DAO-ML: A Modelling Language for the Specification of Decentralized Autonomous Organization Governance*

Sowelu Avanzo[1], Alex Norta[2,3], Julio Linares[4,6], Claudio Schifanella[1] and Marie Hattingh[5]

[1]University of Torino, Italy
[2]Tallinn University, Estonia
[3]Dymaxion OÜ, Tallinn, Estonia
[4]Circles Coop eG
[6]Poetic Technologies uG
[5]University of Pretoria, South Africa

Abstract

Decentralized Autonomous Organizations (DAOs) are a class of blockchain-based systems that support governance processes. Developing DAOs is particularly challenging due to the complexity of designing and validating their governance structures. These differ from traditional organizational forms due to their dynamic adaptability and decentralized nature. Although approaches to model decentralized governance have recently been proposed, they lack specificity to the design of DAOs. Therefore, we analyze the suitability properties of DAOs and develop a modeling language that captures the specificity of their governance structures. Unlike other approaches, the proposed modeling language combines high suitability for DAO development with usability, provided by its graphical notation. A quantitative and qualitative evaluation of the modeling language is performed using an in vivo case study. This involves modeling a DAO-based decentralized governance infrastructure for the Circles UBI (Universal Basic Income) community currency system. This system provides token-based unconditional income to a large number of users worldwide.

Keywords

Decentralized autonomous organization, blockchain, DAO-ML, Organization Model, Governance

1. Introduction

Decentralized Autonomous Organizations (DAOs) are a class of decentralized applications (DApps) that use smart contracts to enable governance processes [1]. Although there are a large number of real-world applications of DAOs in diverse domains [2, 3, 4, 5], recent attention has been paid to the issues that limit the utility of DAOs [6]. In particular, empirical

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*Corresponding author: Sowelu Avanzo
†These authors contributed equally to this work.
soweluelios.avanzo@unito.it (S. Avanzo); alex.norta.phd@ieee.org (A. Norta); julio@poeticte.ch (J. Linares); claudio.schifanella@unito.it (C. Schifanella); marie.hattingh@up.ac.za (M. Hattingh)
0000-0001-7366-1086 (S. Avanzo); 0000-0003-0593-8244 (A. Norta); 0000-0003-0330-0001 (J. Linares); 0000-0001-7449-6529 (C. Schifanella); 0000-0003-1121-8892 (M. Hattingh)

evidence highlights the lack of scalability in voting systems, the excessive disunity of DAO communities, and the lack of participation in voting [7, 8]. These issues relate to the complexity of designing DAOs with governance structures that ensure that all members contribute to specific governance areas and that their actions align with the goals of the system. DAO governance demands novel requirements compared to traditional organizations [9]. In DAOs, roles and permissions are dynamically assigned based on tokenization, allowing for a more flexible and decentralized organizational form, as discussed in [9]. Furthermore, DAO communities can in some cases define the organization structure itself by upgrading the smart contracts of the DAO [9, 10]. Therefore, it is essential to correctly assign permissions to avoid unintended power increases [11].

Few methods and models exist to navigate design alternatives in DAO development. The study in [9] proposes a comprehensive theoretical model for the architecture of a DAO, defining its requirements. The Organization layer is described as the most abstract layer in a DAO, which shapes its organization form. However, the work does not propose a concrete approach to DAO development. Diverse solutions for platform-dependent DAO design handle the complexity of decentralized governance structures, but are constrained by the rapid technological evolution and changing environment [12, 10]. Several modeling languages were developed to specify the governance of traditional organizations, such as Archimate[1], or Organization Models [13]. The latter provide a particularly user-friendly syntax and graphical notation that integrates with other Agent-Oriented methods [13]. Still, these are not tailored to support the specificities of DAO design that we explore in this article. Finally, the Smart Legal Contract Markup Language (SLCML) [14] and the DECENT modeling language make valuable contributions to DAO design [15]. However, while these provide a rich set of concepts related to decentralized governance, a gap remains in specifying how governance structures are concretely implemented in DAOs. Furthermore, neither of those modeling languages includes a graphical notation. This reduces its usability among non-technical stakeholders, unlike agent-oriented modeling methods [13, 16].

To fill the evidence gap in the state-of-the-art, our aim is to answer the following research question (**RQ**): *How to develop a graphical modeling language that supports the specification of DAOs with suitable governance structures?* This is done by responding to the deduced research questions below:

- **RQ1**:*What are the suitability properties for the specification of the organization layer of DAOs?*
- **RQ2**:*What is the ontology that incorporates the main concepts of the organization layer of DAOs?*
- **RQ3**: *What is the extension of the organization model diagrams for specifying DAOs?*

To answer the above research questions, we firstly, generate suitability properties for the DAO organization layer, as defined in [9], based on the existing literature. Second, we extend relevant ontologies to incorporate concepts that facilitate the specification of organizational structures in DAOs. Third, we propose a graphical notation and syntax that extend and formalize organization diagrams [13]. Finally, a qualitative evaluation is performed in the context of the running case

[1]https://www.archimatetool.com/

to ensure relevance to concrete organizational problems. A quantitative evaluation is also performed to ensure that rigor is applied and to compare the results with the state-of-the-art.

The remainder of the paper introduces the case study and methodology used in Section 2, and the background literature in Section 3. It discusses suitability exploration in Section 4, presents the ontology of the modeling language in Section 5, details the syntax of DAO-ML in Section 6, and discusses the evaluation and related work in Section 7. The paper concludes with a summary of the findings, limitations, and future directions in Section 8.

2. Preliminaries

We first discuss the current state of the system addressed by the running case in Section 2.1. Subsequently, an overview of the research methodology is provided in Section 2.2.

