address the whole spectrum of citizen participation
- we propose BBBlockchain, a blockchain-based civic platform consisting of a set of smart contracts and a framework for interaction
- we deploy and evaluate BBBlockchain and its smart contracts to show that our approach is feasible; moreover, we are developing real-world pilot projects to test the platform along selected use cases

The remainder of this paper is structured as follows. In Section II, we explore the design space in urban participation. Subsequently, we establish the potential of a blockchain-based participation platform in Section III and develop various use cases in Section IV. In Section V and VI, we introduce and evaluate the BBBlockchain architecture, respectively. Section VII concludes the paper.

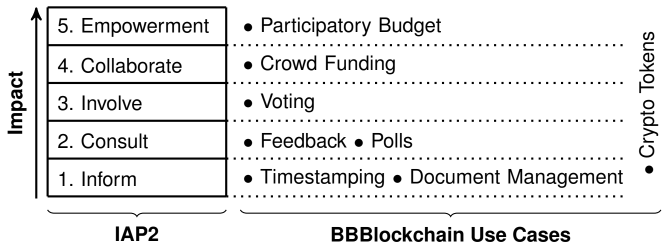

Fig. 1. Layers of participation according to the IAP2 spectrum public participation compared to our use cases.

II. Civic Participation

In this section, we explore the design space of BBBlockchain in urban participation. In particular, we describe the different layers of citizen participation and introduce current demand and challenges to be addressed by BBBlockchain.

A. Layers of Participation

Civic participation has gained significant importance in urban development over the last decade. Cities experience unprecedented transformation challenges in scale and pace, increasingly challenging the adaptivity of communities and citizens alike. In 1969, Arnstein introduced the ladder of participation [1] arguing for increased involvement of the civil society in decision making, so participation is meaningful and produces real impact beyond mere pro-forma processes controlled by planners. Today, the challenges in participatory processes are similar and thus, the participation ladder remains a valid benchmark. Attempts to engage citizens in a dialog about urban development projects are becoming increasingly common. In particular is participation key to successful implementation of development plans, as this depends on the degree to which citizens accept the plans [6]. The degree and quality of involvement however varies.

The IAP2 spectrum of public participation [2] is an international standard, which draws similar steps and outlines a gradual shift in decision-making power from authorities to citizens. As shown on the left of Figure 1, the definition of participation starts from a one-way communication of purely informing the public about ongoing planning processes. The next step is defined as consulting the public by listening to concerns and asking for their input and feedback. This represents a minimum opportunity to influence plans. The next level is to start a dialog with the stakeholders by actively involving them throughout planning processes and thoroughly consider the received feedback in the plans developed. The ultimate decision-making capacity herewith still lies with the authorities. Going further towards direct democracy, collaboration refers to the joint development of solutions between the government and citizens where recommendations are taken up as far as possible. The ultimate step of the ladder is called empowerment. Decision-making power does not remain with the government here but is handed over to the public. For the purpose of our research we build upon this definition of the different levels of involving the public in decision-making.

B. Transparency and Accountability

Two aspects are essential prerequisites for successful urban participation processes: transparency and accountability. Citizens need to be informed about pending changes, the underlying causes, and the foreseeable development trajectories. As these trajectories can induce significant impact, citizens need to rely on the accountability of key stakeholders providing the information. The provision of information is generally associated with the generation of accountability but in fact does not share a causative relationship [7]. While all agree on the relevance of information and its integrity, timely accessibility, and reliability, each key stakeholder in urban development processes is likely to coin the parameters of transparency and accountability differently. Citizens, the private and public sector, and politics for instance often disagree on when and to what extent economic facts such as purchase prices, building cost, and expected rents are made transparent, all justified from respective perspectives, yet potentially detrimental to a successful participation process. The right to information is accepted as a fundamental democratic right and has been widely embedded in urban planning and building legislation [8]. However, beyond legal stipulations the concepts of transparency and accountability are defined by the relationships of the stakeholders involved. The success of these relationships depends on how precisely the two concepts are achieved. Many cities currently aim to capture and channel these relationships in participation guidelines [9], [10].

C. Co-Decision Making and Empowerment

The basic concept behind participation is to balance of power. Currently, the common consent in representative democracies for most urban development issues is for the citizens to hand over the voice to the elected representatives. In a planning context, this means for citizens to be unable to actively shape the urban space, their direct surroundings, and living environment. As elaborated before, many scholars classified the bandwidth of influence citizens have on participatory processes. Public participation in any format constitutes a redistribution of decision-making power and is therefore a highly controversial topic. Participatory processes on an empowerment scale are rarely existing as it represents the far end on of scale referring to a hand-over of decision-making power to citizens. However, the scope of urban transformation is and needs to increase pursuing overarching drivers of change such as the UN Sustainability Goals [11]. Some cities strongly foster innovation in direct democracy as for instance with participatory budgets [12]. Digital technologies do offer platforms to moderate these developments. In particular, the blockchain technology lend itself to be used for rethinking current forms of participatory planning. Although, basic functions of blockchain is to foster transparency and accountability, one of the key functionalities of a blockchain is to act as an intermediary. So, the full potential of this technology can be seen in providing new alternatives for decision-making.

III. Blockchain-based Decision Making

The blockchain technology is increasingly discussed beyond the financial sector for common good applications. Expanding self-governance, participation, and co-creation are three aspects of this emerging research field. Even the potential extent to manage social interactions on a large scale and dismiss traditional central authorities is discussed [13].

