Theme Article

Blockchain-Supported Smart City Platform for Social Value Co-Creation and Exchange

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***Abstract*—Recent technological advances are creating possibilities for novel forms of interaction, collaboration, and organization of labor in Smart Cities. In this paper, we present a reward-driven, Blockchain-backed platform acting as the technological enabler for enactment of ad-hoc, decentralized neighborhood-scale co-creation, collaboration, and citizen engagement activities.**

Historically, the evolution of the Smart City concept was mostly driven by technological advances. At the same time, most concrete Smart City initiatives and pilot implementation projects struggle to achieve a significant uptake and retention of the new technologies due to inability to actively involve citizens and keep them engaged. Therefore, we currently find ourselves in a paradoxical situation, where indisputably worthy technologies developed for a Smart City context are not being used by the inhabitants of the city.

We believe that the full potential of the Smart City vision can only be achieved if all the technological advances are exploited to ultimately enable creation of completely novel societal values. As these values are of exclusive meaning to humans only, humans must necessarily be in the focus of the ICT research in the Smart City context.

In order to connect societal values with the low-level (hands-on) goals of the concrete municipal, research, and commercial efforts, a gradual approach needs to be taken, where the high-level values are achieved through a number of intermediate objectives. In our recent book,[1] we present a vision of such an architecture of values for Smart Cities in more detail.

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One of the key objectives in the architecture of values is the citizen empowerment. This implies the development of a number of technologies to support humans in performing their cognitive, creative, collective, and social activities, both in the physical and in the digital domain.

The above-mentioned vision relies on the acceptance of ad-hoc transactions between unknown people, both in the digital and in the physical domain (e.g., sharing a ride in a private car). The concept is already well-accepted among the general population, having been introduced along with the popularization of the sharing economy, but is not limited to the mere sharing of resources. The appearance of innovative, decentralized, and peer-to-peer collaboration tools enables the exploitation of this principle in a socially responsible form, causing a disruptive societal change. The recent advent of the Distributed Ledger Technology (DLT), commonly and interchangeably referred to as Blockchain (without implying a specific implementation), has resulted in the development of an ecosystem of proven cryptographic and algorithmic techniques that now, for the first time, make it possible to implement the above-mentioned collaboration tools at a commercial scale and quality.

In this paper, we present a Blockchain-backed Smart City platform for societal value exchange and co-creation, named WeValue. The platform facilitates ad-hoc interactions among different city stakeholders (primarily citizens) and enables matching of complementary or similar stakeholder interests, thereby encouraging neighborhood-level value co-creation processes. We describe a reference architecture for our platform and describe its functionalities, execution model, and common usage scenarios. Finally, we discuss the current and future limitations and research challenges.

MOTIVATION

The intensive globalization in the last decades, driven in large part by the rapid advances in Information Technology, has caused a worldwide power shift in favor of large international corporations that is affecting the everyday life of local communities in a variety of ways, e.g., by eliminating local businesses and diverting the local money flows, or by influencing the public opinion. A typical example of this disruption of local communities is using a distant company to act as a mediator in a business transaction that is being executed locally. This has caused the conceptually positive and sustainable concept of sharing economy to become associated with unfair treatment of local community and significantly affect its popularity and uptake.

One of the major reasons why big corporations are successful in profiting from mediation in local human-centric transactions is their wide coverage of the general population, and the fact that they are being familiar and therefore trusted by the users. Ironically, a city (local community) has historically always represented (and still does) such an overarching, trusted authority. And yet, due to a lack of simple and scalable means of participation and co-creation, local communities have not been able to capitalize on the advances in communication and mediation technologies.

With the onset of the Smart City research, we as society are in a position to bring some of this power back to the local communities, by putting to their disposal trusted software tools for communication, co-creation, and ad-hoc transactions. These tools are needed to facilitate interactions among different city stakeholders (citizens, local companies, city representatives, and local NGOs), which currently mainly act and create value in isolation.

