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ORIGINAL ARTICLE

Facilitating cooperation of smallholders in developing countries: design principles for a cooperative-oriented decentralized autonomous organization

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Abstract
Climate change and an increasing food demand due to a growing world population pose significant challenges for agriculture. Smallholders play a decisive role in establishing a sustainable and efficient future agricultural system since they already provide up to 80% of food in developing countries. However, they often face severe obstacles, especially in developing countries, hampering effective and efficient cooperation and productivity. Even though organizations in the form of cooperatives could help overcome some of the challenges of facilitating smallholders' cooperation, they still suffer from structural problems. Further, in many countries, a lack of formal mechanisms to enforce contractual agreements exists. Given such challenges, decentralized autonomous organizations (DAOs) have already proven to provide alternative forms of governance independent of formal contracts or intermediaries. Therefore, this study follows the design science research paradigm to design, develop, and evaluate a decentralized autonomous organization in the agricultural sector that makes use of cooperative principles. This cooperative-oriented DAO is governed by smart contracts and technically enabled by blockchain technology as the underlying infrastructure. Through our developed and evaluated artifact, the AgriDAO, we guide researchers and practitioners on how such a cooperative-oriented DAO could look to solve existing problems related to smallholders and cooperatives. Additionally, we present eight design principles that will guide the development of cooperative-oriented DAOs. Finally, our research shall initiate lively discussion and extensive exploration of this new form of organization.

Keywords Decentralized autonomous organization · Blockchain-based governance · Cooperatives · Smallholders' cooperation · Design principles

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1 Introduction

Already today, the devastating effects of climate change challenge agriculture and put pressure on sustainable agricultural solutions. At the same time, with a world population expected to reach 9.7 billion by 2050 (United Nations 2019), agricultural production must keep pace with the growing demand for food and the ongoing fight against hunger. Smallholders will be essential in establishing future agricultural systems, especially in African, Asian, and American economies. However, to meet the ever-rising level of food demand and allow for sustainable as well as more efficient food production, the structural deficits of smallholders must be overcome (Johansen et al. 2012; FAO 2012). For instance, smallholders lack access to capital, legal services, and information, limiting their investment volume and agricultural expertise. Consequently, strategic and sustainable development in these countries is restrained (FAO 2012; Poole 2017).

However, the enforcement of such contractual agreements can be problematic, especially in countries that lack formal enforcement mechanisms (ASFG 2013). This limitation can undermine the effectiveness of these governance methods. As a result, these organizations often rely heavily on trust among members in an environment predominantly characterized by skepticism and opportunism. This trust issue can lead to an atmosphere of uncertainty and aversion to investment among smallholders, which is a major obstacle to effective collaboration and growth in the agricultural sector (Romero Granja and Wollni 2019).

Decentralized autonomous organizations (DAOs), underpinned by smart contracts and blockchain technology, have been proposed by other researchers as an innovative solution to such governance challenges (Ding et al. 2021). DAOs, functioning on the "code-is-law" principle, create a platform that enables a wholly decentralized, democratic, and trustworthy method of organizational administration. Unlike conventional organizations, DAOs are entirely governed by pre-set codes, thus eliminating potential human errors or biases in decision-making. This unique model promises to bring about a new level of transparency and fairness often lacking in traditional structures.

Against this background, we pose the following research question:

How to design an information system that facilitates cooperation of smallholders in developing countries?

To answer our research question, we adhered to the Design Science Research (DSR) paradigm (Gregor and Hevner 2013; March and Smith 1995), resulting in the design, development, and evaluation of a unique artifact: a DAO in the agricultural sector that makes use of cooperative principles, our so-named cooperative-oriented DAO in the agricultural sector or *AgriDAO* in short. The *AgriDAO* harnesses the principles of existing DAOs but introduces key adjustments to better harmonize the decentralized framework with cooperative ethos. Specifically, we have incorporated a reputation-based system to mitigate the free-rider issue and established a fully democratic voting structure as an alternative to the traditional plutocratic system frequently observed in DAOs. This initiative aims to enhance the current understanding of the design principles needed for an effective DAO, especially in the agricultural sector (Beck et al. 2018; Hsieh et al. 2017). The idea of such a model finds support in recent academic discourse. Risius and Spohrer (2017) had previously suggested the necessity of probing the feasibility of emergent organizational forms like DAOs. Moverover, Beck et al. (2018) have asserted that smart contracts and blockchain technology may offer an apt infrastructure for the execution of novel governance mechanisms, covering crucial aspects like decision rights, accountability, and incentives.

Through our research, we seek to enrich existing design knowledge by both introducing a novel artifact and proposing eight design principles (Seckler et al. 2021). First, our artifact, the *AgriDAO*, serves as a practical blueprint, providing foundational guidance for building a cooperative-oriented DAO tailored to the unique challenges faced by smallholder farmers and cooperatives. Second, we evaluate our artifact's effectiveness and technical feasibility, providing a rigorous assessment of its potential and limitations. The evaluation not only provides further insight into the future development of such organizations but also establishes a springboard for deeper investigation. Third, we present eight guiding design principles that serve as navigational beacons for researchers and practitioners seeking to successfully design and implement cooperative-oriented DAOs beyond this study's designated application area. As these design insights are, to our knowledge, unprecedented, they lay the groundwork for lively discussion and extensive exploration of this new form of organization by both researchers and practitioners.

The paper is structured as follows: Sect. 2 provides the background on the core challenges of smallholders and cooperatives on the one hand and DAOs as a technical solution approach on the other. Through this section, we target creating a common knowledge base and understanding of the key concepts. Section 3 describes our research design based on the Design Science Research (DSR) approach. Following this research approach, we add exemplary cases to underline the practical relevance of the identified problem areas in Sect. 4. Subsequently, we determine adequate solution objectives for our *AgriDAO*. In Sect. 5, we then describe the design and development of the actual artifact. Afterward, we evaluate the artifact based on both evaluation criteria and expert interviews in the fields of DAOs, blockchain technology, cooperatives, and agricultural development in Sect. 6. In Sect. 7, we discuss our main findings and derive design principles for cooperative-oriented DAOs. Finally, in Sect. 8, we outline limitations and future research opportunities.

2 Background

2.1 Core challenges of smallholders

The Food and Agriculture Organization of the United Nations (FAO) defines smallholders as farmers who *"manage areas varying from less than one hectare to 10 hectares (…) characterized by family-focused motives such as favouring the stability of the farm household system, using mainly family labour for production and using part of the produce for family consumption"* (FAO 2012). Information and experience sharing among smallholders are on the agendas of many smallholder organizations, predominantly interacting in developing countries. Since the African Smallholder Farmers Group (ASFG) is one prominent example of such an organization, we believe that the ASFG may represent how such organizations can support smallholders concerning their needs. According to ASFG, smallholders face severe obstacles that limit their productivity, sustainability, and efficiency (ASFG 2013). In particular, three core challenges exist for smallholders: (1) Smallholders significantly lack *access to resources* such as capital, legal services, and information. Those resource restrictions constrain their investment volumes, the expenditure of their agricultural expertise, or the possibility of enforcing contracts. Ultimately, they are confronted with limited productivity and underdeveloped agriculture, leading to a weak market position (ASFG 2013; Hellin et al. 2009; Kamara 2004; Mutero et al. 2016; Omiti et al. 2009; Poole 2017; Salami et al. 2010; Schalkwyk et al. 2012). (2) *Cooperation* is required but still not used to its full potential in many African, Asian, and American countries. The reasons are insufficient capacity and experience to shape an effective and efficient organization (ASFG 2013; Hellin et al. 2009; Jelsma et al. 2017; Montiflor et al. 2011; Romero Granja and Wollni 2019; Salami et al. 2010). (3) This unleveraged cooperation potential is additionally rooted in the conditions in which smallholders operate since the environment is mainly characterized by *distrust and opportunistic behavior*, preventing them from concluding contracts and cooperating in the long term (Romero Granja and Wollni 2019).

To overcome the resulting market imperfections, smallholders tend to interact with intermediaries, even though this collaboration may constrain their profits (Abebe et al. 2016). Thus, it seems worth analyzing ways of enabling cooperation solely among smallholders and without intermediaries.

