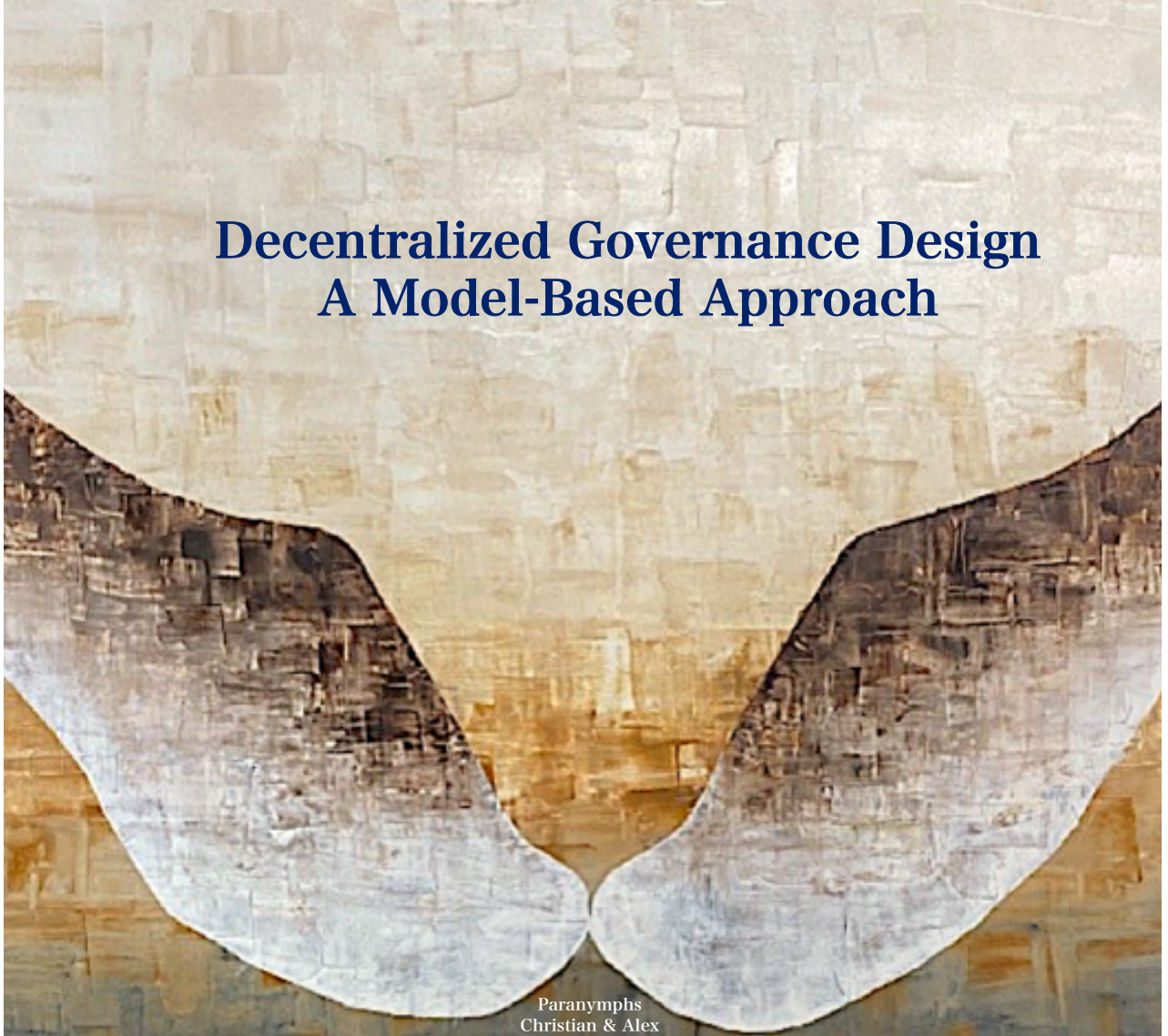
Decentralized Governance Design
A Model-Based Approach



Paranymphs
Christian & Alex
Thank you for holding my hand. It means the world to me, that we fly together.

F. Kaya

Decentralized Governance Design
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Academisch Proefschrift

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Contents

Dedication

The greatest privilege and honor was meeting and teaching Refugee youth. My Ph.D. is dedicated to all refugees in the world, and especially to Shaban Al Dalu, the 19-year-old Computer Science student who was burned alive in a refugee camp.

As It is My Greatest Privilege in Life
That We Walk The Path Together
Hand in Hand
I Honor Your Humanity
I Honor Your Soul
I Honor Your Journey
I Honor Your Beautiful Eyes
I Honor and I Kneel For you
As You Have Given Me Your Trust
I Will Carry you For Always in My Heart

A Refugee is a Human
A Refugee deserves Humanity
A Refugee deserves Respect
A Refugee deserves Dignity
A Refugee deserves Loyalty
We Are Failing Humanity
Climate Change will affect every Human
We cannot lose our Planet and our Humanity
When One Bleeds, we All Bleed

As for I am Arab
As for I am Black
As for I am Asian
As for I am White
As for I am Indian
As for I am Jewish
As for I am Egyptian
As for I am Palestinian
I Am Everything and Nothing all at Once
As My Wish Is To Become An Instrument for Humanity
We have One Human Race, One Planet, and One Consciousness

I AM, FA.

Words of Gratitude

The young mother whispers to her daughter "little freckles, dare to live passionately and be free, just like dandelions." The young mother and little freckles hold the dandelion and gently exhale, as the wind carries the wish of the young mother onward. Along her path, she meets Arch-Mage Young Werther, sitting on his throne and asks her " How do you expect to build, the unforgettable young naive soul? " He holds a dagger in one hand, and a chalice in the other, and says these artifacts represent your quest of humanity and freedom, go forth as you are the universe, explore yourself. She holds the chalice and dagger close to her heart and enters the world of Savants. In her quest she met Wizard Curtains and together with Wizard X her initiation in the unknown took off. Together, the rites and rituals are conceptualized as "DECENT". A vision to design a world that is decentralized and peaceful. Wizard Curtains and Wizard Pianist guide her forward and say wisely, go out and meet other Wizards, as both became the gentle wind under her wings with deep trust in her. The Wizards from Brasil and Spain took her in with curiosity. Enchantress Mojca becomes an anchor in her quest with wisdom. Wizard Curtains and Wizard Meta decide that she should learn true conceptualization. An invitation to the city of dreams follows and Alex teaches her patiently. The generosity of Wizard Meta and Alex knows no boundaries and she admires their academic contribution. Together with Wizard Mathematicians, DECENT is formalized to cross to the other side. Yulu joined and together the DECENT software modeling toolkit is imagined. She meets fellows on the path in becoming wise: Winnie, Nevlynn, Jesse (Wizard LaTeX), Sacheen, XiaoYu, Mona, Amira, Johannes, Fran, Nikos, Angelo, Matthijs, Kine, Isabel, Ahmed, Glenda, Peter, Josef, Toma, Pedro-Paulo, Muhammad, Maja, Gry, Quartz, Henderik, Gianfranco, Raymond, Sjaak, Radu, Lisa, and Sandra, together moments of pure joy are created. Wizards from Belgium host her frequently with great understanding. To conjure worlds, Reinier, Jitze, Michael and Joris join her quest. Enchantress Willemijn & Alchemist Alfons guide her heart towards a deeper knowledge of herself and secrets of the universe are revealed to her. Wizard Medicinae and Wizard Mathematician, listens and offers words of encouragement. Wizard Curtains and Wizard Pianist converse and decide that she has grown, independently. Five Wizards gather and converse if she is ready. Unanimously she is initiated as Wizard Fa. Her talented sister paints DECENT as the wings of an Owl, freedom, to complete the ritual. Off she goes Fa, released as an Owl in spreading her vision carried by the universe as she taps in her own wisdom with love and hope for humanity in her heart. The young mother says continue to dream big, as your journey just started and holds her daughter with unconditional Love, as little freckles says, thank you for your being my dearest mom … mijn allerliefste mamma. Who dares to actually listen ? Who dares to look into the mirror ? Every image, thought, sound, unspoken, spoken word is recorded in the universe. The records will reveal who you are, and what needs to be changed to be in harmony with the universe. Do you have the courage to meet yourself ? Have I not been you ? I was you, I have been you. You are forgiven, we are all forgiven. Brick by brick, I will build the unforgettable, by serving humanity … ***I AM, FA.***

Summary

Over the past decade, we have seen a trend towards centralized digital platforms, which we define as platforms in which the middleman plays a controlling role and typically takes a significant amount of the profit. While the internet is decentralized, Big Tech companies have introduced centralized digital platforms as a means to extract value from society as a business model. Value extraction is a phenomenon that we observe in centralized structures in society. Centralized platforms may have the ambition to control the global market, and in fact want to have a monopoly in that market. Centralized platforms determine the terms & conditions of their platform, which may lead to undesired situations, such as in the case of a content-driven platform where censorship lies in wait.

Decentralized Governance to prevent Value Extraction from Society.
From a societal perspective, decentralization is a response to design digital ecosystems in which (1) value extraction is prevented, (2) transparency is achieved, (3) decision making in terms of defining, monitoring, and executing are governed decentralized. In a decentralized design approach there is more than one party in both the operating ecosystem (producing the actual economic value), as well as in governing the digital ecosystem. We position this as *decentralized governance*, in which the rules of monitoring, decision making and execution are decentralized over multiple parties. If decentralized governance should serve as an alternative for the centralized digital ecosystems, governance should not only be defined in terms of parties, rules, legislation, incentive, and decision-making procedures, but more importantly, should also be supported by technology, to cope with the fast-evolving internet-enabling centralized competitors. Blockchain technology might be a possible solution that may support decentralized governance design. If blockchain technology is used to design a decentralized digital ecosystems, equivalent technology should support the corresponding decentralized governance design.

DECENT Software Modeling Toolkit to Design Decentralized Governance.
We consider blockchain technology as a tool to support decentralized governance, we argue that with respect to decentralized governance, most blockchain technologies are only in their preliminary phase. To become really useful, decentralized digital ecosystems should support on-chain governance that is comprehensible and transparent by design. We consider governance as a topic of design: there is a clear need for software tooling and a modeling language that can contribute in designing decentralized digital ecosystems. Thus, a model- based design is an effective approach to manage and design these complex digital ecosystems. To provide scholars and system designers with an intuitive model-based approach of decentralized governance we propose the DECENT software modeling toolkit. This allows for design, analysis, and evaluation of governance models for digital ecosystems. DECENT has been developed and assessed with industry strength cases in the domain of Peer-to-Peer Energy Trading, Fractional Reserve Banking and Digital Euro.

Samenvatting

In het afgelopen decennium hebben we een ontwikkeling gezien naar gecentraliseerde digitale platformen. We definiëren platformen waarin de tussenpersoon een controlerende rol speelt en meestal een aanzienlijk deel van de winst opstrijkt. Het internet is decentraal, alsnog hebben Big Tech bedrijven centrale digitale platformen geïntroduceerd als een bedrijfsmodel om waarde te onttrekken aan de maatschappij. Waarde-extractie is een fenomeen dat we waarnemen bij gecentraliseerde structuren in de samenleving. Gecentraliseerde platforms hebben de ambitie om de wereldmarkt te controleren en willen in feite een monopolie op die markt hebben. Gecentraliseerde platforms bepalen de voorwaarden van hun platform, wat tot ongewenste situaties kan leiden, zoals in het geval van een content-gedreven platform waar censuur op de loer ligt.

Decentraal Bestuur om Waarde Onttrekking aan de Samenleving te Voorkomen.
Vanuit een maatschappelijk perspectief is decentralisatie een antwoord op het ontwerpen van digitale ecosystemen waarin (1) waarde onttrekking wordt voorkomen, (2) economische transparantie (3) besluitvorming op het gebied van in termen van definiëren, monitoren en uitvoeren decentraal worden bestuurd. In een decentraal ontwerp benadering is er meer dan één partij in zowel het operationele ecosysteem (dat de feitelijke economische waarde produceert), maar ook in het besturen van het digitale ecosysteem. We positioneren dit als decentraal bestuur, waarbij de regels voor monitoring, besluitvorming en uitvoering gedecentraliseerd zijn over meerdere partijen. Als decentraal bestuur kan dienen als een alternatief voor gecentraliseerde digitale ecosystemen, moet bestuur niet alleen worden gedefinieerd in termen van partijen, wettelijke regels, en besluitvormings procedures, maar ook ondersteund worden door technologie. Blockchain technologie zou een mogelijke oplossing kunnen zijn die ontwerp van decentraal bestuur kan ondersteunen.

DECENT Toolkit voor Software Modellering van Decentraal Bestuur.
We beschouwen blockchain technologie als een methode om decentraal bestuur te ondersteunen, echter we stellen dat met betrekking tot decentraal bestuur, blockchain technology zich nog maar in de beginfase bevindt. Om tot een daadwerkelijke toepassing te komen, zouden digitale ecosystemen digitale governance ondersteunen die begrijpelijk en transparant wordt gemaakt door het bijbehorende governance systeem ontwerp. We beschouwen bestuur als een systeem ontwerp: er is een duidelijke behoefte aan software tooling en een modelleertaal die kan bijdragen aan het ontwerpen van decentrale digitale ecosystemen. Om wetenschappers en systeem ontwerpers te voorzien van een intuïtieve model- gebaseerde benadering van decentraal bestuur, positioneren we de DECENT software modeling toolkit. Dit maakt ontwerp, analyse en evaluatie van bestuursmodellen voor digitale ecosystemen mogelijk. DECENT is ontwikkeld en gevalideerd met casussen op het gebied van decentraal energy handel, fractioneel bankieren en de digitale Euro.

1

Introduction

Many companies and even certain governments strive for centrally led systems. At first hand, this might look beneficial, however it can easily result in value extraction, which is not in the interest of society. In addition to fining and giving financial penalties to the well-known centralized digital platforms for taking monopolistic positions, another approach is to encourage and support developing viable and equitable alternatives, organized as decentralized digital ecosystems in which decision power is distributed. Blockchain technology can play an enabling role here, but there is work to do.
First, blockchain systems should provide rich support for decentralized on-chain governance. Second, the expression of governance structures should be closer to the end-users, rather than requiring in-depth knowledge about distributed systems programming.
Third, high-level graphical modeling languages can help here, provided that automated translation of models in these languages to smart contracts is supported. We position and introduce a model-based approach that allows for designing decentralized governance.

1

1.1 Centralized Digital Ecosystem

We have seen the rise of many centralized digital ecosystems in the past decade. Examples include Meta, Amazon, Alphabet, WeChat, Uber, and many more. We position them as centralized digital ecosystems because they are controlled and governed by just one party. Usually, the controlling party takes an intermediate position and plays the role of a trusted party. Often this leads to situations such as exceptional profit, high transaction costs for suppliers, and high switching costs so that the controlling company effectively has a monopoly, easily leading to economic imbalance in society. We refer to this phenomenon as value extraction; parties wringing out an ecosystem, rather than that everyone acting in the digital ecosystem is winning.

Value extraction is not in the interest of society in general and is also not beneficial to many of the parties within the centralized ecosystem. Some countries react to this trend by fining the controlling actor in the ecosystem. We argue that societies should also develop decentralized digital ecosystems, including an equal distribution of decision power over the affected stakeholders in the ecosystem, such that no actor can take a powerful role. Specifically, the governance of ecosystems should be equal and decentralized, following democratic values. We consider blockchain technology as a tool to support decentralized governance but also argue that with respect to decentralized governance, most blockchain technologies are only in their preliminary phase. To be really useful, blockchain systems should ideally support on-chain governance in such a way that it is comprehensible and transparent to all parties involved.

We **define a digital ecosystem as a system of economic actors that depend on each other for their economic survival and well-being, in which economical production is produced using the Internet** [1]. Any company, non-profit organization, or government is part of at least one digital ecosystem. For example, the energy ecosystem consists of generators, distribution and transportation companies, parties providing metering services, and obviously end-users, either companies or households consuming energy. The music ecosystem comprises creative entities such as artists and song writers, producers, radio and television stations, restaurants and bars, intellectual property right societies, and people who listen to music.

Putting into operation a Digital Ecosystem: Platform Structure.
An important part of a digital ecosystem is the platform structure. A platform provides the infrastructure for a digital ecosystem. This is in most cases also the structure in which value extraction can occur. We view the platform as a construct that provides (reusable) products or services to ecosystems. Similarly, a platform may use products or services from other platforms. Take, for example, Android, the operating system for mobile phones. The Android platform provides services by offering an Application Programming Interface (API) to apps such as Facebook, LinkedIn, Google mail, etc. Part of the services of the Android platform is also directly available to the end-user, e.g., the included Chrome web browser. Moreover, the Android platform uses hardware platforms, such as those managed by Samsung, Sony, and many Chinese hardware manufacturers.

Why is Value Extraction a Problem?
Many companies do, or have the ambition, to run a platform and effectively become the middleman between parties. Over the past decade, we have seen a trend towards centralized platforms, which we define as platforms in which a single actor plays a controlling role and, typically, takes a significant amount of the total profit. Most centralized platforms have the ambition to control a global market, and in fact, want to have a monopoly in that market. To achieve this goal, usually exceptional high investments are needed to take most of the market share. Sometimes products or services are offered at cost price or even lower, to attract customers and to destroy the competition. In other cases, suppliers of the platform are encouraged to contribute in return for high fees. After a number of years, when the competition is reduced, customer prices can be increased, and supplier fees may be reduced. Once this happens, the platform owner makes a substantial profit (margins > 30% are not unusual), and often the profit is not proportional to the value created. We call such parties value extractors, indicating that earnings are exceptionally high in relation to the contribution to the ecosystem.

What is the Relation between Value Extraction and Governance?
Value extraction is seen as beneficial for the platform owner, but not for the customer (pays too high of a price) and suppliers (forced to offer their products and services that constitutes losses). It is also doubtful if the monopolistic strategy is beneficial for society as a whole. It may reduce choice for customers significantly, not only in terms of possible sellers but also in terms of alternative products and services available. Due to the international nature of centralized platforms, here is tax avoidance, while the company at hand still benefits from the infrastructure in a country. The centralized platforms also control the terms and conditions of their platform. This may lead to further undesired situations, too, for example, in the case of a content-driven platforms where censorship lies in wait. With respect to digital ecosystems, and thus platforms, we make the distinction between the operation of the ecosystem and its governance. **We define governance of an ecosystem as the set of rules a system has to obey and which are set by another system [1].** This definition needs some clarification. In centralized ecosystems and platforms, there is only one party in the governing role, namely the platform owner. The shareholders govern the platform owner in turn, but this is usually driven by shareholder value, not always in the interest of society, and also a matter of meta-governance. As there is only one governing actor, decision making, e.g., about new rules, is easy. A single enterprise such as Amazon or Google can simply employ hierarchical decision making; in the end, the CEO decides.

Decentralized Governance as a Design Solution to Mitigate Value Extraction.
In a decentralized design there is more than one party in both the operating ecosystem (producing the actual economic value), as well as in the governing digital ecosystem. The latter, digital ecosystem defines rules (and perhaps even legislation) the operating digital ecosystem has to comply with and monitors compliance. Monitoring may lead to revised rules. If needed, incentives in terms of rewards or penalties can be given to stimulate desired behavior. In terms of decision making, a decentralized ecosystem needs to employ some decision model that considers different interests of the participants. There are many of these decision models possible, including voting with many variations (majority vote, delegated vote, rotating vote, etc.).

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Equally important, is the decentralized process that leads to a decision, e.g., orientation on the subject matter, taking a position, perhaps after consulting others. This usually takes the form of a negotiation process. We argue that digital ecosystems require decentralized governance. In other words, if the governance structure is transparent and decentralized, the operating platform will be decentralized and fair for the involved parties as well.

What is Decentralized Governance?
Oxford dictionary defines equitable as: fair and reasonable; treating everyone in an equal way; an equitable distribution of resources[1]. **We define decentralized governance, as the rules of monitoring, deciding and executing are decentralized over multiple parties [1]**. Inspired by [2] and [3] decentralized governance can be achievable if it satisfies a number of the following requirements:

1. All affected participants should be actively involved in the decision process. This is not always easy, most often due to a lack of knowledge, interest, knowledge, or time. Consequently, in many democracies, there are elected parties that represent a large group of stakeholders.
2. All participants should be treated equally, this should be safeguarded by a balanced set of rules.
3. The information needed to make a decision should be freely, timely, and transparently available to parties in a digestible form.
4. The governance process should be timely, meaning that decisions are made.
5. The decision model used should strive for transparency and consensus.
6. All participants should be accountable for their behavior, e.g., meaning that there is a transparent trail of their actions.

Path Towards Decentralized Governance Design.
If decentralized governance should serve as an alternative for the centralized led digital ecosystems, governance should not only be defined in terms of parties, rules (and legislation), incentives, decision-making procedures, etc, but should also be supported by technology, to cope with the fast-evolving internet-enabled centralized Big Tech companies. Blockchain technology is a distributed technology solution that may support a decentralized ecosystem. Many blockchain projects have been developed, but only a few are successful [4]. We claim that the reason for the high failure rate of blockchain projects is that most of them do not remove, or at least reduce, the role of the middlemen [5]. As a distributed technology, blockchain is very expensive, both in terms of design and operation, and hence can only be justified by very large benefits. Also, there might be a shift of benefits from one actor to the other, e.g. by a disruption in the ecosystem. One such disruption can be the reduction or removal of a centralized platform actor, e.g. a transition of eBay to a fully decentralized marketplace [6] where matching and price formation is completely decentralized; hence no single entity can take the powerful position of deciding upon matches and prices.

[1] https://www.oxfordlearnersdictionaries.com/definition/english/equitable

In the above example, the operations of an ecosystem are decentralized to avoid that one actor can dominate the digital ecosystem. However, the rules, e.g. with respect to decentralized matching and price formation, need to be set by someone too, and this is how decentralized governance design can potentially materialize. We consider rule-setting as an important task of the decentralized governance ecosystem. Therefore, we state that if blockchain technology is used to support a decentralized ecosystem, preferably, that same technology should also support the corresponding decentralized governance design.