Apart from trust, one of the major obstacles to a wider uptake of such tools is the question of popularity/usage. A platform that cannot attract and keep the users will not be able to achieve a significant impact. Many contemporary city-run or citizen co-creation platforms are not very good at actively engaging citizens in the long run, as not being able to successfully compete with commercial offers for citizen attention due to a lack of sustainable incentives. It is therefore imperative to design self-sustainable platforms, where the participation itself will be the driving force. This will create an environment that will boost local cohesion, improve decision-making, and create an environment for stronger development of local businesses.

To better motivate the need for a self-sustainable value co-creation platform, we present the following three illustrative scenarios.

Use Case 1: Local Park Refurbishment

A group of citizens from the same neighborhood takes initiative to refurbish the local park. Due to budget cuts, the municipality that is in charge of maintaining the parks is not able to finance the park refurbishment, and is thus unable to respond to the citizens' initiative. The municipality, however, is willing to refurbish the park if private financing is provided. The citizen group therefore submits a request to gather private financing to the WeValue platform, offering in return a number of effort hours to be performed locally. Around the same time, a newly opened restaurant submits a request to hire local helpers to help promote the business by distributing leaflets and bringing in guests. The platform recognizes the complementary nature of the goals and requirements of the three stakeholders (citizen group, restaurant, and municipality), and enables them to enter a contractual agreement that, upon fulfillment that is monitored by the platform, allows each of the stakeholders to achieve the individual goal.

Use Case 2: Energy-Saving Challenge

A local green energy supplier spends significant financial means to place targeted advertisements into the digital content viewed by local customers. The energy supplier is therefore relying on a nonlocal intermediary to reach out to local customers. With a social value exchange platform, the local energy company can "cut out the middleman" and locally implement inventive marketing strategies, thus reducing the expenses, reinvesting the money into the local economy and advertising more effectively and in a socially responsible way. The energy supplier therefore submits a request to the platform for a neighborhood energy saving challenge. All neighborhoods that accept the challenge and collectively achieve specified energy/water savings over a predefined period of time are entitled to a monetary reward that can be either split individually, or used for an improvement/investment into the neighborhood infrastructure.

Use Case 3: Management of Bike-Sharing Fleet

Many cities have actively embraced bike sharing schemes, both in the form of fixed-station solutions as well as in the form of floating bike schemes. However, neither form is typically able to effectively cover the entire city area, they both require a total or partial redistribution of bikes by the bike operator, and there is often not enough available bikes or parking slots on certain locations during the rush hour, while the floating schemes cause a big problem by cluttering the public bicycle parking lots and obstructing pedestrian ways and fire escape routes.

A social value exchange platform can be used to allow the citizens to take part in the redistribution of bikes, thus achieving faster responsiveness, reducing the overall need for redistribution by motor vehicles, enabling a wider coverage of the biking scheme, and ultimately promoting a healthier lifestyle. The fleet management company issues redistribution requests, associated with incentives/rewards for the action performers. The incentives for participating in the scheme include different digital incentive artifacts, where different collectibles reward different actions taken, e.g., relocating a bike where too many bikes are concentrated, distributing the bikes toward the outer districts in the evening to better prepare it for the morning commute to work, responding to an individual's bike order (i.e., similar to ordering an Uber), collectibles for the distance covered (and CO_2 saved).

In this way, the platform effectively plays the role of a social value stock exchange, where the currency are the different digital collectibles exchangeable for services by other fellow bikers, or for other digital/material services by the city or commercial stakeholders.

Why Blockchain?

A sudden rise of interest in the Blockchain technology in the recent years has brought along both positive and negative aspects. The positive aspect is that it has sparked a considerable research and implementational effort and produced many innovative ideas and software tools that have made the creation of commercially fit systems feasible. The negative aspect is the appearance of many proposed systems that misuse the Blockchain's current popularity to gain visibility, thus tarnishing the approaches that use it for the purposes it was designed to handle.