2.2 Cooperatives as a potential organization form and their structural deficits

Enabling effective and efficient cooperation among smallholders may positively affect the social and economic aspects of smallholders. For instance, there might be improvements regarding their market power and bargaining position, exchange of (technological) knowledge, or access to equipment and machines. Hereby, cooperation among smallholders might be realized in the form of a cooperative. LeVay (1983) defines a cooperative as *"an association of persons (either individual people or institutions) who work together to achieve certain commercial objectives"* (p.3). This definition does not include a guideline on how such cooperatives should be organizationally designed. However, a multitude of organizational designs for a cooperative exists. Since the intention for forming a cooperative is relevant to us, we stay with the term 'cooperative' and do not further distinguish cooperative regarding its organizational design.

Even though it is promising to form a cooperative to solve some severe smallholder problems, cooperatives suffer from structural problems. Those may lead to members' discouragement of investing capital or inability to make efficient collective decisions (Tortia et al. 2013). In particular, five core problems exist: (1) First, the *free-rider problem* considers the unequal benefit of undertaken investments between the members. As a result, conflicts and disincentivizing of members can arise (Cook 1995; Tortia et al. 2013). (2) Second, the *horizon problem* describes that the residual claims of members on the asset-generated net income are shorter than the asset life. Due to transferability restrictions and the constrained financial liquidity of residual rights, members hesitate to invest strategically and, therefore, miss chances for growth

(Cook 1995; Porter and Scully 1987; Tortia et al. 2013; Zigran et al. 2015). (3) Third, the *portfolio problem* refers to the members' inability to tailor their cooperative asset portfolio concerning their personal risk preferences. Since the investment decision in cooperatives is typically linked to the patronage decision, members may hold not risk-optimized and, thus, potentially underperforming investment portfolios (Cook 1995; Tortia et al. 2013). (4) Fourth, the *control problem* implicates high transaction costs resulting from monitoring management decisions, lacking options to sanctify managerial misbehavior, and diverging interests (Cook 1994; Staatz 1987; Tortia et al. 2013). (5) Lastly, the *influence costs problem* refers to the members' attempts to influence the collective decisions to their advantage, which causes inefficiencies and unnecessary costs (Cook 1995; Milgrom and Roberts 1990; Tortia et al. 2013).

To solve these problems, Poole and Frece (2010) stress the necessity of *"a new generation of dynamic and alternative forms of commercial organization"* (p.13). Against this backdrop, they proposed to consider the essential organizational principles initiated by the International Cooperative Alliance (ICA) as a guideline to set up a framework for smallholders' cooperatives based on Watkins (1986) and Fairbairn (1994). Given this general framework, an open question remains about how a promising, new, and dynamic smallholder organization could look.

2.3 Decentralized autonomous organizations for facilitating smallholders' cooperation

In 2014, Vitalik Buterin published his famous Ethereum whitepaper, describing the idea of a decentralized autonomous organization based on smart contracts, specifically a DAO. The paper defines a DAO as *"a virtual entity that has a certain set of members or shareholders which (...) have the right to spend the entity's funds and modify its code"* (Buterin 2014, p.23). In specifics, smart contracts are computer programs that automatically execute decisions when certain conditions are met (Kõlvart et al. 2016). Therefore, smart contracts can use external information as input, triggering specific actions according to the pre-defined rules stored in the contract (Truesta et al. 2015). In contrast to traditional forms of organizations, a DAO does not rely on formal or informal contracts but rather on a "code-is-law" basis. This property allows for a high level of automation, differentiating a DAO from a decentralized organization.

DAOs typically leverage blockchain as a foundation for their smart contracts, creating an environment for fully decentralized, democratic, and trustworthy collaborative structures. Blockchain is a particular distributed ledger technology working as a decentralized data management and transaction technology (Yli-Huumo et al. 2016), enabling data exchange over multi-party networks (Xu et al. 2017). The origin of its name stems from the fact that transactions between users are grouped into cryptographically and chronologically ordered, chained blocks. Consensus algorithms secure the correctness and proper order of these transactions, so no central intermediary is required. Given its properties, blockchain technology offers a suitable medium for implementing smart contracts (Szabo 1997) for the first time (DeRose 2016; Wright and Filippi 2015).

While current literature emphasizes the benefits of DAOs in various domains, knowledge of leveraging a DAO that makes use of cooperative principles is still missing. Since blockchain technology is the most suitable technological alternative to technically implement a DAO at the time of writing, we used blockchain technology to design and develop a cooperative-oriented DAO in the agricultural sector, the *AgriDAO*, as our artifact. However, we cannot exclude that other technologies might also be suitable, e.g., other distributed ledger technologies that successively mature and might become an alternative someday.

3 Method

To answer our research question, we followed the Design Science Research (DSR) paradigm (March and Smith 1995; March and Storey 2008; Nunamaker et al. 1990). Its principles originate back to the field of engineering science (Gregor and Hevner 2013). DSR generally seeks to solve problems with practical relevance (Hevner et al. 2004) by designing new and innovative information technology artifacts (March and Smith 1995). Thus, we designed, developed, and evaluated a DAO in the agricultural sector that makes use of cooperative principles to control smallholder cooperation in the *AgriDAO*. In particular, this paper follows the widely accepted design science research approach by Peffers et al. (2007) (see Fig. 1).

At first, the research project started with identifying a practically relevant problem (1). Based on our literature findings, which we presented in Sect. 2, smallholders struggle to fully seize the potential of cooperation, and cooperatives suffer from structural problems. Aiming to solve the identified problem areas, we derived design objectives that a potential solution must provide (2). For determining the final set of design objectives, we used literature from the field of DAOs, blockchain technology, organization theory, development study, and agriculture research. First, all authors reflected on these literature findings separately to generate a set of design objectives, which were later discussed and challenged in a joint workshop session. The result of this workshop session was the final set of design objectives, which all authors had agreed on. To allow for rigorous evaluation, we used the same method to identify evaluation criteria for each of the 16 design objectives. Since the design objectives were rather aggregated to ensure broader applicability going beyond the *AgriDAO*

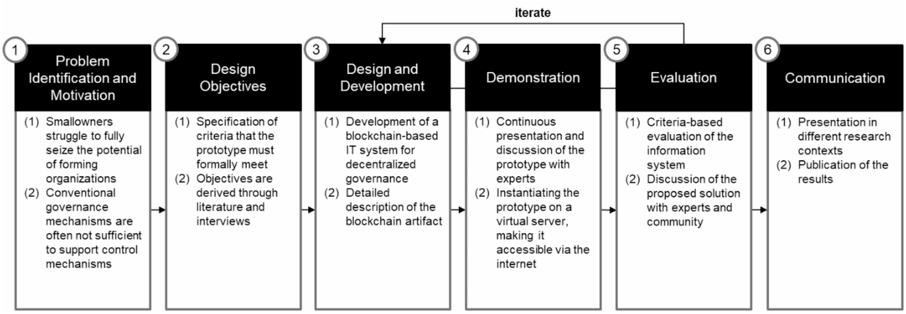

Fig. 1 DSR process for the use case of smallholders in Africa, Asia, and America

as an example of a cooperative-oriented DAO, we stayed on this abstraction level and decided not to concretize the evaluation criteria any further. We employed these design objectives as a starting point for the development of our artifact, which we see as an initial technical prototype, implying that the User Interface only needs to be viable and not yet appealing (3). First, we developed a general system architecture based on blockchain technology. Afterward, we used the Ethereum blockchain to instantiate the artifact (4). The research team iteratively evaluated and refined the design and the instantiation until all members agreed on the artifact's maturity. Through a presentation, we presented our artifact to technical and domain experts and discussed it, which was part of the evaluation. This circumstance enabled us to validate our artifact's effectiveness and technical feasibility. (5). Finally, we discuss the contribution of this paper in the context of smart contract-based governance. Afterward, we propose eight design principles for cooperative-oriented DAOs to support researchers and practitioners in future developments of such a new form of organization. We acknowledge this part as the last step of the DSR approach, namely communication (6). We note that steps (3) to (5) were highly iterative, allowing us to include feedback from the interviews in the development. In the following sections, we will explicitly address these six steps. The overarching research process was also highly iterative, allowing for evaluation, design, and development loops.