A Model-Based Design Approach to Conceptualize Decentralized Governance. Although we think that on-chain governance is the way to proceed, the challenge is to develop governance constructs such that every interested stakeholder can participate and thus can understand. Currently, governance of blockchain-enabled ecosystems requires too much (technical) knowledge of the blockchain programming languages at hand. To solve this knowledge asymmetry, we propose DECENT, a model-based approach for decentralized governance design. It provides a series of intuitive concepts to describe various design artifacts of decentralized governance. The ambition is that such semi-formal models can be used to generate smart contracts for on-chain blockchain platforms. By offering graphical conceptual modeling techniques to express governance design and solutions, we anticipate bridging the gap between technology-oriented smart contracts and business requirements.

In the remaining part of this chapter, we position our research, motivate why we take a model-based approach, and explain the research questions. We conceptualize the dissertation structure with a model see Fig. 1.1. We discuss the academic contribution of our work and acknowledge our peers. Finally, we present the publications list and discuss academic dissemination.

1.2 Research Positioning

In our research we position decentralized governance as a design problem as we want to express the relevant governance artifacts in terms of models. As with any design problem, an important question is which artifacts are required to express design decisions, and more importantly how to represent and conceptualize them. In order to facilitate digital asset and ecosystem design in which decision making is decentralized we propose DECENT [7], a model-based approach that allows for designing, describing and analyzing governance models.

From a societal perspective, decentralization is a response to the desire for designing digital ecosystems (1) in which value extraction is prevented, (2) transparency is achieved and, (3) decisions are made, monitored and executed decentralized. In [8] a distinction is made between governance by design and governance by dynamics. The latter is a case of governance which recognizes that governance is not a static construct, but rather emerges and continues to develop as a result of a changing environment. Although important, in our research we consider governance first as a design problem, in the philosophy of Design Science [9] as an artifact to be designed.

1

Why a Model-Based Approach?
In [10] the authors present a systematic literature overview in which 189 papers are discussed on governance design mechanisms, and state that governance design in digital ecosystems is scarcely investigated. Inter alia, the authors conclude that:

1. Currently, there is no governance design and modeling approach.
2. Decentralized governance is led by design decisions.
3. Governance design is elementary for digital ecosystem design.
4. Governance design is identified as a mechanism to create value and to evolve digital ecosystem design.

Conceptualization of governance is an emerging research field [11], and as such a model-based approach that supports the design of governance and ultimately software tool development. We address the aforementioned research directions through a model-based approach to design decentralized governance [7, 12]. Our vision is that a decentralized digital ecosystem can only succeed if the governance design is led by a decentralized structure. We conceptualize and position decentralized governance as a design artifact. We express artifacts in terms of models [13]. A model-based approach allows for a better and shared understanding of the domain at hand and facilitates semi-automated proof of correctness of models and computer-assisted analysis of the domain at hand. We want to understand whether model-based artifacts can assist in designing and understanding governance in decentralized ecosystems. Often, 'governance' is considered *ex-post*, that is when governance is already in place and up for evaluation. In contrast, we study the topic *ex-ante*, as a topic of design, cf. [14].

Research directions for decentralized governance as identified by a SLR [10].

1. Which artifacts affect governance design decisions?
2. Which mechanisms are used to implement and conceptualize governance design decisions?
3. Which role does a party have in governance design?
4. What are the power relation structures in governance design?
5. The research problem at hand is how to design governance in a decentralized ecosystem.

We propose a model-based design approach to conceptualize decentralized governance. Our model-based approach is coined as DECENT, which is an abbreviation for *Decentralization*. We believe this approach will contribute in modeling digital ecosystems that are transparent and decentralized. We study the phenomenon of decentralized governance in the setting real industry-strength cases in the domains of P2P Energy Trading, Fractional Reserve Banking, and Digital Euro. These industry cases are actual societal challenges in the debate how we want to shape decentralization in the world. The research and design challenge is how to design governance structures which are decentralized in the setting of digital ecosystems.

Decentralized Governance Design for Digital Ecosystems.
We take the approach of examining, exploring the design of digital ecosystems in which decentralized governance plays an important design role. To do so, we study real industry strength cases of: Peer-to-Peer energy trading, Fractional Reserve Banking and Digital Euro. These are decentralized digital ecosystems in which governance structures are prevalent. As we stated earlier, our goal is to connect our research to real-world problems and more importantly, to make it understandable for everyone involved in designing decentralization in digital ecosystems.

- **Ch. 3 Peer-to-Peer Energy Trading.**
  The renewable energy domain is subjected to extensive changes in how we store, consume, produce, trade, and distribute energy. Specifically, dependence on certain countries in the world for energy has accelerated the requirement for a decentralized energy network in Europe. How this should be designed and implemented is a relevant governance question. We explore the case of P2P Energy trading, by deriving decentralized governance structures as input to conceptualize the notion of decentralized governance design. Next to that, we execute a systematic literature review to identity the relevant design artifacts for decentralized governance design.

- **Ch. 4 Fractional Reserve Banking.**
  A Decentralized Financial (DeFI) ecosystem in which multiple groups, e.g. commercial banks and governments are allowed to create and destroy money by law, is framed as Fractional Reserve Banking (FRB). With the rise of multiple crypto-currencies that are highly volatile and not backed by realistic long-term assets raises several governance questions. Thus, the question is to observe and represent governance models how FRB actually is executed and under which governance mechanism it functions. This with the goal to gain a deeper understanding in the governance structures of creation and destruction of FRB money. Next to that, explore if we can represent governance models, with the purpose how to transform FRB money towards a digital currency.

- **Ch. 6 The Digital Euro.**
  To remove centralized financial parties in the payment infrastructure of Europe, the European Commission (EC) proposes the Digital Euro, and it will be likely implemented in the euro-currency zone in the year of 2027[2]. Currently the financial payment infrastructure in Europe is dominated by Big Tech companies. Naturally, this raises governance questions and concerns for the financial stability and security of the payment structures in eurozone (EZ) for the foreseeable future. The European commission decided to explore the Digital Euro, with the main goal to reduce the influence and the monopolistic position of Big Tech companies in Europe. Therefore, it is expected that the Digital Euro will create a unified, safe and secure payment landscape in which data privacy is safe-guarded. This is unlike the Big Tech companies that harvest at an exceptional rate financial and personal data.

[2]https://epthinktank.eu/2023/09/18/digital-euro-package-eu-legislation-in-progress/

1

1.3 A Model-Based Research Approach

Our problem statement is how decentralized governance can be structured and designed within a real world environment, and we want to express this in terms of models (see e.g.[13]). A semi-formal specification as a model facilitates for a better and shared understanding of the domain. Ideally this approach supports automated proof of correctness of models and computer-assisted analysis of the domain (e.g. compliance with governance rules set by law), which we have set as a part of our long-term research goal. We present the research approach in Table 1.1.

In [15] it is stated that a lightweight model-based approach is the pathway to developing a design artifact, as this is explainable to end-users and is a consistent design approach. The authors in [15] discuss and propose a model-based design approach, positioned in the field of business modeling, by taking an engineering approach in developing notations with its related models. The design principle stated by [15] is that notations should be developed in such a manner that it should not require more than a few minutes in explanation in order to be understood by everyone involved in designing a digital ecosystem. The authors also state that in principle design notations are sufficient and precise for architects to make conscious design decisions [15]. We draw upon this pathway in following a model-based design approach in conceptualizing decentralized governance.

With a model-based approach we focus on creating transparency in how the rules of engagement are decided, and more importantly that decentralized governance can be designed. We do so as models offer the unique approach in creating and visualizing transparency in how rules of engagement, and decision making is designed. We state that our design approach may reduce dependency on (blockchain) technology companies. We aim to create a symmetry in terms of creating knowledge in how decision making will be designed and executed for the decentralized digital ecosystem at hand.

We state that a model can be understood by every actor. For a decentralized ecosystem to actually work, it is important that every actor has an equal knowledge basis to design and contribute towards the governance processes and we want to achieve that by introducing DECENT, which is supported by software tooling, that allows for designing, analyzing and conceptualizing decentralized governance design for digital ecosystems.

Research Questions.
Decentralized governance is an emerging research field, this entails there is limited knowledge that we can draw upon. As such, creating knowledge requires a practical design approach. As with any design problem, cf. design science [9], an important question is which artifacts are needed to express decentralized governance. A consistent design approach contributes for (automated) analysis too. We want software-support for the design and analysis of governance models and we refer to this field as computational governance. We deconstruct the problem proposition of conceptualizing and designing decentralized governance in formulating the following research questions, see page hereafter, which will be answered in Ch. 8.

- **RQ1: How do approaches for decentralized governance in digital ecosystems compare?**
  Decentralized governance is a relative novel concept with the introduction of blockchain technology. We look at existing and emerging approaches of how decentralized governance is conceptualized in the setting of digital ecosystems.

- **RQ2: What is a well-founded conceptualization of the notion decentralized governance?**
  We state the design requirements for decentralized governance design as part of the specification phase, consequently we elicit the well-accepted knowledge concerning decentralized governance by carrying out a systematic literature study which is the knowledge acquisition phase, followed by conceptualization using semi-informal UML class modeling, presented as the DECENT meta model. We assess the usefulness of the meta model, by using it as a tool to instantiate and structure the governance of the Peer-to-Peer Energy Trading industry case.

- **RQ3: To what extent can decentralized governance be represented by using existing modeling techniques such as *e*^{3}*value* and BPMN?**
  We use the DECENT meta model as a tool to represent governance models by using existing techniques such as *e*^{3}*value* and BPMN. This approach allows us to determine if using existing techniques will lead towards a viable model-based design approach. Next to that, we assess if we can represent governance models by using the real-industry case of Fractional Reserve Banking in collaboration with a leading commercial bank.

- **RQ4: How can decentralized governance be conceptualized by a graphical notation and supported by software tooling?**
  As we experiment with using existing techniques to represent governance models, we are conclusive that it does not fulfill our design requirements for decentralized governance design. Therefore, we develop the DECENT graphical notation with corresponding software tooling to support a model-based approach of decentralized governance design. This is presented as the DECENT Software Modeling Toolkit.

- **RQ5: Is a dedicated graphical notation helpful in designing, structuring and explaining decentralized governance?**
  We developed the DECENT graphical notation which allows for designing decentralized governance models by using the DECENT software modeling toolkit. To validate and assess the usefulness of the notation, we use it to design the governance system of the Digital Euro case, together with our case study partner.

Table 1.1: Research Approach

Research Question	Chapter	Research Approach
RQ1	Ch.2	Literature review and analysis of the notion decentralized governance in decentralized digital ecosystems.
RQ2	Ch.3	Conceptualization of decentralized governance by constructing a meta model, by means of a systematic literature review. Assessment of the meta model by developing the decentralized governance case of Peer-to-Peer Energy Trading.
RQ3	Ch.4	Experimentation with existing modeling techniques to design decentralized governance, this builds upon the single case mechanism experiment [16] by using the case of Fractional Reserve Banking.
RQ4	Ch.5	Creation of the DECENT graphical notation which allows for constructing decentralized governance models, this follows from positioning decentralized governance as a design artifact, which draws upon prototyping as a method [17].
RQ5	Ch.6	Assessment of the usability of the DECENT graphical notation, by developing decentralized governance models for the case of Digital Euro. This follows from a technical action research approach in which an experimental artifact, in our case the graphical notation is assessed with an industry-strength case [18].

1.4 Original Contribution

We list the following original contribution, in Ch. 7 Discussion we critically assess the contributions. We kindly refer the reader to **Academic Contribution** for an overview of how our peer reviewed publications relate to this dissertation.

I. Defining and conceptualizing the notion of decentralized governance in digital ecosystems.

II. Conceptualization of decentralized governance design by presenting the semantics as a light-weight informal UML meta model.

III. Assessment and evaluation if existing modeling techniques [e^3*value* & BPMN] are suitable to represent decentralized governance models.

IV. DECENT graphical notation to design decentralized governance models which is implemented as the DECENT Software Modeling Toolkit to support design of decentralized digital ecosystems.

V. DECENT: A Model-Based Approach to Design Decentralized Governance, which is Developed and Assessed with the digital ecosystem industry cases of P2P Energy Trading, Fractional Reserve Banking and Digital Euro.

1.5 Dissertation Structure

We explain the structure of this dissertation and conceptualize it as a model, see Fig. 1.1.

- **Ch. 2 Decentralized Governance of Digital Ecosystems**
  We discuss and study the notion of decentralized ecosystems, next to that we explain the governance concerns in Bitcoin and Ethereum and introduce the Governance Paradigm model by explaining the abstract notion of decentralized governance.
- **Ch. 3 Conceptualizing Decentralized Governance Design**
  The DECENT meta model is constructed and introduced. We discuss how we constructed the meta model, the design principles and the systematic literature review we executed. We explore the domain of decentralized governance with a real industry strength case about a decentralized ecosystem for renewable energy trading. The meta model is used as a descriptive tool to instantiate the Peer-to-Peer Energy trading case.
- **Ch. 4 Representing Decentralized Governance with Existing Techniques**
  We conduct an experiment if we can use existing modeling techniques such as e^3*value* and BPMN to design, to do so, we use the case of Fractional Reserve Banking, which is a decentralized ecosystem in which money is created and destroyed by banks.
- **Ch. 5 Visualizing & Implementing the DECENT Graphical Notation**
  We present the DECENT graphical notation, the rationale of the notation and mapping with the meta model. We present how the notation can be used to construct governance models. Next to that, we discuss how we developed the rationale of the graphical notation and explain how the DECENT governance models are constructed.
- **Ch. 6 Assessing Decentralized Governance Design: A Model-Based Approach**
  Design of the Digital Euro governance system by taking the DECENT model-based design approach by using the DECENT software modeling toolkit. We develop several decentralized governance models that visualize the decision making structures for the Digital Euro. We do this to assess the usability of the DECENT graphical notation and software tooling.
- **Ch. 7 Discussion**
  We critically assess the contributions and limitations of this dissertation.
- **Ch. 8 Conclusion**
  We conclude the dissertation by answering the research questions and reflect on future work.

Acknowledgement.
Y. Wang and A. Völz should be acknowledged for their contribution towards the DECENT software modeling toolkit. The commercial bank ABN AMRO, the Market Infrastructure Group and J. Dekker contributed in the DeFi domain and we disclose this research is not funded by them. We thank a central bank (their wish is to remain anonymous) for their contribution. Decentralization has a time evolution element, this follows from academic correspondence with the mathematicians P. Johannesson and A. Fiorentino.

1

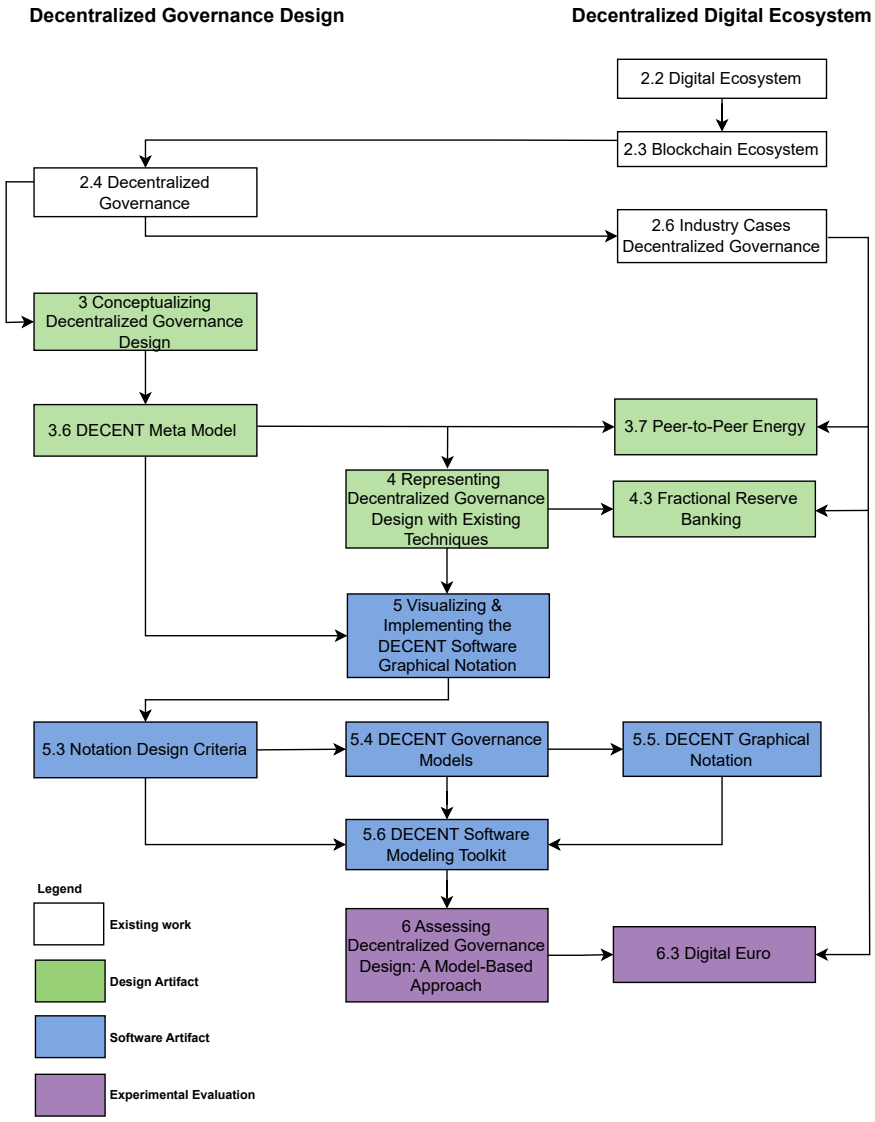


Figure 1.1: Dissertation Structure Model

2

Decentralized Governance of Digital Ecosystems

Decentralization has been a growing trend over the years, with an increasing number of entities moving from centralized ecosystems towards decentralized ecosystems. However, in practice, many digital ecosystems are still effectively governed by one or at most a few parties. For example, Apple governs the ecosystem of iPhones, Google does the same for Android, etc. Decentralized digital ecosystems in general, and blockchain technology in particular are seen by some as the answer to big tech companies that hold substantial centralized power. The question is how to arrive at such a situation without exceptional power concentrations as we currently have. We discuss with concrete examples decentralized ecosystems and analyze the governance protocols of several blockchain ecosystems through a model-based approach. Next to that, we present and discuss the Governance Paradigm model, which gives an abstract notion on decentralized governance structures.

2.1 Introduction

Blockchain technology is an important example of Peer-to-Peer technology that proposes decentralized solutions to avoid centralized components such as brokers and alike. In case of blockchain projects, decentralized solutions boil down to avoiding intermediate parties such as banks, insurance companies, and travel agencies. As such, blockchain is not only a technological debate but also a business- and ecosystem discussion, namely about removal of the middlemen.

In practice, many ecosystems are effectively governed by one or at most a few parties. For example, Apple governs the ecosystem of iPhones, Google does the same for Android, and Cisco is an ecosystem of hard- and software suppliers, consultants, system integrators, and customers, led by, indeed Cisco. Peer-to-Peer ecosystems in general and in particular blockchain technology can be used to build an inclusive, secure, and democratic digital economy in Europe. For example, the infrastructure should be more citizen-centric, privacy-oriented and offer a secure Internet and digital market, by proposing decentralized ecosystem models[1].

In this chapter we will discuss, process and analyze literature with concrete examples of decentralized digital ecosystems as follows.
In Ch. 2.2 we explain the notion of digital ecosystem and how we arrive at the notion of decentralized ecosystem by explaining and illustrating that centralized ecosystems extract value from society.
In Ch. 2.3 we discuss several existing digital ecosystems that utilize blockchain technology. We analyze the governance protocols of Bitcoin and Ethereum. Next to that we discuss the governance concerns in the governance protocols of Bitcoin and Ethereum.
In Ch. 2.4 we explain why centralization is not beneficial for society at large, the notion of value extraction and eliminating the role of the middleman through the promise of blockchain technology. Notion of Decentralized Autonomous Organization (DAO) is briefly discussed.
In Ch. 2.5 the Governance Paradigm Model is discussed and the semantic relevance for decentralized governance design.
In Ch. 2.6 we introduce and present the real industry-strength cases which are used to develop the decentralized governance systems in this dissertation.
In Ch. 2.7 we reflect on this chapter expressed as observations and lessons learned.

2.2 Digital Ecosystem

Every company and individual are part of at least one business ecosystem. **Based on [19] we define an ecosystem as a collection of parties who work cooperatively and competitively to satisfy customer needs.** Well known examples of an ecosystem are Uber, Google, and Facebook. These ecosystems are dominated by only one player. Such ecosystems with a dominant player tend to do value extraction: Companies charge an unreasonably high fees for providing services or goods, which is neither in the interest of, nor sustainable for society.

[1] https://digital-strategy.ec.europa.eu/en/library/european-blockchain-strategy-brochure

To mitigate value extraction, we propose the concept of decentralized ecosystems, which we define as collection of parties who work cooperatively and competitively to satisfy customer needs, and in which decision power is fairly distributed over a (sub)set of parties in the system. Such decentralized ecosystems, specifically in the field of intensive information services, can potentially be realized with Blockchain Technology (BCT) . The most well-known case of BCT is the Bitcoin, in which banks are disrupted by allowing customers and sellers to directly transact with each other, without a bank. BCT enables decentralized business transactions between parties, without a centralized party. Bitcoin has some signs of a decentralized governance process, but the nodes play only a role at the very end of this process, namely by accepting or rejecting the revised Bitcoin Improvement Proposal (BIP), which is merely an operational execution. To enable a truly decentralized digital ecosystem, the key question is: How to govern and design a decentralized digital ecosystem? In a traditional ecosystem, the focal company is governed hierarchically by its board of directors and control led by its shareholders. In peer-to-peer ecosystems, governance evolves to a negotiation game between participants, rather than a hierarchical top-down decision process. **We define governance as a system in which entities set, and decide about, the rules, concerned with structure and processes for decision making, accountability, control and behavior of actors [1]**. Decentralized governance is formed and executed by multiple parties, rather than one powerful actor.