One field which has not yet been proposed is participation in urban development. In the following, we briefly describe the civic tech movement and the role digital technologies have in participatory planning, before providing background information on blockchains and smart contracts to expose it as a key technology for urban participation.

A. Civic Technology

The usage of digital tools for local participatory processes is not new and has been captured in the term *civic technology*. A growing body of literature [14], [15] supports the framing of civic technology as a movement, as mainly citizens led the developments for technology-based participation. It combines a startup mindset and civic participation. The foundation is the wave of technology startups which started to transform various industry sectors. However, civic technology goes beyond being purely profit-driven and focuses on social impacts. The overarching aim is to change how our society interacts with each other and subsequently reinvent current ways of governing. More specifically, civic technology softens boundaries by enabling "government from the outside" [16].

This ties in with ongoing debate around the notion of active citizenship and level of involvement in decision-making. A participatory model of democracy as well as discourse has been highlighted since decades by many scholars as a key element for increased participation [17], [18]. In recent years, however, an increased change in the understanding of citizenship can be sensed. Where citizens used to be more passive, being satisfied with raising their voices every four years via votes, more citizens want to have a stronger say in the policy-making processes. The steady rise of digital tools work as an accelerator as they support these developments of changing how decision-making in our society works.

B. The Role of Digital Tools in Urban Participation

The evolvement of online participation tools is based on the emergence and acceptance of online social networks. As entry barriers into online conversations are often perceived to be lower and a much wider audience can be reached, online communities allow for like-minded citizens to connect and exchange more easily than offline. This has political relevance, when current issues are discussed online. The platforms can act as an instrument for agenda setting and allow for movements and campaigns to form.

Based on previous studies on civic tech [19], the key potential with digital planning are to remove barriers to entry and create an accessible, ongoing engagement process. However, when looking at existing digital tools for participation in cities, most formats rather mirror existing processes instead of using technology's opportunities and make urban planning easily understandable. The authors of [20], for example, conducted a review of 35 civic technology case studies and found that current formats are mostly unidirectional information flows. Further, using digital tools in participation processes does often not result in accountable outcomes.

The transformative capacity is ingrained in civic technology as it is mostly developed bottom-up. However, a key aspect for the success of digital participation is a strong involvement of the government to grant citizens influence on decision-making [20]. In particular, as the motivation to participate is linked to the perceived influence on policy-making.

The decentralized and immutable nature of a blockchain lends itself to address two issues here. First, the blockchain technology allows to exclude monopolistic control over information and thus more trust and transparency. Second, one of the key functionalities of the blockchain is the possibility to act as an intermediary. In a participatory planning context this refers to local governmental institutions steering development processes. Which decisions can be distributed between central authorities and affected citizens to achieve more representative levels of participation, both in quantity and diversity of participants, has to be explored. In the course of our research project, the use of BBBlockchain will be tested in pilot projects in Berlin. The results will be subject of future work and discussed separately.

C. Blockchains and Smart Contracts

In a nutshell, a blockchain is a publicly shared database of information collected in a computer network. There are however three aspects that make blockchains special: 1) a distributed ledger, 2) a medium of exchange, and 3) so-called smart contracts. In the following, we will briefly cover these aspects and provide an overview.

1) Distributed ledger: The way data is recorded in a blockchain is one of the core functionalities, which also provides a main building block of BBBlockchain's transparency campaign. In general, a blockchain basically allows strangers who do not trust each other to mutually agree on a set of shared information. While the notion blockchain refers to a family of protocols, the term *distributed ledger* refers to the underlying data structure.

One of the main aspects is the consensus protocol which is responsible for coordinating changes and to make sure that everybody has the same view on the ledger. Changes can be proposed by all nodes. What makes a blockchain unique is that to this end, no centralized principal database is required. Instead, many copies of the data are kept in different places in the network.

The distributed process of verifying proposed changes and to aggregate them in blocks is called *mining*. In order to mitigate malicious behavior, mining in open networks is artificially made "expensive" to counter false identities which are otherwise able to undermine the consensus. To this end, approaches like Proof-of-Work (PoW) or Proof-of-Stake (PoS) are employed. PoW, as used in Bitcoin and Ethereum, requires solving a cryptographic puzzle and the first one solving it can propose changes that will be accepted by other peers. The solution can be verified by all nodes independently, so no centralized database is necessary. Unfortunately, these puzzles waste computing power and energy by trying to find the solution. This problem is currently being highly discussed by all blockchain communities, e.g., Ethereum's long-term aim is replacing PoW by PoS which uses deposits and monetary punishments instead of cryptographic puzzles. We are aware of the energy wasting problems and expect that technically reliable alternatives will eventually emerge.

Typically, distributed ledgers are designed as immutable append-only data structures. It is therefore necessary to understand the concept of hashing and hash chains. A (cryptographic) hash function deterministically computes a hash value from an arbitrary input, which is neither predictable nor reversible. Hash values can be used as check sums (or hash pointers), a feature distributed ledgers use to implement so-called *hash chains*. A hash chain is designed as a linked list. Each list element contains an identifier, i.e., its hash value, and a hash pointer to its predecessor list element. As a consequence, elements cannot be manipulated unnoticeably as it would break the hash pointer. A blockhain secures the hash chain by making it eventually immutable. That is, as long as the majority of all nodes are honest and follow the consensus protocol, they all come to the same results and the system remains secure [21].

