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NO1S1 - A BLOCKCHAIN-BASED DAO PROTOTYPE FOR AUTONOMOUS SPACE

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ABSTRACT

We introduce our ongoing research on no1s1 ("no-ones-one"), a meditation pod that aims to be the first autonomous space. To frame our early thinking, we conceptualize what we call Decentralized Autonomous Space (DAS) as a Decentralized Autonomous Organization (DAO) linked to a physical location. DAOs leverage a combination of Decentralized Ledger Technology (DLT) and the Internet of Things (IoT) to create self-governing coordination mechanisms through smart contracts. Therefore, DAS can self-create and self-manage, and ultimately self-own. DAS is presented as a potentially disruptive paradigm of future housing and infrastructure with wide-ranging implications to the built environment.

INTRODUCTION

Since Nakamoto (2008) published the fundamental ideas of blockchain in the Bitcoin white paper, blockchain applications have increased across many domains and industries. Blockchain is the most prominent type of distributed ledger technology (DLT), enabling direct peer-to-peer (P2P) transactions of value across a decentralized network that is not controlled by any single entity, but consensus mechanisms (code) that incentivize the participants towards collaboration. Bitcoin was the first and most popular example of such a network. It created a new decentralized monetary system and asset class. However, Bitcoin is likely only a first step towards a new paradigm of economic coordination using blockchain (Davidson et al. 2016, 2018, Miscione et al. 2019).

The rise of the Ethereum blockchain (Buterin 2014) led to the use of (turing complete) scripts called "smart contracts" to encode logic for interaction with transactions in the network. Smart contracts enable the creation of new incentive systems and coordination mechanisms that do not rely on human coordination but still provide interfaces for human interaction. There is much ongoing exploration of what new forms of organization can be supported or replaced through such blockchain based governance.

One of the most interesting new organizational designs is called a decentralized autonomous organization (DAO). A DAO is a blockchain-powered organization that can run on its own without any central authority or management hierarchy (Wang et al. 2019). The management and operational rules of a DAO are solely governed by the rules encoded in smart contracts. Through distributed consensus protocols or other crypto-economic incentives, the DAO is able to self-operate, self-govern and self-evolve (Wang et al. 2019). It is important to note the difference between a DAO and operations that use artificial intelligence (AI). An AI system is designed to make internal autonomous decisions. By contrast, a DAO only defines its coordination rules and governance system. In this way it can make decisions based on external input of participating actors (Vitalik Buterin 2014). These actors only need to own a recognized address, so the actors can be machines, another DAO, or a distributed group of human decision-makers. Therefore, DAOs ultimately allow for coordination mechanisms between both humans and things.

In the past few years, several projects explored the concept of DAOs (e.g. Decred (2021) on the protocol level, or Aragon (2021) on top of Ethereum on the application level). For the most part, current DAOs exist only in a virtual setting. However, it is also possible that the purpose of a DAO is to sustain a physical thing. A thing in turn can also control an address that holds funds and interact with the DAO. McConaghy (2018) describes this new potential reality as self-ownership of things. Physical objects, in combination with the network of sensors and connected devices often referred to as the internet of things (IoT), can then autonomously transact with humans and other things through a form of a DAO. The DAO can also evolve its functionalities, through either the use of AI or collective governance of human participants.

There are various examples proposed for this new vision, from futuristic ideas of artificial life forms (e.g. the plantoids of Filippi (2020)) to self-ownership of self-driving cars or the self-ownership of public infrastructure (e.g. power grids and roads) (McConaghy 2018). A key proposed benefit of self-ownership of things is the removal of rent-seeking human intermediaries (i.e. the motivation for most organizations is to derive some form of profit). Because DAO governance mechanisms allow things and systems to be self-sustaining and non-rent seeking, these things can in turn only seek to cover operational expenses. The savings could be passed on to the users, or profit could be fed back into other community-owned systems.