2.3 Blockchain Ecosystem

Decentralized governance handles the question of whether there is a clear understanding in how rules are created between actors/groups collaboratively, and more importantly the behavior with rules and the actors who set them should be answered and designed. To understand the notion of decentralized blockchain ecosystems with respect to the governance aspect, we discuss the generally known blockchain platforms, namely Bitcoin and Ethereum. Bitcoin and Ethereum are both examples of *non- permissioned* ecosystems, and are decentralized, which implies that everyone can join and exit the ecosystem. In such an ecosystem, to be truly decentralized, it would be reasonable to expect that each participant has a role in the governing ecosystem, which is currently not the case. Another class of blockchain systems is the *permissioned* system, which requires an entity (e.g. a committee) that decides which actors may join and leave the ecosystem. Clearly, such a decision process for entering and leaving the ecosystem is strongly related to governance, which again should be decentralized to be compatible with the most important promise of blockchain, namely decentralization.

The definition of governance that we have provided illustrates the concept on a fairly high abstraction level. It is useful to explain what we mean by governance, but is not very convenient in computational terms. The most important impact of blockchain technology is that a trusted third party, for example, a bank, can potentially be eliminated through computational trust. This has consequences for the network at hand, because a powerful actor (e.g. bank) becomes much smaller or even obsolete. Note that even Bitcoin did not succeed in removing the middleman completely, as there are still identifiable parties required to convert Bitcoins to fiat money and vice versa.

Ethereum Improvement Proposal Governance Model.
A criticism regarding the choice to give the miners final decision power regarding governance issues, is that there is a tendency that miners seem to concentrate, e.g. in China a few years ago, and therefore facilitate centralization of decision power. Ethereum is quite similar to Bitcoin in the sense that it is also a permissionless system; however, Ethereum has a more centralized governance system. The lead developer of Ethereum, Vitalik Buterin, has quite some decision power, which was demonstrated by how the DAO disaster was handled by him. The DAO disaster was dealt with by rolling back the Ethereum blockchain to undo the damage caused by the disaster. It led to a hard fork in which Ethereum Classic remained faithful to the idea that code is law, and the forked Ethereum followed the idea that the DAO as implemented was not the intention of its designers. In both branches of the fork, people took responsibility for a decision. Decision-making processes in Bitcoin, and Ethereum are determined by either off-chain or on-chain governance. On-chain governance (formally defined through its code) can reduce deficiencies that were observed in off-chain, and informally specified, governance blockchain systems. This reduction is especially apparent in the formally defined decision-making process, a key characteristic of on-chain governance, which can positively affect equitable governance.

Ethereum Improvement Proposal.
For Ethereum something exists as the Ethereum Improvement Proposal (EIP) [20]. However, the process descriptions are mainly textual, informal, and high level. The actual processes are much more complicated, and not explicitly articulated. For example, many issues are settled as informal discussions on Reddit. In Ethereum not all participants are actively involved in the governance process (e.g. users and miners). Four discussion platforms are utilized to exchange and organize information about proposals. Anyone may participate in submitting EIPs without any limits. The EIP describes the governance rules and framework informally with off-chain governance. The governance mechanism is not always clear or precisely described (e.g. the number of editors responsible per EIP). Even though hard forks are not a part of the EIP governance process, they do occur. These hard forks result in not effectively meeting the participants' needs. The outcome influences efficiency by fragmenting the system in multiple coexisting blockchains. EIP's process offers the required information through multiple discussion platforms.

Off-Chain Informal Governance Discussions.
The platforms can be accessed by anyone wanting to participate. However, the numerous platforms covering different information causes information fragmentation. Other barriers are informality, technical jargon, and not easy to digest information. Only a small group of core developers vote in the EIP governance process to reach a consensus. The identified EIP editors consist of eight persons, which is a relatively small number and can lead to bias. Miners and users have no voting power in the EIP governance process and must accept the consensus reached by the core developers in order to participate.

Governance concerns with respect to Ethereum Improvement Proposal:

1. **Participation:** Not all participants are actively involved in the governance process, e.g. users and miners.
2. **Rule of Law:** The EIP describes the governance rules and framework rather informally which is off chain governance.
3. **Effectiveness:** Hard forks are not a part of the EIP governance process, however it still occurs. The results of hard forks are leading towards a fragmented system with multiple existing blockchains.
4. **Transparency:** The numerous discussion platforms covering different information causes information asymmetry.
5. **Centralization:** Core developers of Ethereum hold significant decision power, miners and users have no voting power in EIP.
6. **Responsiveness:** Only a certain time frame is identified in EIP's process covering only a specific decision and not the whole governance process, which can lead to a weak governance responsiveness.
7. **Consensus oriented:** Only a small group of core developers vote in the EIP governance process to reach a consensus. Miners and users must accept the consensus reached by the core developers.
8. **Accountability:** Accountability for adopting EIPs lies within a small group of core developers, which is a centralized form of decision making power.

Bitcoin Improvement Proposal Governance Model.
In terms of governance, Bitcoin is the world's first blockchain driven open source system, with all the governance problems that typically come with an open source project. The main artifact in terms of governance is the Bitcoin protocol. This protocol determines how participants are added or removed from the network, how consensus amongst participants is reached (this is needed because the administration of Bitcoin transactions is fully decentralised), and how the mining process of Bitcoins works (this is needed to generate Bitcoins, to validate transactions, and to solve the double spending problem). Obviously, the protocol should be resistant to attacks from malicious parties (under certain conditions). Ultimately, the most important parties regarding governance are the Bitcoin miners. These miners run the Bitcoin network by executing software, and they decide whether to run a new version of the Bitcoin protocol by means of upgrading their software. In case sufficient miners decide not to run the newest (or: a competitive version), and the newest version relaxes the protocol, a hard fork occurs, which in worst case results in a new currency. One could consider the occurrence of a hard fork as a failure in the governance process.
It is useful to understand how a new version of the Bitcoin protocol is developed and, more importantly, decided upon. Initially, Bitcoin protocol development and decision power was end-to-end in the hands of Satoshi Nakamoto, this entails that all proposed changes are reviewed only by Satoshi. In 2011, Satoshi left Bitcoin and handed it over to a specific one-lead blockchain developer.

Bitcoin Improvement Proposal.
For Bitcoin, the governance process is partly described by the Bitcoin Improvement Proposal (BIP) process [21]. Through a model-based approach we modeled the BIP in Fig. 2.1, we only display a partition of the BIP model [22]. For the full BIP model please see[2]. In 2011, the Bitcoin Improvement Process (BIP) was introduced. It entails a standardized process to review new submissions to the Bitcoin protocol. Changes to the Bitcoin protocol are seen as a continuous innovative process which are implemented after consensus has been reached. To create the governance model of BIP we used the available information at: https://github.com/bitcoin/bips

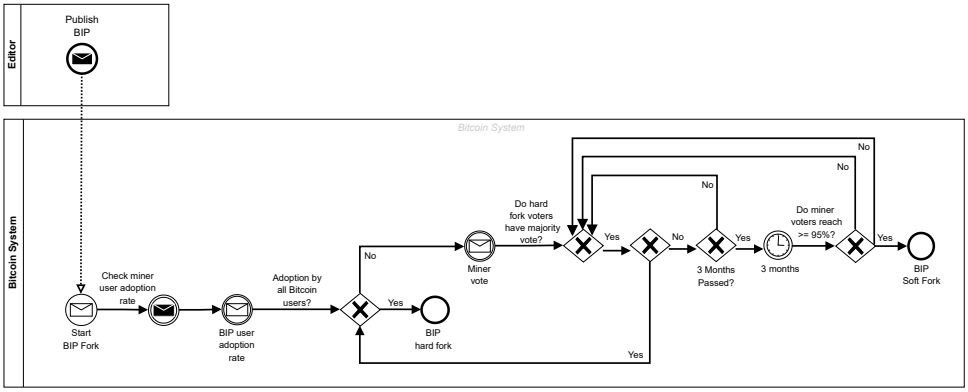


Figure 2.1: Bitcoin Improvement Proposal Model

Next to that, we also harvested more informal information regarding decision processes in Bitcoin at for instance Reddit to create a model-based approach. With the goal to construct the governance model of the BIP and to analyze it. BIP's main objective is everyone can propose changes to the protocol and submit improvements regarding security and stability of the network. A BIP should comply to a predefined format before it is considered further. First, an editor should approve the proposal, and then 95% of the active miners. The role of the editor can be considered as a centralized component in the governance process; they might censor what the miners would see to approve.

Governance concerns with respect to Bitcoin Improvement Proposal.

1. **Participation:** Miners in Bitcoin have the final decision power regarding governance issues, there is a tendency that miners seem to concentrate, this facilitate centralisation of decision power.
2. **Rule of Law:** BIP outlines the governance rules and framework informally with off-chain governance. The governance mechanism is not always clear or precisely described (e.g. status change from final to obsolete).

[2]https://www.dise-lab.nl/wp-content/uploads/2023/12/Bitcoin-BIP-Process_ShivaEtal.pdf

3. **Effectiveness:** The case that hard, soft, and user activated forks occur is evidence that the BIP governance process is not always effective. These forks cause inefficiencies by enabling multiple blockchain's to exist.
4. **Transparency:** BIP's process provides the necessary information through channels such as email and GitHub, which can be freely perceived. However, the barrier exists in being informal, technical, and not clearly presented.
5. **Centralization:** We do not know if Satoshi is a single individual or a group, but it gives the impression that initially, the decision power concerning the BIP is in the hands of a few persons, and quite centrally led.
6. **Responsiveness:** The lack of time-frames for the remaining processes results in poor governance responsiveness, which leads to poor responsiveness and negatively affect participation in BIP.
7. **Consensus oriented:** Every user is able to vote for hard forks and miners for soft forks in the BIP governance process to reach a consensus. The identified BIP editor role consists of only one person, which can entail bias. A miner's voting power depends on the miner's available hashing power. This power centralization can lead to bias consent.
8. **Accountability:** The stakeholders' respective activities represent their responsibilities. Even though a BIP adoption happens in the Bitcoin system which follows its code, it is still voted on by miners and users. Therefore, accountability for the activities taking place in the Bitcoin system lies with the miners and users.

2.4 Decentralized Governance

Blockchain technology is an important example of peer-to-peer technology, which proposes decentralized solutions to avoid centralized components such as brokers and alike. In case of blockchain projects, decentralized solutions boil down to avoiding intermediate parties such as banks, insurance companies and travel agencies. As such, blockchain is not only a technological debate but also a business- and ecosystem discussion, namely about removal of the middlemen. Decentralization has been a growing trend in recent years, with an increasing number of entities moving from centralized towards decentralized systems [23–26]. Decentralization is a concept that emerged and is widely used in the field of public service and economics. To some extent, decentralization had an impact on various public sector competencies, such as levels of investment, public service delivery, education and health indicators, and macroeconomic stability [27]. Decentralization is perceived as a means of promoting individual freedom, greater inclusiveness and a transparent mechanism of decision-making [24].

Centralization leads to Value Extraction.

Decentralized governance as an emerging research topic offers potential solutions to the challenges faced by traditional forms of governance. For example, centralized governance ecosystems often end up with a highly centralized monopoly on the markets in which they are located, which can easily lead to economic unbalance in society and value extraction [22]. Over the past decade, we have seen the rise of many highly centralized ecosystems.

Examples include Facebook, Amazon, Google, WhatsApp, WeChat, Uber, and many more. We call these centralized ecosystems because they are controlled (a.k.a. governed) by companies after which the entire ecosystem is named. The controlling party usually takes an intermediate position and plays the role of a trusted party. Often this leads to situations such as exceptional profit, high transaction costs for suppliers, and high switching costs so that the controlling company effectively has a monopoly, easily leading to economic dis-balance in society. We refer to this phenomenon as *value extraction*; parties wringing out an ecosystem, rather than everyone in the digital ecosystem is winning. Value extraction is not in the interest of societies in general and also not beneficial for many of the parties in the centralized ecosystem. Some countries react to this trend by fining the controlling actor in the ecosystem. In contrast, we argue that societies should develop decentralized ecosystems, including a fair distribution of decision power over the affected stakeholders in the ecosystem, such that no actor can take a too powerful role. Specifically, the governance of ecosystems should also be fair and decentralized. This approach has several potential benefits [28, 29] and we can consider decentralization and the emergence of decentralized governance as a response to the limitations of centralization and the need for a more flexible and adaptable ecosystem.

Notion of the Single Enterprise as an Intermediary.
In many cases, governance is considered from a single actor perspective. Take for example a large bank, in such a case, the bank has governance mechanisms in place to ensure that the operations comply with rules, regulations and laws, and more specifically with the regulatory frameworks for banks. However, the focus is still on the single enterprise in the bank case. In contrast, our work focuses on governance on networks of enterprises end-to-end users which are also called ecosystems. A peer-to-peer driven system is a decentralized ecosystem where one or more intermediate functions are removed. Well known intermediate functions are payment & transaction processing (banks) to facilitate lack of trust between buyer and seller, insurance to facilitate risk sharing, clearing of intellectual property rights, search, etc. Intermediate functions sit between the customer(s) and supplier(s) of goods and services, and in most ecosystems, an intermediate function is performed by a single enterprise. Intermediate parties can become quite powerful, e.g. large banks, Google (intermediate between searchers and suppliers of goods and services), Netflix (intermediate between private persons who want to be entertained and content owners), etc. Intermediate functions are required (for example, often a payment processor is needed) but it is not necessarily the case that it should be performed by single parties; in contrast, they can be performed by peers themselves, or even by the network as such. This is precisely what Bitcoin does; it removes the assignment of the payment processing function to a single bank and instead assigns the function to the nodes in the Bitcoin network.

Blockchain Technology is not the Holy Grail.
Note that even Bitcoin did not succeed to remove the middlemen completely, as identifiable parties are needed to convert bitcoins into fiat money and vice versa. Decentralized digital ecosystems are often enabled by peer-to-peer technology.

Blockchain technology (e.g. as used by Bitcoin) is an example of peer-to-peer technology, but certainly not the only one. For example, Peer-to-Peer technology was and is used to (illegally) share and download music and videos. Whereas we considered the topic of governance in the scope of a single enterprise, this is, however, different for digital ecosystems. First of all, the system to be governed now is the ecosystem, which consists of a number of enterprises. Moreover, it is likely that the governing system is also an ecosystem, perhaps, but not necessarily, with the same parties who participate in the governed ecosystem. Since the governing ecosystem in case of a decentralized digital ecosystems usually consists of multiple independent actors, hierarchical coordination as used in a single enterprise is not an option. Instead, all parties in the ecosystem want to have a say in the governance of the ecosystem at hand. As a result, the governance becomes much more a negotiation process. In the past few years, we have visited a number of blockchain projects, which are supposed to be peer-to-peer ecosystems. In practice however, there often was one dominant player in the ecosystem, namely the company who operated the blockchain. We admit that this is fully against the underlying design philosophy of blockchain technology, but in reality, we see it happen often. It also means that the governance, if thought about it at all, is under control of a single enterprise.

Notion of a Decentralized Autonomous Organization.
Within the domain of decentralized governance, there is the notion of Decentralized Autonomous Organization (DAO) which operates without centralized leadership. A DAO is run through rules encoded as computer programs in the form of smart contracts [30]. A key feature of a DAO is the execution of rules. These rules are executed via smart contracts, which are used as a mechanism to enable participation. A drawback of a DAO is that participants are motivated by incentives to contribute and it is not a self-governing system. DAO is rather technology focused, and not formalized with e.g. conceptual models, and is an ad-hoc driven process [31]. As DAOs are rather technology focused and there is lack of formalization, the governance design is not easily understood by participants [32]. Furthermore, a DAO does not describe the relationships between parties and their roles which can be define, execute, monitor [33]. Governance handles the question who sets and decides the rules of engagement, how is decision making structured and who holds which accountability.

2.5 The Governance Paradigm Model

Decentralized governance is defined and executed by groups and actors, and is as such a paradigm model. We argue that the lack of structured and decentralized governance in digital ecosystems is one of the main reasons why so many blockchain projects fail[3]. Consequently, we consider the design of decentralized governance mechanisms, and the associated software tool support, as crucial for the development of decentralized ecosystems in general, and blockchain systems in particular. We apply the control paradigm of Blumenthal (see e.g. [34] and later [35]) to arrive at the governance paradigm and to explain governance structures.

[3] https://www2.deloitte.com/content/dam/Deloitte/de/Documents/financial-services/Evolution-of-blockchain.pdf

Governance Structures.
Fig. 2.2 shows our governance paradigm model, which has several layers, and as such we distinguish three governance systems:

1. **Meta Governing System:** controlling the governing system (e.g. the government of a country).
2. **Governing System:** monitoring and steering the governed system.
3. **Governed System:** operations of a company that has to obey to rules set by the governing system (e.g. the management of that same company).

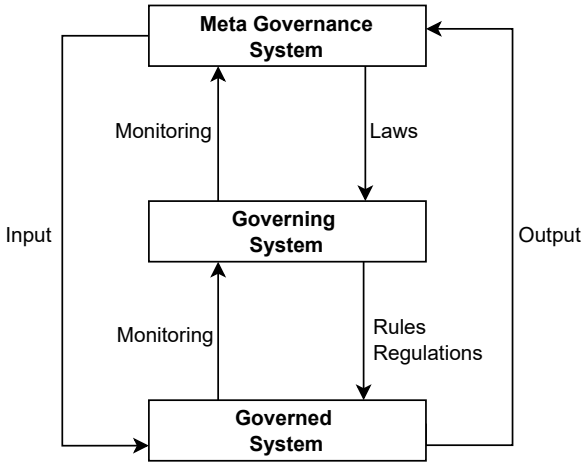


Figure 2.2: The Governance Paradigm Model

Governance Systems.
Essentially, there is a governed system (such as the operations of a company) that has to obey to rules and laws set by the governing system. In most cases, the governing system does not make the rules and laws itself, but only directs the governed system to follow the rules and regulations, as set in the laws by the meta governing system, which can be for instance the government. The rules are normative, e.g., the governed system should comply with these rules. Re-design of rules is based on the monitoring of the governed system, this is executed by the governing system. The governed system performs value-adding operations in which a certain asset is produced. The meta-governance system prescribes the rules for making rules (by the governance system). This implies that the governance system is a governed system at the same time. In our work, **we define a governed system as a decentralized network of enterprises (e.g., a networked value constellation [36] or a digital ecosystem [19]**.

Governed System.
The *governed system* provides monitoring information to the *governing system*, which that system uses to changes rules, and/or to provide monitoring information the environment (e.g. the government and the shareholders of an enterprise). Parties in the environment may use that information to change the rules, regulations and laws. The idea is that by doing these operations, the governed system generates a net positive cash flow. It is very well possible that the governed system and the governing system are part of the same legal entity, e.g. as the workforce of a company (governed system) and its board of directors (governing system). The governed system directly interacts with the environment, e.g. in terms of customers and suppliers. Furthermore, it is important that we understand system as in system's theory: A system consists of entities with relationships. The governed system can be a single person, an enterprise, or even a country. In our work (see also the next section) we consider the governed system as a network of enterprises (also called a networked value constellation or as of today, an ecosystem).

Rules and Regulations.
Regulations and laws are usually set by the government or organizations under control of that government. Rules however are determined by the governing system, e.g. based on the monitoring information, or by internally set (strategic) goals. The scope of the rules is very broad, in fact anything that is needed to control the governed system. It can be about the hire and fire policy of a company, about rules concerning the internal administrative controls, targets in terms of profit, revenues, and costs, roles with corresponding responsibilities of the staff and much more. The Governance Paradigm model is an important instrument we have used, amongst others, to construct the DECENT meta model which will be a topic of discussion in Ch. 3.

2.6 Industry Cases Decentralized Governance

Blockchain technology and its application at a wider large scale is inherently challenging. We believe that blockchain technology can only be successful in the long term if we focus on governance design and at real digital ecosystems. As discussed to abstract our research problem: decentralized governance design, we will focus on real industry-strength cases. Therefore we study the domain of Renewable Energy Transition in the context of Peer-to-Peer Energy Trading Ch. 3, Fractional Reserve Banking in Ch. 4 and Digital Euro in Ch. 6, which are elaborated hereafter.

Peer-to-Peer Energy Trading.
Since the last years, the energy domain is subjected to changes in how we store, consume, produce, exchange, and distribute our energy. This is identified and positioned as the global energy transition. To decrease the reliance and dependency of energy trade with certain countries in the world, have accelerated the need and requirement for a decreased centralized structure in the energy network in Europe. These changes are also rooted in *legislation*, as the global climate agreement states that by 2030, 70% of global energy consumption should come from renewable energy sources. This is often referred as the *'global energy transition'*. In this chapter we give an example of a decentralized energy ecosystem.

Fractional Reserve Banking.
The financial domain is subjected to decentralized governance structures in how money is created, stored, exchanged, consumed and destroyed. Many commercial banks have the possibility to create and destroy money, we refer to this as Fractional Reserve Banking. For example, commercial banks hold saving accounts of customers. Usually, commercial banks try to make more money with the deposited money. This can be done in various ways, for example by investing the money in companies. This comes however with substantial risk. The commercial banks can also use money for loans to their customers (e.g. for mortgages, or credit lines). The commercial bank is then allowed to *multiply* the money that they have, and give out loans for the resulting multiplied amount of money. So, the net effect is that the bank earns interest, without not having most of the money not in their possession.

Digital Euro.
The European Union are concerned with the fact that control of the payment structure in Europe is concentrated at Big Tech companies. Consequently, governments are investigating how to offer a new digital currency to the people, while at the same time having governance mechanism in place that are on par with the traditional money Euro, such as privacy. Concretely, the governance initiative proposes the Digital Euro as an answer to decentralize the European payment infrastructure and break monopolized structures. An important feature of each currency is how money is created and destroyed. In the Bitcoin, this occurs through the process of 'mining'; there is no explicit way to destroy money in the Bitcoin, except by losing the private key that gives access to the user's wallet. Currently, a traditional Euro is created by commercial banks, as the assets of their customers are used to capitalize and to create loans. Another method is to simply print more money, which is the privilege of the European Central Bank and its national counter parts. How to design such a Digital Euro that is on par with the design principles of crypto-currencies is a topic of governance design.

