Tokenization of sustainable real estate in Smart Cities

Monetization as basis for construction, authorization and carbon neutralization in CPS

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***Abstract*—Tokenization is a new means to monetize assets in new decentralized economies. New types of tokens allow for the tokenization of physical assets and real-world projects. They can also be used to monetize digital assets in Cyber-Physical Systems, as well as provide a decentralized means to authorize access to such devices and systems. This paper describes one such effort, where this new type of tokens acts as the basis for financing the construction of sustainable real estate (smart buildings), as well as provide a means for private investors (owners) and other interested third parties to gain access to revenue, as well as cyber-physical systems and digital twins within the constructed smart buildings, in an interoperable and transparent manner. Interoperability with underlying systems and equipment is performed using IEEE P1451.99 IoT Harmonization interfaces. Monetization of underlying resources allows for advanced optimization of the process, in accordance with principles defined within Industry 4.0, smart cities, sustainability and quality of life for citizens.**

Keywords—Tokens, CPS, Monetization, Blockchain, Distributed Ledger, DLT, Cryptography, IoT, Harmonization, Interoperability, Decentralized Finance, DeFi, Industry 4.0, Sustainability

I. Introduction

Digital tokens are most often cryptographically protected digital representations of some form of a digital object or claims that can be easily transmitted and processed in decentralized networks. Depending on the construction of this digital object, the token may represent different things, and can be used for various purposes. There are simple tokens, as well as more advanced tokens. Well-known tokens include objects such as Java-Web-Tokens (JWT) [1], used for cybersecurity purposes in communication between machines, or Fungible Tokens (FT) and Non-Fungible Tokens (NFT) on Ethereum blockchain [2-4], used for decentralized financial applications, promising to achieve accurate, efficient and timely payment management, eliminating highly intermediated payment applications [5], also these units of value are stored in a digital wallet where the real economic and environmental benefit is fairly monetized [6].

While tokens used for purely computational, communicational or informatics purposes (such as JWTs) can be issued by *Trust Providers* directly, distributed financial systems place other requirements on tokens: They must be *transparent* and *auditable* as well, otherwise trust is lost in the underlying token and its related asset. Also, tokens for financial purposes need to have the concept of *ownership* clearly defined. Users needed to be able to prove they are owners of their tokens. Furthermore, this ownership must be unique, and transferrable in a secure manner. These were some of the underlying principles behind creating FTs and NFTs on the Distributed Ledger Technology (DLT), as implemented by the Ethereum blockchain. This allowed anyone to audit transactions, as they were stored in blocks in Ethereum, and were publicly available to anyone for analysis. But banking and financial regulations also require financial institutions to *Know Your Customer* (KYC) [7], to be allowed to participate in monetary transactions. This places new requirements on tokens that underlying financial applications use, requirements for which FTs and NFTs are ill-equipped.

The so-called *smart contracts* underlying the creation of such FTs and NFTs lack legal and regulatory integrity. They are not contracts, as humans understand the concept. Instead, they only consist of unapproved, and immutable code persisted on the blockchain, and has therefore been called an unfortunate naming convention by one of its inventors [8]. Furthermore, KYC is impossible for regular users and operators on the Ethereum blockchain. It is designed to make the identification of actors very difficult.

Ensuring the legal integrity of tokens becomes urgent when creating tokens linked to physical assets, projects, events, services or activities, including the obligations and compliance of the parties in the construction of the tokens. Not only is there a KYC requirement in such cases, but to ensure legal integrity or compliance with rules and regulations specific to the use case for which the token was created. A new kind of smart contract is clearly needed for these purposes. Value-added tokens facilitate specific impact and cultural policies, and ultimately combine Smart City qualifications [9].