2) Medium of exchange: The most prominent usage of blockchains are so-called cryptocurrencies, which use the distributed ledger for the accounting of units. The most prominent example is Bitcoin. It enables a peer-to-peer payment system without a third party, e.g., a bank or clearing house. Because its coins cannot be generated freely and due to supply and demand, they gained real monetary value. Coins can be exchanged, e.g., to Euros or U.S. Dollars at so-called crypto-exchanges, or used as means of payment. The consensus protocol then ensures that a transaction can only be executed once, so they cannot be spent or exchanged again. In order to motivate processing new transactions and executing the resource consuming mining, Bitcoin peers earn rewards for proposing new valid blocks.

3) Smart contracts: The success of Bitcoin inspired the development of new capabilities. Among others, smart contacts can be considered as second generation of blockchain technology. Although Bitcoin already implements a script language for executing transactions, it is very limited and not Turing-complete. Ethereum is another popular blockchain technology framework which offers more powerful computing capabilities than Bitcoin. Besides the same electronic cash features Ethereum can also execute smart contracts. Smart contracts are distributed programs stored in the blockchain, which are typically much more powerful than normal coin transactions. Everyone can execute such a smart contract but is bound to its program code and the consensus rules, like with coin transactions. So, the outcome of a smart contract can be verified by all peers in the blockchain network. Already in 1997, Szabo [22] explained the concept of a smart contract, which can embed contractual clauses in hardware and software. For example, a smart contract could control access to a car, i.e., opening the doors and starting the engine, by checking ownership rights on the blockchain. Selling a car would accordingly involve transferring ownership rights in exchange for a payment. The smart contract basically takes over a notarial function and still does not require a physical third party but the blockchain itself. With smart contracts and public blockchains token transfer becomes completely transparent and traceable, so no token can get lost without notice; or votes during a ballot, messages during a chat, or even published documents, respectively. In the following section, we will apply these features to urban participation.

Proposing changes and using others computing capacities is not free, of course. On public blockchains transaction fees apply for all proposed changes or the execution of a smart contract. But it would not be reasonable to charge fees for using BBBlockchain, when users participate actively. Therefore, we provide an interface and take care of fees. For more details on the potential costs of hosting BBBlockchain see Section VI.

IV. Use Cases for Urban Participation

In alignment to the IAP2 spectrum of public participation, we developed a series of promising use cases for deploying BBBlockchain in urban development processes. Figure 1 provides an overview and assigns the use cases to the respective layer of participation.

In the following, we first explore the tool's potential to enhance the coherence, integrity and trustworthiness of information sharing throughout the often complex and protracted development processes. BBBlockchain aims to integrated information flows of the three major stakeholder groups in participatory processes: private and public sector and civil society. Hence, the inclusivity and legibility achieved will be decisive for the platform's success. Secondly, we investigate BBBlockchain's potential to sustain an ongoing engagement (consultation) amongst the stakeholders along the process and finally we will reflect its potential to enable genuine empowerment of citizens in decision-making. We also seek to increase and diversify participation by testing the use of so-called tokens across all use cases outlined above.

A. Timestamping and Document Management

Our first use case makes use of a blockchain inherent feature: it exploits the immutability combined with the frequent creation of blocks to realize a so-called *timestamping service.* It addresses the first layer and most fundamental layer of participation to generate transparency, i.e. *Inform.*

With BBBlockchain we provide a continuous overview across ongoing urban development projects and document the planning and approval process. To this end, we manage, archive, and secure documents, e.g., land-use plans, urban development contracts and general building information and specifications. As already explained in Section III-C, the distributed ledger cannot only be used to record transactional data, but virtually any data type. Instead of saving files (e.g., large text files or videos) directly in the blockchain, we store files in a cloud storage and save their hash values in the blockchain. This is mainly driven by cost reduction reasons. We use hash values as lightweight representations (usually only a few bytes) that is independent of the file size of the referenced document. As calculating such a hash value is mathematically very easy, but reverting it to its origin is a very hard problem, it is difficult to manipulate data without changing its hash value. Hence, we can establish the immutable time of publication of entries, which is called timestamping. A crawler finds new files automatically and submits their hash values to the smart contract. Such a crawler is also called *oracle* by providing off-chain information for the smart contract. It does not compare the content with the hash value, as this happens independently on the users' devices. In case a file is changed or missing retrospectively, the authors can add a reason, so the app shows an error and an associated error message. Another safety layer in timestamping would be estimated time spans utilizing block issuing rates. Finally, sequencing could be deployed to verify the order of publication of individual data or documents. To this end, users can verify the integrity of documents by downloading them from the cloud storage, calculating the hash values locally, and comparing them with the hash values in the blockchain.

We have implemented a timestamping service for BBBlockchain using a smart contract. Stakeholders can publish documents via an online content management system (CMS), in our case a WordPress instance. We use an extension that takes new files, calculates its hash values, and registers them at our timestamping smart contract. Posts, including attached files, then appear in our app and can be accessed by all users. The smart contract for timestamping only contains a list of file URLs, the files' hash values, and the authors. It also restricts access on who can propose changes, e.g., developers, planning authorities, or citizen representatives.