2.7 Reflection

In this chapter we explored the notion of decentralized governance design in existing digital ecosystems such as Bitcoin and Ethereum. Next to that we studied the Governance paradigm model to understand the semantics from a model-based perspective. We structure the reflection of this chapter based on Goal, Subject Area and Intended User Base, expressed as observations and lessons learned.

Goal.
The main goal of this dissertation is to develop a model-based approach by conceptualizing decentralized governance. This should serve as an instrument to model, design, and structure decentralized governance for digital ecosystems.
Sub-Goal.
The sub-goal for this chapter is review and analysis of the notion of decentralized governance in digital ecosystems.

Subject Area. Notion of Decentralized Governance in Bitcoin, Ethereum and DAO.
Observations.
O1.1 Governance structures, in terms of decision making at Bitcoin and Ethereum are to a certain extent still centralized.
O1.2 DAO is rather ad-hoc with emphasis on operational execution of governance rules and is not conceptualized with models.
O1.3 The only artifact in terms of governance is the Bitcoin Improvement Protocol which determines how participants are added or removed from the network, which is not very much related to true decentralization.
Lessons Learned.
L1.1 A drawback of a DAO structure is the off-chain coordination mechanism. Consequently this structure suffers from the inevitable drawbacks like progressive centralization of governance, increased governance costs and reduced governance initiative of participants.
L1.2 The identified governance concerns in Ethereum and Bitcoin rise from a lack of transparency related to which participant has which role, it is informally orchestrated and could benefit from a conceptualized approach.

Modeling. Understanding the notion of decentralized governance through models.
Observations.
O2.1 Decentralization is a societal response in removing the middleman.
O2.2 The Governance Paradigm Model (Fig. 2.2) provides a basic set of semantics for decentralized governance.
O2.3 The Governance Paradigm Model conceptualizes the notion of the environment, e.g. in terms of customers and suppliers, as meta governance.
Lessons Learned.
L2.1 Governing a decentralized digital ecosystem consists of multiple actor/group, and as such, hierarchical coordination is not an option.
L2.2 The Governance Paradigm Model provides a stepping stone as an important instrument in understanding how decentralized governance can be conceptualized.
L2.3 In order to design and conceptualize decentralized governance, we first have to understand which artifacts are of relevance and discuss the definitions.

Next step. Understanding the notion decentralized governance design by analyzing existing digital ecosystems has led to the conclusion we will conceptualize the notion of decentralized governance design by constructing the DECENT meta model. To do so we execute a literature review, to identify the relevant design artifacts. In order to assess the meta model, we use the case of P2P Energy trading in describing and conceptualizing decentralized governance structures. To visualize the P2P energy trading ecosystem, in conjunction with the meta model case instantiation, we will develop an e^3*value* model.

3

Conceptualizing Decentralized Governance Design

The energy domain is a complex ecosystem in which many actors participate. In the European Union (EU), the energy domain is changing significantly as part of the energy transition. An important change is the decentralization of energy, in order to achieve the goal of the EU to become more self-sufficient with respect to energy. An example of decentralization is the bilateral trade of energy between households that generate energy by solar panels and consume energy. A key question is how to design governance structures for such an ecosystem that facilitates decentralized trading. We propose the DECENT meta model, which is a conceptualization of decentralized governance design, which results from an extensive literature study in the field of decentralized governance. We asses the DECENT meta model by using it as a tool to describe governance structures of the industry-strength case of Peer-to-Peer energy trading.

3.1 Introduction

We are interested in how to design governance for decentralized ecosystems and to what extent we can express decentralized governance in model-based artifacts. Concretely, we do so by means of a project about renewable energy that facilitates peer-to-peer energy trading. We have been actively involved in this project in the role of a blockchain consultant and researcher. The project consortium[1] consists of an energy certification body, a research institute, and a blockchain technology platform provider, and works on the energy transition towards renewable energy project that facilitates peer-to-peer energy trading.

To understand the notion of decentralized governance and its relevant design artifacts, we study the OurEnergy case about decentralized energy trading. Next, we execute a systematic literature review in the domain of renewable energy trading to develop a notion of decentralized governance design. This project is coined as OurEnergy, a project that envisions a new energy market that helps to increase the effective utilization of local renewable energy sources through a platform designed for peer-to-peer energy trading. The trading platform, which is built as a blockchain solution, introduces a new market on which energy can be exchanged, for example, amongst the members of a local energy community, and makes use of blockchain technology to provide full transparency and guarantees about the origin of renewable energy.

In this chapter we will conceptualize the decentralized governance design by constructing a meta model. To do so, we take the following steps:
In Ch. 3.2 we present our design approach for conceptualizing the notion of decentralized governance.
In Ch. 3.3 we introduce the real-industry strength case of peer-to-peer energy trading, which is a decentralized digital ecosystem that will be used as input to assess the usefulness of the meta model.
In Ch. 3.4 we introduce and rationalize the design requirements for the meta model.
In Ch. 3.5 we execute a literature review for knowledge acquisition to identify the relevant design artifacts required for the construction of the meta model.
In Ch. 3.6 we conceptualize the meta model, and each design artifact is explained in detail.
In Ch. 3.7 we assess the meta model, we do so by instantiating the case of P2P Energy trading, next to that we develop an e^3*value* model.
In Ch. 3.8 we present our reflections structured as observations and lessons learned.

[1] https://data.rvo.nl/subsidies-regelingen/projecten/ourenergy

3.2 Design Approach

For our design approach in developing a notion of decentralized governance, we take a systematic literature review approach, that we will explain in detail. The relevant research question for this section is:
What is a well-founded conceptualization of the notion decentralized governance design?
In order to have a clear understanding of the relevant design artifacts for decentralized governance we first have to conceptualize the design domain of decentralized governance. To do so, we construct a meta model of the notion of decentralized governance design. **We define governance in decentralized ecosystems as ...“understanding and creating a set of rules that defines engagement between several actors or groups collaboratively” [1].** The definition of governance that we have provided illustrates the concept on a fairly high abstraction level. It is useful to explain to others what we mean by governance, but is not very convenient in computational terms, or as an aid in designing a governance system for a particular ecosystem. Therefore, we propose the DECENT meta model for the notion of decentralized governance, which is solid grounded in literature. DECENT comes from the word *decentralized*, and acts as an abbreviation. To explore decentralized governance and the construction of the meta model we focus on governance in the energy sector. **To construct the meta model, see Fig. 3.1, we formulate the following design process:**

- **Ch. 3.3 Exploration**
  We focus on digital ecosystems with real industry-strength cases to conceptualize decentralized governance, to work with cases that affect society at large, this approach contributes to create a focal point of true decentralization, not only from a technological perspective but also from a societal perspective.
- **Ch. 3.4 Requirement**
  Requirements regarding meta model construction can be expressed in terms of: goal, purpose, subject area, and intended user base.
- **Ch. 3.5 Knowledge Acquisition**
  Following our requirements, we execute a systematic literature search on the concept of decentralized governance in ecosystems, as defined by our *purpose* requirement. We do so by eliciting well-accepted knowledge concerning decentralized governance by carrying out a systematic literature study.
- **Ch. 3.6 Conceptualization Meta Model**
  We conceptualize the meta model based on the knowledge and specification phase. We consider the meta model as a semi-formal, explicit specification of a conceptualization of a domain, namely decentralized governance in ecosystems (see e.g. [37–39]). The idea of explicit specification goes via a semi-formal specification, in our case a UML class diagram.
- **Ch. 3.7 Assessment: Peer-to-Peer Energy Trading**
  We argue that in order to develop decentralized governance, we have to understand the to-be developed domain and the related relations within a real-world setting. Therefore, we are motivated to explore and assess usability of the meta model as a tool to instantiate decentralized governance with the industry-strength case of Peer-to-Peer Energy Trading.

3.3 Exploration

We use the real-industry strength case of peer-to-peer energy trading because we want to explore and understand decentralized governance in digital ecosystems. To do so, we first give a project description of the case.

Peer-to-Peer Energy Trading Case Introduction.

An important part of the energy transition is that private households contribute to renewable energy generation, often by employing Photo-Voltaic (PV) cells on their roof. To give a clear example in how the energy sector is transitioning we look at the energy network in the Netherlands. The current regulation is beneficial to households, as they are allowed to subtract the generated energy by their PV cells from the energy they consumed *on a yearly basis*. This *regulation* is called 'the netting agreement', and ensures that households receive the same amount of money for the energy generated as they have to pay for energy consumed, provided that the total amount of energy generated is equal or smaller than the total amount of energy consumed. The caveat is in the fact that during summer households generate more energy than they can consume, and during winter they consume more than they produce. The netting agreement ignores this timing effect and assumes that the surplus of energy generated during the summer can be 'stored' somehow for consumption during the winter. Storing electrical energy is very expensive and not efficient. Therefore, during summer, large scale generators are switched off (so that the surplus of PV cell energy can be consumed) and during winter the same generators are switched on again (so that shortage of PV cell energy can be compensated for). Switching off large scale generators is costly, because when switched off, these generators do not produce an income. As the netting agreement does not have a fee for switching off these generators, large energy suppliers are complaining that they pay the bill for the 'netting agreement'.

Discontinuation of the Energy Netting Agreement to Achieve Decentralization.

Consequently, the Dutch government plans to discontinue the netting agreement, and instead installs a regulation that allows for different tariffs for electricity consumption and production, and moreover do not allow netting anymore; e.g. a fee is paid for generated energy and charged for consumed energy directly, without yearly netting. Obviously, the selling price for generated energy by larger suppliers is (much higher) than the price these same suppliers pay to buy household-PV cell generated electricity. Due to other upcoming *regulation*, it will be possible for prosuming households to *sell* electricity directly, e.g. with other households, for a substantial *higher* price (e.g 0.10 Euro/KWh) than households would receive from traditional large suppliers (e.g. 0.06 Euro/KWh) Hence the ecosystem is beneficial for both the prosumers ("produce" and "consume" energy) and consumers, the latter is also the role executed-by the consumer. This will allow and enable for a decentralized energy network in which energy storage, production, consumption, and trade can be organized decentralized.

3.4 Requirement

Requirements regarding the decentralized governance design to construct the meta model can be expressed in terms of: goal, purpose, subject area, and intended user base.

1. **Goal.**
   Our goal is to develop a model-based approach by conceptualizing the domain of decentralized governance in digital ecosystems (see e.g. [37–39]). To do so we design a tractable, lightweight informal meta model with a minimum number of concepts. We consider the meta model as a semi-formal, explicit specification of a shared conceptualization of a domain, namely decentralized governance in ecosystems (see e.g. [37–39]). The idea of explicit specification goes via a semi-formal specification, in our case a UML class diagram. More formal approaches such as the Unified Foundational Ontology (UFO) [40] can also be used, but for our purpose, UML class diagrams are sufficient. We use a more tractable form of the UML class diagram notation, consisting of classes, properties, associations, generalizations (is-a), and cardinality constraints.

2. **Purpose.**
   The meta model should serve as an instrument to guide and express governance decisions regarding an ecosystem. In a later stage of the research, it should also provide the foundation for *computational* decentralized governance; which e.g. can be used as on-chain governance of blockchain platforms such as Tezos [22, 41]. The meta model can be best characterized as a *reference* meta model, which is an meta model designed to describe a certain domain [42, 43], in our case decentralized governance.

3. **Subject Area.**
   The meta model is about decentralized governance. We have defined governance as "the set of rules a system has to obey, and which are set by another system" [1]. As governance is a very broad topic, we narrow the subject area down to (1) *decentralized governance* in (2) *ecosystems*. An ecosystem is "a collection of companies that work cooperatively and competitively to satisfy customer needs" [19]. The notion of "decentralized" implies that governance is exercised by more than one party, e.g. a subset of the parties in the ecosystem under consideration, and often results in a multi-party process (e.g. voting) to take governance decisions. This leads to our definition of decentralized ecosystem governance: set of rules an ecosystem has to obey, and which are set by (a subset of) parties in that ecosystem.

4. **Intended User Base.**
   We concentrate on the first purpose of the meta model, namely representing governance decisions by stakeholders who have to design governance for a particular ecosystem. These stakeholders can be persons representing the parties in the ecosystem and their consultants. We assume however knowledge about conceptualization (e.g. obtained by a suitable training). The second purpose, supporting decentralized computational governance, has as its 'users' blockchain platforms that can use the meta model as a basis for computational support.

3.5 Knowledge Acquisition

Following the requirements and to ensure a commitment, regarding a shared understanding, we execute a systematic literature search on the concept of decentralized governance in ecosystems, as defined by our *purpose* requirement. We do so by eliciting well-accepted knowledge concerning decentralized governance by carrying out a systematic literature study. To understand governance and its layers, we revise the generic control paradigm of Blumenthal [35] to arrive at a more specific governance paradigm (see Fig. 2.2). In earlier work [5] we developed this governance paradigm to distinguish the various levels of abstraction where governance can occur. We first distinguish and define three governance systems following the governance paradigm [35]:

1. Governed system (operations of a company) that has to obey to rules set by the governing system (e.g. the management of that same company).
2. Governing system that monitors and steers the governed system.
3. Meta governing system that controls the governing system (e.g. the government of a country).

Since decentralized governance is a broad construct to understand, we have deliberately chosen to focus on governance within a specific domain, namely renewable energy ecosystems. We admit that this affects external validity of the meta-model (e.g. usability of the meta-model in other domains), but it is a required step to arrive at a meaningful meta model, and in subsequent research, we extend it to other domains. Also, the energy domain is currently one of the most advanced fields in terms of decentralization and governance structures. We use to the general notion of governance by following the governance paradigm [35], as a method to classify the governance concepts in the literature review.

Systematic Literature Review Process.

1. For the systematic literature review, we use the following topic descriptors: “Renewable Energy Governance”, “Meta-Governance Ecosystem”, “Governance Ecosystem”, “Governed Eco-system”, “Governance Definition”, “Decentralized Energy Ecosystem,” “Peer-to-Peer Energy Trading”.
2. We analyzed over 150 peer reviewed papers and over 80 papers were selected based on specific topics they discuss. We only include papers, that discuss (1) governance (due to the topic of interest), and (2) the energy domain (to restrict the scope since the notion of governance is overwhelming).
3. Then, the selected papers, are summarized based on the abstract, keywords, definitions of governance and decentralization (and motivation), and governance-related concepts distinguished.
4. Subsequently, we classify governance concepts in the papers using the *governance paradigm*: (being) *governed* system, the (exercising) *governance* system, and the *meta-governance* system (governing the system).

5. Following the governance paradigm, we observe that the same terminology in governance-related papers re-occurs at these different abstraction levels; hence we use the three abstractions to reduce and unify terminology found in the publications. All these systems provide monitoring data (e.g. about being compliant) to the hierarchical higher system (doing the governance), which in turn provides rules to lower (governed) system. We have found that the same terminology in governance-related papers re-occurs at these different abstraction levels; hence we use the three abstractions to reduce and unify terminology found in the publications. This results in a shortlist of governance concepts.
6. As our *goal* is to design a tractable, lightweight meta model with a minimum number of concepts, we reduce the shortlist even further by focusing on nouns only (or concepts that can easily be formulated as nouns), and by clustering closely related concepts. To understand the relations between the concepts a cross reference analysis between the concepts is performed. By doing so, we are able to minimize the number of meta model concepts significantly.
7. As a final step, the DECENT meta model is created (using informal UML), see Fig. 3.1.

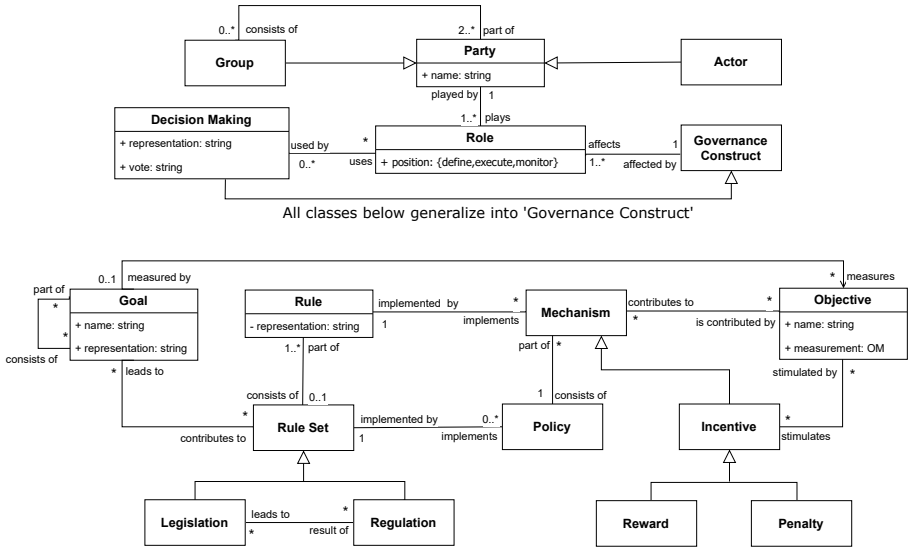


Figure 3.1: DECENT Meta Model

3.6 Conceptualization: The DECENT Meta Model

We now arrive at the *conceptualization phase*, by constructing the meta model by explaining each concept by giving the definition, properties, relations and illustrate the concept with an example of the peer-to-peer trading case. We consider the meta model as a semi-formal, explicit specification of a shared conceptualization of a domain, namely decentralized governance in ecosystems (see e.g. [37–39]). The idea of explicit specification goes via a semi-formal specification, in our case an UML class diagram. More formal approaches such as the Unified Foundational Ontology (UFO) [40] can also be used, but for our purpose, UML class diagrams are sufficient. We use a more tractable form of the UML class diagram notation, consisting of classes, properties, associations, generalizations (is-a), and cardinality constraints. The level of conceptualization of the meta model should correspond to our *purpose* requirement (assisting governance decisions in ecosystems), as well as to the *intended user base*: stakeholders of the parties in ecosystems as well as their consultants.

In contrast to the many machine processable models, the meta model has a limited number of concepts and relations, such that it can easily be explained to practitioners. A minimized meta model, cf. Occam's razor, is an important *feature* of the meta model. We discuss the meta model here below (see also Fig. 3.1), to make it explainable we give an example of each meta model concept of the Peer-to-Peer energy trading case.

Party.

Definition: A party is any entity that can play a *role* regarding a *governance construct*.

Explanation: A party is the abstraction of an *actor* or a *group*. Both can play several *role*s as one unit of control regarding *decision making* in relation to a governance construct.

Properties: A party has a *name* that uniquely identifies the party. This can be a company name, the name of a private person, but can also refer to a particular aggregation such as group, e.g. government.

Relations: A party *plays* one or more governance *role*s. A party is *part-of* a *group* or an actor.

Example: See *actor* and *group*.

References: [44]

Governance construct.

Definition: All meta model concepts, except *party*, *group*, *actor* and *role* are abstractions and generalized into the notion of *governance construct*. Governance construct modify group, party, actor, their associated roles and the decision making.

Explanation: The abstraction *governance constructs* is needed because a *party*, via its *role* can be related, in different ways, to each of the various governance constructs.

Relations: A governance construct is the generalization of *rule*, *rule set*, *mechanism*, *policy*, *goal*, *objective*, and *incentive*. To avoid cluttering of the diagram, these generalization relations are not presented graphically, and because of the nature of the meta model which represents decentralization.

References: [45]

Role.

Definition: A role is the position that a *party* has towards a governance construct.

Explanation: Sowa [46] defines roles as relations to individuals (called 'actors' by us). According to [47], roles depend on relationships. We focus on the notion of the *position* of the party in relation to the governance construct.

Properties: A role has a *position*, which is a selection of *set* (e.g. determine a rule), *execute* (e.g. be compliant to a rule), and *monitor* (collect information to check compliance to a rule).

Relations: A role is *played-by* a *party*. A *governance construct* is *affected-by* one or more roles. A role *uses decision making* to reach agreement. The choice for a particular decision making method depends on the role a particular *party* has in relation to the *governance construct* at hand.

Example: The EU *set*s the objective of CO_2 emission reduction with x Mton/year, The Netherlands executes (being compliant with) CO_2 emission reduction with y Mton/year, the EU *monitors* compliance of The Netherlands with the set CO_2 emission reduction goal.

References: [46, 47]

Actor.

Definition: An actor is an entity that is responsible for its survival and well-being.

Explanation: The actor is perceived by itself and its environment as independent. This definition is imported from the e3value ontology [48] and focuses on the capacity of the actor to take its own legal and economic decisions. We argue this capacity is the basis underlying any governance activity. A taxonomy of actors may be useful, e.g. the government, companies, branch organizations, non-for-profit organizations, persons, in general actors who determine the kind of governance, actors who have to comply to the stated governance, and actors who monitor compliance with governance (see the *role* concept below).

Properties: n.a.

Relations: An actor *is-a party*.

Example: The Netherlands (government), The EU (meta-government), PV cell owner (household).

References: [48]

Group.

Definition: A group is a collection of *parties* that share one or more characteristics.

Explanation: Sometimes, a group rather than a single *party* plays a governance *role*. Examples include a branch organization, or even a society. Grouping can be based on characteristics, e.g. the same *goal*.

Properties: n.a.

Relations: A group *is-a party*. A group *plays* one or more governance *role*s. A group *consists-of* one or more *parties*.

Example: The EU citizens.

References: [48]

Decision making.

Definition: Decision making refers to a collection of different methods used by a *party* to take a decision, or to reach agreement in case of a *group*.