From the technical perspective, the principal idea behind the WeValue platform is the combination of a centralized social/collaborative computing system with the concept of decentralized trust ("trustlessness") delivered through the use of Blockchain technology. This technological interplay allows to combine the versatility in matching and managing complex collaborative workflows, offered by the centralized model, with the publicly verifiable transparency and accountability, and the ability of an automated and commonly agreed proof and enforcement of contract stipulations. The latter provides a technological foundation for ensuring a high level of citizen control over own data and participation conditions, which could not be effectively achieved by a fully centralized, authority-managed solution. Therefore, from economical perspective, the Blockchain-based approach enables transforming a centralized platform into a free market for the exchange of values, which naturally attracts participants (stakeholders) thereby fueling the participation necessary for the viability of the platform.

WEVALUE PLATFORM

Traditionally, markets are viewed as a locus of exchange, where businesses decide what products and services to offer to customers, while customers are separated from the value creation process. WeValue disrupts this traditional model by enabling both parties to engage in value co-creation process as well as by allowing for value trading.

On the one hand, our platform enables bidirectional, city-wide value co-creation. The value creation starts bottom-up, from the local neighborhoods that share the strongest common values, interests, and goals. Conversely, high-level Smart City Key Performance Indicators (e.g., sustainabledevelopment.un.org/sdg11) provide a feedback loop and can act as general guidelines and incentives to steer the Smart City value creation. For example, societal added value is clearly associable with the increase in engagement of citizens and other city stakeholders in a community. It becomes especially impactful and meaningful when the value is co-created by different disciplines, communities, and society categories.

On the other hand, WeValue acts as a value exchange by enabling trading in values. Value is a subjective matter that cannot always be generalized and put in terms of money. It is not always convenient or even possible to trade in money. Therefore, we enable direct and unconstrained co-creation of and trading in value.

The core concepts behind the WeValue's approach are Value Agents and Value Contracts. Next, we describe them in more detail.

Value Agent

A Value Agent is a software agent actively representing a participating stakeholder, starting from the moment a request is submitted to the platform. Thereafter, the agent participates in the task matching and the orchestration process, in which it reacts to the existing and newly submitted tasks in an attempt to identify and negotiate with other agents a task composition that would be acceptable to the stakeholder it represents. After a potentially suitable task composition has been made, the stakeholders give their approval before a Value Contract is created.

Value Contract

A value contract is based on the Blockchain Smart Contract technology, used as a formal specification of the achieved agreement for the execution of a collaborative activity. The value contracts programatically encode contractual obligations and automatically, in a trustless manner, enforce the fulfillment of such obligations by establishing a publicly verifiable accountability and transparency record, as well as possible rewards and penalties. The value contract is eventually invoked by the agents that represent the involved stakeholders, who do it to indisputably prove the fulfillment of the contractual obligations by the represented stakeholder and determine possible rewards for the stakeholder. The inputs used for contract verification are coming from the agreed oracles.

The main elements of the value contract include a set of inputs and output rewarding actions. The input actions specify the offered and requested services, and the acceptance conditions that will be used in the negotiation process. For example, in the simplest form, the input actions specify the service Sx the stakeholder X is willing to offer in exchange for the service Sy provided by a still unknown stakeholder (or collectively by a group of stakeholders) Y. The rewards