For the evaluation and refinement of the design artifact, we first assessed the artifact based on different evaluation criteria. Second, we conducted expert interviews with relevant stakeholder groups to verify the criteria-based evaluation. Specifically, we conducted semi-structured interviews (March and Smith 1995) with technical experts (DAO, blockchain) and domain experts (cooperatives, agricultural development). Since our artifact is a prototype, we did not interview smallholders as end users because this would not have been purposeful against the defined evaluation targets. Through Table 1, we provide an overview of our selected interview partners. Each interview took around 60 min and was initiated with a short presentation by the interviewer to provide basic information about blockchain and DAO in general and the *AgriDAO* in specific. We did so to ensure a common understanding among the interviewees. For the analysis of the interviews, we used qualitative techniques, which included the transcription and coding of the interviews (Mayring 2014). Regarding the latter, our design objectives functioned as initial codes to which we assigned the interviewees' statements.

Table 1 Overview of interviewees

Expert ID	Field of Expertise	Type of Organization
Technical Expert (TE1)	DAO, Blockchain Technology	Research Institute
Technical Expert (TE2)	DAO, Blockchain Technology	Research Institute
Technical Expert (TE3)	DAO, Blockchain Technology	Research Institute
Domain Expert (DE1)	Agricultural Development (Africa)	Research Institute
Domain Expert (DE2)	Agricultural Development (India)	e-Agriculture Company
Domain Expert (DE3)	Cooperative Mechanisms	NGO for Supporting Sustainable Development

4 Problem identification and design objectives

Following the DSR approach, we analyzed the specific obstacles of smallholders and the challenges of cooperatives. In addition to our problem identification in the background section, we added exemplary cases to underline the practical relevance of the respective problem area (PA), primarily since DSR aims to solve practical problems. Thus, we provide an overview of our results in Table 2.

After identifying the problem areas, we derived design objectives for a cooperative-oriented DAO in the agricultural sector to solve our practical problem, consisting of the challenges of smallholders and cooperatives. Due to this problem division, we provide smallholder- and cooperative-specific design objectives.

On the one hand, we identified nine smallholder-specific design objectives: *Provide sufficient incentives to prevent free-riders (DO-S1)*: There need to be working incentive mechanisms to balance the profit inequality between members with more investment efforts and members with fewer investment efforts (Giannakas et al. 2016). *Allow for exit including getting some funding back (DO-S2)*: Allowing members to leave the cooperative under permission to get some funding back is an essential enabler for long-term investments or investments in intangible assets due to the minimized risk of benefit losses (Nganwa et al. 2010). *Ensure low operative running costs (DO-S3)*: The organization's running costs (e.g., for monitoring) need to be low to reduce transaction costs and guarantee cooperative productivity (Poole 2017). *Prevent managerial misbehavior (DO-S4)*: Managerial misbehavior can be prevented through transparency, adequate governance mechanisms, and the members' ability to sanctify misbehavior (Nganwa et al. 2010). *Provide objective decision-making mechanisms (DO-S5)*: The provision of objective decision-making is required to counter potential influence costs (Cook and Iliopoulos 2016; Poole

Table 2 Exemplary cases for identified problem areas of smallholders and cooperatives

Problem Areas			Exemplary Cases
Smallholder-specific	PA-S1	Lacking access to capital, legal services, and information	Mozambique (Veldwisch et al. 2013); South Africa (Mutero et al. 2016); Kenya (Kamara 2004); Kenya (Kibet et al. 2009)
	PA-S2	Missing cooperation	Kenya (Gyau et al. 2016); Meso-America (Hellin et al. 2009)
	PA-S3	Distrust and opportunistic behavior	Ecuador (Romero Granja and Wollni 2019)
Cooperative-specific	PA-C1	Free-rider problem	South Africa (Lyne et al. 2008); KwaZulu-Natal (Nganwa et al. 2010)
	PA-C2	Horizon problem	Various cases worldwide (Franken and Cook 2019; Nganwa et al. 2010); KwaZulu-Natal (Nganwa et al. 2010)
	PA-C3	Portfolio problem	Various cases worldwide (Franken and Cook 2019); KwaZulu-Natal (Nganwa et al. 2010)
	PA-C4	Control problem	KwaZulu-Natal (Nganwa et al. 2010)
	PA-C5	Influence costs problem	KwaZulu-Natal (Nganwa et al. 2010)

2017). *Provide options for secure property rights management (DO-S6)*: Agricultural productivity is limited due to the high insecurity of property rights of land tenure. Thus, enabling this security will positively impact agricultural performance (Cook and Iliopoulos 2016). *Provide means of contract enforcement (DO-S7)*: The solution should provide means of contract enforcement to reduce insecurities in land tenure and stabilize agricultural development (Poole 2017). *Allow for resource pooling and access to finance (DO-S8)*: Resource pooling is necessary to enable smallholders' access to inputs and credits (Kelly 2012). Besides, to prevent portfolio underperformance, allowing investments based on the individual risk attitude is reasonable (Cook 1995). *Provide transparency on decision-making and execution (DO-S9)*: The solution should provide transparency to foster trust to support contract conclusions between members and between the organization and external stakeholders as well as long-term cooperation (Romero Granja and Wollni 2019).

On the other hand, we found seven cooperative-specific design objectives based on the principles of the ICA (2018): *Provide a voluntary and open membership (DO-C1)*: The joining of the organization should be possible for everyone willing to accept the rights and duties of such membership. *Guarantee democratic member control (DO-C2)*: Due to the democratic framework of the organization, members should have the same chance to participate. Also, the organization has to ensure the equality of power distribution among gender and wealth. *Enable member economic participation (DO-C3)*: The organization's capital should be a shared property that might be invested in further developing the organization and its members. *Guarantee autonomy and independence (DO-C4)*: The organization should be driven by its members and, therefore, be autonomous and independent from other organizations' interests. *Provide education, training, and information (DO-C5)*: The organization should provide education and training to its members to foster reasoned decisions on the organizations' development and to enable appropriate cooperation. *Enable cooperation among cooperatives (DO-C6)*: Cooperation within and outside the organization is vital for the organization's development. *Enable concern for the community (DO-C7)*: To guarantee the execution of the members' interests, the members shape the organization through member-approved policies.

In the second step, we determined the criteria of how those identified design objectives can be evaluated and which problem area would be resolved by the respective design objective. Therefore, Table 3 summarizes the design objectives and their evaluation criteria concerning the relevant problem areas.

5 Design, development, and demonstration

The design objectives were the foundation for developing our artifact, a cooperative-oriented DAO, the so-called *AgriDAO*. The *AgriDAO* is a DAO in the agricultural sector that makes use of cooperative principles allowing its members to control cooperation. Its primary purpose is to facilitate smallholders' collaborative activities. Subsequently, the *AgriDAO* shall enable financial inclusion (i.e., access to inputs and credits) and coordinate long-term sales and corresponding sales contracts. Coordination uses a propose-and-vote approach, thus, providing a democratic decision-making

Table 3 Design objectives for a cooperative-oriented DAO in the agricultural sector

	Design Objectives		Evaluation Criteria	PA
	ID	Description		
Smallholder-specific	DO-S1	Provide sufficient incentives to prevent free-riders	Evaluation of incentive mechanisms	PA-C1
	DO-S2	Allow for exit including getting some funding back	Evaluation of exit conditions and implications	PA-C2
	DO-S3	Ensure low operative running costs	Evaluation of monitoring costs	PA-C4
	DO-S4	Prevent managerial misbehavior	Evaluation of governance	PA-C4
	DO-S5	Provide objective decision-making mechanisms	Evaluation of decision-making procedure	PA-C5
	DO-S6	Provide options for secure property rights management	Evaluation of fulfillment	PA-S1
	DO-S7	Provide means of contract enforcement	Evaluation of enforcement procedures	PA-S1
	DO-S8	Allow for resource pooling and access to finance	Evaluation of investment options	PA-C3 & PA-S1
	DO-S9	Provide transparency on decision-making and execution	Evaluation of transparency of business processes	PA-S3
Cooperative-specific	DO-C1	Provide a voluntary and open membership	Evaluation of entrance burdens and restrictions	PA-S3
	DO-C2	Guarantee democratic member control	Evaluation of control mechanisms such as conditions and implications of entry, exit, and decision-making	PA-S3
	DO-C3	Enable member economic participation	Evaluation of fulfillment	PA-C2
	DO-C4	Guarantee autonomy and independence	Evaluation of resistance against external influence	PA-C5
	DO-C5	Provide education, training, and information	Evaluation of access to knowledge, training, and information	PA-S2
	DO-C6	Enable cooperation among cooperatives	Evaluation of cooperation mechanisms	PA-S2
	DO-C7	Enable concern for the community	Evaluation of fulfillment	PA-S2

process. The entire proposal-making and -voting process as well as all services are backed by smart contracts and the underlying blockchain infrastructure. This setup allows for automation (Fridgen et al. 2018), interoperability (Korpela et al. 2017), as well as security and trust building (Beck et al. 2016). Besides, all interactions between a member and the *AgriDAO*, including its services, can be executed using a user interface that a web frontend or smartphone application can provide.