Explanation: In decentralized governance, understanding the path how decisions are made is important. In case of a single *actor*, decision making can be rationalized using a set of prioritized criteria, in case of a *group*, the *actors* in the group should come to an agreement regarding a particular topic. This can be done in various ways, e.g. hierarchical (one *actor* is appointed as the decision maker), various ways of voting (delegation, referendum), etc. Note: since 'decision making' *is-a governance construct*, a *party* can have a particular *role* in relation to the particular decision making instance. If for example the *role* is 'set', this states that the *party* decides about the decision making method to be used, but not necessarily that the actor *makes* the decision.

Properties: Decision making has a *representation*, e.g. by using an ontology on decision making, such as [49–51].

Relations: Decision making is *used-by* a *role*.

Example: Decision making, voting, and delegated voting are decision-making examples, and voting is an attribute of decision making.

References: [49–54]

Rule.

Definition: A rule is a proceeding that is required, permitted or prohibited.

Explanation: Holistic view of rules execution that is required to achieve a desired outcome.

Properties: A rule has a *representation*, formal or informal that captures the rule. Rules can be expressed by means of existing techniques such as LegalRuleML [55], or more recently, Symboleo [56].

Relations: A rule can be *part-of* (multiple) *ruleset*(s). Rules can be *implemented-by* means of *mechanisms*.

Example: Maximum kWh that can be traded per day in order to prevent overload of the energy infrastructure.

References: [57–65]

Rule Set.

Definition: A rule set is a coherent set of *rule*s.

*Explanation: Goal*s and *Policy* have a cohesive, related, set of rules that contribute to satisfying the goal and/or have an implementation in terms of a policy. Usually, a number of related rules are needed to reach a goal.

Properties: n.a.

Relations: A rule set *contributes-to* satisfying a *goal*. A rule set is *implemented-by* a *policy*.

Example: See legislation and regulation.

References: n.a.

Legislation.

Definition: Legislation is-a *rule set* and set (*role*) by a government.

Explanation: Legislation (a.k.a. as the law) has a formal character. Note that here are a few *roles* relevant; the government *set*s legislation and compliance to regulation is *monitored* by the government too. Actors in a society have to comply (*execute*) with the legislation. In terms of *meta-governance*, in a democracy individuals *monitor* the government, e.g. in terms of reaching *set objective*s.

Properties: n.a.

Relations: Legislation *leads-to regulation*.

Example: Laws that determine which renewable energy sources can be utilized.

References: [58, 66–69]

Regulation.

Definition: Regulation is-a *rule set* and can be set (*role*) by any (group of) actor(s).

Explanation: Regulation is similar to *legislation* but where the government has the monopoly to set legislation, regulation can be set by one. As such, it has not a formal legal character in the sense of laws. Regulation can be set by a society of actors, a branch organization, or even can be self-imposed by one or more actors ('self-regulation').

Properties: n.a.

Relations: Regulation can be the *result-of* (often a further detailing) *regulation* but this is not required.

Example: Regulation that allows and enables peer-to-peer energy trading.

References: [61, 64, 66, 70]

Goal.

Definition: A goal is desire to fulfill, for which a *party* has committed resources for.

Explanation: The idea that a party has to commit resources in order to achieve a goal is important; there is no free ride. Goals can be set by a single actor, by a group (e.g. a community), or even a society (e.g. the Sustainable Development Goals (SDGs) of the United Nations.

Properties: A goal *name* that uniquely identifies the goal, and a *representation*.

Relations: Goals can be part of a goal hierarchy using the *consists-of* relationship. Goals lower in the hierarchy (partly) contribute to satisfaction of the goal higher in the hierarchy. Goals may have constraints (not represented in the meta model), indicating that multiple goals must be satisfied (AND), a selection of goals must be satisfied (OR), or are exclusive (XOR), see [71] for an example). Satisfaction of a goal is *realized-by* one or more *objective*s.

Example: Achieve reduced CO_2 emissions.

References: [9, 62, 66, 72, 73, 73]

Objective.

Definition: Objectives measures satisfaction of a goal.

Explanation: Goals are stated qualitatively (CO_2 reduction), objectives allow to measure achievement of the goal (100 Mton CO_2 reduction in 2030). In some cases, multiple objectives need to be achieved for goal satisfaction. We do not include an ontology to represents the actual *measure*, but instead rely on existing ontologies, e.g. the ontology units of measure (OM) [74], or [75] for a survey.

Properties: A goal *name* that uniquely identifies the objective, and a representation of the *measurement* of the objective, e.g. using OM.

Relations: An objective(s) *realizes* a *goal*. Reaching an objective can be *stimulated-by incentive*.

Example: Enhancing the energy efficiency of 1,5 million homes and a reduction of 1 Megaton CO_2 for utility buildings.

References: [62, 73, 76–78]

Policy.

Definition: A policy is a plan for action, consisting of coherent set of *mechanisms*, to implement a particular *rule set*, being either a *legislation* or a *regulation*.

Explanation: To achieve a *goal* through a (complex) set of *rule*s, often a set of *mechanism*s are needed, that potentially reinforce each other to comply to the *rule set* and ultimately *goal* satisfaction.

Properties: A policy has a *name* that uniquely identifies the policy.

Relations: A policy *implements* a *rule set*. A policy *consists-of mechanism*s, which applied in combination, comply to the rule set.

Example: Collective set and describes how to reduce CO_2 emissions *goal* and which actions are required.

References: [58, 70, 76, 79–82]

Mechanism.

Definition: A mechanism contributes to (partial) satisfaction of a *goal* (via its associated *rule*, part of a *rule set* in terms of reaching an *objective*.

Explanation: Typically, a mechanism is process-oriented. Hence, process modelling techniques such as the Business Process Modelling Notation (BPMN) [83] can be used to represent a mechanism. Note that BPMN has also a notion of *actor* by means of resource pools.

Properties: A mechanism has a *name* that uniquely identifies the mechanism. A mechanism has a *representation*, e.g. a BMPN model

Relations: A mechanism *implements* a *rule*. A mechanism is *part-of* a *policy*. A mechanism *contributes-to* reaching an *objective*. A mechanism is the generalization of *incentive*.

Example: Clean development *mechanism* to reduce emissions by buying greenhouse gas reduction units from mainly developing countries.

References: [63, 84, 85]

Incentive.

Definition: An incentive is a stimulation to achieve *objectives* and indirectly adhere to *rule*s.

Explanation: Actors can be motivated to strive for reaching an *objective* and hence *goal* satisfaction. This motivation can be impacted positively by a *reward* or negatively by a *penalty*.

Properties: An incentive has an *expression* stating the reward of penalty.

Relations: An incentive is a *mechanism*, and as such can *implement* a *rule*. An incentive is the generalization of *penalty* and *reward*. An incentive *stimulates* to reach an *objective*.

Example: See reward and penalty.

References: [59, 66, 70, 77, 77, 84, 86–91]

Reward.

Definition: A reward is a motivation to achieve *objectives* and indirectly adhere to *rule*s.

Explanation: A reward is an example of the carrot and stick; desired behavior results in a reward.

Properties: n.a.

Relations: A reward *is-a incentive*.

Example: Energy tax system with incentives for energy efficiency and CO_2 reduction.

References: [66, 70, 77, 86–89]

Concept: **Penalty.**

Definition: A penalty is a punishment if *objectives* are not met and *rule*s are not adhered to.

Explanation: A penalty is an example of the carrot and stick; unwanted behavior results in a penalty.

Properties: n.a.

Relations: A penalty *is-a incentive*.

Example: EU members who fail to meet their targets face a penalty in the form of a periodic penalty payments.

References: [59, 77, 84, 89–91]

3.7 Assessment Peer-to-Peer Energy Trading

Following our meta model design process, we have arrived at the *assessment phase*. We do so by using the case of peer-to-peer energy trading that we have been involved with. In the case of renewable energy which will be discussed, the stakeholders in this project are struggling to understand the notion of decentralized governance. For the meta model we foresee the use as a *tool* for vocabulary to express decentralized governance decisions regarding digital ecosystem design.

3.7.1 DECENT Instantiation

What follows now is that we use the meta model as a tool to instantiate the governance structures of the P2P energy trading case, and to test it on descriptive validity. We do so by demonstrating and describing the governance structures of the peer-to-peer energy case by using the DECENT concepts and their relations as conceptualized in the meta model, see Fig. 3.1. The *italic* words in the text refer to the meta model concepts. Next to that we also conceptualized the case as an e^3*value* model, see Fig. 3.2.

Climate Legislation.
The European Union (EU) (an instance of *group*), who *plays* a *defining role*, *affects* the *goal* in becoming the first climate-resilient and neutral society by 2050. Satisfaction of this *goal*, is *realized-by* the *objective* to reduce the carbon emissions with 50% in 2030 (*measure*), and to be climate neutral in 2050 (*measure*). The arrangement that should accomplish the *goal* is the 'Green Deal', which *leads-to legislation* referred to as the EU climate law. This *legislation consists-of* a series of *rules*. One example of a *rule* is that "Union-wide emissions and removals of greenhouse gases regulated in Union *law* shall be balanced at its latest by 2050, thus reducing emissions to net zero by that date" [92]. The formulation of the *rule* comes very close to the formulation of the stated *objective*. The climate *legislation* is *implemented-by* various *policies*, e.g. the "creation of markets for climate-neutral, circular economy products" [93]. The *policy consists-of* several *mechanisms* including "supporting cost competitiveness of climate neutral and circular economy solutions", "public procurement and standards supporting market creation", and "empowering customers and consumers" [93]. The EU climate *law* also comes with various *penalties*: for example car manufacturers have to comply with a specific emission target *objective*, which is *stimulated-by* a *penalty* of "95 Euro per g/km of target exceedance" [94]. This *penalty* also *is-a mechanism* and hence partly *implements* a *rule*. The member states *groups* of the EU have implemented the Green Deal, first by ratifying the EU climate agreement in national laws. Representation in terms of the meta model follows the schema of the EU, with specific local arrangements.

Energy Transition.
An important *goal* of this energy transition, is the use of renewable energy. For the peer-to-peer trade of energy there is a *group consisting-of actors*, both prosumers and consumers, who together form the *group* Cooperation. This *group* plays a *defining* and *monitoring role* in terms of (self)*regulation*, *rules*, etc. The *group uses* a *decision making* procedure, e.g. based on voting.

Consequently, the *group* Cooperation should not be considered as a centralized party, but as a cooperation of *actors part-of* a *group*. The *goal* setting of CO_2 emission reduction as *defined-by* the EU, reaches through national *legislation* prosumers and consumers. Prosumers have *executing role*s, namely "produce" and "consume", the latter is also the *role executed-by* the consumer. Prosumers are *groups* because there are many of them (e.g. households). Prosumers own PV cells and likely batteries (e.g., in their electric cars) to store electricity temporally. A *group* is a set of homogeneous actors that share the same characteristics. *Actors* are also economically independent such as the *actor* Electricity Trader. The Cooperation, which is a *group* aggregates electricity power from Prosumers and can, therefore, negotiate through *incentives*, a better deal with the Trader. In the same way, the Trader delivers electricity against favorable conditions, *incentives* to Prosumers via the Cooperation if there is not enough electricity generated by the Prosumers themselves.

Peer-to-Peer Energy.
As can be seen from the mode, see Fig. 3.2, the Prosumer uses first energy ('consume' value activity) from its own PC cells and/or batteries. Similarly, if the Trader generates more electricity than it requires, as a *rule* it first stores the energy in a battery component. If there is still a surplus of electricity, as part of the *policy* the Prosumer sells electricity to other Prosumers: the peers. The same happens if a Prosumer consumes more than it can obtain from its PC cells or batteries; then, it first obtains electricity from other Prosumers. To be *incentivized* to all parties, the peer-to-peer electricity price should be higher than the price the Trader would pay while buying (so more than 0.06 Euro/KWh) but lower than the price the Trader charge while selling (so lower than 0.20 Euro/KWh). This gives sufficient *incentives* for price negotiations between Prosumers (peers), as this represents the peer-to-peer trading.

Blockchain Platform.
Furthermore, the Cooperation provides a service to the Prosumers, namely an IT-enabled blockchain energy trading platform, which is a *mechanism*. Part of the *mechanism* is (dis)aggregation of electricity to the trader, to sell a surplus of electricity of the Prosumers, or to buy electricity for the Prosumers in case the Prosumer do no have sufficient electricity himself. This way, the Cooperation *goal* ensures that at all time the supply and demand of electricity are in balance, which is an *objective* for the electricity grid and proper execution of the *rule-set*.

3.7.2 Governance Model using e^{3}value

Following the DECENT instantiation of P2P energy trading, we give a high-level overview of the peer-to-peer energy trading case, for which we also have developed an *e^{3}value* model for, to explore if it is useful to visualize the peer-to-peer energy trading part. The question is whether an *e^{3}value* model can represents governance decisions adequately. In [95] a number of governance mechanisms have been identified based on a systematic literature review of 63 studies on governance for digital ecosystems. The study of [95] focuses on digital ecosystems with one dominant actor, which differs from a decentralized ecosystem. However, we consider the study as a useful starting point because most of these mechanisms are also applicable to decentralized ecosystems.

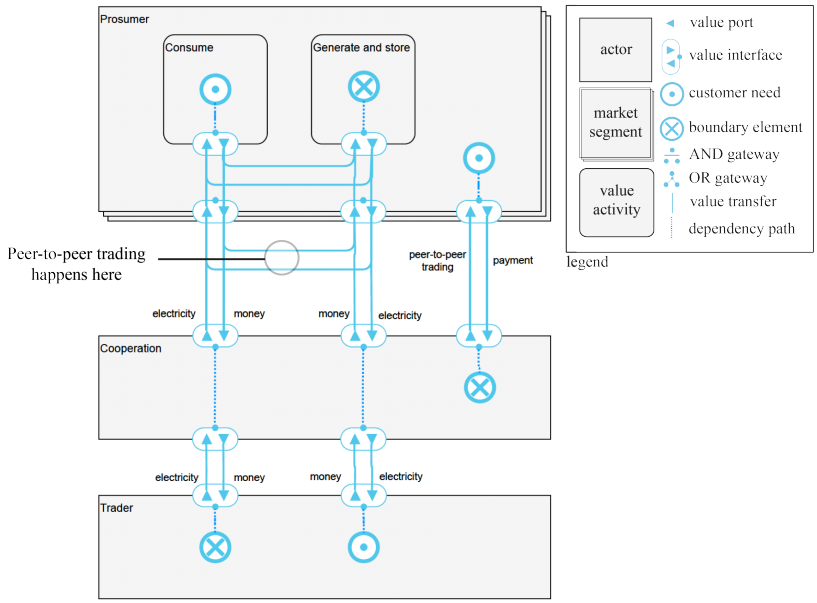


Figure 3.2: e^{3}value P2P Energy Trading Model

The decentralized ecosystem for energy trading, in terms of an *e^{3}value* model, is described in Fig. 3.2. Note, this is a case overview of peer-to-peer trading from a business model perspective. The *e^{3}value* model is the outcome of several workshops with stakeholders but is simplified (some parties are left out) to allow for a compact presentation. In [95], several classes of governance mechanisms are identified that can be used to design governance in digital ecosystems, we focus on the value creation mechanism. Each class of governance mechanism has sub-classes (see below). We use these governance mechanisms to evaluate per governance mechanisms to what extent our *e^{3}value* model for Peer-to-Peer energy trading can represent governance decisions.

Governance Decisions Based on the *e*³*value* Model.
The value creation aspect considers how value is created and distributed. The revenue model shows how each actor earns money. In the *e*³*value* model, this is shown by means of value transfers. In the peer-to-peer energy trading case, a Prosumer pays a lower price for electricity than the fee a Trader would charge. The electricity case has a close resemblance to the idea of partnering. Effectively, partners (the Prosumers) team up to provide each other electricity and act as one to the electricity market if there is a surplus of shortage in electricity. This partnership cannot easily be observed in the *e*³*value* model, because in *e*³*value*, a partnership has a different meaning, namely two or more actors offering or requesting objects of value together as one proposition. Can lead to stimulation of co-investments and sharing network costs. Each Prosumer has to invest in technology to participate in the digital ecosystem. Although not visible in the graphical model, this can be represented to quantify the model, which is a standard feature of the *e*³*value* method.

For shared-costs, all Prosumers contribute to the financial sustainability of the Cooperation. This can be seen from the value transfer of peer-to-peer trading. We observe that *e*³*value* represents governance decisions regarding the revenue model. However, partnering of Prosumers cannot really be represented in *e*³*value* the notion of partnership needs to be revisited, e.g., by introducing different kinds of partnerships. Investments and cost-sharing can be represented if the model is quantified. Coordination of players seems to be more a business process design issue than a business (value) model concern. Roles and responsibilities can be partly represented by value activities; risk and expectations by running what-if scenarios, which is a standard functionality of the *e*³*value* toolset.

3.8 Reflection

In this chapter we presented the conceptualization of decentralized governance design as the DECENT meta model. The relevant design artifacts and related semantics are identified via systematic literature review. To test and study the meta model we used the industry strength case of P2P energy trading in the setting of the EU Green Deal. By using the meta model case instantiation, we also constructed an e^3 *value* model to visualize the digital ecosystem of P2P energy trading. Therefore, we address the conceptualization of the DECENT meta model as following: Goal, Subject Area, and Intended User-base expressed as observations and lessons learned.

Goal.
The main goal of this dissertation is to develop a model-based approach by conceptualizing decentralized governance. This should serve as an instrument to model, design, and structure decentralized governance for digital ecosystems.
Sub-Goal.
The sub-goal for this chapter is conceptualizing decentralized governance design using a semi-formal UML class diagram approach.

Subject Area. Conceptualization Decentralized Governance Design.
Observations.
O1.1 The meta model is a technical representation of decentralized governance design constructed by means of a systematic literature review.
O1.2 Identification of the relevant design artifacts, enriched with well-defined semantics.
O1.3 For the meta model we foresee multiple uses, since it is well-defined, we will use the vocabulary of the meta model to instantiate a case to describe governance structures.
O1.4 The meta model as a starting point for computational governance to implement and execute the governance models.
O1.5 The following governance constructs in the meta model can benefit from an implementation perspective: *rule set* (LegalRuleML|Symboleo) [55, 56] and *mechanism* (BPMN) [83].
Lessons Learned.
L1.1 The DECENT meta model fulfills our goal of conceptualizing the notion of decentralized governance design.
L1.2 Using the meta model to describe the governance structures and industry case instantiation is useful, but still rather abstract.
L1.3 To structure decentralized governance we have to conceptualize governance design decisions, as this will contribute in formulating a consistent approach.
L1.4 A graphical representation of decentralized governance would be of help to explain and visualize the notation in digital ecosystems.

Modeling. Assessing the usefulness of the DECENT meta model in conjunction with *e*^{3}*value* as an instrument to formulate, design and structure decentralized governance for the P2P Energy Trading case.
Observations.
O2.1 To study and observe the meta model from an assessment perspective, we applied it to the real industry case of P2P energy trading.
O2.2 At a certain abstraction level, the meta model can represent the EU Green Deal and P2P energy trading.
O2.3 Using the meta model conceptualization of P2P energy trading, as an instrument to create an *e*^{3}*value* model to visualize the digital ecosystem of P2P energy trading.
Lessons Learned.
L2.1 The *e*^{3}*value* model visualizes the governed energy ecosystem, and the meta model case instantiation represents how this can be governed.
L2.2 To increase the usefulness of the meta model we will relate DECENT concepts to existing visual modeling languages: *e*^{3}*value* and BPMN notations to represent decentralized governance models.
L2.3 The meta model as a stand alone instrument to visualize and explain decentralized governance to industry consultants is not a suitable approach.
L2.4 The *e*^{3}*value* model is a business modeling language which was instrumental in P2P energy trading from a digital ecosystem perspective to explore decentralized governance structures and related decisions.

Next step. In the following Chapter 4, we introduce the industry case of Fractional Reserve Banking (FRB). We do this by committing to our design goal, which is to study and develop decentralized governance design in the context of real world digital ecosystems. We will further assess the meta model by using the case of FRB which is about creation and destruction of fiat money. Next to that we will extent the usability of the meta model to relate it to existing modeling techniques (*e*^{3}*value* and BPMN) to represent and visualize decentralized governance structures for digital ecosystems.

4

Representing Decentralized Governance with Existing Techniques

We are interested if we can use existing modeling techniques such as e^3 value and BPMN to:
(1) Design and visualize decentralized governance structures.
(2) Extend and assess the usability of the meta model.
We do so by relating the DECENT meta model with e^3 value and BPMN notations to structure decentralized governance design. We develop the case of Fractional Reserve Banking (FRB), which is a decentralized finance (DeFi) ecosystem specifically about rules for commercial banks how to create and destroy money. This is a case of decentralization, as many banks are licensed to do FRB, governed by national central banks and European Central Bank.

4.1 Introduction

The DECENT meta model provides an abstract way to represent decentralized governance designs. To increase the usefulness of the meta model and its applicability, a concrete graphical representation of a governance model is necessary [96]. The research question in this chapter is if we can use existing techniques to represent governance models. We are interested if we can use existing techniques that we can employ to cover and represent governance models related to the meta model. Using existing techniques can potentially contribute to increasing the acceptance of the DECENT meta model and its usability. Therefore, we are motivated in experimenting with *e*^{3}*value*[1] and the Business Process Model Notation (BPMN) [83] to develop and design governance structures. In order to derive the governance design structures we relate *e*^{3}*value* and BPMN concepts to the meta model. An important prerequisite for understanding and designing decentralized governance is taking a multi-actor approach [97]. We acknowledge that actor/group perspectives are important when developing decentralized governance; therefore, we selected *e*^{3}*value* and BPMN, as both languages offer a (1) multi-actor approach and (2) a model-based design approach. In our previous work [1, 7, 98], we had good experiences with semi-formal UML to represent parts of a DECENT governance model, we now employ *e*^{3}*value* and BPMN.