2.1. Circles UBI Running Case

Community Currency Systems (CCSs) support the circulation of tokens used as local means of exchange complementary to national currencies [17]. The tokens are accepted by voluntary agreement and managed by social-economy organizations with the aim of bootstrapping local trade and providing humanitarian aid. As evidenced in [18], the decentralization of CCS governance remains an open problem. The running case focuses in particular on Circles UBI (Universal Basic Income) [18], whose goal is to provide token-based unconditional income to its users. Policies that regulate the issuance and interoperability of different tokens are established and enforced through smart contracts [19]. In the following, we discuss the main challenges facing the current version of the system that we address as part of the modeling language evaluation. Circles Coop eG, the organization that manages the system, aims to transform passive UBI receivers into active providers of goods and services, which can be paid for in Circles tokens. To achieve this goal, the development team is advancing the concept of *group currencies*. A *group currency* is a convertible token type for the Circles community currency, whose governance is collectively managed by a specified group of users of the system [20]. A Circles UBI user can become a member of a given group by depositing (staking) their own Circles tokens and obtaining *group currency* tokens in return. Multiple groups shall co-exist in the system, representing the different organizations involved, such as associations, local businesses, self-organized collectives, and the Circles Coop itself. Each group shall be able to define its own policies governing membership requirements, issuance, conversion rates, and distribution of its own token type, hence supporting tailored economic environments that reflect the group's objectives and values. The *group currency* smart contracts, which can be found in [20, 21], currently implement a simple governance logic. However, this governance logic is not suitable for complex interactions, which involve dynamic policy adjustments. Still, developers and members of the cooperative express the difficulty in adapting existing DAO-based governance mechanisms to the specificities of the CCSs, given their inherent complexity. Therefore, modeling the decentralized governance infrastructure for Circles UBI based on DAOs enables the evaluation of the applicability of the modeling language in a real-world context.

2.2. Methodology

The Design Science Research (DSR) framework is adopted in this study to respond to the RQs. It provides a methodology to create new design theories represented by constructs, models, and methods based on the iterative development and evaluation of information system artifacts [22]. The developed artifact's relevance is ensured by addressing unsolved organizational problems, and theoretical foundations from the knowledge base are applied to achieve rigor in the iterative development and evaluation process. The first *design artifact* developed in the research process consists of a classification of reference requirement sets that provide the suitability properties of DAO governance (RQ1) based on the relevant specifications. The second is an ontology that models the Organization layer of DAO architectures (RQ2), and the third consists in the syntax for specifying DAO-ML models (RQ3). We follow the **case study** research strategy outlined in [23] for the evaluation of the modeling language. Data to assess the needs of the running case were collected in an empirical evaluation of the utility of Circles UBI in [18] and through additional semi-structured interviews with developers and members of the organization that developed the CCS. The structural correctness of the developed DAO models is verified on the basis of the syntactic rules presented.

3. Related Works

The theoretical model proposed in [9] defines three characterizing layers of DAO architectures. These focus on the relevant perspectives of *organization*, *coordination*, and *execution*. In the *organization* layer, the governance structure is defined based on the strategic goals of the DAO. The *coordination layer* is concerned with technologies supporting decision-making, including voting protocols and tokenized incentives. In the execution layer, the tasks defined in the upper layers are executed by smart contracts. Approaches focused on the development of DApps successfully target crucial issues of the *execution* layer, but fail to address complexities relevant to *coordination* and *organization*. Some examples include IContractML 2.0, which is focused on smart contract modeling [24], or the T-DM method [25, 26]. Studies [27, 8] enable the selection of a suitable voting protocol and token economy design for a DAO, respectively. These aspects are relevant to the *coordination* of DAOs. Still, they fail to target the other layers' complexities. A decision model was proposed in [10] to select among several alternative platforms supporting DAO deployment, including Aragon[2], DAOstack[3] or Colony[4]. However, the decision model needs to be updated to reflect the rapidly evolving features of the DAO platforms. This highlights a limitation of the approach and the need for platform-independent design [10]. Other works specifically address role-based access control, which is a key aspect of the organization perspective of DAOs [12, 28]. Still, they focus on the platform-dependent design features and lack general applicability. Traditional approaches to model the governance structure of traditional organizations include organizational model diagrams. These were proposed as part of the core Agent-oriented methodologies [13], which are particularly suitable for the platform-independent design of socio-technical systems. In organizational models, *roles*

[2]https://aragon.org/
[3]https://www.alchemy.com/dapps/daostack
[4]https://colony.io/

embody distinct functions and responsibilities in an organization, represented as the actor icon in UML diagrams with a textual description of the role. Relationships in these models are peer collaboration (*is-peer-to*), control dynamics (is-controlled-by), benevolence (is-benevolent-to), and aggregation (*aggregates*), representing the relation between a more general and a more specialized role. All such relations are illustrated with directed association links between roles. This notation is suitable for representing simple governance structures in organizations, but it lacks suitability for decentralized governance of DAOs. Finally, we consider DECENT and SLCML ontologies as the necessary foundation adopted to extend capabilities of organizational model diagrams [29, 15, 14]. The former supports the specification of inter-organizational collaborations among DAOs and legally relevant smart contracts [14], the latter models abstract governance-related concepts. Still, none of the two models concepts related to membership and permission handling logic, crucial to the concrete implementation of DAO governance structures.

4. Suitability Properties of Decentralized Autonomous Organization Governance

This section addresses RQ1 by providing a model of the organization layer of DAO architectures represented as a class diagram in Figure1. We first present the model and subsequently justify it based on relevant DAO specifications and literature.