II. Smart Contracts in IEEE P1451.99

IEEE P1451.99 IoT Harmonization Working Group has published interfaces [10] for a new type of decentralized Digital Identity and Smart Contracts, for cross-domain autonomous interoperability for the Internet of Things (IoT). While these interfaces are still in development, and may be subject to change, these smart contracts are modelled to resemble how legally binding contracts are created. They contain both human-readable text, as well as machine-readable instructions. A method also exists to protect the legal integrity of smart contracts created using IEEE P1451.99. Smart Contract templates are first created. They include, apart from machine-readable and human-readable content, also role, part and parameter definitions, as well as rules for validation and integrity. A Smart Contract template must be manually inspected and validated by the Trust Provider, before it becomes approved. The Trust Provides in effect becomes an *electronic notary* in its domain of influence. Automated smart contract generation based on such approved templates then becomes possible. When creating a smart contract based on a contract template, only signing parts, and parameter values, complying with validation and integrity rules defined in the template, can be changed. This ensures the integrity of the smart contract, as well as the compliance to underlying legal or regulatory framework being used. The federated digital identity can then be used to verify the identities of parts signing contracts, as well as assure sufficient information is known about these parts, for KYC regulations to be fulfilled. All identities, smart contracts and signatures are cryptographically protected. Tokens created using smart contracts, as defined in IEEE P1451.99 can therefore be made to be legally binding, making it possible to tokenize not only digital assets, but also physical assets, projects, events, services and other activities.

Central in P1451.99 is the concept of a *Broker*. Brokers help negotiate connections between entities in the network in a secure manner. They also provide *decision support* to devices, who are not able to, by themselves, resolve security problems, or know who or what their owners authorize them to do. These Brokers act as *Trust Providers* in the network, as they also validate and cryptographically protect the integrity of generated objects, such as digital identities, smart contracts (and tokens, where this is applicable).

A. Examples of IEEE P1451.99 smart contracts

Some examples of smart contracts that can be modelled using IEEE P1451.99 include:

- Legally binding contracts and agreements between companies and systems, for automation.
- Human-readable contracts and sworn statements, such as notarial documents, with machine-readable information for integration with automated systems (Cyber-Physical Systems).
- Declarative agreements for automation, such as Data Protection Agreements, or Conditions of Use, for data exchange, authorization, or provisioning of personal or sensitive information.
- Consent-based contracts for privacy, which require that only parts in the contract have access to the information, and that the contract can be revoked and forgotten.
- Automated and legally binding contractual payments, including conditional payments that can be processed only on the fulfillment of legally binding obligations. This includes contracts for the monetization of access to devices and/or their data.
- Asset-backed tokens and related contracts, which protect the ownership or lease of the physical assets forming the base of the digital instruments and their values.

III. Neuro-Ledger

IEEE P1451.99 does not prescribe a persistence layer, and therefore not a Distributed Ledger where contracts and identities are stored. This is considered *implementation specific*. Instead, the focus of IEEE P1451.99 is related to the real-time communication between nodes in the federated network, and how objects are protected, how access is authorized and how content and integrity is validated and assured. It also defines how IoT, and CPS-related information is exchanged between parties, and how ownership of devices and their information is defined and protected. It provides interfaces and tools necessary for actors in the network to perform validation and authorization tasks necessary for autonomous real-time interoperation across domains in a decentralized and federated network. It does not, by itself, provide a means for third parties to audit transactions in the form of a distributed ledger.

For the purposes of auditing transactions, we have chosen to use the *Neuro-Ledger*® [11], which runs on a commercial broker called a *Neuron*™, implementing IEEE P1451.99, including digital identities, smart contracts, and interoperable, harmonized communication with sensors, actuators and other types of devices. The Neuro-Ledger is a next generation Distributed Ledger, which solves many of the issues identified for blockchain-related ledgers (such as Ethereum), including privacy issues [12], scalability and sustainability [13]. By using the Neuro-Ledger, all agreements made using IEEE P1451.99 also become auditable, for the life cycle defined individually for each object in the ledger. Resilient immutable persistence is also provided, during this life cycle.

A. eDaler

As with many Distributed Ledger Technologies, a cryptographically protected digital payment mechanism is available, built on-top. For the Neuro-Ledger®, this payment mechanism is called *eDaler*®. eDaler is a *stablecoin*, tied to a currency determined by the Trust Provider. This allows participants in the network to perform, with a minimum of risk:

- Manual instant payments, from one part to another.
- Autonomous payments, from one system to another.
- Offline payments, when there exists no connectivity, for one part, or another. Offline payments can also be used as promises, guarantees, and do not need to be processed.

- Conditional payments, payments that can only be processed if a specified smart contract has been signed and is considered valid.

- Contractual payments, payments that are defined in a smart contract, and executed when the contract is signed and becomes valid. This includes payment distributions.

- Payment models via *state machines*. Underlying smart contracts can be used to define state machines that operate on internal or external *stimuli*. States and state changes can execute payment instructions. Such state machines can be used to model complex financial models, including loads, leases, subscriptions and projects.