To do so, we examine the industry-strength case of Fractional Reserve Banking (FRB) in collaboration with a leading commercial bank from Europe. Fractional Reserve Banking is about commercial banks governed by central banks, who are allowed to create, distribute and destroy money. Commercial banks use this FRB as a mechanism to create profit. The FRB mechanism utilizes assets from their own ecosystem (e.g. assets from their customers) as an input to create and destroy money. This is a case of decentralization because (1) there is no centralized group creating and destroying money, this right is given to commercial and central banks, and (2) the rules are decided and monitored by several groups.
This chapter is structured as follows:
In Ch. 4.2 we explain the design approach.
In Ch. 4.3.1 we instantiate the Fractional Reserve Banking case using the meta model.
In Ch. 4.3.2 we present the DECENT governance model using *e*^{3}*value*.
In Ch. 4.3.3 we present a DECENT governance model using BPMN.
In Ch. 4.4 we reflect on this chapter, based on observations and lessons learned.

4.2 Design Approach

We are interested if we can capitalize on the DECENT meta model by relating it with existing modeling techniques. Concretely, we want to examine if we can represent and design decentralized governance by using *e*^{3}*value* and BPMN. The research question we are interested in to explore and to answer is thus formulated as:
To what extent can decentralized governance be represented by using existing techniques such as e^3*value and BPMN?* To do so, we take a single-case study experiment research approach [9] in a real-world context together with a leading commercial bank, namely ABN AMRO.

[1] https://e3value-user-manual.thevalueengineers.nl/

We are well aware that a single-case study experiment has its limitations, however usability of the meta model can only be assessed if it is used in a real-world context. The topic of the experiment will be Fractional Research Banking (FRB), which is a financial system to create and destroy money by commercial banks, which is regulated by central banks. We develop an *e*^{3}*value* and BPMN model to capture and represent aspects of governance design decisions for FRB. The developed models are discussed in several workshop sessions with the market infrastructure group from the commercial bank for validity purposes. This process in getting the models and the governance design decisions to a certain standard and the collaboration occurred over a period of two years.

4.3 Fractional Reserve Banking Conceptualization

In several highly interactive workshop sessions with the commercial bank ABN AMRO, we elicit the governance constructs for FRB by using the meta model, see Fig. 3.1.
What follows now is an expression and description of FRB in terms of the DECENT meta model. In order to create governance models, we need to formalize the decentralized governance aspects of the case, to do so we use the meta model as tool. To emphasize the use of the relevant DECENT decentralized governance concept as clear as possible for the case, we use *Italic words* that represents and refers to the DECENT meta model concepts. The FRB case description expressed in DECENT concepts, serves as input, and vice versa, for the *e*^{3}*value* and BPMN models.

4.3.1 DECENT Instantiation

Identification of Actor and Group.
A debitor, creditor, commercial banks, Basel Committee, the European Central Bank (ECB) and National Central Banks (NCB) and the Basel Committee are all instances of *party*. A *party* can be either an *actor* or a *group*. There is an important difference between an actor and a group. The former models entities perceived as independent, the later describes an aggregation of entities. A debitor and a creditor are *actors* who wants to deposit or attract (e.g. loan) money, as the decision making is independent and identifiable as just one actor. Whereas the Basel Committee, commercial banks, European Central Bank and national central banks are *groups*, as the decision making occurs in a structure of multiple entities working together to reach consensus.

Role of Fractional Reserve Banking.
Each *party* plays one or more *role*s towards a *governance construct*. In FRB, the *Group* Basel committee, in collaboration with *Group* European Central Banks *sets* how much money can be created to *stimulate* the economy with the total amount of loans. As a *group* in their 'setting' role, they use a *decision making* procedure, for example a majority vote. FRB is steered and *decided* through *goals*. The *group* Basel Committee has the *goal* to maintain resilient banking systems through EU-wide regulation. The *goal* of the *group* European Central Bank (consisting of the National Central Banks) is to maintain trust in the euro as a currency. Also, the *group* NCB have the *goal* to regulate and provide financial stability.

Money Creation.
The debitor as an *actor*, has the *goal* to increase capital through receiving interest; the creditor's as an *actor goal* is attract capital in return for interest paid. The amount of money that can be created using FRB as *mechanism* is determined through a *rule-set* that takes the shape of *legislation* and *regulation*. A commercial bank, which is a *group*, can also create by *legislation* money with a banking license obtained from the *group* national central bank. Actual execution of the *policy* defines *legally* the terms and how much money can be created based on the amount of capital the *group* commercial Bank, has access to.

Rule Set to Increase Trust.
A *policy* leads to *mechanism* to actually govern and *regulate* the *rule-set*. With the *mechanism* that consists of *policy* and *incentive* a *group* such as European Central Bank and the *group* National Central Bank have direct insight in and influence financial risks the *group* commercial banks have on their balance sheet. Steering and achieving *goals* of every *party* are stimulated via *incentives*. If a *party* does not implement the *policy* and exceeds the *rule-set*, which consists of *legislation, regulation* as set by the *party* European Central Bank, a *penalty* is introduced. Consequently, a *reward* is that the e.g. the *group* commercial bank can report in their financial statements that the *rule-set* are *monitored*. This can lead to increased trust in the ability of the *group* commercial bank to control their financial risks.

4.3.2 Governance Model represented in e^{3}value

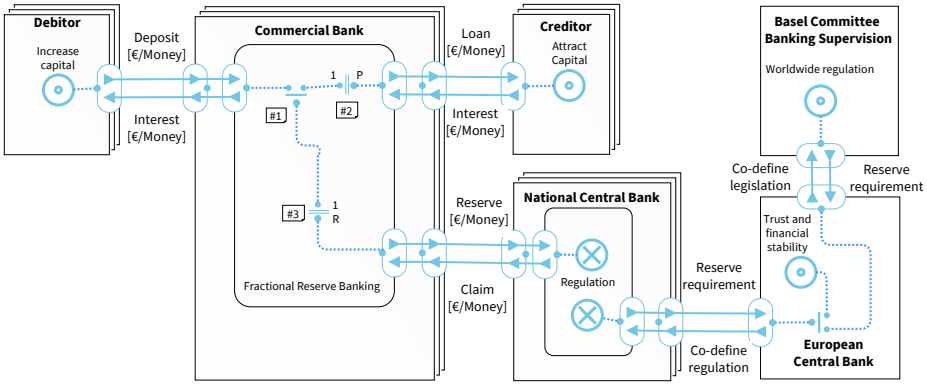


Figure 4.1: *e^{3}value* Governance Model FRB

We present an *e^{3}value* model in Fig. 4.1, of FRB, based on the instantiation in Ch. 4.3.1, concepts from the meta model are represented in *italic*. We used the meta model as a tool to demarcate and instantiate the governance constructs. The *actors* in that corresponds with the meta model (see Ch. 4.3.1) result in: *e^{3}value actors*; in case there is only instance (e.g. European Central Bank) or *Market Segment* if there are multiple instances (e.g. national central banks in EU). *Group* has no corresponding construct in the *e^{3}value* language, hence we used the *actor* construct here (in which [44] an extension of *e^{3}value* is proposed, amongst others with the concept of *group*).

These *actor*s and *groups* have *need*s, e.g. the Debitor has the need to increase its capital, and the European Central Bank has the need for trust and financial stability. Some of these needs can be quantified, e.g. the need to increase or to attract capital. In such a case, the need corresponds to the DECENT *goal* and the related *objective*.

Table 4.1: e^3*value* Governance Design Decision

e^3***value* Concept**	**FRB Governance Design Decision**
Actor Market Segment Customer Need	Debitor: Increase capital. Commercial Bank: Earn profit through interest on loans. Creditor: Attract capital. National Central Bank: Controlling inflation through monetary policy. European Central Bank: Assert trust & financial stability in the Euro currency. Basel Committee: Worldwide regulation to achieve uniformity in capital markets.
Value Activity, Transfer, Object	Financial stability through (R) reserve requirement.
Dependency Path	Formula Fraction (R) reserve requirement: $\frac{1}{R}$. Formula Fraction *(P)* to create money: $1-R$. Total amount of loans is regulated by National Central Bank through fractional *(R)* requirement. For the remaining *(P)* a Commercial Bank is allowed to create money. Commercial bank stores deposits and create loans.

Value activities, value transfer and value object may correspond to DECENT *Mechanisms & Policy*. *Value transfers* such as 'co-define regulation and legislation'. As the reserve requirement determines also how much money the commercial banks as a *group* can create. The value transfer could be seen as *regulation* from the *group* national central banks as the *policy* requires the commercial banks to allocate deposits from debitors to directly to the account of the national central bank. This is connected to control inflation, and secondly to maintain trust in the euro as a currency. The *dependency path* in the e^3*value* model depicts how FRB works from an economic value perspective, and show how the DECENT *Rules* operate. We briefly explain this dependency path that starts with two needs: 'increase capital' and 'attract capital'. Actually, this is a two-sided market [48], where the commercial bank matches the savings of debitor with the loan of the creditor.

- The obtained capital as savings, say E 100,000,- is received from the debitor (annotated with #1).
- A fraction R (say 0.1, thus E 10.000,-, annotated #3) of the money is handed over to the National Central Bank as reserve requirement (this is part of the regulation).
- The remaining part of the money, ($P = 1-R$, thus 0,9 / # 90.000,- annotated with #1) is multiplied by 10, resulting in money creation of E 900.000,- is available to create loans, annotated with #2.

Table 4.2: Concept Mapping e^3*value*

DECENT Concept	***e*^{3}*value* Concept**
Actor	Actor or Market Segment
Group	Group (extension of e^3*value* in [44])
Goal, Objective	Customer Need
Mechanism, Policy	Value Activity, Value Transfer, Value Object
Reward, Penalty	Value Transfer, Value Object
Rule set, Rule	Dependency Path

As from the point of view of the debitor, the money remains at its bank account, money is created (# 900,000,-). The fraction R is an intrinsic part of the governance because it is set in a prescriptive way by the European Central Bank, together with Basel Committee and executed by National Central Banks. Conceptualization and description of FRB leads to Table 4.1, in which we present governance design decisions, as expressed by the e^3*value* model in Fig. 4.1.

Relating DECENT to *e*^{3}*value*.
Table 4.2 relates the DECENT concepts to the e^3*value* concepts. A customer need in e^3*value* is not precisely the same as a *goal* in DECENT, but it closely relates to it. A DECENT *goal* is an ambition to fulfill, for which a party has committed resources for. An objective makes a goal quantifiable. In e^3*value*, a need is the lack of something valuable that the actors want to acquire from another actor or Market Segment. In e^3*value* a customer need can only be satisfied by some object of value if a reciprocal object of value is returned. A mechanism (and its composition into a policy) in DECENT deals with the operational implications of *rules* and *objectives*.

A mechanism in DECENT corresponds to a value activity in e^3*value*, as it is work that an actor does in an economic sustainable way, e.g. creates added value for itself. There is overlap between mechanism/policy and the value activity (but refers to the execution of something), but there are also differences. First, for the execution of a mechanism/policy one or *more* parties may be required, a value activity is always performed by precisely one actor/market segment. Second, there is a difference in granularity between both concepts. A requirement for a value activity is to create added value for the performing actor/market segments. This implies that more fine-grained activities that only result in expenses are not distinguished as separate value activities. Instead, such activities are intrinsic part of a larger value activity.

In DECENT, a mechanism can be a fine-grained activity, e.g. to define and illustrate how the mechanism precisely works. Sometimes, mechanisms are of value for others. Thus, a mechanism can result in value transfers and the corresponding value objects. An incentive and penalty in DECENT are a set of reciprocal value transfers in e^3*value*, because they always imply that something of value is transferred from one actor to the other. Rules for rule-sets in DECENT can be modeled as dependency paths in e^3*value*, as long as the rules have an economic value connotation.

4.3.3 Governance Model represented in BPMN

We present the BPMN model, Fig. 4.2, which is a process perspective on Fractional Reserve Banking, based on the DECENT case instantiation in Ch. 4.3.1. With this BPMN model we represent a Governance Model of how Fractional Reserve Banking, money creation is executed. Concepts from the DECENT model are shown in *italic* again. With BPMN it can be visualized explicitly which *party* executes which *role* and how these processes of money creation are *defined* and *monitored*.

A *role* is to *define* a need from customer the to deposit cash and a need to obtain an asset by requesting a loan. These processes for requesting a loan and depositing cash are facilitated and *executed* by the *group* commercial Bank. The total money availability for money creation is influenced by the *actor* Debitor and on the *group* European Central Bank. Based on deposits from the customer *actor*, the money multiplier works. The total amounts a commercial bank has in savings, is multiplied, which follows from the *rule-set* that determines that a commercial bank can create money. All these financial transactions are executed via *group* commercial bank. An important *role* in FRB is anti-money laundering (AML). This *role* of AML is *executed* by the *group* commercial bank and *monitored* by National Central Bank. Table 4.4 presents the governance design decisions, as expressed by the BPMN model, see Fig. 4.2.

Relating DECENT to BPMN.

Table 4.3 relates the DECENT meta model concepts, and their relationships to the relevant construct(s) in BPMN. In BPMN, the way to model Actors is via Resource Pools. There is no direct corresponding construct for the Group, but often the Resource Pool is used too, with the addition that many of these Resource Pools of the same kind may exist. BPMN is in particular effective in modeling the DECENT Policy and Mechanism constructs in depth. In fact, we consider the BPMN language as a tool to specify policies and mechanisms in a much more fine-grained way. The BPMN notion of Activity, plus all concepts to express a control flow, such as Gateways correspond to the DECENT Policy and Mechanism concepts. In case Decision Making in DECENT can be expressed as a (collection of) Activity it can be modeled in BPMN as well. Penalties and Incentives will result in Message Flows between actors, hence they are related. Rules and Rule-sets in DECENT may require BPMN Data Stores, to make them persistent.

Table 4.3: Concept Mapping BPMN

DECENT Concept	BPMN Concept
Actor & Group	Resource pool
Decision Making, Mechanism	Activity, Control Flow constructs such as Gateway, and Sequence flow
Penalty & Reward	Message Flow
Goal & Objective	Event
Rule, Rule-set, Policy	Data Artifacts

Table 4.4: BPMN Governance Design Decision

BPMN Concept	**FRB Governance Design Decision**
Resource Pool	Debitor, Commercial Bank (CB), Creditor, National Central Bank (NCB.)
Activity, Control flow, Sequence, Gateway	Deposit check for anti-money laundering by CB. Money inflow from Debitor: Deposit. Money outflow from CB to Debitor: Interest on deposit. Deposit claim increase/decrease at debitor account. Update FRB database with cash inflow/cash withdrawal based on deposit and loans in and outflow. Money outflow to Creditor at CB: Create loan and interest. Money inflow from Creditor at CB: Interest + repayment loan. Money outflow from CB to NCB: Reserve requirement. Calculate reserve requirement by NCB and CB: Deposit*R%. Calculate money multiplier by CB: Deposit*($\frac{1}{R}$). Update reserve requirement account at NCB.
Message Flow	Acceptance and/ or rejection of money deposit by CB. Acceptance and/ or rejection of reserve requirement by NCB. Debitor and CB exchange terms of contract for deposit. Creditor and CB exchange terms of contract for loan. NCB and CB exchange terms of regulation. Legal right to create loans by NCB.
Event	Objective measurable by quantifiable formulas
Data Artifacts	Debitor and Creditor Database at CB. Money Multiplier Database at CB. Fractional Reserve Database at CB and NCB. Loan and Deposit Database at CB. Deposit and loan application sheet via Debitor at CB. Condition sheet for Deposit and Loan provided by CB. Condition sheet for Reserve requirement by NCB.

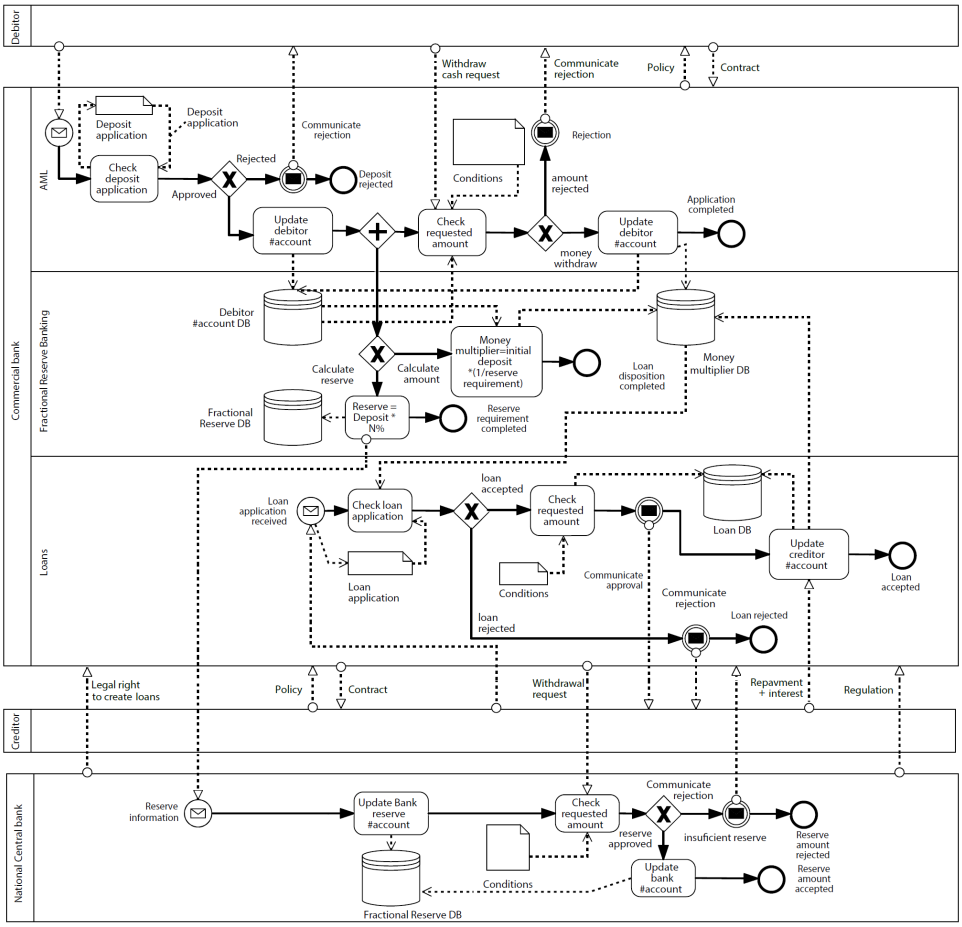


Figure 4.2: BPMN Governance Model FRB

4.4 Reflection

In this chapter we used DECENT meta model as a descriptive tool to instantiate governance structures and descriptions of Fractional Reserve Banking (FRB).
Next to that, we experimented with *e*^{3}*value* (business modeling language) and with BPMN (process modeling language) to represent DECENT Governance models.
We related DECENT concepts with *e*^{3}*value* and BPMN notations. We did this to study and learn if we can visualize governance and derive its related governance design decision structures. We address the usefulness of using existing modeling *e*^{3}*value* and BPMN in conjunction with the DECENT meta model as following: Subject Area and Intended User-base expressed as observations and lessons learned.

Goal.
The main goal of this dissertation is to develop a model-based approach by conceptualizing decentralized governance. This should serve as an instrument to model, design, and structure decentralized governance for digital ecosystems.
Sub-Goal.
The sub-goal for this chapter is to be conclusive if using existing modeling techniques, to represent DECENT governance models is of value. To do so we related the DECENT meta model concepts to *e*^{3}*value* and BPMN notations.

Subject Area. The models should be exclusively about decentralized governance.
Observations.
O1.1 The role [define, execute, monitor] that a party plays towards the governance constructs could not be represented.
O1.2 The method a party uses to take a decision about the governance construct could not be represented.
O1.3 The governance construct modifies party their associated roles and decision making, this could not be represented.
O1.4 Decision making at the level of governance construct could not be represented.
O1.5 Decentralization as a concept occurs for each governance construct through Party-Role and this could not be represented.
Lessons Learned.
L1.1 The role [define, execute, monitor] a party plays regarding the governance construct should be made visually explicit.
L1.2 A party who takes the decision, using vote, about the governance construct should be made visually explicit in the design.
L1.3 Governance construct has different levels of decentralization and this should be designed explicitly.
L1.4 How a decision is reached between the parties and the governance construct at hand should be designed and expressed visually tractable.

Modeling. Exploration if decentralized governance models can be designed using *e*^{3}*value* and BPMN, and if our case-study partner can understand the notion of decentralized governance through the models.
Observations.
O2.1 Creating an *e*^{3}*value* model is of value to visualize the digital ecosystem as this contributed during the design meetings about the Fractional Reserve Banking case.
O2.2 Traceability and consistency between DECENT, *e*^{3}*value* & BPMN did not contributed in discussions with our case-study partner.
O2.3 Data redundancy is occurring by using three (DECENT, *e*^{3}*value* and BPMN) modeling languages.
Lessons Learned.
L2.1 Requiring a stakeholder to learn three modeling languages (DECENT, *e*^{3}*value* & BPMN) is not a productive nor an effective design approach.
L2.2 Our goal is to design tractable decentralized governance models with a minimum number of concepts, using BPMN with the extensive set of notations does not serves this goal.
L2.3 A BPMN model could be of use for technical implementation of governance structures in the setting of on-chain computational governance.
L2.4 Experimenting with *e*^{3}*value* and BPMN proved to be valuable in the context of how a "decentralized governance notation" should be visualized and designed.

Next step. Following our observations and lessons learned, we are conclusive in that decentralized governance cannot be designed using existing modeling languages. Therefore, we decided to create the DECENT graphical notation that allows for designing decentralized governance models, this is of discussion in Ch. 5 and Ch. 6.

5

Visualizing and Implementing the DECENT Software Graphical Notation

To graphically represent and design decentralized governance, we develop a graphical notation, implemented as the DECENT software modeling toolkit. For the implementation we use the meta case tool ADOxx development platform. The graphical notation allows to design and represent decentralized governance models. Following the defined meta model semantics, we explain the design principles and the rationale of our design decisions for the DECENT graphical notation and DECENT software modeling toolkit systematically.