The provision of verified information across long-term and often controversial processes can thus be established by BBBlockchain, which would represent a major step forward towards higher degrees of transparency in most urban development projects. Stakeholders gain a transparent information platform, which cannot be manipulated once data has been published. For instance, public participation regulations can stipulate the provision of specific information at certain points of time in the planning process by the respective stakeholders. Using BBBlockchain, interested parties, such as residents, can verify whether this information was provided in time and if this information has since been tampered with or been deleted. This enables all stakeholders to prove or assess, if information has been provided in time and has been adhered to in the planning, permitting and construction process. We hope to establish in our selected pilot projects, which we conduct in Berlin, that this BBBlockchain functionality not only improves the transparency but the accountability of all parties involved in the participation process.

In order to open this service to a stakeholder pool with maximum diversity we also investigate suitable visualization techniques to increase the legibility of crucial information underlying the planning and permitting process.

B. Feedback and Social Networks Integration

While it is essential to provide comprehensive and reliable information, it is equally important to *consult* and *involve* citizens in urban development projects (IAP2 Level 2 and 3). To this end, we integrate a feedback mechanism. Citizens can submit their feedback, e.g., comment on information provided, participation workshops, or statutory planning information. We record this event as hashed representation in the blockchain but refrain from recording plaintext for the same reasons as specified above. In this way, we also reduce to opportunity for abuse of BBBlockchain as described in [23].

We also explore the integration of social networks as feedback channels. For this purpose, we deploy a crawler looking for static hash tags related to BBBlockchain projects. Found messages, e.g., on Twitter, will be hashed and the hash values will be saved on the blockchain. Another approach is generating unique hashtags on demand for specific topics managed by one of our smart contracts. App users then can open documents and start a discussion on a topic with others on social media and the crawler can relate the messages to specific topics. Again, in order to reduce the memory footprint and mitigate abuse, we do not record the plaintext. At the same time, we outsource the detection of abuse to the respective social media platforms. Please note however that deleted messages can still be detected by comparison with the stored timestamps.

In general, our app displays a notification if it detects a deleted message. BBBlockchain is hence establishing a multichannel consultation and targeted involvement tool. As urban development projects are highly diverse and cannot easily be standardized, BBBlockchain needs to enable the flexibility to respond to specific communication channels to be agreed between the stakeholders from the outset of a project.

C. Opinion Polls and Voting

For further options to consult and involve the public, we distinguish between *opinion polls*, which are a consultation feature and *votes*, which we consider as a form of co-decision-making. Depending on the impact and the institutionalization of BBBlockchain voting, we advance into the fourth and fifth of the IAP2 levels of participation, *collaborate* and *empowerment*.

For example, housing developers or housing associations might commit to public participation on different development or design options [10], including a binding vote for the preferred option. In current practice, these rare votes are mostly neither legally binding nor sufficiently transparent. Even with fully committed urban developers the effort to conduct reliable votes often proves to be too onerous and difficult. It often boils down to participation meetings and paper-based voting. As a consequence, the current situation suffers from a lack of inclusiveness and trust issues. With BBBlockchain, we aim to overcome these issues in order to enable a more prolific use of voting in urban participation processes.

While we envisage different ways to instantiate polls and votings, the easiest way is to save electoral processes in an array, where each element represents a voting choice and with a public function for increasing the respective counter. However, this approach is vulnerable to fraud as voting multiple times by repeatedly calling that function becomes possible. We therefore need a mechanism to validate and authenticate voting rights, e.g., the voter's identity or a digital certificate of eligibility to vote. To prevent fraud, BBBlockchain issues registered voting tokens for each eligible citizen. The right to vote can only be exercised when a valid token is passed with the function call.

In general, though, electronic voting inherently suffers from certain disadvantages [24]. Most notably, the necessary prerequisites for voting, e.g., identity checks, are harder to establish and sustain online as in the offline world. This raises a number of challenges for blockchain-based voting and boils down to a tradeoff: On the one hand, blockchain offers unconditional voting transparency and auditability. On the other hand, achieving strong anonymity proves to be a challenge, because all votes in a blockchain are fully traceable. As a first step, we use pseudonyms as a first way of achieving privacy. In the future, we intend to explore stronger privacy-enhancing technologies, including homomorphic encryption and anonymous broadcasts [25]. However, contrary to public elections votes, in urban development projects the local reach might allow or demand the public identification of the voters. In [4] for instance, video chat or video proofs are used for identification. To be clear, BBBlockchain is not intending to replace offline voting. Aligned to the project's overall motivation to foster the diversity and inclusiveness of public participation in urban development projects, we investigate the pros and cons of blockchain-based voting to widen the available set of tools to deploy.

D. Tokenization

One reason for the current popularity of blockchains is the token system. We consider the tokenization as a cross-cutting aspect that can augment most of the use cases discussed above in one way or another. For example, we use tokens to manage voting rights and to incentivize participation. While many means of deployment are conceivable, tokenization will likely have the highest impact on the upper layers of participation as tokens by definition are an instrument of exchange.

We distinguish between *coins* and *tokens* to emphasize technical variations and different use cases. Cryptocurrencies issue coins as their inherent trading instrument, which typically has monetary value, and use a blockchain to record transfers and balances. In Bitcoin, for instance, coins serve as means of payment but also to incentivize miners and therefore keep the system running. Some blockchain-based systems also offer ways to create and issue custom tokens on top of the infrastructure. These tokens are issued and managed by smart contracts and hence not inherent to the system. They can follow their own specific rules, but still offer basic functionalities like checking balances or executing transfers. For instance, Ethereum offers standards for implementing custom tokens [26]. In BBBlockchain, we use both, coins and tokens: Since coins have a monetary value, we use them to manage for instance a participatory budget, an increasingly popular instrument for co-decision making, which we discuss in the next section (see Section IV-E). Since tokens, on the other hand, can be decoupled from monetary value, we use them as voting tokens and in various targeted forms to incentivize participation. In the following, we elaborate the latter use case.