- Payments across currency boundaries can be performed if integration with currency index services is available, and the corresponding smart contract agreements have been signed.

B. *Neuro-Features*

Tokens created on the Neuro-Ledger using IEEE P1451.99 smart contracts designed for this purpose, are called *Neuro-Features*™ [14]. Neuro-Features can tokenize both digital as well as physical assets and activities and are therefore suitable for our project of tokenizing the construction of real estate and subsequent profit-sharing arrangement of renting the realized apartments, as well as providing third-party access to systems and services in the smart buildings for operational purposes. Each Neuro-Feature token has a unique owner, and there is a method of transferring ownership, based on monetary transact-ions using eDaler. Tokenization may prove to be a viable funding source for those relatively poorly capitalized financial markets [15]. As with smart contracts in IEEE P1451.99, tokens are given a life cycle. This means you can define temporary or short-lived tokens, as well as more long-lived tokens.

For our purposes, we use the unique ownership of a Neuro-Feature token to represent the owners' share in a project, in this case, maintaining apartments in apartment buildings financed by the original token, receiving revenue based on renting them to third parties. Tokens vary in value, in accordance with rules of supply and demand, as revenue can be compared to interest, if the monetary means are used elsewhere.

The attribute of Neuro-Feature tokens to be cryptographically signed by multiple parties and functions builds trust and value. Apart from the creator, owner, and trust provider signing token contracts, third party certifiers, appraisers, assessors and witnesses may also sign contracts, further increasing trust, as they can assess whether or not legal frameworks and underlying certifications are being followed.

C. *Examples of Neuro-Feature tokens*

Some examples of Neuro-Feature tokens that can be modelled on the Neuro-Ledger using IEEE P1451.99 smart contracts for this purpose, include:

- Fungible Tokens

- Non-fungible Tokens

- Asset-based Tokens (based on land or real estate.)

- Ownership in production facilities with profit-sharing (shares in companies, power plants or manufacturing.)

- Transferrable Leases

- Transport package in a Supply Chain, including inter-modal logistics.

- Negotiable rights, such as emission rights

- Limited services (for example, seats at restaurants, theatres, events, or travel.)

- ESG Investment and Integrated Risk Management

- Decentralizing governance and smart cities.

IV. TOOLS

To be able to sign smart contracts defined by IEEE P1451.99, a participant needs a Digital ID. An open-source, free-to-use, App for Android and iOS is available for human users [16-17]. Libraries are available for machine users through the repository hosted by IEEE P1451.99 presented earlier [10]. The App (Fig. 1) allows the user to create a digital identity, and to sign smart contracts, all using of the interoperative interfaces defined by IEEE P1451.99. The App also contains a wallet for eDaler and Neuro-Features. Using the App alone, you can create tokens and trade them manually, between app users.

Smart contracts in P1451.99 are cryptographically signed XML documents. These can either be created using an XML editor with support for XML Namespaces, and then uploaded to any IEEE P1451.99 compliant broker. You can also use the *LegalLab* tool (Fig. 2), available in a second public open-source repository [18] to design, propose and create smart contracts on brokers. The tool also supports machine translation of contracts into multiple human languages, permitting creation of contracts that cross not only domain boundaries, but human language boundaries as well.

To simulate algorithmic, network, communication and human behavior using statistical distributions, as well as to measure corresponding impact and results in IEEE P1451.99 networks, the *ComSim* tool can be used. In ComSim, simulation models are described using XML, and results can be exported to XML, or to human-readable Markdown, automatically documenting results, including UML use case graphs, flow charts, and result diagrams (Fig. 3).