5.1 Introduction

Governance design is important required for digital ecosystems as we have observed in the cases of Peer-to-Peer Energy Trading [99] and Fractional Reserve Banking [12]. The question is how a governance model should look like, and more importantly how it can structured and designed by using a model-based approach. Visualization of the design artifact, reflecting important design decisions, is crucial to communicate with stakeholders [47, 48]. We have experimented (1) if we can use existing modeling techniques (e^3*value* and BPMN) for decentralized governance design, and (2) if we can conceptualize decision making about *defining, monitoring and execution* of governance constructs [1, 7, 12].
As we have discussed earlier in Ch. 4.4, two crucial design concerns we have found by using existing modeling techniques is that (1) the decentralization aspect related to each governance constructs *cannot* be represented (2) the role of the party in relation to each governance construct *cannot* completely be conceptualized. The structure of this chapter is as follows.

In Ch. 5.2 we explain our design approach.
In Ch. 5.3 we present the design criteria to develop the graphical notation.
In Ch. 5.4 we construct and explain the DECENT governance models.
In Ch. 5.5 the DECENT graphical notation rationale is presented and explained.
In Ch. 5.6 the implementation of the graphical notation and the models as the DECENT software modeling toolkit in ADOxx, are explained, next to that we provide a structured overview of the meta model mapping and the notation.
In Ch. 5.7 we conclude this chapter.

5.2 Design Approach

As we have evaluated in Ch. 4.4 existing conceptual modeling techniques, such as e^3*value* and BPMN do not full-fill our design criteria of a model-based approach to design decentralized governance. We have a well-defined set of the meta model semantics that we can draw upon (see. Ch. 3.6). By taking the meta model as a baseline, we develop the DECENT graphical notation. This graphical notation is implemented as the DECENT software modeling toolkit which allows to create and design DECENT governance models. To do so, we follow the principles of rapid prototyping [17], as it allows us efficiently change and revise the visualization, this approach contributes to shape, observe and study the phenomena of decentralized governance within a software environment. The technology we use to develop a graphical notation (which follows the meta model semantics), is a meta case software tooling platform: ADOxx [100]. The assessment of the graphical notation and governance models will be of discussion with the case of Digital Euro in the next chapter of this dissertation in Ch. 6.

5.3 Notation Design Criteria

For the graphical notation we present the following design criteria as inspired by [101, 102] and we follow the meta model requirements as discussed in Ch. 3.2. The main design goal is as we formulated before, a light-weight tractable notation with a limited number of concepts and relations, such that it can easily be explained to practitioners. A minimized notation cf. Occam's razor, is an important *feature* of the graphical notation.

1. **Semantic Mapping.**
   We follow the meta model semantics to a certain extent. We make the remark here that we will reduce the amount of relationships in the notation to construct governance models. Next to that we will also combine some meta model concepts in the graphical notation. This allows us to simplify the notation and makes it easier to explain, learn and to apply. The mapping of the meta model to the graphical notation is presented in Ch. 5.6.
2. **Intuitive**.
   It should be designed in such an approach, that in principle no computing knowledge is required by the end-user, as the graphical notation should be applied intuitively. Graphical notations should be logical and connected to the real-world application. The notation and interpretation should be directly deductible from the used visual constructs, and known universally as a logical symbol. Too much symbols within a model do not contribute in understanding and explaining the model. As such complexity should be avoided, and notations should be combined. We take semantic perversity into account when designing graphical notations [103–105].
3. **Decentralization.**
   When constructing the models, we consider the following model distinctions that infer decentralization. The first model is the representation of the governance constructs: objective, goal, legislation, regulation, rule set, rules, mechanism, policy, incentive, reward and penalty. We refer to this model as the governance construct and the role a party plays should be made directly visible. For example, group and actor use their associated role [Define, Monitor, Execute] in the decision making procedure to modify the governance construct. Decision making also contains the vote attribute, which form together with the governance construct the semantics of the decentralized graphical notation.

5.4 DECENT Governance Models

In this section we present and discuss the DECENT graphical notation. We will construct in total five models using the DECENT graphical notation. We present the governance model that combines the governance construct together without the abstraction of decision making, party and role. We present the following DECENT governance models: Governance Construct, Goal-Objective, Rule Set, Incentive and Policy-Mechanism. We have made a distinction between the high-level overview of the governance construct model versus the governance construct model that visualizes how the decision making is occurring decentralized.

5.4.1 Governance Construct Model

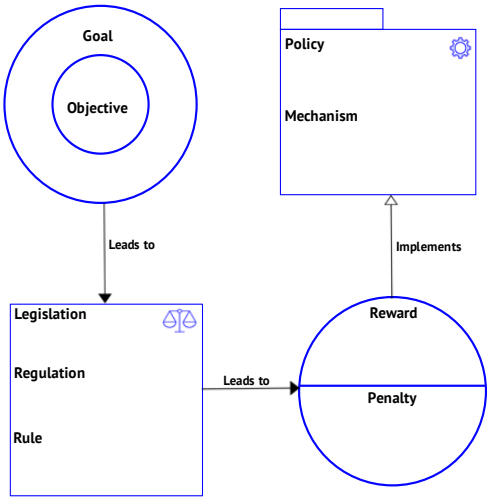


Figure 5.1: Governance Construct Model

In Fig. 5.1 we present the Governance Construct model, which is a collection of: Goal-Objective, Rule Set, Incentive and Policy-Mechanism, form together the semantics of the Governance Construct model. The governance construct visualizes: Goal-Objective which *leads to* Rule-Set, which *leads to* Incentive and is finally *implemented by* Policy-Mechanism. First the goals and objectives should be set, consequently followed by the rule set. The rule sets lead to incentive, which is penalty and reward can be formulated. The governance construct Policy-mechanism implements the vision and selection of the technology to execute the policy. This governance construct model can be deconstructed into four separate governance models, which allows to understand the semantics of party-decision-voting structure and the role a party plays that affects the relevant governance construct via decision making, this decomposition per governance construct visualizes decentralization.

5.4.2 Goal-Objective Model

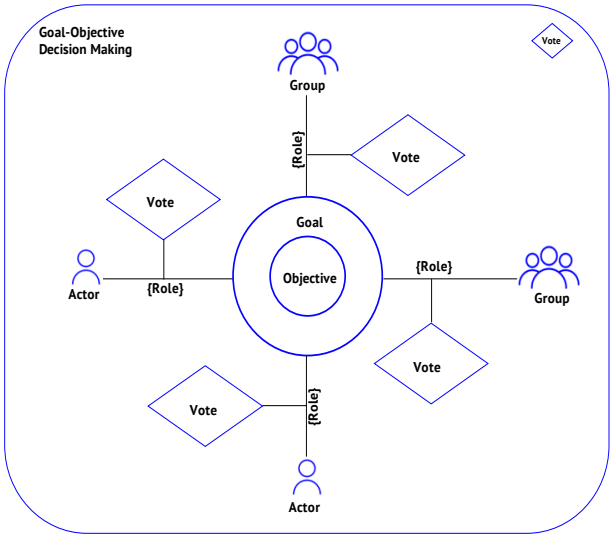


Figure 5.2: Goal-Objective Model

In Fig. 5.2 we present the Goal-Objective model. This is a decomposition from the Governance Construct model as presented in Fig. 5.1. The focus is on the construction of the goal-objective and how the decision making occurs. The model represents the decision making about the goal-objective. Several decisions are represented concerning the construct goal-objective: For example, relations between the actor/group and their role towards goal-objective are identified. The decision/voting structure is represented and it is transparent for every actor/group how their role is influencing the voting structure. An objective is associated to numeric parameters. This formalizes the fact that an objective measure, and realizes achievement of the quantitative stated goal. We remark that it is possible that a goal can be multiple objectives. Also, a goal may consist of sub-goals.

5.4.3 Rule Set Model

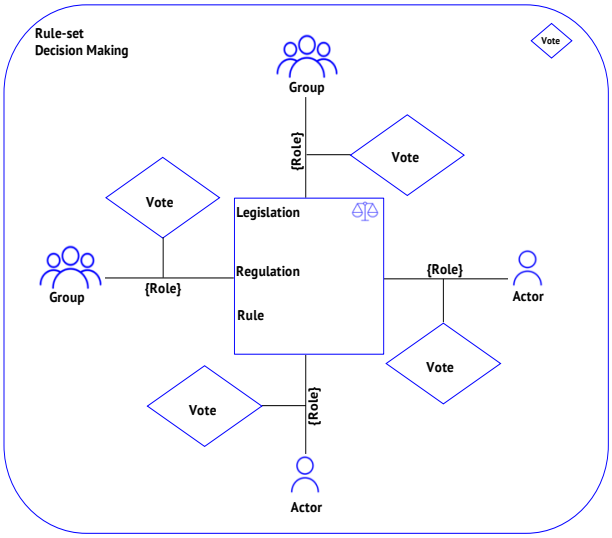


Figure 5.3: Rule Set Model

In Fig. 5.3 we present the Rule Set model. This is a decomposition from the Governance Construct model as presented in Fig. 5.1. The focus is on the construction of Rule set, which consists of: Legislation, Regulation and Rule. This is represented as a square, as for governance it is important to understand the set of rules influencing the decision making. Specifically, within a decentralized ecosystem that can be subjected to laws and regulations. It is important to incorporate the legislation, regulation and the position of the actor/group towards the design of the Rule Set construct. For example, the legislation is defined and decided by the group government. The decision structures are formed by the following: actor/group, their role and position towards the construct and the voting structure. All these factors influence together how the rule set is designed. The monitoring (which is set via role) of the legislation is done by for example a sub-set of the government, in the form of regulation. Next to legislation and regulation, the digital ecosystem can also set its own rules, which formalizes as self-governance. The Rule Set should be formulated in such manner that it will contribute in achieving the goal-objective construct.

5.4.4 Incentive Model

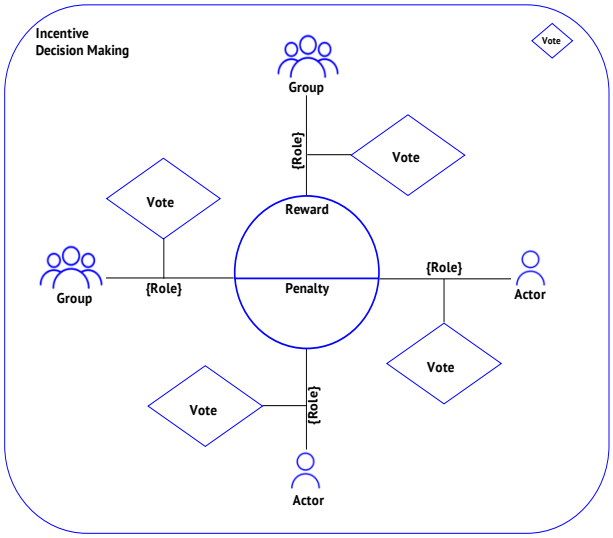


Figure 5.4: Incentive Model

In Fig. 5.4 we present the Incentive model. This is a decomposition of the Governance Construct model as presented in Fig. 5.1. The focus is on the construction of the Incentive structure which consists of: Reward and Penalty, this is represented as a circle. Reward and penalty are opposites but an important governance constructs to put the system at hand into motion. Incentive structures, if well-designed, will lead towards action and implementation of Rule Set via the Policy-Mechanism construct. Ideally to achieve consistency and rigor, the incentive is decided based on the Rule Set model. This is to ensure traceability within the digital ecosystem. However, it is not exhaustive as the incentive also consists of reward, which is a stimulation to achieve a certain outcome, which can be modeled as well.

5.4.5 Policy-Mechanism Model

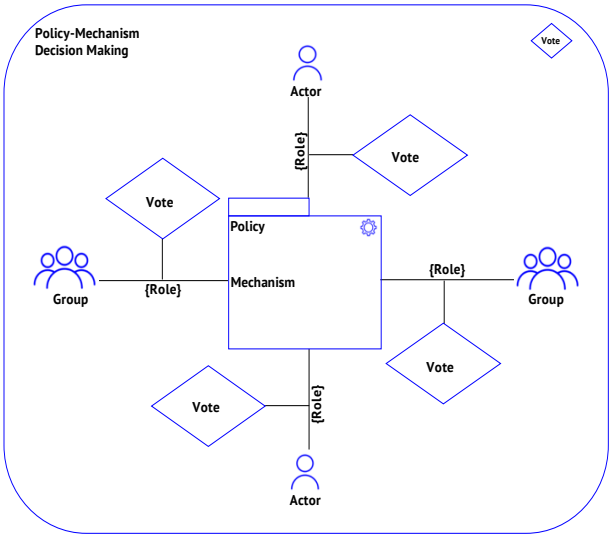


Figure 5.5: Policy-Mechanism Model

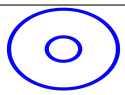
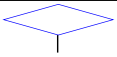
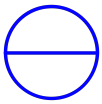
In Fig. 5.5 we present the Policy-Mechanism model. This is a decomposition of the Governance Construct model as presented in Fig. 5.1. Governance is about the process and system of decision-making as well as policy, and ultimately the implementation within a digital ecosystem or society at large. Decentralized governance can only work and succeed on the long-term, if all governance constructs are conceptualized within the policy that is implemented via the construct of mechanism. A policy is a plan for action which implements the rule set, and a policy consist of mechanism. Consequently, mechanism implements a rule, is part-of a policy, contributes-to reaching an objective, is a generalization of incentive, and contributes to satisfaction of a goal. Ideally the policy-mechanism model should be constructed following the constructs of Goal-Objective, Rule Set, and Incentive. This is to ensure consistency and rigor. For the implementation of policy via mechanism again several decisions have to be designed, this occurs via the actor/group, their corresponding role and the voting structure. It is stated that a mechanism is usually process-oriented and can be represented, for example, by a BPMN model. While many governance mechanisms are indeed process-oriented, there are also those that go beyond processes.

5.5 DECENT Graphical Notation

We want to create and implement a software modeling toolkit that supports the proposed notation which allows for decentralized governance design:

1. To develop a model-based approach that allows for decentralized governance design.
2. A baseline for computational governance, which is our long-term research goal.

Table 5.1: DECENT Graphical Notation

DECENT Concept	Graphical Notation	Description
Actor		An independent entity represented by the icon of a person.
Group		A group is a collection of entities that share one or more characteristics, represented by the icon concatenation of multiple persons.
Goal-Objective		Consists of two circles, as the inner circle represents a goal and the outer circle represents objective.
Decision making		Decision making used by a party to take a decision, this occurs via the construction of vote, represented as a diamond upper right.
Vote		Vote is part of decision making and represented as a diamond-line.
Rule Set		Rule Set consists of legislation, regulation and rules, represented as a rectangle boundary. Rule Set is about fairness, hence the scale of justice upper right.
Incentive		Penalty & reward as a graphical segmentation in a circle acting as two opposites, which form together the semantics of incentive.
Policy-Mechanism		A policy is a document represented as the icon file explorer. Mechanism is part of policy and implements the policy, represented by the icon engine.

Group-Actor Notation.
There is an important difference between an actor and a group. The former models an actor perceived as independent, the latter describes an aggregation of a party. Thus, an actor is not a group, and a group is not an actor. We state that a party is either an actor or a group, hence translating the relation “actors extend parties" and “groups extend parties". There is a semantic difference when an actor, which can independently take a decision, represented as just one actor and a group which takes a decision collectively, represented as multiple actors. We remark that it is possible that a group can consist of groups. A Party, can be a Group or an Actor, uses decision making and voting to modify governance construct according to their role. Group and actor with their associated role [Define, Execute, Monitor] and the decision making that occurs is dynamic. This structure can and will change over time, as governance is not set in stone. The governance construct that a group and actor have to decide over is: goal-objective, Rule Set, Incentive, and Policy-Mechanism. In turn, the governance construct modify group, party, actor, their associated roles and the decision making via a decentralized construction. This is a clear modeling decision that infers decentralization. Actor and group can be directly defined and interpreted. This is an important requirement to visualize how an actor and a group reaches a decision via their assigned role and the attribute vote, that affects the governance construct.

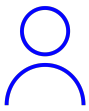


Figure 5.6: Actor Notation

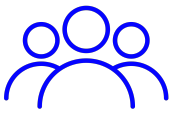


Figure 5.7: Group Notation

Goal-Objective Notation.
We state that every goal may be associated with numeric parameters via objective. This formalizes the fact that an objective measure and realizes achieving a quantitative stated goal. We remark that it is possible that “a goal consists of multiple goals". For cohesion, we decided that goal and objective can be presented as one icon, represented as two circles. The inner circle represents a goal. The outer circle represents an objective. The circles have the same center however with a different radius compared to the center of the circle as an objective makes the goal measurable and act as refinement of a goal. Concatenation of goal-objective within one notation, reduces complexity and it infers that a goal without an objective, and vice versa cannot be formulated separately.

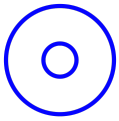


Figure 5.8: Goal-Objective Notation

Decision Making-Vote Notation.
Decision making is used by a party in a specific role and it refers to a collection of different voting strategies used by a party to take a decision, this occurs via the construction of a vote. Let vote be an attribute of decision making which is represented as a string. Decision making should occur for every governance construct via the decentralized structure of the role that a party plays. For example, to establish a decentralized constellation, role of [Define, Execute, Monitor] and the decision making should be decentralized via several actor/groups, and not concentrated at one party. Decision making is used by a role, which is played by a party, to affect the governance construct. To visualize the decentralized structure decision making should be represented as a rectangle, and with vote upper right within decision making as a diamond shape. The rectangle shape of decision making structures and organizes the governance construct, and implies that everything that occurs within the rectangle, a decision materializes.

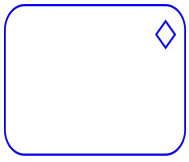


Figure 5.9: Decision-Vote Notation

Rule Set Notation.
A rule is an elementary concept that cannot be fragmented in smaller rules. Rules are part-of (multiple) rule set(s). Legislation and regulation extend rule sets. Concepts: legislation, regulation, rules form the semantics of the Rule Set. We formalize that a legislation and regulation are two different concepts. Regulation such be formulated as a result of legislation. Legislation and regulation extend rule sets, and we formalize that rule set consists of rules. This structure can be represented into one icon as a rectangle boundary with upper right the scale of justice to achieve equitable governance. This rectangle allows to represent the rules, legislation and regulation in one icon and reduces complexity and couples the rule set in one icon. Legislation, regulation and rules are represented as a string within the rectangle boundary.

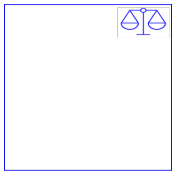


Figure 5.10: Rule Set Notation

Incentive Notation.
We decided to design Incentive as one icon, as this ensures that consistency is formulated, and balance is achieved. Penalty and reward are represented as a graphical segmentation of a circle acting as two opposites, which form together the semantic of incentive. An incentive is the generalization of penalty or reward. Incentive is a stimulation to achieve objectives and adhere to rules. It has an expression stating the reward or penalty. Incentive can contribute to achieving or implementing adherence to a rule operationalized either as penalty or reward. Penalty can be formulated as a sanction if objectives are not met. Reward is a motivation to achieve objectives. Thus, incentive is a result that follows if a rule is adhered to, or not respected.

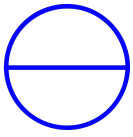


Figure 5.11: Incentive Notation

Policy-Mechanism Notation.
A policy is a document that is implemented by the mechanism, represented by the icon file explorer. Mechanism is part of policy represented by the icon engine. A policy implements the rule set structure, and incentives extends mechanism. Policy consists of mechanism and is a plan for action. A mechanism implements a rule, is part-of a policy, contributes-to reaching an objective, generalization of incentive, contributes to satisfaction of a goal. It is stated that a mechanism usually is process-oriented and can be represented, for example, by a BPMN model. While many governance mechanisms are indeed process-oriented, there are also those that go beyond processes. A policy is a governance construct that is a clear plan for action and requires implementation.

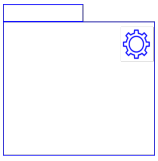


Figure 5.12: Policy-Mechanism Notation

Relationship Notation The meta model (see Fig. 3.1) represents eleven relations, to present these all graphically is not in line with our design requirement as it would make it overly complex and difficult to create models. Therefore, we present three relationships: *role*, *leads to* and *implement*. These relations infer decentralization, and this construction allows to connect several governance constructs to achieve a meta-governance level view, see Table 5.10.

Role Relationship [Define, Execute, Monitor] structure is a decentralized constellation and can prevent centralization. If one specific party uses all roles, it is immediately clear that decentralization is not the main motivation in shaping the digital ecosystem at hand. Role is only visible in the governance construct models, and not at the higher abstract level that represents all governance constructs.

Leads to is a relationship construct that connects the governance constructs: goal-objective, rule set and incentive within a governance model. Ultimately, the governance constructs, are **Implemented** via the governance construct: policy-mechanism.

Table 5.2: DECENT Relation Notation

DECENT Concept	Graphical Notation	Description
Role		The position a party takes related to the governance construct, which can be: Define, Execute or Monitor, represented as a line.
Implements		Governance construct put into effect, represented as a straight line with hallow arrow head.
Leads to		Leads to connects the governance construct, represented as a straight line with a solid arrow.

Role Relationship Notation.
Let [Define, Execute, Monitor] be a set of strings, that are called Roles. A party plays the role assignment structure, by using decision making to affect the governance construct. We remark here, that role is an objectified relationship within the meta model and represented as a relationship with the notation as well.
The role relationship structure, uses decision making to affect the governance construct, therefore we have decided to represent the role structure as a relationship noted as a straight black line. We use text here to distinguish the role in detail, which can be: *Define*, *Execute* or *Monitor* when constructing the governance models.

Figure 5.13: Role Relationship Notation

Leads to Relationship Notation.
We state that goal-objective structures should *lead to* legislation-regulation-rule structure. The *leads to* infers decentralization, as multiple governance constructs should be designed separately and more importantly this relationships links the governance constructs towards implementation. Represented as a straight line with a solid arrow.