1) Voting tokens: We use tokens for authenticating whether a user is eligible for participating and voting. The amount of tokens can indicate the user's priority, e.g., more spent tokens gives their voting more weight—however that depends on the voting scheme. By doing so, we could give residents living in the vicinity more voting tokens than citizens more distant to a project. Along the lines of the concept of liquid democracy, users could delegate their voting-rights to somebody else. This functionality enables both, higher participation ratios (representative can vote even if the user is unavailable) and accumulation of influence with individually legitimated representatives with certain knowledge sets or user status (e.g., mobility specialist or official tenant representatives). While it would also be possible to issue tokens in exchange for real fiat money or coins, we distance ourselves from this approach as incentivizing via monetary value is democratically questionable.

As a side effect tokens can be used for reaching anonymity during votings: tokens can be issued as QR codes, for example, shuffled, and sent to residents. The shuffling of QR codes leads to non-tracable pseudonyms. While this seems a reasonable approach to achieve a certain degree of anonymity in practice, we prefer cryptographically secured electronic techniques over analogue techniques.

2) Incentivization: Tokens provide a plethora of opportunities to incentivize participation. The BBBlockchain project will need to balance the emerging technical opportunities with the overarching goals to increase the uptake and diversity of participation processes.

The use of the BBBlockchain app triggers the release of tokens, which subsequently can be collected and used for, e.g., discounts. As a reward system we provide an interface for shop operators, who could offer services or discounts in exchange for tokens. For instance, cafes close to the project's location could offer a fixed-price discount, so they can attract new customers. More importantly the targeted provision of tokens can draw in citizens to support analogue on-site participation formats such as permanent exhibitions or workshops in neighborhood cafes. To further increase interest or site visitors we can also spread tokens over the neighborhood or in institutions of particular interest to the project, e.g., via printed QR codes (municipalities, developers showrooms, etc.). They could also be integrated in relevant documents, so interested parties get rewarded once they participate in the process.

E. Participatory Budget and Crowdfunding

As introduced before, BBBlockchain can execute votes utilizing smart contracts with legally binding results. It can also enforce the contractually agreed results. Participatory budgets represent a powerful form of participation benefiting from this functionality. Current analogue formats reserve a certain part of the public budget centrally administered by the municipality. The deployment of this part of the budget within predefined use corridors is directly decided by the citizens using votes. In our use case we explore a participatory budget in coins locked in a smart contract outside the control by a central authority. A simple example is the selection of public art in housing projects. Developers reserve the mandatory budget for artwork (in some countries such as Germany building projects are legally required to fund art with a certain amount of the overall construction costs) and let the inhabitants, neighbors or a wider group of citizens vote for their preferences. After the voting, the winning artist will be contractually commissioned and the budget transferred. A participatory budget secured by a smart contract hence establishes is a real hand-over of decision-making power to the eligible group of participants. As the voting results are executed directly, authorities or developers cannot interfere with the citizens' decision anymore.

Similarly, we can use a smart contract to implement crowdfunding. Crowdfunding is a way of online-fundraising. Projects can collect small donations from a large amount of people. In an urban context, crowdfunding can serve as an alternative way to (co-)finance smaller projects for the neighborhood. The provision of funds by many can be considered as a public vote to realize certain projects and similar to BBBlockchain's functionality to enable participatory budgeting, the smart contract can enforce execution once the funding goal is reached. From a technical perspective, many variants are feasible. An alternative funding methodology would be crowdsourced participatory budgets. Likewise, we can implement the concept of matching funds, where a certain amount of crowdsourced coins are matched from other sources such as a housing agency.

The transition of decision-making power in urban development from institutions thus far elected to represent the common good directly to citizens obviously challenges the current balance of direct and representative democracy. BBBlockchain enables functionalities so far unavailable or unfeasible to use in an urban development processes and this project will need to research and redefine the boundary conditions sustaining both, citizens empowerment and the common good.

V. BBBlockchain Architecture

The heart of BBBlockchain lies at its smart contracts. We have implemented them in Solidity which is a turing-complete and object-oriented programming language for the Ethereum Virtual Machine. We decided to build upon Ethereum, because it is a public, permissionless, and established blockchain, which offers enough flexibility to implement our platform, which all are very important properties for our vision. In the following, we will present the BBBlockchain architecture and reason on our design decisions.

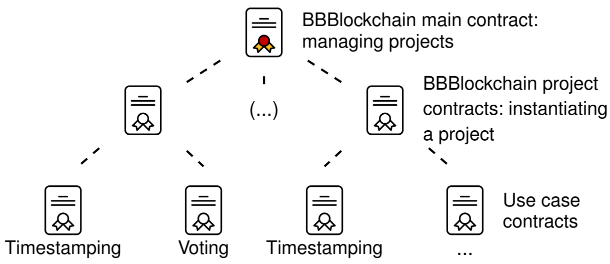

Fig. 2. Smart contract architecture of BBBlockchain.

A. BBBlockchain Smart Contracts

The main BBBlockchain smart contract manages multiple other smart contracts for building projects and handles all permissions. Once deployed it provides all data for the app and manages multiple building projects and their use cases. As shown in Figure 2, it serves as entry point and its contract address is available via DNS[1]. Although we are committed to a permissionless platform, not everybody is allowed to manage our projects freely. We differentiate between read-only calls and writing transactions in the smart contracts. All data are stored openly for read-only access, but managing the smart contract is only allowed for a closed user-group representing the key stakeholders.