Fig. 1. TAG digital ID App - main page

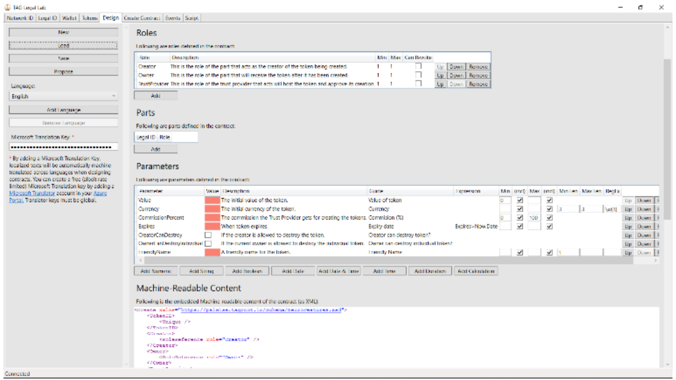

Fig. 2. LegalLab – contract design page

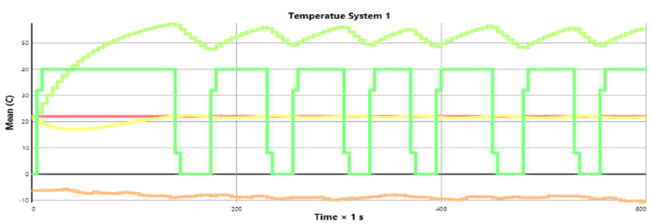

Fig. 3. ComSim – automatically generated graph of simulated device

ComSim can also be used to compare differences between protocols (such as XMPP, MQTT, MQ, HTTP and CoAP) in different settings, to measure and test device, component and back-end performance, and to simulate different behaviors. It can also be used to create simulated devices of different types, during development. Actions are distributed using statistical distributions over time (such as Normal, Gamma, Exponential, Uniform, χ and χ^2). Results are compared with expectations in the resulting report. ComSim is also available in a public open source repository [19], and is easily extensible regarding actions, protocols and distributions.

V. Marketplace

To commercialize tokens, an open marketplace is needed. The Neuro-Ledger contains a generic back-end marketplace, where items can be auctioned, and services be requested using requests for tenders, and offers can be made on these tenders. Publishing items for sale, offering to buy items, requesting tenders, or offering on available tenders, are all performed using IEEE P1451.99 smart contracts, designed for these purposes. Items that can be traded include Neuro-Feature tokens. This permits Industry 4.0-type cross-domain optimization by third parties of any type of service or activity, based on such tokens.

The marketplace provided by the Neuro-Ledger only offers machine interfaces for trade. Interfaces for human trade is also required. Apart from the interfaces made available in the TAG Digital ID App, a web-based marketplace is also required. For the project described in this paper, such a special marketplace is developed. This marketplace is intended for human users. While the underlying interaction, are based on IEEE P1451.99 smart contracts and digital identities, which can be standardized for interoperability, human-based interfaces are proprietary. This human-oriented marketplace also publishes interfaces for its users to transfer money to and from bank cards or bank accounts, and eDaler.

VI. PropiToken

The *PropiToken*™ [20] is a Neuro-Feature token developed by the LynxNode Trust [21]. It tokenizes the physical asset throughout its life cycle, in this case a smart building, for lease. Administration, interoperability, and third-party participation are highly automated, simplifying processes to reduce costs. The owners of the tokens become, in effect, "shareholders" of the project and the resulting real estate. Receiving income proportional to your participation as defined by the token. Income from rent, as well as automated interaction with underlying systems by third parties, and then reduced by administrative costs, fund savings, etc., result in a net profit that is proportionally shared among token owners, in an automated and transparent manner.

This automated profit-sharing among token owners, allows tokens to become an interesting digital asset, that investors (small and large) can use to gain monetary interest on their invested capital. The return on investment of the PropiTokens is compared to other forms of capital investment, such as bank interest, investment in funds, stock shares, and other types of tokens or derivatives. Taking into consideration returns of investment, as well as risks, investors determine in what assets to invest. As investment is made in real estate (in the PropiToken case), investing in real estate tokens also becomes a means to offset inflation in the underlying monetary systems. These aspects create incentives to buy such tokens, effectively financing the underlying smart real estate construction project. As tokens are also long-lived, a second-hand market is natural: The value of a token, according to supply and demand, is an evaluation of the efficiency of the administration and environmental performance of the assets, in an effective and verifiable way. Sensors and real-time reporting are used to optimize the operation and to increase the quality of the service. Interoperability and automation permits revenue from interaction with surrounding third-party businesses, while at the same time promoting sustainability in the area in an intelligent way.

A. Legal Framework

The underlying legal framework for the token, which is digitalized into the underlying IEEE P1451.99 smart contracts, is developed by lawyers at LynxNode, specialized in the field of real estate in Chile, where the construction occurs. Construction companies build and later administer the real estate, when in operation. To assure that legal requirements are met, LynxNode hosts the necessary IEEE P1451.99 broker, and ensures legal requirements specified in the tokens and smart contracts are met. This includes, litigation, if necessary, to assure the rights of token owners are met. This transforms LynxNode into a Trust Provider, as they project trust into the network, and allow investors to trust the underlying digital assets.