Our model defines the on-chain permission management logic of DAOs that shapes their organizational form. Such logic is implemented by a *permission manager*, that determines which *roles* can assign *permissions* or delegate power to other roles and how the roles are assigned to autonomous or human agents. The *permission_manager* associates a set of *permissions* with the corresponding *roles*. It *consists_of* two mechanisms: *permission_assignment* and *role_assignment*. The former enables the grant and revocation of a given set of *permissions*. The latter defines which *roles* can be revoked or granted permissions by superior roles, in the event that a hierarchical organizational structure is adopted. DAOs employ various methods for assigning *membership* and *roles* to *agents*, including the purchase or staking of governance tokens, election or invitation to take part in specific *committees*. *Permissions* are key to enforce the *power* of a given *role* or *committee* within the organization. We propose a classification of permissions enforced by DAOs into three types based on their impact on system functionality, which can be defined through the *permissions_type* attribute. *Structural* permissions are critical for safety, as they involve actions that can modify core functionalities of the DAO. Some examples include smart contract upgrades altering access control policies or decision-making protocols. *Strategic* permissions mainly affect token economy policies without changing the structure of the DAO. These involve actions like minting tokens, managing the DAO treasury, voting, and proposal submissions, which are crucial for coordination within the DAO. *Operational* permissions have a lesser impact, as they relate to resource access and task execution.

In DAOs, the community of users can be segmented into *committees*, which allow focused deliberation on specific *governance areas* by designated *roles*. Both *DAOs* and *committees* are modeled as *organizational units* which can in their turn become members of committees and take on integral roles in decision-making processes. Finally, in order to meet the scalability

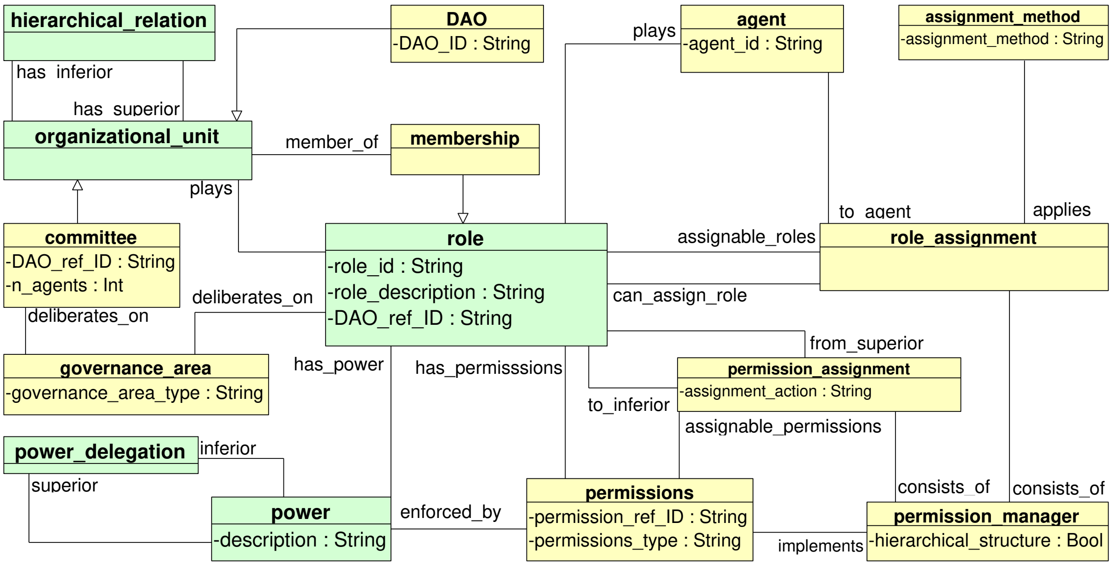


Figure 1: DAO organization model. The green classes are present in the SLCML ontology [14].

requirements of DAOs, several areas of their governance are supported by off-chain execution. For this reason, in addition to supporting smart contracts, DAOs rely on *off-chain* and *hybrid* modes (*governance_area_type*), as per the snapshot voting systems [7], for governance areas with lower security requirements [30, 7, 9].

In the remainder of the section, we report references to relevant literature analyzed to develop the organization layer model. Studies in [28] and [11] highlight the relevance to DAOs of role-based access control policies and provide a reference model of permission-management, in DAOs, respectively. Study in [31] highlights the presence of committees as sub-communities of DAO users deliberating on specific governance areas. Also studies in [9, 8] highlight the importance of establishing focused deliberation on pertinent governance areas based on the long-term organizational goals of the system. The dynamic configuration of permission assignment is presented as an essential requirement for DAOs in [12]. This work presents a system where roles form hierarchies and permission inheritance is handled on-chain, thereby supporting complex governance structures. Also the multiple DAO implementations analyzed in [32] reveal the presence of both hierarchical and flat organizational structures in DAOs. Diverse studies discuss the characteristic autonomous execution of proposals and interaction with the environment, to fulfill which the DAO itself acts as an autonomous *agent* [33] [5]. Furthermore, our classification of permissions in DAOs is supported by [9, 10], which discuss the capability of DAO communities to modify the organization structure by upgrading core smart contracts, and by Zhao et al., [30], who distinguish between operational and strategic tasks in DAOs.

[5]https://aragon.org/agent

5. DAO Governance Ontology

In this section, we respond to RQ2 by presenting the ontology of the DAO-ML approach. As we aim to achieve extensibility of our approach and leverage on previous efforts to model DAO governance, the ontology extends and integrates with the DECENT and SLCML ontologies, offering complementary perspectives. To achieve this goal, we firstly translated the DECENT ontology into Web Ontology Language 2.0 (OWL) for compatibility with SLCML. Secondly, we merged DECENT and SLCML, and enriched the resulting ontology with 11 new classes, 10 object properties, and 11 data properties that align with the DAO-relevant concepts discussed in Section 4 and represented in Figure 1. We then specified domain and range restrictions for each new property and modified the domain and range restrictions for the *consist_of*, *implements*, and *plays* object properties, which existed in the DECENT ontology to reflect the relations depicted in Figure 1. Furthermore, we restricted the range of assignmenet_action data property, limiting the selection to *revoke* or *grant* actions. Likewise, we restricted the range of *governance_area_type* to *on_chain*, *hybrid* or *off_chain*, and the one of *permissions_type* to *structural*, *strategic* and *operational*, based on the classification of permissions described in the previous section.