An urban development project can have multiple use cases which are implemented as separate smart contracts. The main smart contract therefore maintains a list of all use case contracts. Currently, we have implemented open-source solutions for the following use cases: timestamping, polls, voting, and our own crypto token. We use the smart contract verification on Etherscan[2] for publishing the smart contracts and directly linking them to the deployed instances. As every urban development project pursues its own participation strategy, we followed a modular approach; each use case can be activated individually, repeatedly or simultaneously, e.g., voting. And as these strategies often change over time new functionalities can be developed and added any time.

B. Infrastructure

BBBlockchain relies on the Ethereum blockchain infrastructure and does not necessarily rely on self-hosted infrastructure. We do not expect however that our users are familiar with maintaining an Ethereum wallet and interacting with a smart contract. We therefore implemented a mobile app for iPhone and Android devices, and also provide a website, which provides the most of the functionalities. We also do not expect users running a full node and thus provide an API which basically mirrors all smart contract functions and manages the blockchain interactions. The API provides access to our

[1]TXT Record: contract.bbblockchain.de
[2]https://etherscan.io

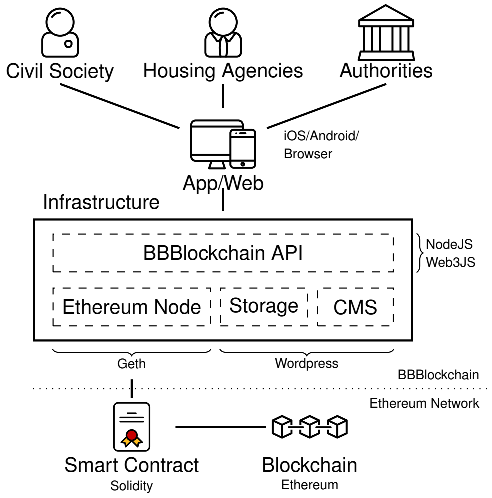

Fig. 3. Infrastructure and used technologies of BBBlockchain.

fully synchronized Ethereum node and executes all smart contract calls. The app not only visualizes the API's data, but also verifies hash values locally to check for integrity (see Section IV-A). Nevertheless, users could at any time also execute the smart contract functions by themselves without the API, because all BBBlockchain smart contracts are stored in a public blockchain, which is open-source available. Lastly, we do not expect users to pay for their transactions, so we cover transactions fees within BBBlockchain. While users can opt to run their own node and verify transactions for complete transparency, they have to pay the transaction fees in this case themselves. At the time of writing, though, our smart contracts are deployed and tested in the Rinkeby testnet of Ethereum, which is virtually identical to the Ethereum mainnet but does not charge any fees.

Figure 3 shows the basic technical infrastructure and which technologies were used. The node and the storage can both be mirrored by anybody for enhancing transparency. Again, our infrastructure is only provided for keeping participation barriers low, especially by not operating full Ethereum nodes on mobile devices. Our hosted Ethereum node could be replaced by other trustworthy parties as the source codes are open-source. For independence from Ethereum networks the smart contracts are also compatible with Quorum [27], which is a permissioned version of Ethereum for enterprise usage.

We also want to point out our focus on barrier-free access and inclusiveness of our app. It is very important for us to make the documents as easily accessible as possible. New technology features like push notifications on mobile devices also allow to inform about updates instantaneously.

C. Public permissionless blockchains

First, we need to differentiate public and private blockchains: as the name already implies public blockchains can be accessed publicly (whereas private blockchains keep all data confidential) and therefore are the only option for our intentions. When it comes to so-called *permissioned* and *permissionless* blockchains the decision seems not as clear. The pros and cons of both are not obvious and have a direct impact on the transparency and integrity of the BBBlockchain. Basically, the two approaches follow different strategies on who can participate in the consensus algorithm, i.e., who can become a miner (or validator).

Permissionless blockchains generally allow anyone to join the network, become a miner, and help to verify the blockchain. Thus, they require a global consensus between miners and nodes. It is not necessary to assume that nodes trust each other, but that the majority is benign and uses the same consensus protocol. In contrast, permissioned blockchains allow only a selected group of nodes, i.e., so-called validators, to verify and advance the blockchain. It implies a authority that decides on who is allowed to join, and who not. Permissioned blockchains should not be confused with permissions in smart contracts, though. Although a smart contract can limit who interacts with it, e.g., who can participate in a poll, it does not matter whether the blockchain itself is permissioned or permissionless.

In general, the consortium of miners/validators can also mutually agree to change data stored in the blockchain. For BBBlockchain, we opt for a permissionless blockchain, in our case Ethereum, to provide full transparency of all stored data. Since we do not have influence on the consensus algorithm, Once published data cannot be manipulated unnoticed; neither by us, urban housing societies, or government, as long as not more than half of the Ethereum network approves it.