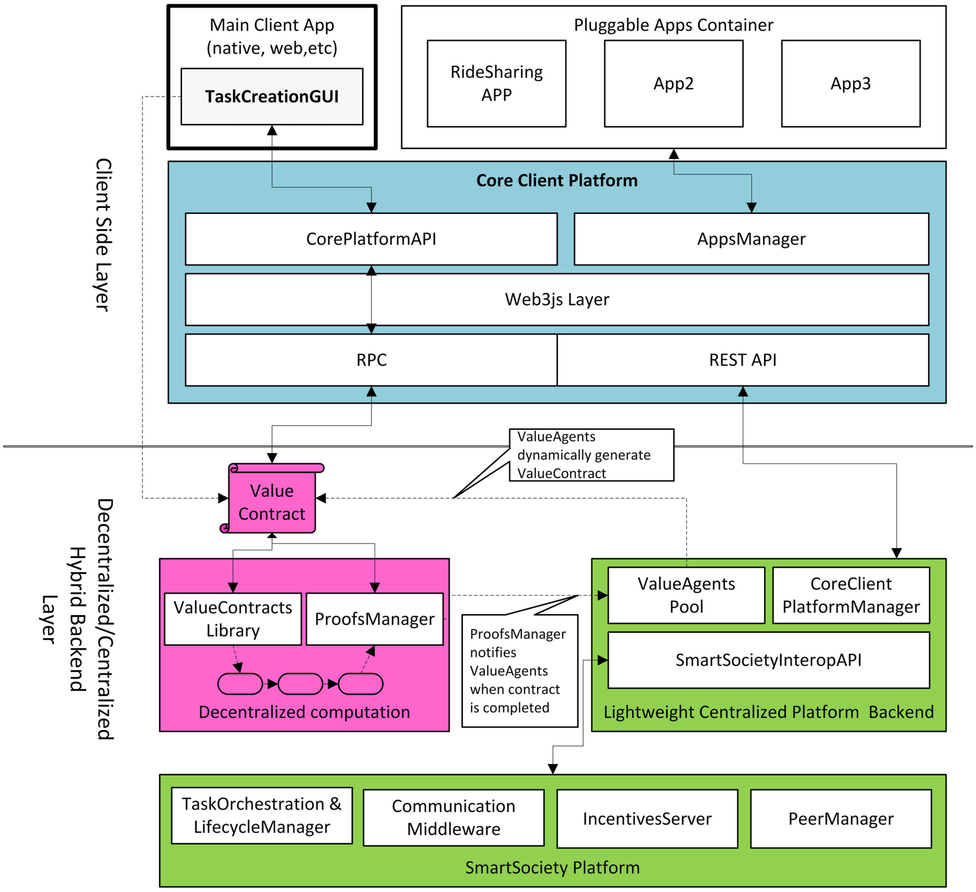

Figure 1. Architecture of the WeValue platform.

that are specified as output serve as incentive mechanism to increase the likelihood of attracting other complementary (matching) tasks. In general, when the stakeholder interests are not fully aligned and complementary, the incentive mechanisms encoded in the value contract are used to facilitate the automated negotiation process and lead to a successful conclusion of the value contract among the value agents.

Platform Architecture

Figure 1 shows a high-level architecture overview of the WeValue platform. The platform consists of two main layers: a Client Side Layer and a Decentralized/Centralized Hybrid Backend Layer.

The most important component of the Client Side Layer is the Core Client Platform. It is responsible for managing custom WeValue Apps that run on top of the WeValue platform and mediating all the communication with the Hybrid Backend Layer. The main reason for adopting this "heavy client" architecture is to support the novel Decentralized/Centralized Hybrid Backend architectural design.

The Hybrid Backend Layer is more complex and contains two main facilities, first, Decentralized Computation Facility, which is based on DLT and, second, Lightweight Centralized Platform Backend. In a nutshell, these components have the following main responsibilities.

- Decentralized Computation Facility—It is responsible for executing the Value Contracts in a trustless manner.
- Lightweight Centralized Platform Backend—It is responsible for providing mechanisms to support managing Value Agents execution lifecycle.

The SmartSociety platform[2] (www.smartcollectives.com) for collaborative computing provides a set of APIs, which are utilized by the

Value Agents for task orchestration, communication with the users, privacy, and reward management. The SmartSociety platform provides an open-source software toolset for end-to-end lifecycle management of complex, human-centric collaborative activities. Its principal components modified for the use in WeValue platform include the following.

- PeerManager—A centralized data-store for user and group profiles. It manages all sensitive user information, and supports data minimization, obfuscation and privacy policy definition, providing a rich and privacy-preserving environment to deal with personal data, in line with the recent European regulation.
- Communication Middleware—It provides the facilities for peer-to-peer and group-based communication. It supports routing and exchange of messages with different protocols, message transformation, and the definition of personalized delivery policies. Communication with users is supported via popular commercial protocols to allow a broader integration with existing communication software and allow inclusion of peers into the platform.
- Task Orchestration and Lifecycle Manager—It provides the lifecycle management functionality for collaborative tasks. We alter the SmartSociety's default task execution model to enable a seamless integration of the value agents and value contracts into the SmartSociety execution model.
- Incentive Server—It allows defining and executing incentive actions upon specified conditions to reward participants (both via monetary and nonmonetary, e.g., gamification techniques). Through integration with the Task Orchestration and Lifecycle Manager, it allows the WeValue platform to administer the rewarding/penalizing actions specified in the Value Contracts.