This ties into the potential of blockchain governance to empower and scale communities aligned with principles of the sharing economy (Pazaitis, De Filippi & Kostakis 2017) or common pool resources theory (Maples 2018, Rozas, Tenorio-Fornés, Díaz-Molina & Hassan 2018). In theory, a DAO can set up coordination mechanisms so that a community can co-create the respective organizational system. In the larger picture, this has the potential to shift current power structures away from centralized corporations towards user communities that decide on their own system's functionalities and governance rules.

Overall, DLT and IoT create new opportunities to rethink ownership and autonomy of things through decentralized coordination mechanisms. Given these possibilities, we see a need to investigate how this will impact the future built environment.

MOTIVATION AND CONTRIBUTION

The application of DAOs to create self-owning things remains a conceptual idea with little application or operalization. In particular, we find no existing application of DAOs to physical spaces in the built environment. As described above, it seems that the application of DAOs to the built environment is likely to shape how physical space will be built, owned and operated in the future. There is a need to investigate the feasibility, opportunities, and challenges for the application of DAOs to the built environment. Therefore, the paper offers a starting point to conceptualize what we call decentralize autonomous space (DAS) through the current research project no1s1 - a self-owning meditation pod.

First, we present a preliminary conceptualization of DAS. The conceptualization serves as an overview on areas that could be coordinated autonomously and therefore as a road map for future research.

Second, to showcase the feasibility of autonomous space, we introduce the ongoing research project no1s1, a full scale building prototype that implements autonomy regarding chosen management aspects through DLT and IoT.

AUTONOMOUS SPACE AS DAO

We define DAS as the manifestation of a DAO linked to a specific physical location in the built environment. To structure our thinking around potential functionalities of DAS in consideration of the no1s1 prototype, we propose a preliminary conceptualization in Figure 1. We identified two main categories for autonomy: "creation autonomous" and "management autonomous". Furthermore, there will always be "human interaction" because of the human-centered design of DAS.

Creation Autonomous

DAS has the ability to self-create. In the terms used for the built environment, this means that a DAS can commission and coordinate its own design and construction. Design autonomy means that the DAS creates a set of rules to solicit design proposals, and then select a final design. Examples of blockchain-based design management using DAOs show that it is possible to coordinate the architectural design process (Dounas, Lombardi & Jabi 2020). Construction autonomy means that the DAS can request, approve and monitor construction activities. While no current examples yet exist, blockchain-based governance mechanisms have been proposed for integrated project deliveries to manage construction projects (Hunhevicz, Brasey, Bonanomi & Hall 2020). Creation autonomy could also leverage exiting synergies with emerging topics like mass-customization and product configurators for modular construction (Cao, Bucher, Hall & Lessing 2021), or new exploratory approaches of autonomous digital fabrication and robotics (Pereira da Silva & Eloy 2021), e.g. with drones (Wood et al. 2019) or self-reconfigurable robotics (Seo, Paik & Yim 2019). In most cases, financial autonomy (described below) must be present at the initiation of the project to commission the self-creation.

Management Autonomous

DAS has the ability to self-manage its own space. Autonomy for space requires self-management of three areas: finance, operation, and maintenance.