VI. Evaluation and Discussion

A. Methodology

We decided to use the permissionless Ethereum infrastructure for hosting BBBlockchain. Ethereum provides the blockchain technology and an existing broad peer-to-peer network, but using its infrastructure is not completely free or charge. Joining the network, validating transactions, and querying data is free for everyone, but proposing changes on the blockchain will cost flexible fees. Depending on the consumed processing power of a transaction and how many transactions were proposed during the same time span, the fee rises—in a supply and demand manner. A transaction consists of a set of predefined meta data, e.g., sender and receiver addresses, and a linear set of instructions. The instructions can send coins or execute arbitrary executable computer code, or both. Ethereum defines the so-called *gas cost* for each instruction, depending on the complexity and resource consumption. The fee then has to be paid to the miner of the transaction before it is executed, stored, and broadcast to other nodes. Other cryptocurrencies can handle transactions fees differently, of course. Before requesting a change the sum of all gas cost will be calculated and the proposer sets a price he is willing to pay per gas in *Ether* and a certain limit he is willing to pay for the whole transaction (so-called *gas limit*) [28]. The transaction fee results from summing up how often an instruction was executed multiplied with its price. The gas

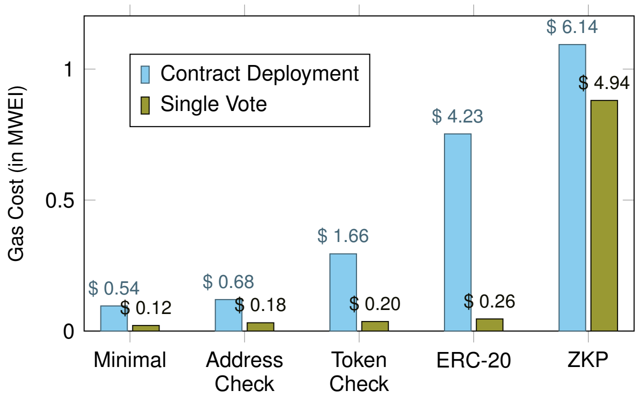

Fig. 4. Gas costs for deployment and submitting a single vote using different voting schemes.

limit by the proposer set prevents that code ends up in an infinite loop or uses disproportionately computing resources. If the proposer undercharges their gas prices miners ignore the transaction.

In the following, we evaluate the gas costs for various contract types, including timestamping and voting. We also evaluate the total expected costs of deploying BBBlockchain. To this end, we use the median gas price and Ether exchange price to USD of the past year (from the day of writing). That is, we used the median gas price of $14,330,651,283$ Wei ($\times 10^{-18}$ Ether) and USD 195.97 per Ether for estimating costs [29]. We provide a public Git repository[3] with our test contracts that we used to calculate the gas costs for our evaluations.

B. Timestamping Costs

For us and BBBlockchain hosts it is especially interesting how much providing an API costs. For example, predicting how expensive it is to offer a timestamping service is important for operating the platform: The deployment of the timestamping smart contract costs approximately $2,428,484$ gas, which is about USD 8.82. Timestamping a data item and adding it to the blockchain, i.e., registering a hash value with our smart contract, costs approximately $214,650$ gas, which is about USD 0.60 for each timestamp.

C. Voting Costs

As already mention, the costs highly depend on the complexity of the instructions set and the current demand. In order to get a first overview, we distinguish between different voting techniques. We therefore evaluated the gas costs of different voting schemes implemented in Solidity as shown in Figure 4: The minimal implementation allows unlimited voting without any control mechanisms. The address check implementation saves the sender's address after voting and validates before voting, so one can only vote once per sender address. That leads to slightly higher smart contract deployment and voting fees. The token check implementation is more complex, requiring a secret token for voting, so deployment is more expensive because of expensive hashing function. With ERC-20, we allow to set a weight to a vote and transfer voting rights to another persons, leading to a more much more complex smart contract. On the other hand, voting can become cheaper, because on can vote multiple times for one option in on transaction with a higher vote weight. At the end we evaluated voting with a Zero-Knowledge-Proof (ZKP) for validating voting tokens and ensuring anonymity. We used ZoKrates [30] for generating a validator smart contract and proofs for the voting tokens. Validating voting tokens with complex mathematically proofs become much more expensive.

[3]https://gitlab.tubit.tu-berlin.de/robtu7/bbb-gaseval

D. BBBlockchain Deployment Costs

Deploying cost for a complete BBBlockchain project can be estimated as well. The gas cost is achieved by deploying the main contract ($1,281,973$ gas), utility contracts ($758,106$ gas), a building project ($2,383,215$ gas), and its use cases. The gas cost also depends on the meta data and therefore can only be approximated. Using the same gas price and Ethereum exchange rate, we assume deploying BBBlockchain cost at least USD 12.42 right now, plus the individual gas costs for the use cases.

VII. Conclusion

Together in an interdisciplinary research effort we aligned urban development and computer science. Our project BBBlockchain provides a blockchain-based platform for participation during urban development processes. We showed how complex and long-term planning processes can offer more transparency, and even how trustful co-creation can be enabled. Therefore, we have modeled real-word participation processes in smart contracts, and enabled citizen to monitor all actions. Especially if participants do not trust each other, blockchain functions as a mediator and medium in between. Despite the fact that BBBlockchain relies on permissionless blockchains to avoid centralized data-ownership as in server-client architectures, we evaluated that the additional costs are reasonable. We do not claim blockchain solves all trust issues by definition, but we consider the trade-offs between its risks and disadvantages on the one hand, and its potential and novel possibilities on the other hand.

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References

[1] S. R. Arnstein, "A ladder of citizen participation," *Journal of the American Institute of planners*, vol. 35, no. 4, pp. 216–224, 1969.
[2] IAP2, *IAP2's Public Participation Spectrum*, 2014. [Online]. Available: https://www.iap2.org.au/Tenant/C0000004/00000001/files/IAP2_Public_Participation_Spectrum.pdf.