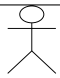
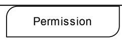
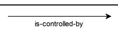
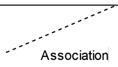
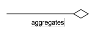
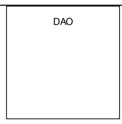
To develop the ontology, we adopted the Protégé editor [6], and we checked it for soundness using the HermiT reasoner[7]. HermiT is a Protegè plugin designed to perform consistency checks on OWL ontologies. This serves to determine whether an ontology is logically consistent and to prevent undesirable inferences from occurring. Since the Role class was present in both DECENT and SLCML, we merged the two classes, ensuring that all properties were preserved. We briefly outline below the main connections we established between the newly developed tier and classes present in DECENT and SLCML. *Permissions* are modeled as a subclass of *Rule Set*, belonging to DECENT (not represented in the reported class diagrams) [34]. Furthermore, *Policy* is a superclass of the *permission_manager* (Figure 1), while the *role_assignment* and *permission_assignment* specialize the *mechanism* class. The newly developed tier of the ontology also extends the *resource perspective*, part of SLCML [14, 35], as the newly developed classes and properties model the access control policies of DAOs which concretely enforce power delegations and hierarchies of roles and *organizational_units* defined in it. Furthermore, both the *DAO* and *committee* classes extend the *organizational_unit* class (Figure 1).

6. DAO-ML Syntax and Notation

In orer to respond to RQ3, we describe the DAO-ML elements, properties and graphical notation in Table 1, and we derive syntactic validation rules in Table 2. To ensure syntactic correctness of the models, we adopt XML Schema Definition (XSD). The XSD document in Appendix A.1 defines the desired structure of XML documents representing DAO-ML models. For rules that cannot be directly enforced through the generated XSD, we also adopt Xpath queries to validate conditions 3 to 6 in Table 2. While the original organization diagrams only include *role* elements [13], DAO-ML diagrams include *committee*, *governance_area*, *DAO* and *permission* elements. The relations of standard organization models *is_controlled_by* and *aggregates* are

[6]https://protege.stanford.edu/
[7]http://www.hermit-reasoner.com/

Table 1
DAO-ML model elements and properties.

Elements	Notation	Description	Properties
role		Function performed by a set of agents in the DAO governance.	role_ID; role_name; assignment_method; agent_type;
committee		Organized group of agents deliberating on a set of governance_areas.	committee_ID; committee_description; n_agent_min; n_agent_max; appointment_method;
governance_area		Domain of interest under the consideration of a given *committee* or *role* in a DAO.	gov_area_ID; gov_area_description; implementation;
permission		Authorization to perform a given action enabled by the organization.	allowed_action; permission_type;
is_controlled_by		Power relationship over a role or committee. The controller can grant, revoke or delegate permissions to the controlled.	source_ID: role; committee; target_ID: role; committee;
associated_to		Assignment of a *governance_area* or *permission* to a committee or a role.	source_ID: role; committee; target_ID: permission; governance_area;
aggregates		Indicates membership of a committee, or aggregation into more general roles or committees from specializations.	source_ID: role; committee; target_ID: role; committee;
DAO		DAO system involving roles, committees, governance areas, and permissions included in the square.	DAO_ID; DAO_name; *mission_statement*

also included in our modeling language. These in the DAO context assume the following meanings: the relation *is_ controlled_by* specifies the power a role has to delegate, grant, and remove permissions from another role. For simplicity, we omitted from the model the relation *is-benevolent-to*, which is present in the original Organization models. Also the relation *is-peer-to* is omitted, as it can be specified as the absence of control relations among roles. The association relation serves two distinct purposes: it represents the assignment of a given *permission* to a *role* or *committee*, hence entitling the agents playing the role or the committee to perform the described actions. Alternatively, it can represent the contribution of a given *committee* or *role* to a*governance_area* of the DAO. The *aggregates* relation can either indicate participation of a role

Condition	Verification	Formalization
1. *Each DAO-ML diagram should specify at least one DAO*	XSD: `<xs:element name="DAO" minOccurs="1">`	$\lvert D_{ID}\rvert \geq 1$
2. *All elements in the diagram should have unique IDs*	XSD: `type="xs:ID" use="required"`	$\forall e \in E, \text{unique}(e_{ID})$
3. *Associated* elements reference valid IDs	XPath: `//Role/associated_to | //Committee/associated_to ⊆ //GovernanceArea/@gov_area_ID | //Permission/@permission_ID`	$A_{assoc} \subseteq G_{ID} \cup P_{ID}$
4. *Roles aggregate* into Roles or Committees	XPath: `//Role/aggregates ⊆ //Role/@role_ID | //Committee/@committee_ID`	$R_{agg} \subseteq R_{ID} \cup C_{ID}$
5. *Committees aggregate* into Committees	XPath: `//Committee/aggregates ⊆ //Committee/@committee_ID`	$C_{agg} \subseteq C_{ID}$
6. *Is Controlled By* relations must reference valid IDs	XPath: `//Committee/is_controlled_by | //Role/is_controlled_by ⊆ //Committee/@committee_ID | //Role/@role_ID`	$A_{ctrl} \subseteq C_{ID} \cup R_{ID}$

Table 2
Syntactic Validation Rules for DAO-ML Diagrams. **Legend:** $E = \{D, R, C, G, P\}$ where D - DAO, R - Role, C - Committee, G - GovernanceArea, P - Permission. $A_{assoc}, A_{ctrl}, C_{agg}, R_{agg}$ represent sets of IDs for all elements *associated_to*, *is_controlled_by*, *aggregates* for Committees and *aggregates* for Roles, respectively. $D_{ID}, R_{ID}, C_{ID}, G_{ID}, P_{ID}$ denote the sets of IDs for each element type.