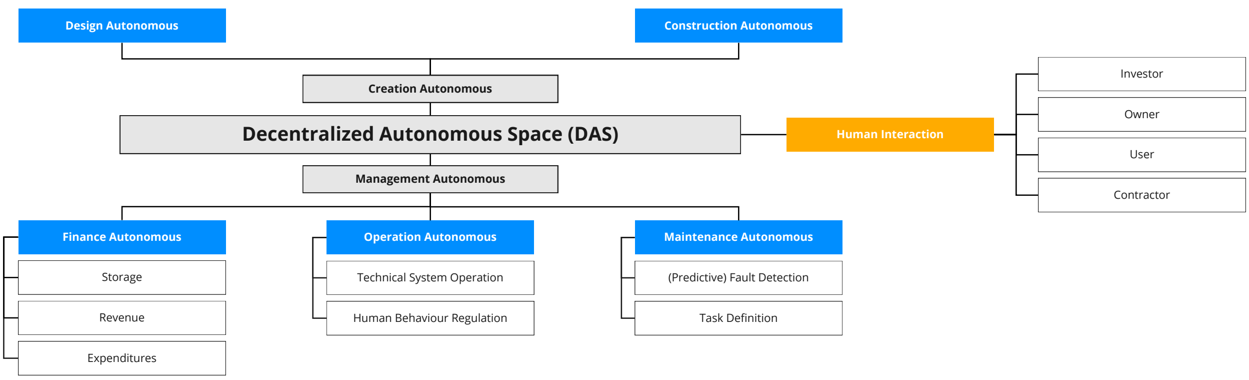

Figure 1: Preliminary conceptualization of decentralized autonomous space (DAS).

Finance Autonomous

Financial autonomy for DAS begins with the self-storage of funds in a treasury. Every blockchain address can hold funds in its native cryptocurrency. Without such a treasury, self-ownership is not possible. Furthermore, DAS requires a form of revenue generation. These funds can then be spent for needed expenditures and investments. For example, revenues can be used to pay for work (by humans or machines) related to operation and maintenance, or for liability insurance usually required for owners of assets in the built environment.

Operation Autonomous

Operational autonomy is related to the technical systems of the DAS. Technical systems include the network of control systems, sensors, and smart devices currently found in most buildings and infrastructure. For operational autonomy, the DAS should control these systems through inputs from sensors and smart devices (i.e. IoT). Technical systems can be reactive or proactive. Reactive technical systems respond to human activities within space. Proactive technical systems influence human behaviour through incentive mechanisms. For example, a DAS can use variable pricing based on the demand of usage to influence users. DAS can also use tokens or currency to influence decisions, such as the use of non-monetary incentives (e.g. reputation-based tokens) (Pazaitis, De Filippi & Kostakis 2017) on the blockchain to incentivize diligent behaviour (e.g. to prevent vandalism).

Maintenance Autonomous

Maintenance autonomy ensures longevity of operations. Therefore, the DAS needs the ability to detect faults. If a failure or error occurs, the DAS must be notified either through its sensing inputs, through human feedback, or proactively through predictive maintenance feedback from live usage data. In case of necessary maintenance, the DAO needs coordination mechanisms to define and commission the required maintenance for the space.

Human Interaction

Finally, DAS must be capable of human interaction. While in theory DAS could be fully independent of human guidance (e.g. governed through the use of advanced AI), it is unlikely that such governance will be feasible or even desirable in the near future. Instead, the DAS will act autonomously for its own creation and management by implementing the rules and guidelines encoded in its smart contracts on the blockchain. The selection and guidance of which rules to use and what these rules do will require human interaction and decision making. Therefore, we find it most likely that humans will be involved in the decision making, functionality reviews, and execution of physical work for a DAS.

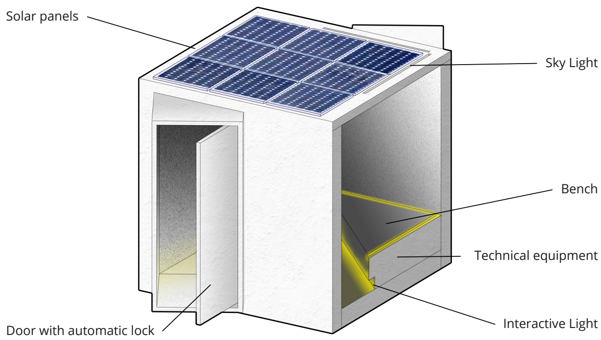

Figure 2: Rendering of the final no1s1 prototype.

This is also related to the so-called "oracle problem" (Caldarelli 2020). In essence, the problem is that blockchain can verify data integrity on its own ledger and network, but cannot know if inputted data by humans or sensors are correct in the first place. This creates a gap between the physical and digital world that can be intentionally exploited by malicious actors. Therefore, a DAS should implement coordination mechanisms to reduce the possibility of wrong data input. Most likely, this process will also involve human action to check on the correctness of data, e.g. through peer-review mechanisms. Nevertheless, the DAS can stay in control of financial aspects and coordinate work, so is still self-owning.