B. Monetization of Smart Services

Many digital services in a smart building can be monetized in the new urban digital and green economy [22]. The underlying IEEE P1451.99-based infrastructures also makes monetization of such systems possible. Such monetization is done using smart contracts, used together with the *decision support* edge service available in the brokers. Each provisioned device in the network also has a unique owner. This owner is responsible for providing the decision support system with information on how third parties can interact with their devices (Fig. 4).

IEEE P1451.99 contains harmonized interfaces for interacting with sensors, actuators, and *things* in general. When a provisioning thing receives a request, it does not know how to handle, it asks the underlying decision support edge service what it is supposed to do. If the service knows, it replies. Replies can be either "Yes", "No", or "Partial", in which the thing restricts the original request to include only what the owner authorizes.

If the decision support edge service does not know what to do, it always tells the device No. At the same time, a message is pushed to the owner, which may be a slow human. The owner, in turn, responds in its time. Through these responses, the decision support service learns, and the next time the thing asks for help, it can respond in a better way, and always in accordance with the specifications of the corresponding owner.

This provisioning of access rights and authorizations, can also be automated, using IEEE P1451.99 smart contracts. Using such smart contracts, the device owner can specify the rules for which its devices operate. These smart contracts may also include payment instructions, making it possible to create provisioning contingent on payment on demand, or on access. Anyone signing such a provisioning smart contract, is granted the corresponding access rights, and instant payments are automatically performed, in accordance with embedded instructions and performed use.

An overview of modules defined in IEEE P1451.99 that help with IoT Harmonization and Interoperability (Fig. 5) is available in [23], a reference broker, partly financed by Swedish Internet Foundation (IIS) and GOTO10, and free to use.

C. Examples of monetizable services

Following are two short examples, limited for space, of smart cross-domain services in smart buildings that are easily monetizable using the mechanisms presented in this article:

- Access to buildings is safely automated with digital signatures and user identification. Residents or administrators, knowing the expected visitors, grant access rights based on digital visitor identities directly. Access is obtained by scanning a QR code and performing a digital signature with the application. Small micropayments can be collected for commercial entry to the building, such as deliveries.
- Access to utility metering to selected insurance companies is provided directly by residents, to reduce risks and premiums through monetary reimbursement using smart contracts.

VII. Creturner Token

The *Creturner Token*™ [24] is another example of a NeuroFeature token. It is directly related to the extraction of CO_2 from the atmosphere and permanent underground storage of the carbon. Excess heat from their solar-panel facilities is used to dry, and later carbonize organic waste material (such as stumps and other residues). Generated carbon is then crushed, mixed with water, and finally stored in disused mines. This has multiple environmental benefits. Not only is CO_2 extracted permanently from the atmosphere. Hazardous materials in the mines are also bound to the active carbon. The mine is then closed, and the legal framework assures this disused mine cannot be opened again and be used as a future carbon mine. A certified and legally binding process is provided by Creturner giving a corresponding emission right to the owner of a token for several years. By

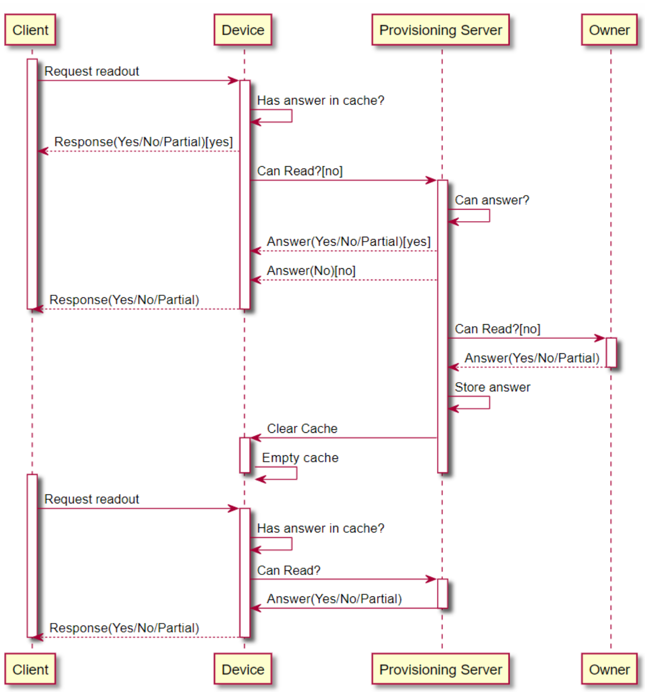

Fig. 4. IEEE P1451.99 Provisionins Service providing real-time decision support to a device, based on Owners wishes.