in a *committee*, or indicate the specialization of a role into sub-roles with more specific functions. The *DAO* element represents the boundaries of the system and the organization. It is represented graphically by a square that shows the name of the DAO and the *mission_statement*, describing the long-term organizational goal. Multiple organizations and inter-organizational relations can be represented in one diagram. Each *role* element includes a unique identifier string (*role_ID*) and a name (role_name). Furthermore, the Role element includes the specification of the method by which the role is assigned to an agent (assignment_method), and which types of agents can take the given role in the organization: either an *autonomous_agent*, or a *human* actor (or any if non specified). Likewise, each *committee* element includes a unique identifier (committee_ID), a textual description of the committee's purpose (committee_description). Furthermore, metadata include the appointment method, analogous to the assignment_method for roles. A numerical limit on agent membership can be imposed (n_agent_max, n_agent_min). Governance areas are characterized by a textual description of the domain (gov_area_description) and whether the governance area is deliberated in an *on-chain*, *off-chain*, or *hybrid* mode (*implementation*). *Permission* metadata include a textual description of authorized actions (allowed_action), and the type of permission granted (permission_type), which can be *structural*, *strategic* or *operational.*

7. Evaluation

In this Section, we present a twofold evaluation of the DAO-ML modeling language. We first discuss and validate the DAO-ML model of the running case in Section 7.1. Subsequently, we quantitatively evaluate the modeling language in Section 7.2.

7.1. DAO-ML Model of the Circles DAO

In Figure 2, we illustrate the DAO-ML model of the Circles DAO, aiming to support both developers and non-technical stakeholders in the analysis and communication of the requirements for the organization layer of the DAO. The Circles DAOs are designed to establish the foundation for the decentralized governance infrastructure of the CCS and address the challenges discussed in Section 2.1. The diagram graphically displays the main Governance Areas addressed by the DAO and associates them to relevant roles and committees, hence establishing a division of responsibilities within the organization. The governance structure specification is further refined by defining permissions, the roles, committees and control relations at a high level of abstraction. Three roles are defined: Group Members, Active Members, and a Treasury Manager. Any user becomes a member of the DAO by depositing Circles tokens, hence obtaining group currency tokens in return. Group Members can become Active Members by providing contributions attested by the community. These shall be rewarded by the distribution of a token named *Perishable Share*. This token type is characterized by an expiration date to ensure continuous contribution and prevent power concentration. Four committees structure the DAO's collective decision-making, ensuring focused deliberation on pertinent issues. The General Assembly includes all Group Members. The Community, Technical and Economic Councils, shown in the figure, are composed of Active Members exclusively. The General Assembly deliberates on the *governance area* concerning the provision of services by Group Members. Services provided are compensated in group currency tokens. Any group member can propose to provide a service for the community, whose acceptance or rejection is evaluated collectively by the Assembly. The Community Council is formed by active members of the DAO, selected according to a rotation policy. The members of this committee can vote to modify group membership requirements and contribution attestation metrics (Group Membership and Attestations). The Economic Council, formed by the most active members of the community, makes decisions concerning the collateral types accepted and held in the treasury of the DAO, which can include stable coins. The Treasury Manager, controlled and periodically elected by the Economic Council, is tasked with managing the Circles tokens held in the treasury in the best interest of the community by funding projects proposed by Group Members. Finally, the Technical Council has the most extensive permissions (categorized as structural), which concern the upgrading of smart contracts of the DAO and Group Currency. The self-loop in the control relation indicates that the committee can also upgrade the policies and permissions that enable its own operations. This group holds the responsibility to handle emergency situations, due to malfunctioning of the system, for instance.

The syntactic correctness of the DAO-ML model of the running case was evaluated in two ways: first, the XML in Appendix A.2 was validated against the XSD in Appendix A.1. This ensured that structural conditions 1 and 2 are respected (Table 2). The validation shows that the