5.1 Smart contracts and AgriDAO design

We developed various smart contracts that implement functionalities. For instance, those exist for the organization's founding, adding new members, creating proposals like buying a new machine, voting for proposals, and, eventually, leaving the organization. We adapted design decisions from existing DAO concepts, such as *The DAO* (Jentzsch 2016) and DAOStack (Dounas and Lombardi 2019). Those concepts primarily include the idea of having a modular set of smart contracts, providing long-term adaptability. However, due to the specific use case scenario, we had to make various adaptions to existing designs. In the following, we briefly describe the main implemented functionalities, for which Fig. 2 summarizes the smart contract design of the *AgriDAO*.

To become a new member of the *AgriDAO*, existing members must first decide whether they agree on the new member. More specifically, a potential member (e.g., a smallholder) requests to join the *AgriDAO*. Then, all existing members can vote on allowing the smallholder to enter the *AgriDAO* democratically. If joining the *AgriDAO* is denied, the underlying smart contract refuses to accept any new applications from that person for a specified period.

Performing a new business transaction in the *AgriDAO* builds on a corresponding proposal for action. Proposals include necessary information on the planned activity and may optionally refer to a smart contract, formally describing the appropriate action. Based on such a proposal, other members can discuss the raised topic and eventually employ the "VotingMachine" contract to give their votes. Following this approach, the *AgriDAO* follows a grassroots democracy, where potentially every decision is made by the organization's members (Merkle 2016). Only when the majority of members of the *AgriDAO* accept a proposal, the related activities are performed, and the proposed business transaction can be executed.

Existing DAO designs use the token amount of a member to calculate the voting weight. However, such an approach would result in a plutocracy, where the individual's power is directly based on their economic power, i.e., the tokens the individual owns (Beck et al. 2018; Dupont 2017; Jentzsch 2016). Therefore, to fulfill

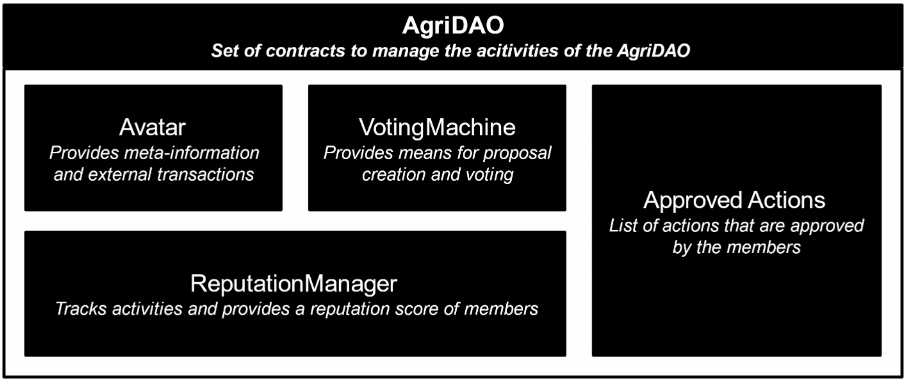

Fig. 2 Smart contract design of the AgriDAO

the requirement of a democratic approach, we decided against such a design and favored a reputation-based voting system. In the beginning, each member has the same weight but can accumulate additional weight by taking an active role in the *AgriDAO* (e.g., by voting on proposals). Hence, participation is directly rewarded with higher voting power managed by the “ReputationManager” contract, potentially providing additional incentives to use the system (Beck et al. 2016).

We implemented an “Avatar” contract to establish identification and interaction with other parties (e.g., investors or retailers). The Avatar features basic meta-information about the organization, such as its name and mission. Furthermore, it manages the wallet of the *AgriDAO* and appropriate assets. Consequently, any financial transaction origins from the Avatar. The actions mentioned above regularly make use of the Avatar to run transactions. For example, an approved action can take control of the Avatar and then carries out business transactions in the name of the *AgriDAO* and with the respective assets.

5.2 Implementation

Based on the above design, we implemented an artifact instantiation on the Ethereum test environment. Ethereum is a public permissionless blockchain with low entry barriers and offers Turing-complete smart contracts, which we use for developing business logic (Buterin 2014). The prototype helped us to understand the feasibility of the design better. In particular, we employed the Infura service to gain access to the Blockchain. Employing such a gateway, smallholders can use the Ethereum network without hosting their own nodes. Smart contract programming was performed using Solidity and Truffle for deployment. Five smart contracts represent the main *AgriDAO* functionalities. Two additional smart contracts are used for the mintable ERC20 token implementation and further five smart contracts are employed for additional helping functions, including access and roles management as well as safe math features.

While the *AgriDAO* resides on the Blockchain, interaction with it differs from traditional organizations. Therefore, the underlying blockchain network is used for conducting business transactions. However, to reduce barriers to accessing the *AgriDAO* services, our artifact also provides a graphical user interface. This interface augments our *AgriDAO* with a decentralized application (see Fig. 3). Users can employ the interface to interact with the *AgriDAO*, without programming code-level calls of smart contract functions. We implemented the graphical user interface using the ReactJS and Ionic framework, which allows for hybrid app development, providing not only native app support for Android and iOS but also a web-based representation. Therefore, any user owning a respective device with access to the Internet can use the underlying *AgriDAO*, ensuring broad applicability. The app also supports wallet functions by employing Metamask for managing crypto materials and, hence, authentication when using the decentralized application.

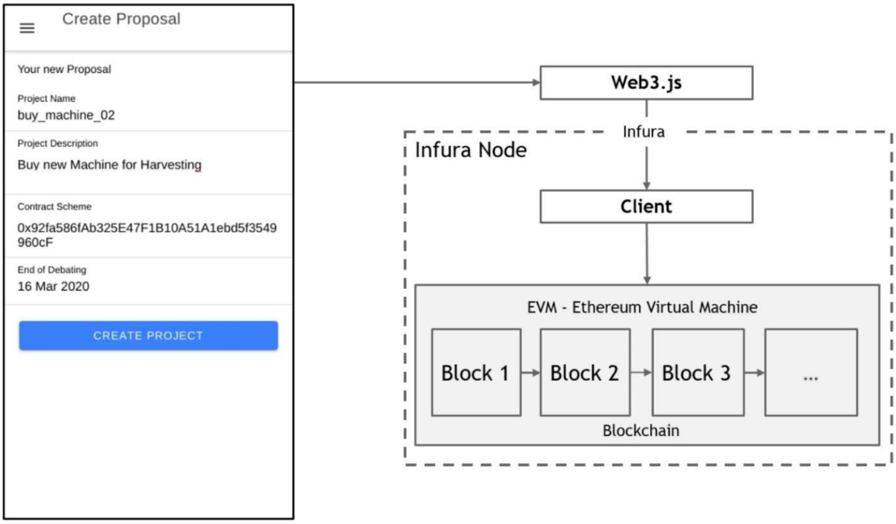

Fig. 3 Architecture of the AgriDAO decentralized application

5.3 Demonstration

For the demonstration of our artifact, we refer to an exemplary use case where the members of the *AgriDAO* seek funding for a new harvesting machine. Figure 4 provides a simplified Unified Modeling Language sequence diagram, giving an overview of the involved stakeholders and activities.

The process starts with a proposal from a member, i.e., a proposal creator publishes the proposal of buying a new harvesting machine using createProposal(). Once the proposal is created, members will receive a newProposalEvent, notifying them about the new proposal. This proposal includes general information such as the proposal name or description and an action, referencing the smart contract that consists of the formal representation of the proposal. In the example, the smart contract contains functions for collecting funding from investors and payment transfers to the harvesting machine's eventual seller. The members of the *AgriDAO* can now individually vote and decide whether they would like to accept the proposal or decline it. As soon as the pre-defined voting time elapses, the proposal creator receives a notification. It must be noted that the time is globally set in the Avatar smart contract and can be changed by vote. If the proposal was successful, the member could register the action using registerAction(). The appropriate action now becomes an integral part of the *AgriDAO* so that corresponding actions in the organization's name can be performed.