Platform Usage Overview

Figure 1 illustrates how the WeValue platform formalizes the user-defined tasks as Value Contracts and supports their execution in a trustless manner. These logical interactions are depicted as dashed arrows in the figure. This process can be broken down into the following general steps.

1. The user creates a task by utilizing the TaskCreationGUI component, specifying input actions and output rewards upon fulfillment.
2. The platform assigns a Value Agent to this task.
3. The Value Agents on the platform (Value Agents Pool) coordinate among each other to find matching contracts. The coordination process is supported by the SmartSociety platform—in particular, the Task Orchestration and Lifecycle Manager component.
4. Once the matching is completed, the involved Value Agents dynamically generate a Value Contract, sign it and record it on a Blockchain. All Value Contracts by default include specific generic functionality, which is provided by the Value Contracts Library and Proofs Manager components. Such functionality is used to support transforming actions to rewards, lifecycle management of the Value Contract (e.g., its expiration time), and proof generation.
5. Finally, once a task is completed, Proofs Manager records this information on the Blockchain and notifies Value Agents that the contractual obligations have been fulfilled.

Task Lifecycle Model

The WeValue task lifecycle model is depicted in Figure 2. It is based on SmartSociety's Collective-Based Tasks[2], requiring two passes through a sequence of different internal states. Each state resembles different steps of task matching (depicted in red in Figure 2) and task acceptance (depicted in blue in Figure 2), ultimately leading to creation and execution of a Value Contract.

Matching phase The main purpose of Matching Phase is to enable finding users who can fulfill the required actions that are specified in a task. When a task is submitted to the platform and a corresponding Value Agent is created, the task enters the Continuous Orchestration state. All tasks in this state are subject to automated negotiation and matching performed by the Value Agents. Establishing a match implies that a subset of agents mutually agrees on a complementary set of input actions. As time passes, new