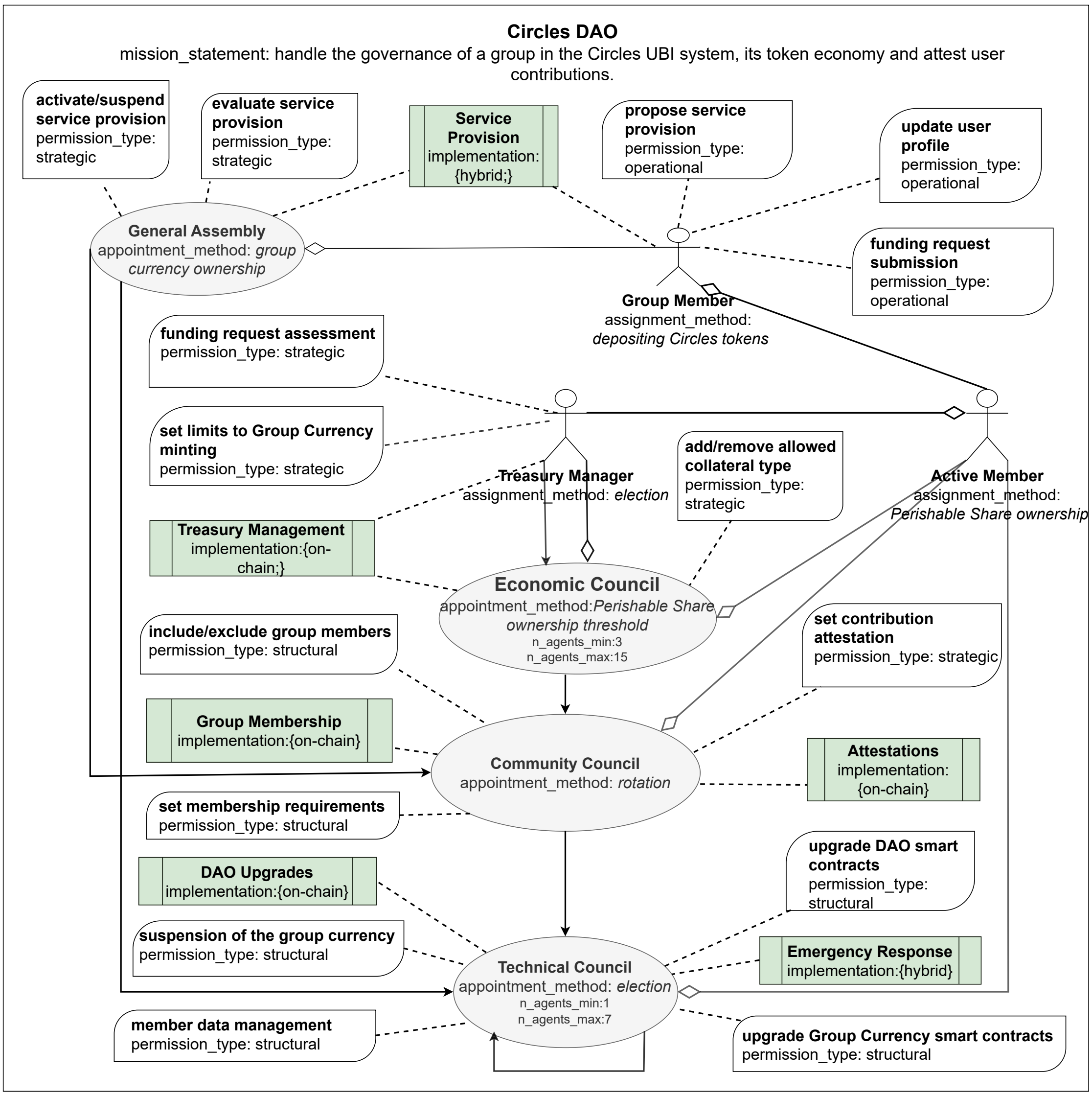


Figure 2: DAO-ML model of Circles UBI Group Currency DAOs.

XML document was valid against the schema provided. Subsequently, following the approach described in [36], we applied the Xpath queries described in rows 3 to 6 of Table 2 and verified that the relative constraints were satisfied. The analysis of the query results showed that all the conditions hold and, therefore, the DAO-ML model of the Circles DAO is valid. To conduct the evaluation, we adopted the Liquid Studio validation engine[8].

[8]https://www.liquid-technologies.com/xml-studio

7.2. Quantitative Evaluation

The DAO-ML was subsequently evaluated using the framework in [37]. This provides a guideline to quantitatively evaluate the suitability of graphical modeling languages with respect to an ontological reference meta-model. DAO-ML is compared with three other modeling languages: the original Organization Model syntax, DECENT and SLCML. Since the ontology developed in Section 5 includes all concepts from the meta-models of the DECENT and SLCML ontologies [34, 14], the modeling languages can be compared with the newly developed one. Considering that we aim to evaluate the suitability of the different modeling languages for the development of DAOs specifically, we restrict our reference meta-model to the set of concepts referring to the suitability properties outlined in Figure 1, which are also part of the ontology presented in Section 5. The framework enables the analysis of the following properties: *construct redundancy*, *construct overload*, *construct excess* and *construct deficit*. *Construct redundancy* is calculated by dividing the number of constructs that represent the same concept in the reference meta-model by the total number of constructs in the modeling language. *Construct overload* occurs when a single construct refers to multiple concepts in the meta-model. It is measured by dividing the number of overloaded constructs by the total number of constructs in the language. *Construct excess* is measured by dividing the number of constructs with no corresponding concepts by the total. *Construct deficit* evaluates the completeness of the modeling language for the given domain. It is measured by dividing the number of concepts in the reference meta-model that are not represented by any construct in the target language by the total number of concepts in the meta-model. Table 3 reports the evaluation results for DAO-ML, standard Organization Models, DECENT, and the core constructs of eSML and SLCML. As the core set of concepts defined in eSML that model the resource perspective are also included in SLCML, we compare the 14 original eSML constructs specifically, defined in [35]. In order to more accurately take into account the interconnections among concepts within the ontology, constructs that map to a super-class of the set of DAO-relevant classes in the ontology, are also counted as representing the DAO-relevant sub-class. In our modeling language, we did not provide constructs explicitly mapping to the concept of *agent*, *assignment method* and *organization unit*, even though we included opportune metadata to specify the assignment of roles to agents. For this reason, the construct deficit amounts to 21.4%. Furthermore, two constructs are overloaded (permission and control relation) out of 8 (25%). The *associated to* construct maps to the permission manager class, as it links roles and committees with relative permissions, while the *aggregates* construct maps to the *membership* class. DAO-ML has neither construct redundancy nor construct excess. DAO-

Table 3
Comparison of Modeling Language Suitability for DAO development

Metric	DAO-ML	Organization Model	DECENT	SLCML - eSML
N. of Constructs	8	5	16	14
Construct Redundancy	0%	0%	0%	14.3%
Construct Overload	25%	40%	12.5%	14.3%
Construct Excess	0%	60%	68.7%	85.7%
Construct deficit	21.4%	85.7%	43%	50%
Graphical notation	+	+	-	-

ML displays a higher construct overload (25%) compared to the DECENT modeling language (12.5%), as in both languages 2 constructs are overloaded, but DECENT has twice as many constructs as DAO-ML. The results, therefore, reveal that the modeling language improved its suitability with respect to the basic Organization Models, and provides relatively higher suitability compared to existing languages for decentralized governance specification. DAO-ML provides a graphical notation, which SLCML and DECENT do not provide, and has a smaller number of constructs (8), compared to the other two languages. Furthermore, it includes a formal definition, which, to the best of our knowledge, is not the case for Organization Models. As we specifically aimed at high usability, we did not provide constructs expressing all concepts present in the meta-model. However, metadata in the proposed language enable users to specify crucial aspects concerning the assignment of roles and committee membership to agents.