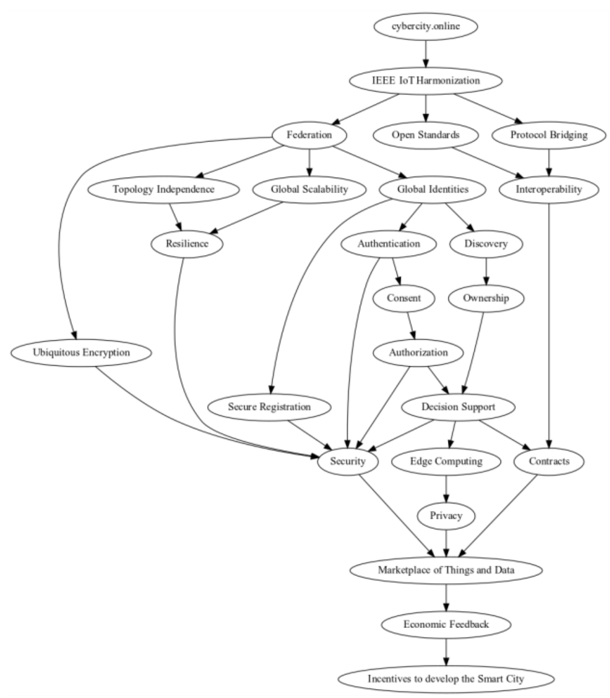

Fig. 5. IEEE P1451.99 incentivising the development of the Smart City

buying a newly minted token, the investor finances a certain amount of carbon extraction for a certain number of years, depending on token size. As the cost of extracting CO_2 using their method is lower than the value of the corresponding emission rights, as determined by the E.U, this creates a strong incentive to buy such tokens. The owners of Creturner tokens receive not only the corresponding emission rights, certified by environmental authorities, they also receive tokens with their own inherent value and that can be traded on open second-hand markets. A production facility buying tokens to offset (for example) five years of carbon emissions can, as time progresses, sell tokens, or buy new tokens, if emissions from their production decrease or increase. This, in turn, creates a second-hand demand for the tokens, and therefore a means to create sustainable projects, even short-lived ones.

A. CO_2 Emission rights

Government authorities sell emission rights, giving industry permission to emit corresponding amounts of carbon into the atmosphere. This method restricts emissions but does not compensate for it. A better approach is to invest in carbon extraction methods, that truly offset emissions. Through collaboration with the government authorities, holding a Creturner Token gives the owner a corresponding emission right automatically. Instead of limiting emissions, it also compensates for it, permitting zero emission.

B. Value of a Creturner Token

The designed life expectancy of a Creturner Token is five years. During this time, emission rights are provided continuously, and in proportion to the original size of the token. Value of the token is determined by the amount of time left of the 5-year period, and the current price of carbon emissions. The less time left, the less the token is worth. The higher the carbon-emission price, the more valuable the token becomes. Holding tokens is therefore also a hedge against rising carbon emission right prices in the future. Furthermore, most of the profit generated by Creturner tokens are returned to token owners as an interest dividend. This further increases the value of the token on the second-hand market and makes it an interesting token from an investment perspective. It also creates strong economic incentives for climate compensation.

VIII. Summary

Digital tokenization can be used to finance physical projects, including smart city projects. The example presented in this article, is the construction of sustainable real estate in smart societies. The method requires that the smart contacts on which the tokens are based, can be made legally binding, and that sufficient trust and interest can be injected into the system to interest investors to buy tokens. The proposed architecture is based on interfaces defined in IEEE P1451.99. The same infrastructure used to create tokens, can also be used for provisioning of smart services, both within the project, as well as with external third parties, across domain boundaries. It can also be used to monetize digital assets and information. To offset environmental impacts of construction, the same interoperable infrastructure and means of tokenization and monetization can be used.

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