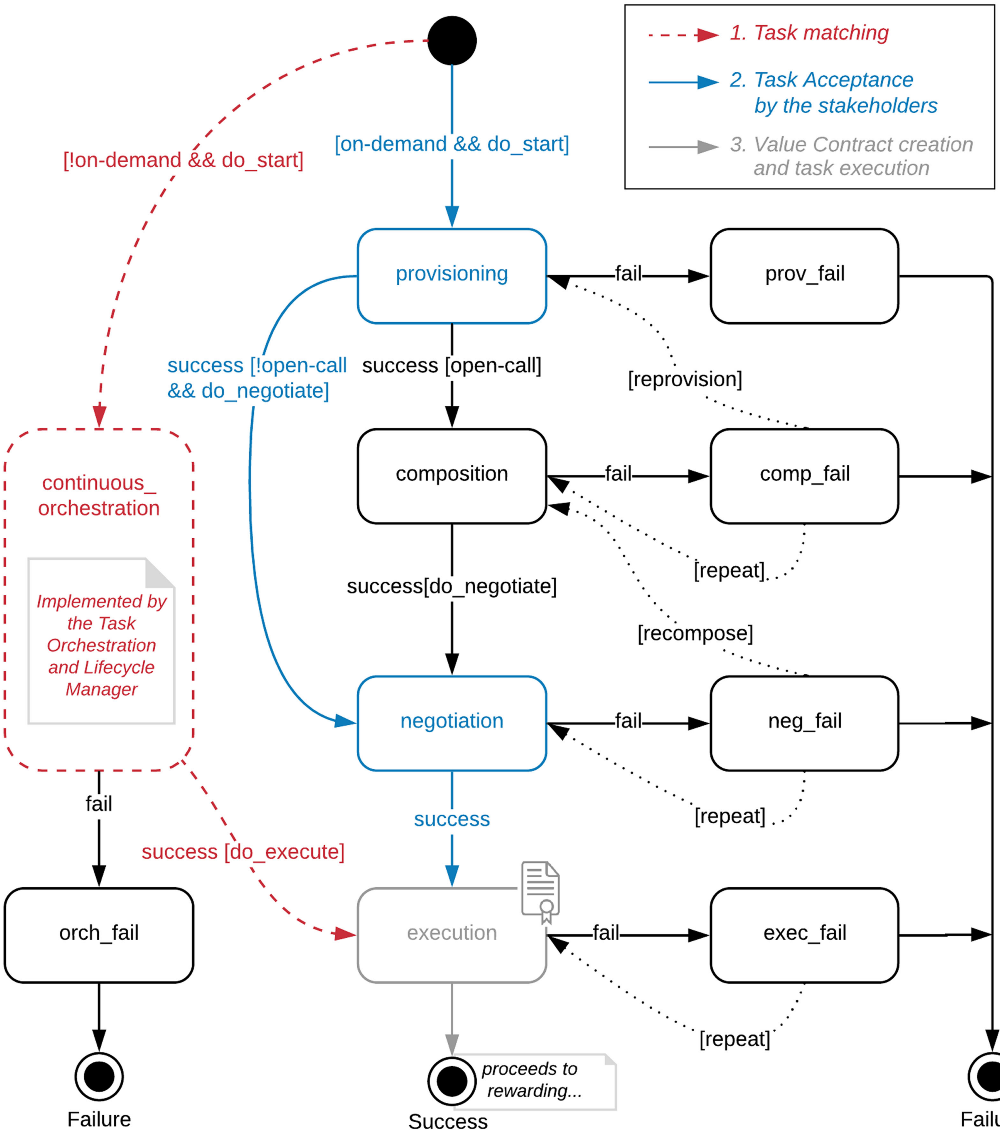

Figure 2. Execution model of a WeValue task.

tasks enter the state, or external/internal conditions change, making new matches possible. The agents therefore continuously re-evaluate the overall state, depending on the orchestration strategy they employ.

The outcome of the matching phase is an ordered set of viable matches, where the order is determined by the quality of the match. After that the task is moved into the execution state. The task is then "frozen" in the execution state, waiting on the execution of a joint parent task. Finally, the Value Contract gets created and signed by the Value Agents, hence representing the joint interest of matched agents.

Task acceptance and execution phase The Value Contract gets internally submitted for execution to the platform by the agents, but follows a different path through internal states (see Figure 2, step 2). The Provisioning and Negotiation states are used to contact the participating users and get their explicit approval for one of the matches. Unlike the original task lifecycle model,[2] in our case the state is limited to a single negotiating strategy, namely a simple "approve" or "reject." If all stakeholders confirm their approval, the WeValue platform automatically generates the code for a Value Contract, based on the specified input and output actions. The Value Contract is then stored on the distributed ledger. It is used to allow for subsequent orchestration, overseeing and verification of the fulfillment of the contract stipulations in a decentralized and autonomous fashion.

Once the conditions of the Value Contract have been successfully fulfilled, the rewarding logic contained in the Value Contract gets invoked. This logic ultimately invokes the API of the Incentive Server component to execute or schedule the agreed rewarding actions. This successfully completes the Value Contract and terminates the individual tasks.

Discussion

In order to fully realize the presented vision and take it to a postprototype maturity level, several technical challenges still need to be solved.

One such challenge is the automated generation of Blockchain Smart Contracts, and consequently of our Value Contracts. Generally, there are inherent technical complexities related to generating all but the simplest Smart Contracts automatically. However, recent advances in this field,[3] as well as commercial solutions for workflow-based systems, such as Unibright (unibright.io), can serve as a solid baseline for future development.