In our example, previous funding from investors, such as private investors or banks, is required. Therefore, an investor can call the getDetails() function to receive details of the planned actions and general information about the AgriDAO, including registered assets and the organization's financial situation. If the investors agree to fund the *AgriDAO*, they can call fundAction(), automatically transferring Ethereum's cryptocurrency Ether from the investor's wallet to the *AgriDAO*. If the required funding amount is met, purchaseMachine() will get automatically executed, which trans-

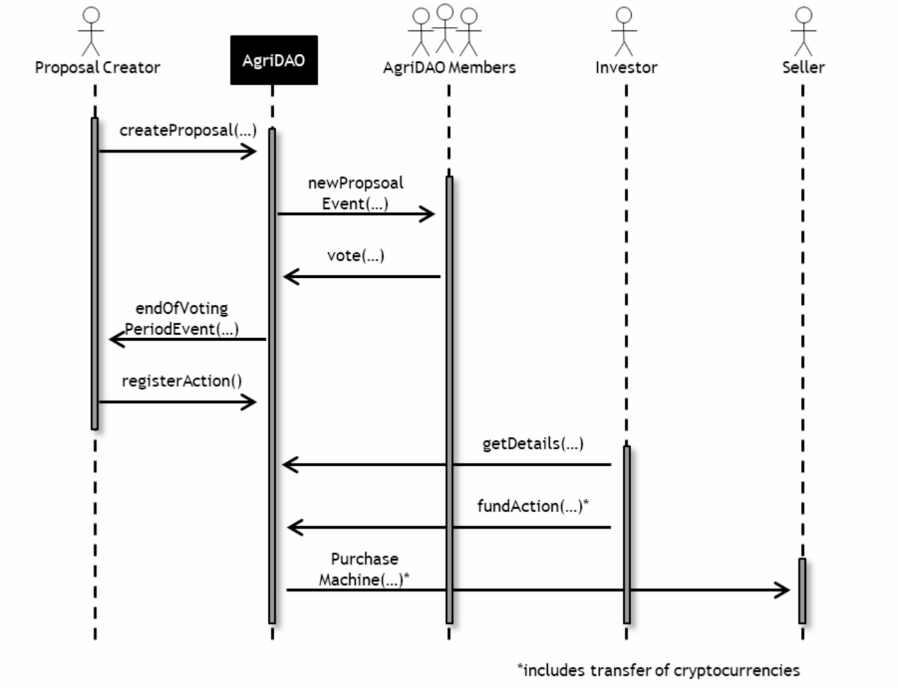

Fig. 4 Simplified sequence diagram of an exemplary use case: Raising funding for a new harvesting machine

fers the money to the harvesting machine's seller and registers the machine as a new asset of the *AgriDAO*.

6 Evaluation

As stated above, we conducted several interviews to evaluate the final artifact. This procedure helped us to validate the artifact's effectiveness and technical feasibility. We first mapped our findings from the literature screening, the artifact's development process, its instantiation, and the expert interviews with the pre-defined design objectives, which we qualitatively assessed and summarized in a table afterward. Thus, we refer to literature and interviewee statements in the criteria-based evaluation. As a second part of the evaluation, we present insights into the interviews with further feedback on our artifact, going beyond the criteria-based assessment.

6.1 Criteria-based evaluation

Since we used the presented design objectives from Sect. 4, the criteria-based evaluation is also divided into smallholder-specific and cooperative-specific criteria. First, we illustrate the smallholder-specific evaluation findings.

Provide sufficient incentives to prevent free-riders (DO-S1) - evaluation of incentive mechanisms: The voting mechanism is reputation-based, where active users might gain higher voting weight and more power to steer the organization. Furthermore, any proposal might also include a reward payment automatically triggered if the organization members accept the proposal. Thus, users are incentivized to create proposals in the community's sense [TE1, TE2, TE3].

> *"I see the need for incentivization to solve the free-rider problem." [TE2]*

Allow for exit including getting some funding back (DO-S2) - evaluation of exit conditions and implications: Blockchain technology allows for extensive logging of various actions, including members' engagement and financial involvement. When a user decides to leave the *AgriDAO*, this log can be used to identify the amount of investment. Based on a pre-defined parameter, the user can get a proportion of funding back, which is crucial for participation [TE3].

> *"I do think it might make sense to pay out a certain security deposit [in the case of an exit]." [TE3]*

Ensure low operative running costs (DO-S3) - evaluation of monitoring costs: As the smallholders' financial situation is critical, costs for decision execution should be as low as possible [DE2]. Therefore, autonomous, decentralized decision execution, which does not need monitoring, reduces a cooperative's cost to a minimum. Yet, cost estimations also need to consider infrastructure costs (Buterin 2014).

> *"They don't even have money for food for the next day." [DE2]*

Prevent managerial misbehavior (DO-S4) - evaluation of governance: The *AgriDAO* can be entirely member-driven and does not have to rely on management. Thus, the concept of decentralized decision-making and governance prevents any managerial misbehavior. In *The DAO*, so-called curators were installed to avoid managerial misconduct, which TE1 and TE3 viewed skeptically. In their opinion, curators would undermine the core concept of decentralization and trust without intermediaries. Therefore, we decided not to implement curators in the *AgriDAO* and provide an information system without intermediaries.

> *"If all parties trust the curators, those can be useful, however, users would depend on the good will of the curators. Decisions are understandable, but difficult to reverse." [TE1]*

Provide objective decision-making mechanisms (DO-S5) - evaluation of decision-making procedure: In the case of majority-based decisions, actions will be executed autonomously and in compliance with member coherence. Nevertheless, due to the transparency of the Blockchain, members can monitor the current state of decision-making (Beck et al. 2018). However, transparency might lead members to make their voting decision dependent on already conducted votes (Tarasov and Tewari 2017), which is also confirmed as a risk by DE3.

> *"If I can see the current status of the votes before submitting my vote, it is not entirely democratic in my understanding. For me, this is a form of manipulation. As a voter, you could be influenced by the opinion of others." [DE3]*

Provide options for secure property rights management (DO-S6) - evaluation of fulfillment: Blockchain and smart contracts ensure that property rights concerning machines or land are enforced (Kshetri and Voas 2018). Nevertheless, TE3 raises awareness of the multiple corruption possibilities caused by the oracle problem concerning the input of trusted data to the Blockchain. Caldarelli et al. (2020) also stress the importance of addressing the oracle problem for assessing blockchain applications in sustainable contexts. Specifically, persons with malicious intentions can tamper with the *AgriDAO* due to actions taking place off-chain. However, DE1 stated that due to the proximity of smallholders, the oracle problem could be solved by employing social control mechanisms (e.g., public shaming) and does not need to be further addressed on the technology layer.

> *"Social control through the proximity of farmers to each other in real life could be an important aspect in the AgriDAO." [DE3]*

Provide means of contract enforcement (DO-S7) - evaluation of enforcement procedures: Due to autonomous contract execution after positive voting, no manipulation is possible. Instead, contracts and their execution are enforced, which is a suitable approach due to the lack of contract enforcement options in developing countries [DE2]. In the context of smart contracts, TE2 highlighted that these contracts might not be juridical and, therefore, not legally binding for the contractual parties. As a recommendation, TE2 proposed implementing a mechanism similar to the general terms and conditions that members must accept when entering the *AgriDAO*.

> *"The problem is that we do not have contracts. This is why people are abandoning the law. There are even no contracts for jobs (...)." [DE2]*

Allow for resource pooling (DO-S8) - evaluation of investment options: Through the option to make proposals that reflect a common member interest, acquisitions, and resource pooling is enabled, which is the nature of a cooperative [DE3]. Resource pooling is essential as smallholders have insufficient investment capacities, and creditors do not support them due to the risky investment environment [DE2]. In this context, TE1 stated that allowing donations through external parties might generate cash flow without prompting the members' decision authority.