In addition to their role as users of the space, humans can also interact with DAS in other ways, such as investing in the project, holding tokens that signify ownership or decision-making rights, or working for the DAS to provide a service (e.g. holding a maintenance contract to clean the DAS). The challenge of human interaction is to define coordination mechanisms that align human interest with the long term interests of the DAS. Here, insights from the concept of sharing economy or common-pool resource theory can guide creation of such governance mechanisms for human interaction with DAS.

NO1S1 PROTOTYPE

We introduce no1s1, an ongoing research project to build the first full-scale DAS prototype. The focus lies on simple functionalities for the smart contracts of the no1s1 DAO and their interaction with the physical space through sensors and smart devices (IoT). It can be understood as a minimum viable prototype (MVP) that will be extended and improved over time. The main research purposes are:

- Demonstration of the concept of autonomous space and its technical feasibility.
- Study and spark discussion on the socio-technical impact of autonomous space.
- Identify technical, legal, and regulatory challenges of autonomous space for future research.

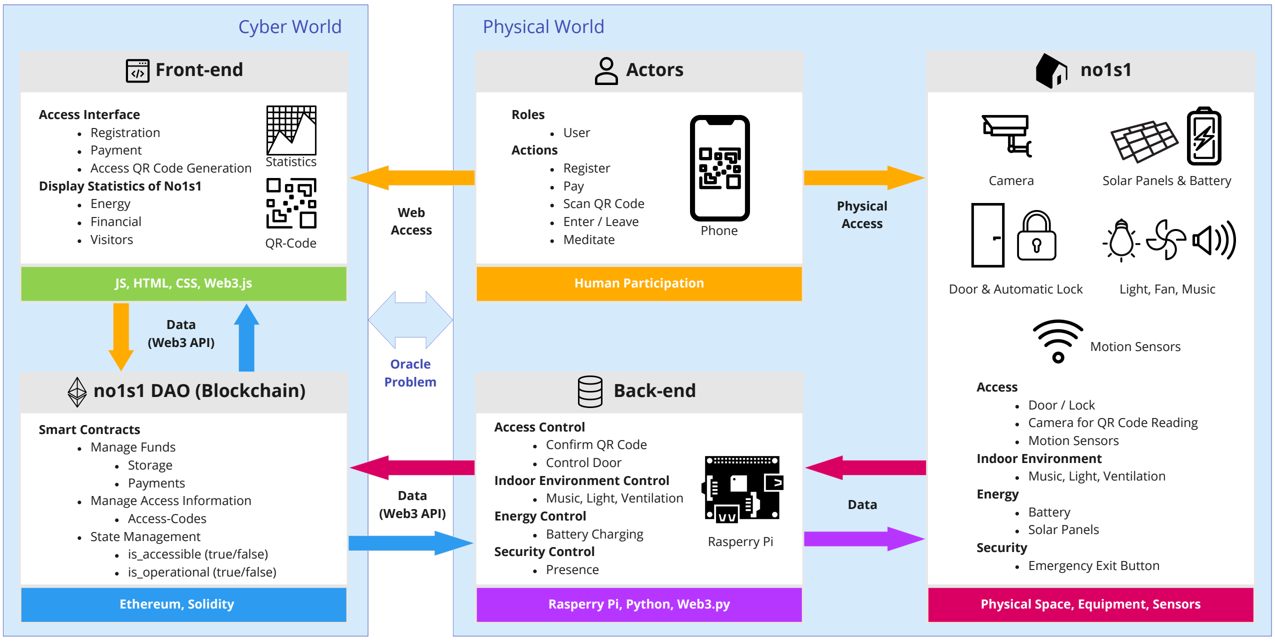

Figure 3: Technical overview of the five proposed components for DAS. The information transition from the actors to the DAO needs to be ensured, both directly through the front-end (orange arrow, counter-clockwise) and indirectly by capturing user behaviour at no1s1 (orange & red arrows, clockwise). The actors also need to understand the DAO response, either visualized in the front-end (blue arrow, clockwise) or through interaction design at no1s1 controlled by the back-end (blue & purple arrow, counter-clockwise).