8. Conclusive Remarks

This article discusses the development of DAO-ML, a modeling language to specify DAOs with suitable governance structures. We performed a suitability exploration of concepts related to the organization layer of DAO architectures [9], based on which we developed an ontology. Finally, we develop a graphical notation to specify DAO models and demonstrate the syntax of the modeling language.

We evaluated DAO-ML by specifying the requirements for the decentralized governance infrastructure of Circles UBI, a community currency system that provides an unconditional income to a large number of users worldwide. In this context, DAOs enable users to actively participate in CCS governance. This demonstrated the real-world applicability of the proposed language, which enabled us to model the governance structure of the desired DAO at a high level of abstraction. We also performed a quantitative evaluation of DAO-ML, which highlights its greater suitability for modeling the organization layer of DAOs compared to other relevant modeling languages. Furthermore, given the limited number of constructs and the presence of graphical notation, it presents a higher usability for non-technical stakeholders. However, the presented evaluation is limited in scope and should be expanded by evaluating semantics and pragmatics through dedicated workshops involving practitioners, as demonstrated in [38]. In addition, the scope of the findings presented in this article is limited to the organizational layer of DAOs. Further extensions should focus on developing domain-specific languages for DAO development comprising the other layers. Future work will focus on two main areas: the further formalization of the developed and tested DAO-ML constructs and the development of tool support and a comprehensive method for the proposed modeling language.

A. Appendices

A.1. DAO-ML XML Schema Definition

```
<?xml version="1.0" encoding="utf-8" ?>
<!--Created with Liquid Studio (https://www.liquid-technologies.com)-->
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
    <!-- Organization Diagram -->
    <xs:element name="DAO-ML_diagram">
        <xs:complexType>
```

```xml
            <xs:sequence>
                <!-- DAO Element -->
                <xs:element name="DAO" minOccurs="1" maxOccurs="unbounded">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="Role" minOccurs="0" maxOccurs="unbounded">
                                <xs:complexType>
                                    <xs:choice minOccurs="0" maxOccurs="unbounded">
                                        <xs:element name="is_controlled_by" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                        <xs:element name="associated_to" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                        <xs:element name="aggregates" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                    </xs:choice>
                                    <xs:attribute name="role_ID" type="xs:ID" use="required" />
                                    <xs:attribute name="role_name" type="xs:string" use="required" />
                                    <xs:attribute name="role_assignment_method" type="xs:string" use="required" />
                                    <xs:attribute name="agent_type" use="required">
                                        <xs:simpleType>
                                            <xs:restriction base="xs:string">
                                                <xs:enumeration value="human" />
                                                <xs:enumeration value="autonomous_agent" />
                                            </xs:restriction>
                                        </xs:simpleType>
                                    </xs:attribute>
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="Committee" minOccurs="0" maxOccurs="unbounded">
                                <xs:complexType>
                                    <xs:choice minOccurs="0" maxOccurs="unbounded">
                                        <xs:element name="is_controlled_by" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                        <xs:element name="associated_to" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                        <xs:element name="aggregates" type="xs:IDREFS" minOccurs="0" maxOccurs="unbounded" />
                                    </xs:choice>
                                    <xs:attribute name="committee_ID" type="xs:ID" use="required" />
                                    <xs:attribute name="committee_description" type="xs:string" use="required" />
                                    <xs:attribute name="n_agent_min" type="xs:integer" use="optional" />
                                    <xs:attribute name="n_agent_max" type="xs:integer" use="optional" />
                                    <xs:attribute name="appointment_method" type="xs:string" />
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="GovernanceArea" minOccurs="0" maxOccurs="unbounded">
                                <xs:complexType>
                                    <xs:attribute name="gov_area_ID" type="xs:ID" use="required"/>
                                    <xs:attribute name="gov_area_description" type="xs:string" use="required" />
                                    <xs:attribute name="implementation" use="required">
                                        <xs:simpleType>
                                            <xs:restriction base="xs:string">
                                                <xs:enumeration value="on-chain"/>
                                                <xs:enumeration value="hybrid"/>
                                                <xs:enumeration value="off-chain"/>
                                            </xs:restriction>
                                        </xs:simpleType>
                                    </xs:attribute>
                                </xs:complexType>
                            </xs:element>

                            <xs:element name="Permission" minOccurs="0" maxOccurs="unbounded">
                                <xs:complexType>
                                    <xs:attribute name="permission_ID" type="xs:ID" use="required" />
                                    <xs:attribute name="allowed_action" type="xs:string" use="required" />
                                    <xs:attribute name="permission_type" use="required">
                                        <xs:simpleType>
                                            <xs:restriction base="xs:string">
                                                <xs:enumeration value="structural" />
                                                <xs:enumeration value="strategic" />
                                                <xs:enumeration value="operational" />
                                            </xs:restriction>
                                        </xs:simpleType>
                                    </xs:attribute>
                                </xs:complexType>
                            </xs:element>
                        </xs:sequence>
                        <xs:attribute name="DAO_ID" type="xs:ID" use="required" />
                        <xs:attribute name="DAO_name" type="xs:string" use="required" />
                        <xs:attribute name="mission_statement" type="xs:string" />
                    </xs:complexType>
                </xs:element>
            </xs:sequence>
            <xs:attribute name="name" type="xs:string" use="required" />
            <xs:attribute name="uniqueID" type="xs:ID" use="required" />
        </xs:complexType>
    </xs:element>
```

```xml
</xs:schema>
```