> *"A cooperative has the idea of regionality. (...) Originally, farmers could no longer afford the seed and joined together to get a discount. This has then developed more and more." [DE3]*

Provide transparency on decision-making and Execution (DO-S9) - evaluation of transparency of business processes: Blockchain technology transparently and securely logs any action of the *AgriDAO* and its members (Conley 2017). The experts emphasized that transparency should be provided for the internal members of the *AgriDAO* and external parties [TE1, TE2, TE3, DE1, DE2]. Thus, decision-making and execution are valid for everyone as long as it is settled on the Blockchain.

> *"For Smart Contracts, there is a need to reduce the social imbalance between economically struggling and economically strong people. Accountability comes with transparency. (...) So [transparency] has to come with the blockchain." [DE2]*

In the second step, we provide insights into the cooperative-specific evaluation findings.

Provide a voluntary and open membership (DO-C1) - Evaluation of entrance burdens and restrictions: The *AgriDAO* design ensures that anyone with Internet access can become a member. Nevertheless, the final decision, whether a new member can join, is dependent on the democratic choice of the existing members. TE2 stated that this gatekeeping process is a necessity to prevent manipulation.

> *"I imagine implementing something like voting on who gets accepted into the AgriDAO, or peer reputation systems in a work-of-trust sense to link the AgriDAO to real-world identities." [TE2]*

Guarantee democratic member control (DO-C2) - Evaluation of control mechanisms such as conditions and implications of entry, exit, and decision-making: In contrast to traditional organizations, decision-making is not controlled by contracts or loose agreements but instead based on computer code that is enforced by the Blockchain (Wright and Filippi 2015). In the *AgriDAO*, tamper-secure smart contracts define a voting-based decision-making process. Thus, decisions are made by the members rather than by intermediaries (Merkle 2016). However, TE2 notes existing manipulation potential and a transparency lack outside of the AgriDAO due to missing control over off-chain actions.

> *"Another issue you could think about is how the system could be manipulated. (...) For example, a financially strong investor could buy more tokens and manipulate the voting to enforce his interest." [TE2]*

Enable member economic participation (DO-C3) - evaluation of fulfillment: Due to smart contracts, the *AgriDAO* can directly own cryptocurrencies and tokens, eventually representing real-world assets (Buterin 2014). Potentially, any member of the organization can use these assets by creating a proposal addressing them, which supports the overarching goal of a cooperative [DE3].

> *"Everyone invests what he or she can and gets the same benefit in return." [DE3]*

Guarantee autonomy and independence (DO-C4) - evaluation of resistance against external influence: Decision-making of the *AgriDAO* is fundamentally made by the members and, therefore, independent from other market participants and intermediaries. In this context, DE2 recommended using an unbiased infrastructure for decision independence so parties outside the organization cannot influence the members' decisions.

> *"We need an unbiased infrastructure without someone in the middle." [DE2]*

Provide education, training, and information (DO-C5) - Evaluation of access to knowledge, training, and information: Our artifact design does not automatically ensure the provisioning of education or training. Nevertheless, members might make proposals, suggesting the contractual assignment of these tasks to professionals, like consultancy firms or universities.

> *"The topic of education is important. How do you show people the ways in which they interact and how can you disseminate this [information]? For example, against the background of financial literacy, it may be that the understanding regarding the concept of saving is not uniform among members." [TE2]*

Enable cooperation among cooperatives (DO-C6) - evaluation of cooperation mechanisms: Smart contracts allow the implementation of arbitrary business transactions (Christidis and Devetsikiotis 2016). The Ethereum protocol treats smart contracts the same way as regular users (Buterin 2014). As such, there is not only interaction between the organization and particular people, but it is also possible to allow any interaction between multiple cooperatives. The smart contracts should be designed depending on the smallholders' intentions for action [TE3].

> *"For small processes that do not seem enormously relevant at first glance, the question is whether it is even worth setting up such a complicated coordination process. (...) It depends very much on the needs of the farmers: If they want to take out a joint loan or finance something collectively, then a simple logic of a smart contract would be enough. If the goal is to go significantly beyond that, then you have to include more [in the smart contract] than financing a major acquisition." [TE3]*

Enable concern for community (DO-C7) - evaluation of fulfillment: The *AgriDAO* is based on the principle that each member can participate and vote. Through the votes and proposals, members can shape the cooperative to ensure that the cooperative follows the members' interests. Hereby, members must be informed about the proposals' existence and content [DE3].

> *"I often felt that people did not know what to vote on and were very easily influenced because of it." [DE3]*

The results summarized in Table 4 illustrate that the developed artifact may help to overcome the fundamental problems of smallholders and cooperatives. We used a qualitative approach for the summarizing evaluation: We assessed whether the AgriDAO has either improved (+) or deteriorated the situation (-) for smallholders or whether the situation remains unchanged (0).

6.2 Further feedback from the interviewees

Besides evaluating the design objectives, we also got a thorough picture of our design solution on a more holistic level through the expert interviews, which we present and discuss in the following.

TE1 challenged the analogy to The DAO and mentioned that DAO concepts and governance mechanisms do not apply to all organizations to the same extent.

> *"Can you even compare [the AgriDAO] to the original DAO, as there were completely different motivations behind it?" [TE1]*

Due to its specific context, we had to alter various design decisions compared to existing DAO designs, which led to the conclusion that various applications of DAOs require different design efforts. The interviewees also supported this understanding.

Besides, TE2 and TE3 focused on various attack scenarios. One emphasis was the entry of a new participant in the *AgriDAO*. Even though new members are chosen and confirmed by existing members, there is still potential for corruption and tampering of voting taking place off-chain. One solution approach may be a peer-to-peer reputation system for voting, as proposed by TE2 to confirm the identity of new members.

Table 4 Evaluation of design objectives' fulfillment in the AgriDAO

	ID	Description of Design Objective	Evaluation
Smallholder-specific	DO-S1	Provide sufficient incentives to prevent free-riders	+
	DO-S2	Allow for exit, including getting some funding back	+
	DO-S3	Ensure low operative running costs	0
	DO-S4	Prevent managerial misbehavior	+
	DO-S5	Provide objective decision-making mechanisms	0
	DO-S6	Provide options for secure property rights management	0
	DO-S7	Provide means for contract enforcement	+
	DO-S8	Allow for resource pooling	+
	DO-S9	Provide transparency on decision-making and execution	+
Cooperative-specific	DO-C1	Provide a voluntary and open membership	0
	DO-C2	Guarantee democratic member control	0
	DO-C3	Enable member economic participation	+
	DO-C4	Guarantee autonomy and independence	+
	DO-C5	Provide education, training, and information	
	DO-C6	Enable cooperation among cooperatives	0
	DO-C7	Enable concern for community	+

"Promising could be a peer-to-peer reputation system [when entering the organization] to ensure that persons are who they claim they are." [TE2]

Furthermore, all three technical experts assessed the comprehensibility and trust in the programming code of the contract schemes as crucial during the interviews. As smallholders do not have coding expertise, they might need a foundation providing a framework that implements certain functionalities. However, the foundation's capability of assessing all specific design objectives of the *AgriDAO* a priori is questionable. Consequently, there is a high probability for a rigid system without sufficient flexibility to face the dynamic adequately. Also, there is an increasing centralization and dependence of smallholders on a foundation. In the case of a smallholder not wanting to trust a third party, the experts claimed to facilitate a rough understanding of programming codes.

"Trust in people is replaced by trust in technology, which in turn is created by people [due to the need for programming code]." [TE3]

We know the importance of guaranteeing a cooperative's core principle of providing one equal vote for each member, which DE3 also stressed in the evaluation.

"I understand your thoughts and think it is very important [to separate tokens from voting rights]. However, with the cooperative, it is basically like this: everyone invests whatever he or she can and gets the same benefit in return. This also means that you really only get one voting right." [DE3]

However, we decided to implement a reputation-based voting mechanism in which members can gain higher voting weight if they are more active in the organization. In particular, this includes participating in voting or making proposals. Ultimately, active members get more power for the organizations' steering, which we found a suitable incentive to ensure willingness for participation and enable purposeful cooperation.

Overall, the experts agreed on the suitability of our prototype to tackle the problem areas related to smallholders and cooperatives. Thus, we could show that a cooperative-oriented DAO might be an innovative and promising solution to enable smallholders' purposeful cooperation.