Functionality

The meditation pod is designed as a simple modular constructed cube that will host a quiet internal space for one person to meditate (see Figure 2). The pod will be self-owned and self-operated by smart contracts. The proposed revenue for financial autonomy will be generated by offering time slots for quiet meditation in exchange for currency. The electrical energy that supports the system operations will be generated from the top solar panels and stored in a battery.

The functionality of a mediation pod was chosen because of several reasons. (1) The meditation pod can be built as a small module that can also be moved to various exhibitions for demonstration purposes. (2) The meditation pod is relatively simple to use with only one functionality and reduces effort to think about complicated user interaction and user interfaces. (3) The meditation pod requires enough technical equipment to act as an effective proof of concept but does not require extensive cyber-physical coordination. (4) The use case aligns with the emerging concept of the sharing economy, offering a private space that can be used by anyone.

Technical Setup

To connect the physical concept of no1s1 with the digital world, the proposed technical setup of no1s1 is presented in Figure 3. We suggest five primary interacting components for any DAS: the physical space and equipment, the front-end, the back-end, the blockchain-based DAO, and human participation. These five components are needed to bridge the gap between the digital and the physical world and transmit data to the no1s1 DAO and back to the user or the physical no1s1.

Actors

For human participation in no1s1, the autonomous meditation space is provided as a service to human users. In turn, the DAS earns rewards to pay for operations and maintenance. Therefore, an important part is the definition of human interaction (see Figure 3, Actors). For that, two feedback mechanisms are necessary to transmit information from the actors to the DAO. The first mechanism is for direct user interaction with the smart contracts (e.g. payment) through the web front-end (see Figure 3, counter clockwise orange arrows). The second, indirect feedback mechanism captures user behaviour in the physical space through IoT (see Figure 3, clockwise orange & red arrows). For now, the DAS only considers users. Further human participation in the DAS should be considered in future work. Humans will need to make decisions about modifications or changes to the DAS. Humans can also act as investors providing input funds to the DAS or as contractors who are paid funds by the DAS in exchange for work performed.

no1s1 (physical)

For the physical space and equipment (see Figure 3, no1s1), no1s1 requires several technical systems for operation. First, the energy for the module is self-generated through the solar panels. A battery stores the energy and provide power for technical equipment. If the energy level drops below a level that makes the module insufficient for use, then no1s1 is not operational. When a user wants to use the meditation pod, they will purchase access (see below for front-end set up). In exchange, a user will receive a QR code, which must be scanned by a camera to gain access to the module. An automatic lock then opens to unlock the entrance door. To ensure a comfortable environment, no1s1 includes LED light strips, speakers for meditative music, and a fan for basic ventilation. Motion sensors verify occupancy of the meditation pod. For security reasons, we implement an emergency exit button that users can press at any time if they need to exit the space.

Back-end

For the back-end, no1s1 will require a set up to monitor and control the physical systems (see Figure 3, Back-end). For now, we control the physical systems by Python scripts running on Raspbian OS and a Raspberry Pi. Additionally, an Arduino-based maximum power point tracker (MPPT) is used to control the electricity flow between the solar panel, the battery and the Raspberry Pi. The back-end ensures data transmission of captured user behaviour and other relevant data of the technical systems to the DAO smart contracts (see Figure 3, red arrows). Moreover, it controls the technical equipment based on the DAO response (see Figure 3, purple arrow).

Front-end

For the front-end (see Figure 3, Front-end), no1s1 requires a graphical web user interface that enables human interaction with the no1s1 smart contracts. The users can register and pay to access no1s1. It also stores and displays finance, energy, and visitor-statistics of no1s1 that are retrieved from the smart contracts.

no1s1 DAO (Blockchain)

The smart contracts on the blockchain (see Figure 3, no1s1 DAO) represent the core elements of no1s1's autonomy. For now, we plan to deploy them on the Ethereum blockchain. The smart contracts control the main "states" of no1s1 anchored in the blockchain. Example states can be the amount of funds owned by no1s1, whether no1s1 is operational at a moment in time and access is possible, or if current service is down. To change a state, a transaction needs to be signed by the involved addresses. The back-end can trigger transactions based on usage data, either on a regular basis (e.g. battery charging levels), or by certain actions (e.g. user verifies QR-code). In addition, human actors can trigger transactions through the front-end. If a state changes, an event is emitted that can be caught by the front-end and back-end (see Figure 3, blue arrows), which triggers an update on the front-end or initiates technical control mechanisms in the back-end respectively.