Listing 1: DAO-ML Schema Definition

A.2. Circles UBI DAO-ML Model

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- Created with Liquid Studio (https://www.liquid-technologies.com) -->
<DAO-ML_diagram xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
                xsi:noNamespaceSchemaLocation="XSD_TDM_Decentralized_Organization.xsd"
                name="Group Currency DAO Diagram"
                uniqueID="GCDAOdiagram">
    <DAO DAO_ID="GCDAO" DAO_name="Group Currency DAO" mission_statement="Managing the governance of Group Currencies in the Circles UBI system.">
        <Role role_ID="GroupMember" role_name="Group Member" DAO_membership_refID="GCDAO" role_assignment_method="depositing Circles tokens" agent_type="human">
            <associated_to>propose_service_provision</associated_to>
            <associated_to>update_user_profile</associated_to>
            <associated_to>funding_request_submission</associated_to>
            <associated_to>ServiceProvision</associated_to>
        </Role>
        <Role role_ID="TreasuryManager" role_name="Treasury Manager" DAO_membership_refID="GCDAO" role_assignment_method="election" agent_type="human">
            <aggregates>EconomicCouncil</aggregates>
            <aggregates>ActiveMember</aggregates>
            <associated_to>funding_request_assessment</associated_to>
            <associated_to>set_limits_to_group_currency_minting</associated_to>
            <associated_to>TreasuryManagement</associated_to>
            <is_controlled_by>EconomicCouncil</is_controlled_by>
        </Role>
        <Role role_ID="ActiveMember" role_name="Active Member" DAO_membership_refID="GCDAO" role_assignment_method="Perishable Share ownership" agent_type="human">
            <aggregates>CommunityCouncil</aggregates>
            <aggregates>EconomicCouncil</aggregates>
            <aggregates>TechnicalCouncil</aggregates>
            <aggregates>GroupMember</aggregates>
        </Role>
        <Committee committee_ID="GeneralAssembly" committee_description="General Assembly" appointment_method="group currency ownership">
            <associated_to>activate_suspend_service_provision</associated_to>
            <associated_to>evaluate_service_provision</associated_to>
            <is_controlled_by>TechnicalCouncil</is_controlled_by>
            <is_controlled_by>CommunityCouncil</is_controlled_by>
        </Committee>
        <Committee committee_ID="EconomicCouncil" committee_description="Economic Council" n_agent_min="3" n_agent_max="15" appointment_method="Perishable Share ownership threshold">
            <associated_to>add_remove_allowed_collateral_type</associated_to>
            <is_controlled_by>CommunityCouncil</is_controlled_by>
            <associated_to>TreasuryManagement</associated_to>
        </Committee>
        <Committee committee_ID="CommunityCouncil" committee_description="Community Council" appointment_method="rotation">
            <associated_to>Attestations</associated_to>
            <associated_to>set_contribution_attestation</associated_to>
            <associated_to>set_membership_requirements</associated_to>
            <associated_to>GroupMembership</associated_to>
            <associated_to>include_exclude_group_members</associated_to>
            <is_controlled_by>EconomicCouncil</is_controlled_by>
        </Committee>
        <Committee committee_ID="TechnicalCouncil" committee_description="Technical Council" n_agent_min="1" n_agent_max="7" appointment_method="election">
            <associated_to>upgrade_Group_Currency_smart_contracts</associated_to>
            <associated_to>member_data_management</associated_to>
            <associated_to>suspension_of_the_group_currency</associated_to>
            <associated_to>DAOUpgrades</associated_to>
            <associated_to>upgrade_DAO_smart_contracts</associated_to>
            <associated_to>EmergencyResponse</associated_to>
            <is_controlled_by>TechnicalCouncil</is_controlled_by>
        </Committee>
        <GovernanceArea gov_area_ID="ServiceProvision" gov_area_description="Service Provision" implementation="hybrid"/>
        <GovernanceArea gov_area_ID="GroupMembership" gov_area_description="Group Membership" implementation="on-chain"/>
        <GovernanceArea gov_area_ID="DAOUpgrades" gov_area_description="DAO Upgrades" implementation="on-chain"/>
        <GovernanceArea gov_area_ID="Attestations" gov_area_description="Attestations" implementation="on-chain"/>
        <GovernanceArea gov_area_ID="TreasuryManagement" gov_area_description="Treasury Management" implementation="on-chain"/>
        <GovernanceArea gov_area_ID="EmergencyResponse" gov_area_description="Emergency Response" implementation="hybrid"/>
        <Permission permission_ID="activate_suspend_service_provision" allowed_action="suspend service provision" permission_type="strategic"/>
        <Permission permission_ID="evaluate_service_provision" allowed_action="evaluate service provision" permission_type="strategic"/>
        <Permission permission_ID="propose_service_provision" allowed_action="propose service provision" permission_type="operational"/>
        <Permission permission_ID="update_user_profile" allowed_action="update user profile" permission_type="structural"/>
        <Permission permission_ID="funding_request_submission" allowed_action="funding request submission" permission_type="operational"/>
        <Permission permission_ID="set_limits_to_group_currency_minting" allowed_action="set limits to group currency minting" permission_type="strategic"/>
```

```xml
      <Permission permission_ID="add_remove_allowed_collateral_type" allowed_action="add/remove allowed collateral type" permission_type="strategic"/>
      <Permission permission_ID="funding_request_assessment" allowed_action="funding request assessment" permission_type="strategic"/>
      <Permission permission_ID="set_membership_requirements" allowed_action="set membership requirements" permission_type="structural"/>
      <Permission permission_ID="suspension_of_the_group_currency" allowed_action="suspension of the Group Currency" permission_type="structural"/>
      <Permission permission_ID="upgrade_Group_Currency_smart_contracts" allowed_action="upgrade Group Currency smart contracts" permission_type="structural"/>
      <Permission permission_ID="upgrade_DAO_smart_contracts" allowed_action="upgrade DAO smart contracts" permission_type="structural"/>
      <Permission permission_ID="include_exclude_group_members" allowed_action="include/exclude members" permission_type="structural"/>
      <Permission permission_ID="set_contribution_attestation" allowed_action="set contribution attestation" permission_type="structural"/>
      <Permission permission_ID="member_data_management" allowed_action="member data management" permission_type="structural"/>
    </DAO>
</DAO-ML_diagram>
```

Listing 2: Circles UBI DAO-ML Model

Acknowledgments

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