"You created a valuable architecture [for which] the separation of tokens and voting rights is a core value proposition." [TE1]

7 Discussion of results and derivation of design principles

In the first step, we reflect on and discuss our findings. Afterward, we derive design principles by triangulating our findings from the literature analysis related to smallholders, cooperatives, and DAOs, our observations during the artifact's development process, and the feedback received during the interviews to formulate design principles. Specifically, every author first came up with a proposal of design principles, which were then discussed in a joint workshop session with all authors. As a result, we could identify a final set of eight design principles. Those shall function as a guideline for researchers and practitioners to design and implement cooperative-oriented DAOs and are, thus, of socio-technical nature.

7.1 Discussion of results

Our artifact underlines the possibility of implementing a DAO that makes use of cooperative principles to facilitate cooperation of smallholders. Instead of relying on traditional contractual agreements, the *AgriDAO* employs smart contracts to reduce transaction costs when enforcing contracts. The *AgriDAO* also improves transparency and a democratic decision-making process. With the development of the *AgriDAO*, we started to rethink organizations in agricultural contexts. The *AgriDAO* may play a decisive role in initiating "*a new generation of dynamic and alternative forms of commercial organization*" (Poole and Frece 2010, p.13). In the following, we will discuss these issues in more detail.

Following Poole (2017) as well as Romero Granja and Wollni (2019), especially uncertainty in farming cooperatives can lead to rising transaction costs (Cook and Iliopoulos 2016), reduced investments, and ultimately hinder the sustainable development of these initiatives. Employing smart contracts and blockchain technology, the *AgriDAO* may help realize a higher level of transparency for all stakeholders, including members of the organization and external partners. Considering the potentially lower transaction costs accompanied by higher transparency (Edwards et al. 2007) and additional certainty provided by the contract enforcement mechanism of the Blockchain (Savelyev 2017), the *AgriDAO* might foster more long-term investments and eventually more profitable, efficient, and successful cooperation of smallholders in trust-free environments.

Our research was motivated after identifying the potential of the DAO concept to complement the core principles of cooperatives. Therefore, we decided to employ both concepts and develop a DAO in the agricultural sector that makes use of cooperative principles, the *AgriDAO*. For cooperatives and DAOs, voluntary and open membership, democratic member control, member economic participation, or autonomy and independence are pivotal. Thus, we designed our *AgriDAO* based on the concept of *The DAO* and implemented multiple smart contracts to steer the organization. Nevertheless, we decided against *The DAO*'s voting mechanism since it would promote plutocracy. Instead, we employed a reputation-based voting system to strengthen democratic principles and assure that voting power is independent of the members' economic status. Thereby, we could resolve this conceptual mismatch. Even more, we could implement an immaterial incentive mechanism through the reputation-based voting system to enhance members' participation and concern for the community. Through our evaluation, we confirmed our assumption that cooperatives and DAOs have much in common and provided evidence that the design of the *AgriDAO* sufficiently fulfills the design objectives. Only the entry into the *AgriDAO* (i.e., the membership itself) is subject to a gatekeeping process and is not entirely open. While the guidelines of the ICA (2018) do not follow any legal definition, we believe that it might provide the first indication for research on how to treat such kind of organization. In Table 5, we summarize major commonalities and differences between the characteristics of cooperatives, DAOs, and our AgriDAO.

Given our results, existing theories on organizations and specifically on cooperatives might be applicable to smart contract-governed organizations. For example, as Hart and Moore (1999) proposed, the problem of complete contracts might still be valid for DAOs. Hereby, the authors conclude that complete contracts are generally prohibitively expensive, providing evidence that smart contracts cannot cover all eventualities. Therefore, an adequate "depth" of the contents of contracts must be found (Mehar et al. 2019). In the *AgriDAO*, such eventualities might either come in programming flaws, e.g., the one that hit *The DAO* (Dupont 2017), or unforeseen situations not covered by the program code. In the case of *The DAO*, an unknown individuum exploited the underlying contract and drained around 50 Mio USD worth of tokens. As this person did not break the code but instead used it unintendedly under the code-is-law paradigm, discussion arose about whether this behavior should be regarded as "right" or "wrong". In the end, this discussion led to the decision of the core development team of Ethereum to perform a fork (Merkle 2016). This choice resembles the conclusion of a court when traditional contracts show potential loopholes and an entitled party has to decide how to solve the issue (Krasa and Villamil 2000).

7.2 Design principles

Introducing a novel artifact and proposing eight design principles adds value to the current research and enriches the existing body of knowledge (Seckler et al. 2021). In particular, we deliver insights into how the concept of DAOs as a new form of organization and cooperatives as a rather traditional and established form of organization could be combined to create value. Our developed and evaluated artifact, the *AgriDAO*, demonstrated that designing a DAO in the agricultural sector that makes use of cooperative principles is possible. Thus, our artifact serves as a practical blueprint and guides building a tailored DAO to address the challenges of smallholders and cooperatives. It further enables s starting point for deeper investigations in the future. Finally, we propose eight principles to design and implement cooperative-oriented DAOs, which shall guide researchers and practitioners in future developments of such organizations. Since these design insights are, to the best of our knowledge, the first

Table 5 Commonalities and differences between cooperatives, DAOs, and AgriDAO

	Cooperative	DAO	AgriDAO
Open access for interested members	✓	✓	✓
Automatic enforcement of contracts		✓	✓
Capital-independent, democratic voting mechanism	✓		✓
Immaterial incentive mechanism for participation			✓

of their kind, we hope they will mark a starting point for lively discussion and extensive exploration of this new form of organization by researchers and practitioners.

Table 6 summarizes the identified design principles and the problem areas they address.

The following provides more detailed information for each of the eight design principles.

DP1 Use a public infrastructure that allows for pseudonymity to prevent influence-taking between members within the decision-making process.

The foundation for a trustworthy environment where smallholders are willing to cooperate and no smallholder is discriminated against is pseudonymity. Our artifact, the *AgriDAO*, used a public permissionless infrastructure to ensure such pseudonymity per default. Thus, network participants can interact pseudonymously in the *AgriDAO*. Only entering the *AgriDAO* is not possible in a pseudonymous manner, as the assignment between persons and their voting rights would be difficult, as users must be identified, so a multi-registration is not possible. Furthermore, it must be assured that new members are the persons they claim to be. The pseudonymous use of the *AgriDAO* contributes to solving the influence costs problem (PA-C5), as pseudonymity is a prerequisite to prevent members from influencing others in the decision-making process to enforce their goals.

Table 6 Design principles and addressed problem areas for cooperative oriented-DAOs

Identified Design Principle	Addressed Problem Area
DP1: Use a public infrastructure that allows for pseudonymity to prevent influence-taking between members within the decision-making process	PA-C5: Influence cost problem
DP2: Use standards, application programming interfaces, and standardized processes that provide guidelines for interacting with the DAO and for using its functions to support cooperation within and between different DAOs	PA-S2: Missing cooperation
DP3: Use cryptocurrencies and tokenization that facilitate the transferability of (monetary) assets to support strategic and long-term investments	PA-C2: Horizon Problem
DP4.1: Use smart contracts that automatically execute predefined actions to facilitate the collective allocation of resources	PA-S1: Lacking access to capital, legal services, and information
DP4.2: Use smart contracts that allow for automatic enforcement of business rules when certain conditions are met to make the monitoring of decision-making obsolete	PA-C4: Control problem
DP4.3: Use smart contracts that create a trust-free environment due to the “code-is-law” paradigm to prevent distrust and opportunism	PA-S3: Distrust and opportunistic behavior
DP5.1: Use a reputation-based voting system with automatic counting of members’ participation in proposal creation and voting that allows for dynamic adaption of the voting weight to provide incentives for members’ commitment	PA-C1:Free-rider problem
DP5.2: Use a reputation-based voting system that supports democratic decision-making to enable investment decisions reflecting members’ individual risk perception	PA-C3: Portfolio problem

DP2 Use standards, application programming interfaces, and standardized processes that provide guidelines for interacting with the DAO and for using its functions to support cooperation within and between different DAOs.

This design principle describes the necessity to provide a clear structure in using the DAO. While rules and guidelines restrict the flexibility of an organization, they also deliver clarity to follow processes. Without well-defined processes, users might be overwhelmed by how to use the functions of the DAO or, even worse, cannot understand the effect of specific actions. Thus, well-defined processes are required for the easy and predictable use of the DAO. In the case of the *AgriDAO*, most operative actions follow a simple "proposal-voting-action"-principle and define respective functions. Similar to token standards such as ERC20, it is necessary to provide overarching standards so that the functions and interfaces for interacting with the DAO become predictable. Such standards do not only help to interact with DAOs but ultimately also to build them in the first place. Finally, this standardization and formalization supports smallholders' cooperation since it guides smallholders on how an organization can be shaped effectively and efficiently (PA-S2).