Second, in order to make the WeValue platform suitable for a wider usage, scalability issues related to its decentralized (Blockchain-based backend) part need to be addressed. Early generations of DLT implementations are notoriously characterized by low scalability, both in terms of speed and costs. Fortunately, the third generation DLT solutions based on Gossip protocol or directed cyclical graphs are showing several orders of magnitude improvements regarding transaction processing throughput. Off-chain consensus solutions, such as Lightning Network,[4] store only the minimum information into the Blockchain and process the transaction in a peer-to-peer fashion when possible. Sidechains[5] allow pegging/connecting different Blockchains together. This in turn allows a private sidechain to implement a cheaper and more scalable solution for proof of work (e.g., NIPoPoW).[6] TrueBit[7] employs an incentive model to outsource the validation computation and reduce the redundant network node computations in a Blockchain network. All these techniques are making it possible to reasonably assume that in the near future the scalability issue will be considerably mitigated.

Finally, as any system dealing with personal data of its users, WeValue needs to strike a particularly balanced approach in dealing with privacy on one hand, and transparency on the other. While fully addressing this issue is one of the future tasks for us, the dual architectural (centralized/decentralized) approach was greatly influenced by this challenge. The centralized backend components are designated to store all the personal/sensitive data, as this data is required for the Value Agents to represent the user's interest in negotiations. For this purpose, WeValue relies on the existing SmartSociety security and privacy features. On the other hand, while Value Contracts need to be publicly verifiable, they do not necessarily need to contain publicly visible information. Instead, they need only to refer to the documents (e.g., via their hashes) that can be accessed/decrypted by the involved parties. A good example of this approach is Chainpoint (chainpoint.org), a platform that allows trustless document versioning and timestamped proofs of existence, which works by aggregating hashes of multiple documents inside a Merkle tree and storing its root to a public Blockchain.

RELATED WORK

The systems dealing with general, complex, activities performed both in the digital and in the physical domains, involving both human and machine elements (services, sensors, and devices), characterized by a high degree of self-organization and adaptation are called Cyber–Physical–Social Systems (CPSS). This definition describes an environment where the social and the digital fabric merge with the physical world, and human interactions ever more often take place with, or are mediated by software services, pervasive devices, sensors, and actuators.

A Cyber–Physical–Human System (CPHS) in its latest iteration, as described by Sowe and colleagues,[8] is an extension of the CPSS, where humans are expected to play a more prominent role ("people in the loop"). While bearing striking similarities with the concept of Social Compute Unit[9] (mostly with respect to the human service capability description model), a major novel distinguishing characteristic of a CPHS is the requirement to accommodate for the human unpredictability and the need for incentivization.

Incentives are a frequently used mechanism to entice citizen participation in the Smart City contexts. They are predominantly used in two ways—as simple material rewards to attract participants to collective events, or within gamified environments. Gamified environments are used to train people (e.g., serious games),[10] or to raise awareness/informedness or engage people through entertaining activities.[11,12]

Recently several approaches that utilize Blockchain in Smart Cities have emerged. In their paper,[13] Sun and colleagues presented a conceptual approach of putting the model of sharing economy on the Blockchain and analyze its benefits. Similar approaches address combining the Blockchain and sharing economy models in particular Smart City domains, such as transportation[14] or digital infrastructure.[15] Such approaches aim to utilize Blockchain to further promote the traditional sharing economy model.

Conversely, WeValue proposes a paradigm shift from such traditional models, which have shown to have significant drawbacks in practice, to more socially responsible value co-creation and exchange (sharing) model.

CONCLUSION

Recent technological and societal developments combined with the shift toward the sharing economy put the citizens of a Smart City in the position to be more than mere consumers of smart services. The future Smart Cities will see the citizens and other city stakeholders actively engage in co-creation and collaboration activities with the prospect of actively shaping the city. By encouraging the value exchange among stakeholders, such activities will create the base for novel business and labor models with local scope. Furthermore, the increase in stakeholder interactions will have a positive impact on the social integration of local communities and boost the citizen participation in municipal decision-making. Offering a globally applicable, local environment for unmediated, trustless citizen value exchange, the WeValue platform represents a step in this direction.

In order to fully realize the presented vision, there are still considerable technical and research challenges to be addressed, mostly related to the scalability of the Blockchain technology and management of privacy. In the course of our future research efforts, we intend to explore the discussed solutions for these challenges in order to improve scalability and usability of the WeValue platform.

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