DISCUSSION

The presented ideas are in a very early state. The research on the final prototype (see Figure 2) is still ongoing, but an alpha prototype of no1s1 (see Figure 4) was constructed to test the feasibility of the technical architecture. The alpha prototype implements and connects the needed technical components (see Figure 3), although with still limited functionality and usability. Nevertheless, the no1s1 alpha prototype demonstrates that DAS is (within limitations) already possible and has interesting application areas.

Figure 4: The no1s1 alpha-prototype tests feasibility of the technical system.

Overall, we intend to stimulate with this paper more thoughts and research around the topic of DAS. For this purpose, and the challenge to discuss in depth this early research, we present instead an incomplete list of questions that appeared most interesting to us when working on no1s1. The questions will also guide our further research on the topic.

Conceptualization

- Which functionalities are necessary to define space as autonomous?
- Will DAS ultimately replace current ownership structures?
- What are the most promising application areas of DAS?
- Does DAS necessarily involve concepts of the sharing economy, i.e. is DAS in the end really owned by no one, or instead by anyone?
- What are the worst possible outcomes with self-ownership of buildings and infrastructure?

Prototype

Technical aspects

- Which DLT is best suited for the no1s1 DAO (Hunhevicz & Hall 2020)?
- How to ensure security against hacks of no1s1 as in the infamous example of ”the DAO” (Mehar et al. 2019)?
- How to achieve adaptability (e.g. replacing the smart contracts) of the no1s1 DAO without risking manipulation?
- What are ways to increase trustworthiness of data input into the no1s1 smart contracts, e.g. how can no1s1 verify with certainty that work tasks were done and determine whether a payout is appropriate?
- How would AI be applied to DAS?

Socio-technical aspects

- How can a self-owning building be resilient against exploitation or attacks by humans?
- Who designs and finances the house in the first place when it is not a research project?
- Can the concept of self-owned houses lead to lower living cost because there are no profit seeking intermediaries?
- How to overcome socio-technical barriers for no1s1 (Li, Greenwood & Kassem 2019)?
- Would organic growth of DAS be enough for adoption or does it require external policies?

Regulatory and legal aspects

- Are new legal frameworks needed to deal with autonomous entities?
- Do autonomous entities need to comply with current legislation? How can this be assured if no1s1 is not programmed to do so?
- What if no1s1 becomes very rich but no one can access the money?
- Is the house liable if it does not provide a promised service or someone gets hurt inside?
- Does no1s1 have rights and could e.g. call the police if rioters occupy it?

CONCLUSION

Decentralized autonomous space (DAS) could disrupt the built environment in many ways. Self-ownership of physical space would allow in theory a self-sustaining and non-rent seeking built environment that could replace current organizational structures. We identified similarities to principles of the sharing economy and community driven organizational structures as in common pool resource scenarios. In the end, physical space could just ”be”, provide its services, and be used, co-created, and governed (within the specified rule-set of the DAO) by a human collective.

Even though DAS seems futuristic, it is already now possible to experiment with this new concept. The introduced ongoing research on the prototype no1s1 should demonstrate feasibility of autonomous space. no1s1 - a mediation pod - is governed by a DAO on the Ethereum blockchain that implements aspects of operational and financial autonomy. However, the MVP still has many limitations and only materializes a very small subset of what may be possible in the future. More insights are expected to follow with further research and the construction of the final no1s1 prototype.

Overall, this paper introduces our early thinking to help frame the research on no1s1, and intends to draw attention to the possibilities and many unknowns on the topic of DAS.

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