DP3 Use cryptocurrencies and tokenization that facilitate the transferability of (monetary) assets to support strategic and long-term investments.

Long-term cooperation and collective investments are rarely possible in an environment characterized by mistrust and opportunistic behavior. Therefore, a cooperative-oriented DAO must provide means for trustworthy interactions and, in the best case, financial collaboration. Therefore, cryptocurrencies and tokenization play an essential role in the *AgriDAO*. In particular, cryptocurrencies enable an overview of the undertaken investments and generated benefits for the members since all activities are logged onto the blockchain. If a member leaves the cooperative, it is possible to get insights into the corresponding investment history, which is why the *AgriDAO* supports strategic investments for growth and ultimately contributes to solving the horizon problem (PA-C2).

DP4.1 Use smart contracts that automatically execute predefined actions to facilitate the collective allocation of resources.

Smart contracts used in the *AgriDAO* allow for the collective allocation of resources since they can automatically execute predefined actions when certain conditions are met. For instance, purchasing a harvesting machine could require more money than one person owns, and, thus, members must allocate their resources to buy the machine. Such allocation of resources is not restricted to monetary assets but is also possible for legal services and information, which consequently could increase their productivity and agricultural expertise as well as strengthen their currently weak market position (PA-S1).

DP4.2 Use smart contracts that allow for automatic enforcement of business rules when certain conditions are met to make the monitoring of decision-making obsolete.

In currently existing cooperatives, opportunistic behavior, distrust, and lack of control prevent cooperation, contract conclusion, and reduction of transaction costs. Against this backdrop, we decided to shift the power from humans to machines and create a trust-free environment (i.e., smart contracts) as code is law. Based on self-executing code (i.e., smart contract "VotingMachine"), the *AgriDAO* enables the monitoring of management decisions, prevents managerial misbehavior, and enforces willingness for long-term cooperation and contract conclusion in general. Thus, smart contracts simplify monitoring management decisions and make them almost obsolete, ultimately reducing transaction costs (PA-C4).

DP4.3 Use smart contracts that create a trust-free environment due to "code-is-law" to prevent distrust and opportunism.

A trust-free environment contributes to cooperation independent of the trust between the collaborating people. In the context of the *AgriDAO*, entering the *AgriDAO* goes along with the member's agreement to accept the rule defined by the community. The rules members agreed on are more than loose, informal, or voluntary. Instead, those rules are implemented as code in the smart contracts and follow the logic of "code-is-law". Consequently, members can be sure that actions are performed as they are supposed to be. Thus, smart contracts hinder opportunistic influence-taking on actions after their initiation. If members want to change how actions are performed, they must change existing smart contracts or create new ones. Both require negotiations and a consensus between the members. We are optimistic that through the creation of a trust-free environment, distrust, and opportunistic behavior can be overcome (PA-S3).

DP5.1 Use a reputation-based voting system with automatic counting of members' participation in proposal creating and voting that allows for dynamic adaption of the voting weight to provide incentives for members' commitment.

Despite the *AgriDAO* being developed as an alternative to existing cooperatives, the grassroots democratic principle of the organization demands incentives for the members' active participation. Accordingly, members must be incentivized to create new and vote on existing proposals. Thus, we implemented a reputation-based voting mechanism that automatically rewards members who actively participate and act on behalf of the organization (i.e., smart contract "ReputationManager"). The reputation then directly indicates the members' voting power. Furthermore, linking access to certain services might also be possible, implying that only active members can use them. Therefore, this design decision contributes to solving the free-rider problem by incentivizing members to participate in the decision-making process (PA-C1).

DP5.2 Use a reputation-based voting system that supports democratic decision-making to enable investment decisions reflecting members' individual risk perception.

The last design principle builds on the fact that voting power should not exclusively depend on a user's tokens to enable democratic decision-making. For example, in *The DAO*, members can gain additional voting power by acquiring other ERC20 tokens. While this approach might offer ample incentives to purchase souvenirs and eventually invest in the organization, it does not fulfill the requirements of a cooperative. Instead, it creates a plutocratic system, with wealthier members having higher voting power. In the case of the *AgriDAO*, voting power is initially equally distributed and can be positively influenced by the member's participation, executed by the reputation-based voting mechanism. This design decision also ensures that investment decisions follow approximately the average risk perception of the DAO members. Thus, it does not solve the portfolio problem on an individual level but facilitates an average-weighted global solution (PA-C3).

8 Conclusion

We designed, developed, and evaluated a DAO in the agricultural sector that made use of cooperative principles, which we named cooperative-oriented DAO. This form of DAO could appropriately address the unique challenges of smallholders and cooperatives in developing countries. Based on the DSR paradigm, the *AgriDAO* and the corresponding design principles generate applicable solutions for the purposeful cooperation of smallholders in a trust-free environment. In particular, by presenting and discussing insights into the design of the *AgriDAO*, this paper makes various contributions to research and practice. Our research aims to enrich existing design knowledge by introducing a novel artifact and proposing breakthrough design principles (Seckler et al. 2021). First, through our artifact, we provide fundamental guidance on how a cooperative-oriented DAO in the agricultural sector can be designed to address the problems of smallholders and cooperatives. Second, we assessed the artifact's effectiveness and technical feasibility through our performed evaluation. At the same time, we identified the potentials and limitations which may function as valuable input for the future development of such organizations and enables deeper investigations. Third, our derived eight design principles provide guidance for successfully designing and implementing cooperative-oriented DAOs. As these design insights are, to the best of our knowledge, unprecedented, they shall initiate lively discussion and extensive exploration of this new form of organization by both researchers and practitioners.

In agriculture, cooperatives are a long-established way to coordinate cooperation (Zigran et al. 2015), and our research provides initial evidence that a DAO making use of cooperative principles may offer various benefits for smallholders. Even though the *AgriDAO* does not mark the first instantiation of a DAO, we demonstrate that the concept can be altered to perform tasks that conventional cooperatives typically perform. Such DAOs might also add value to other use cases where cooperatives are often considered a valid form of organization. Thus, our work builds the basis for developing and introducing cooperative-oriented DAOs in various other domains.

Although we pursued a rigorous research approach, our study is subject to three main limitations that stimulate future research. First, the oracle problem concerning the input of trusted data to the blockchain arose. This problem is common in blockchain-based applications and, therefore, not specific to our case. However, due to the possible level of automation in our analyzed case, incorrect real-world information can lead to the organization's improper actions. Consequently, we are aware of the oracle problem and propose using insurance, such as trusted third parties, as a potential solution, which should be examined and evaluated in more detail in future research. Second, the question of which smart contracts should be selected for performing transactions remains. The interviewed experts assumed that this decision might also depend on the number of transaction costs, given that smallholders' financial resources are limited. As a basis for corresponding decision guidelines, there needs to be a holistic assessment considering the effort and expenses of a transaction within the *AgriDAO* in a real-world environment. Third, we note that even though our design solution was evaluated by experts in the field of DAOs, blockchain technology, cooperatives, and agricultural development, the *AgriDAO* as a prototype was only implemented in a laboratory environment. Thus, future studies can further build on our situated artifact to test it more rigorously and, consequently, accumulate knowledge on that topic (vom Brocke et al. 2020). In particular, we see the development and implementation of the *AgriDA*O in a real-world setting as a promising future research approach. Therefore, we invite scientists and practitioners to build upon our research to initiate pilots for such DAOs in developing countries. Evaluating those pilots might provide further and deeper insights, e.g., regarding a cost comparison of technology implementation and resulting benefits or the system's usability from the end user's perspective. Also, the technological awareness and willingness, access to the Internet, and readiness to adopt such technologies could be assessed by including smallholders or smallholder representatives.

Despite the limitations and future research potentials, we made an initial step toward facilitating the cooperation of smallholders in developing countries through an emerging organizational form, the cooperative-oriented DAO.

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Declarations

Competing interests The authors declare that they have no known competing interests that are directly or indirectly related to the work submitted for publication.

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