[3] Liqd, *Adhocracy*, Accessed: 2019-04-30. [Online]. Available: https://github.com/liqd/adhocracy4.

[4] DemocracyEarth, *Sovereign*, Accessed: 2019-04-30. [Online]. Available: https://github.com/DemocracyEarth/sovereign.

[5] *The social coin*, Accessed: 2019-04-30. [Online]. Available: https://thesocialcoin.com.

[6] Y. Rydin, *The purpose of planning: Creating sustainable towns and cities*. Policy Press, 2011.

[7] J. Fox, "The uncertain relationship between transparency and accountability," *Development in Practice*, vol. 17, no. 4-5, pp. 663–671, 2007.

[8] BMJV and Bundesministerium der Justiz und für verbaucherschutz, *§ 3 BauGB - Beteiligung der Öffentlichkeit*, 2017. [Online]. Available: https://www.gesetze-im-internet.de/bbaug/__3.html.

[9] UN HABITAT, "INTERNATIONAL GUIDELINES ON URBAN AND TERRITORIAL PLANNING," UN Habitat, Nairobi, Tech. Rep., 2015. [Online]. Available: www.unhabitat.org.

[10] Degewo, Howoge, Gesobau, Gewobag, Stadt&Land, and WBM, "Leitlinien für Partizipation im Wohnungsbau," Tech. Rep., 2017. [Online]. Available: www.inberlinwohnen.de.

[11] UN, "Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development," United Nations, Tech. Rep., 2018. [Online]. Available: https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%20refinement_Eng.pdf.

[12] Y. Cabannes, "Participatory Budgeting in Paris: Act, Reflect, Grow," in *Another city is possible with Participatory Budgeting*. Y. Cabannes, Ed., Montréal, New York, London: Black Rose Books, 2017, pp. 179–203. [Online]. Available: https://budgetparticipatif..

[13] M. Atzori, "Blockchain technology and decentralized governance: Is the state still necessary?" *Available at SSRN 2709713*, 2015.

[14] R. Rumbul, "Who benefits from civic technology," *Demographic and public attitudes research into the users of civic technologies*, vol. 7, p. 2018, 2015.

[15] J. Hendler, O. Sosnik, G. Prudner, D. Chernicoff, J. McCarthy, O. Ree, and C. Keefe, *Engines of change: What civic tech can learn from social movements*, 2016.

[16] N. David, J. G. McNutt, and J. B. Justice, "Smart cities, transparency, civic technology and reinventing government," in *Smart Technologies for Smart Governments*, Springer, 2018, pp. 19–34.

[17] B. Barber, *Strong democracy: Participatory politics for a new age*. Univ of California Press, 2003.

[18] J. S. Dryzek, *Deliberative democracy and beyond: Liberals, critics, contestations*. Oxford University Press on Demand, 2002.

[19] A. Wilson, M. Tewdwr-Jones, and R. Comber, "Urban planning, public participation and digital technology: App development as a method of generating citizen involvement in local planning processes," *Environment and Planning B: Urban Analytics and City Science*, vol. 46, no. 2, pp. 286–302, 2019.

[20] J. Saldivar, C. Parra, M. Alcaraz, R. Arteta, and L. Cernuzzi, "Civic technology for social innovation," *Computer Supported Cooperative Work (CSCW)*, vol. 28, no. 1-2, pp. 169–207, 2019.

[21] J. A. Kroll, I. C. Davey, and E. W. Felten, "The economics of bitcoin mining, or bitcoin in the presence of adversaries," in *Proceedings of WEIS*, vol. 2013, 2013, p. 11.

[22] N. Szabo, *Smart contracts*, https://web.archive.org/web/20160323035617/http://szabo.best.vwh.net/smart.contracts.html, Accessed: 2019-01-04.

[23] R. Matzutt, J. Hiller, M. Henze, J. H. Ziegeldorf, D. Müllmann, O. Hohlfeld, and K. Wehrle, "A quantitative analysis of the impact of arbitrary blockchain content on bitcoin," in *Proceedings of the 22nd International Conference on Financial Cryptography and Data Security (FC)*, 2018.

[24] B. B. Simons, "Electronic voting systems: The good, the bad, and the stupid," *ACM Queue*, vol. 2, no. 7, pp. 20–26, 2004.

[25] P. McCorry, S. F. Shahandashti, and F. Hao, "A smart contract for boardroom voting with maximum voter privacy," in *Financial Cryptography*, ser. Lecture Notes in Computer Science, vol. 10322, Springer, 2017, pp. 357–375.

[26] F. Vogelsteller and V. Buterin, *Ethereum ERC-20*, https://eips.ethereum.org/EIPS/eip-20, Accessed: 2019-03-27.

[27] JPMorgan Chase & Co., *Quorum whitepaper v0.2*, Accessed: 2019-04-05.

[28] G. Wood, *Ethereum: A secure decentralised generalised transaction ledger byzantium revision (3e36772 - 2019-05-12)*, Accessed: 2019-05-14, 2017.

[29] *Etherscan.io charts*, Accessed: 2019-05-09. [Online]. Available: https://etherscan.io/charts.

[30] J. Eberhardt and J. Heiss, "Off-chaining models and approaches to off-chain computations," in *Proceedings of the 2nd Workshop on Scalable and Resilient Infrastructures for Distributed Ledgers*, ACM, 2018, pp. 7–12.