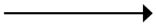


Figure 5.14: Leads to Relationship Notation

Implements Relationship Notation.
Ultimately, all governance constructs should be implemented. This is conceptualized via the governance construct of policy-mechanism. Policy implements, goal-objective, rule set and incentives structures via mechanism. Governance constructs are put into effect, represented as a straight line with hallow arrow head.

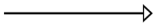


Figure 5.15: Implements Relationship Notation

5.6 DECENT Software Modeling Toolkit

To implement the graphical notation and the models as a software modeling toolkit, we use the technology of ADOxx®, which is a development and configuration platform for implementing modeling tools[1]. More importantly, ADOxx allows for rapid software prototyping, it supports the implementation of individual modeling languages, modeling processes and corresponding functions such as visualization [106]. We present how we mapped the meta model with the graphical notation. The graphical notation is consequently imported in ADOxx and we describe how the semantic of the proposed graphical notation is implemented in ADOxx.

Video Impression DECENT Software Modeling Toolkit in ADOxx.
For an impression how the graphical notation can be used to create DECENT governance models by using the software modeling toolkit, we refer to the following video:
https://www.dise-lab.nl/wp-content/uploads/2023/09/DECENT_Modeling-platform_Example.mp4

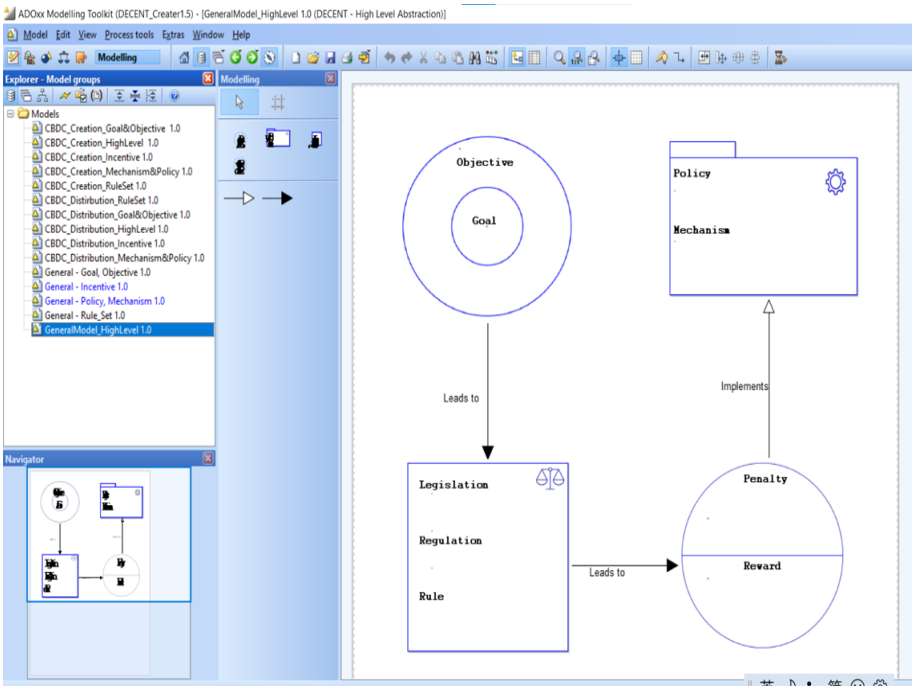


Figure 5.16: DECENT Software Modeling: Governance Construct Model Example

[1] https://www.omilab.org/adoxx/

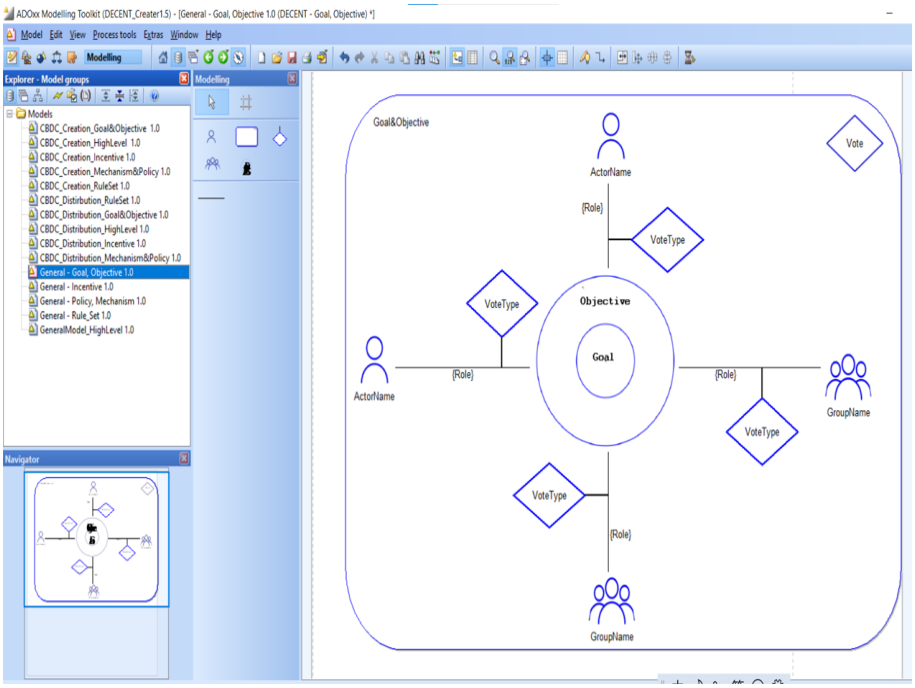
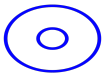


Figure 5.17: DECENT Software Modeling: Goal-Objective Model Example

Table 5.3: ADOxx Mapping: Party

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Group	Class	Class		Every entity belongs to a group or an actor. There is an important difference between an actor and a group. The former models entities perceived as independent, the latter describes an aggregation of entities. We state that a party is either an actor or a group, hence translating the relation “actors extend parties" and “groups extend parties".
Actor	Class	Class		See Group.
Party	Class	N/A	N/A	N/A

Table 5.4: ADOxx Mapping: Goal-Objective

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Goal	Class	Class defined as [Goal-Objective]		Goal is associated with numeric parameters via objective, this formalizes the fact that an objective measure and realizes achieving a quantitatively stated goal. Represented as graphical notation: goal-objective.
Objective	Class	Class defined as [Goal-Objective]	See Goal.	See Goal.

5

Table 5.5: ADOxx Mapping: Rule Set

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Rule Set	Superclass	Class defined as [Rule Set]		Rules are part of rule sets. Legislation and regulation extends rule set. A rule is an elementary concept. Four concepts: legislation, regulation, rules and rule set are a part of the decentralized structure of rule set and represented into one graphical notation.
Legislation	Class	Class defined as part of [Rule set]	See Rule Set.	See Rule Set.
Regulation	Class	Class defined as part of [Rule Set]	See Rule Set.	See Rule Set.
Rule	Class	Class defined as part of [Rule Set]	See Rule Set.	See Rule Set.

Table 5.6: ADOxx Mapping: Incentive

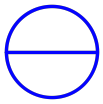
DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Incentive	Superclass	Class defined as [Incentive]		Incentive is the generalization of penalty or reward. It has an expression stating the reward or penalty. Penalty and Reward as a graphical segmentation in a circle acting as two opposites, which form together the semantics of Incentive, represented as one graphical notation.
Reward	Class	Class defined as part of [Incentive]	See Incentive.	See Incentive.
Penalty	Class	Class defined as part of [Incentive]	See Incentive.	See Incentive.

Table 5.7: ADOxx Mapping: Policy-Mechanism

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Policy	Class	Class defined as: Policy-Mechanism		A policy implements the legislation-regulation-rule structure, and incentives extends mechanism. Mechanism is part of policy and implements the policy. A policy is a collection of documents represented as the icon file explorer, mechanism represented by the icon engine which forms policy-mechanism.
Mechanism	Class	Class defined as part of Policy-Mechanism	See Policy.	See Policy.

Table 5.8: ADOxx Mapping: Decision Making-Vote

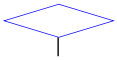
DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Decision Making	Class	Class		Decision making refers to a collection of different voting strategy used by a party to take a decision, this occurs via the construction of vote, represented as a diamond upper right.
Vote	Attribute	Class		Vote is a deconstruction from decision making, represented as a diamond.

Table 5.9: ADOxx Mapping: Governance Construct

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Governance Construct	Generalized Class	Generalized Class	No Graphical notation	Concatenation of the following meta model concepts: Goal-Objective, Rule Set, Incentive and Policy-Mechanism, each governance construct can be modeled separately by combining notations. We will demonstrate this in Ch. 5.4.

Table 5.10: ADOxx Mapping: Relation Notation

DECENT Concept	DECENT Type	ADOxx Type	ADOxx Notation	Design Rationale
Implements	Relationship	Relationship		Governance construct put into effect, represented as a straight line with hallow arrow head.
Leads to	Relationship	Relationship		Leads to former structure contributes to the existence of the latter represented as a straight line with a solid arrow.
Role	Objectified Relationship [107]	Relationship		The position a party takes related to the governance construct, which can be: Define, Execute or Monitor, represented as a line.

5.7 Reflection

The DECENT meta model is a conceptualization of decentralized governance design. Visualization of the design artifacts, which reflects important design decisions is crucial to communicate with stakeholders. We developed the DECENT graphical notation and implemented this as the DECENT software modeling toolkit in by using ADOxx. We can only address the usefulness and evaluate, if we can design the decentralized governance system through models by using the DECENT notation and software it with a real-industry case.

Next step. The DECENT graphical notation and software should be assessed to evaluate the usefulness. We will do so by using the case of Digital Euro in Ch. 6. The Digital Euro is developed by the European Union as a disruptive design approach to eliminate Big Tech companies (trusted third parties) from the European payment infrastructure. The Digital Euro is applied as an instrument to decentralize the financial domain in Europe. Concretely, we will design the decentralized governance system of the Digital Euro system by using the DECENT graphical notation and the meta model. We will create DECENT governance models which will be designed using the DECENT software modeling toolkit.

6

Assessing Decentralized Governance Design: A Model-Based Approach

Financial ecosystems and their related transactions are increasingly relying on Big Tech payment service providers such as Apple Pay and WeChat. Consequently, Big Tech companies also take a powerful position in the payment infrastructure. Such dominance may be avoided by developing harmonized decentralized governance structures in which centralization is avoided. The increased reliance on Big Tech companies motivates the European Union (EU) and national governments to investigate alternatives, such as developing an EU native payment infrastructure. Recently, the EU communicated their intention for a Digital Euro. The Digital Euro is specifically aimed to decrease the dependency on largely uncontrolled Big Tech payment service providers. In this chapter, we explore the governance structures related to the Digital Euro through DECENT governance models. To do so, we apply the graphical notation and develop governance models using the DECENT software modeling toolkit. The governance models are developed together with a leading Dutch commercial bank.

6.1 Introduction

In the previous chapter we developed the DECENT graphical notation, and we are interested if we can apply, and consequently assess, the graphical notation to a real industry-strength case. The case we will use is the Digital Euro. Together with a commercial bank, we analyze and develop their governance positioning towards the Digital Euro. We have developed the domain of Digital Euro in multiple workshop sessions with a commercial bank from Europe. The Digital Euro as a topic is still an exploratory design and research field, as both central banks and commercial banks identify this as a System under Design (SuD), with many design decisions to be taken along the way. The European Commission recently adopted a proposal on the implementation of the Digital Euro[1]. The Digital Euro will not only impact the payment infrastructure, as it is a new currency structure that will co-exist next to the banknotes and coins of the Euro. Essentially, the Euro will be available in a digital structure and in a cash (banknotes and coins) structure. This is a major change, as now multiple parties can create, destroy and distribute money, it is expected that the Digital Euro will follow decentralized finance (DeFi) structures, as settlement with Digital Euro may occur directly between peers. We have developed the DECENT graphical notation and software tooling that allows for designing decentralized governance models, and also to analyze the several governance construct which follows from the meta model instantiation. Next to that, we want to assess the usability of the graphical notation and the governance models, to do so we use the case of Digital Euro.

The structure of this chapter is as follows.
In Ch. 6.2 we first explain our design approach.
In Ch. 6.3 we conceptualize the Digital Euro case using DECENT, we develop and design DECENT governance models for the Digital Euro and each governance model is analyzed.
In Ch. 6.4 our case-study partner, the commercial bank ABN AMRO evaluates the DECENT design approach for Digital Euro.
In Ch. 6.5 we reflect on the use of the DECENT graphical notation and models for the Digital Euro case, expressed as observations and lessons learned.

6.2 Design Approach

In our research we are interested in conceptualizing the domain of decentralized governance, first we provide summarize of the work done so far:

1. We developed a notion of decentralized governance design presented as the meta model in Ch. 3.
2. Assessment of the meta model, to use as a tool to describe and structure decentralized governance design using the cases of: P2P Energy Trading in Ch. 3 and Fractional Reserve Banking in Ch. 4.
3. Experimentation if existing modeling techniques (e^3*value* and BPMN) allow for representing a governance model, by following the meta model in Ch. 4.
4. Creation of DECENT graphical notation, and implemented as the DECENT software modeling toolkit in Ch. 5, as this should allow for designing, structuring, and explaining decentralized governance.

[1] https://www.ecb.europa.eu/press/pr/date/2023/html/ecb.pr230628~e76738d851.en.html

How do we know whether the developed notion of decentralized governance and the graphical notation is correct and more importantly how we will execute the assessment. To revisit the research question which is the focal point in this chapter:
RQ: Is a graphical notation helpful in designing, structuring and explaining decentralized governance?

In order to answer the research question, we follow the principles of technical action research [18]. The goal of technical action research is the use of an experimental artifact to learn about its effects in practice. The experimental artifact here is the DECENT graphical notation. To learn about the effects of the DECENT governance models, we develop the case of the Digital Euro. This is an important step in order to assess the usability of the DECENT graphical notation and corresponding models.

6.3 Digital Euro Conceptualization

The banking landscape is changing, due to rise of Big Tech companies that offer financial payment instruments. In addition to these developments, with the introduction of Bitcoin, many parties are now offering unregulated cryptocurrencies, and this market has grown significantly. Traditionally, central banks play a centralized role in the governance of the current fiat money ecosystem, e.g. to guarantee economic and financial stability by implementing monetary policies, for example to achieve low and stable inflation. Big Tech dominance in the financial domain and the growth of unregulated cryptocurrencies requires an answer from the central banks, and that answer is the Digital Euro, a digital currency that should allow for decentralization both in operations and governance structures.

What is the Digital Euro?
The Digital Euro is a digital currency, denominated in the national unit of account, which is a direct liability of a central bank, such as physical cash and central bank settlement accounts [108]. The Digital Euro will allow central banks to regain control of the disparity currently occurring within the financial domain. The development of the Digital Euro is in full swing, and the Digital Euro as proposed by EU is very much ongoing a System Under Design (SuDs). In [109] several worldwide initiatives of the Central Bank Digital Currency (CBDC) are analyzed, and conclude that one of the biggest challenges of implementing such a currency is designing the related governance structures. It is also stated that only a central bank can issue a Digital Euro and is the sole custodian [98]. By introducing the Digital Euro, a central bank can streamline payment transactions to protect the privacy of citizens and ensure that citizens and companies have equal access to trustworthy digital payment solutions with no data harvesting occurring. However, how to design and introduce a Digital Euro, since it involves a complex redesign of the financial ecosystem with many participating actors, is identified as a governance design challenge [109].

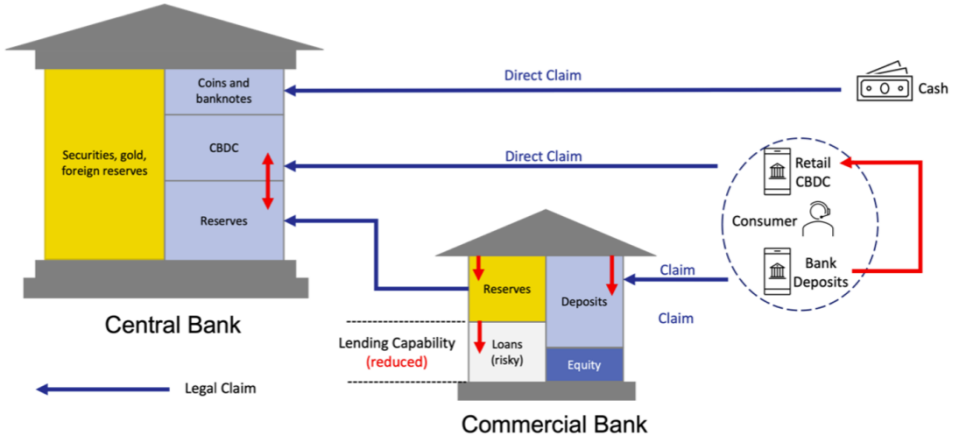


Figure 6.1: Digital Euro Balance Sheet

Digital Euro Balance Sheet Impact.
To visualize the impact of the Digital Euro[2] as represented in Fig 6.1 there is a clear impact on the balance sheet of the commercial banks with the introduction of the Digital Euro. The total assets of the commercial banks decrease and their total lending capacity, which is enabled by the Fractional Reserve Banking (FRB) mechanism, will also decrease. We observe that FRB money is affected by the introduction of the Digital Euro. The decrease of the balance sheet assets of the commercial bank could potentially lead to increase of balance sheet assets of the central banks, with the introduction of the Digital Euro. The sole custodian of the Digital Euro is the European Central Bank (ECB) and the claim on this Digital Euro is directly backed by ECB. In Fig 6.1 it is stated that cash will continue to be made available to the public, and the distribution of cash is currently executed by the commercial banks. It is in line of the expectations that distribution of the Digital Euro will be executed by the commercial banks as well next to cash.

[2]https://www.wsbi-esbg.org/wp-content/uploads/2023/03/ESBG-paper-on-a-digital-euro-what-it-means-for-savings-and-retail-banks.pdf

6.3.1 DECENT Instantiation

We now conceptualize the Digital Euro using the meta model to instantiate the case, the *italic words* refer to the meta model concepts. We do this because we want to describe the case of Digital Euro from a decentralized governance perspective using the meta model as a descriptive tool, we do this together with our case study partner, the commercial bank ABN AMRO.

Identification Groups and Actors.
A *Party* represents any participant in the Digital Euro ecosystem, for example citizens, commercial banks, the European Central Bank, national central banks and customers that engage directly with commercial banks by taking a loan or depositing money. In the current system design, without the Digital Euro, there is no direct relationship with the European and national central banks with citizens. The Digital Euro is used as a *mechanism* to harmonize the payment infrastructure. For example, a citizen owning a digital wallet is an independent entity capable of making their own economic and legal decisions. A *Group* is a collection of Parties that share one or more characteristics, for example, the decision making method. A *Group* is, for example, several commercial banks, all of which have to comply with the same *Rule-Set* that are set and governed by another *Group*, such as the European Central Bank.

Privacy of Digital Euro.
A *Party* can play several *Roles* with respect to governance in a particular digital ecosystem, e.g., a central bank plays a *monitoring* role in relation to commercial banks. In the meta model, *Roles* focus on the position of the *Party* in relation to a *Governance Construct*. The *Role* is a form of decentralization, as each governance construct is influenced by the *Role* that a *Party* plays via decision making. The position of *Role* is, e.g., *Define* a rule, *Execute* (e.g. be compliant to a rule, and *Monitor*, e.g., collect information to check compliance to a rule). The European Union, a *Group*, sets the General Data Protection Regulation (GDPR) in Europe, and the European Central Bank sets that a Digital Euro must safeguard citizens' privacy and prevent data harvesting. The commercial banks, again a collection of multiple banks, concatenated as *Group*, ensure users' privacy when operating (*executing*) Digital Euros, and the Central Bank *monitors* compliance of the commercial banks with GDPR.

Different Roles to Prevent Centralization.
The *Governance Construct* serves as an essential part of the meta model as it collectively represents the subject that an *Actor* or *Group* plays a *Role* in. The *Governance Construct* is the generalization of *Decision Making, Rule, Rule Set, Mechanism, Policy, Goal, Objective, and Incentive*. Modeling this way implies that an *Actor or Group* can play a *Role* in all these constructs. The *Governance Construct* is a form of decentralization, as each *Governance Construct* has to be decided separately by the several *Parties* and this contributes to decentralization, as just one *Party-Role* combination cannot define, execute and monitor the governance construct. For example, the European Central Bank, *defines* via *Role*, the *Rule* that the Digital Euro should be distributed via the *Group* commercial banks. The *Group* European Central Bank, *defines* via the *Role* and the *Rule set* that the Digital Euro will co-exist with cash and commercial bank money. Furthermore, the Digital Euro liability will be carried directly by the *Groups*: European Central Bank and the national central banks.

Legislation to Regulation Roles.
A *Governance Construct* may be affected by one or more *Roles*. A *Role* uses *Decision Making* to reach an agreement. Decision Making refers to a collection of methods used by a *Party* to take a decision regarding a *Governance Construct*. The choice for a particular *Decision Making* depends on the *Role* a particular *Party* has in relation to the Governance Construct at hand. A *Rule* expresses something required, permitted or prohibited (e.g. Digital Euro must consider anti-money laundering and counter financing of terrorism risks). A *Rule Set* is a coherent set of rules (e.g. EU Anti-money Laundering Directive EU 2015/849). *Legislation and Regulation* are specific types of *Rule Sets*. *Legislation* is set by a governmental body, for example by the *Groups* European Central Bank and national central banks. *Regulation* can be set by a society of actors, a branch organization, or even can be self-imposed by one or more actors ('self- regulation'). The *Group* national central banks plays an important *Role* specifically for money that the commercial banks create, coined as Fractional Reserve Banking money, *monitoring* occurs via reserve requirements. Therefore, a *regulation* does not necessarily always have a formal legal character in the sense of laws, however, it can follow from *legislation*.

Harmonization of EU Payment Infrastructure to Prevent Value Extraction.
A *Rule Set* is implemented by a *Policy*, which can be defined as a plan of action, consisting of a coherent set of *mechanisms* to implement a *Rule* that follows from *legislation* and *regulation*. A *policy* as defined is that the Digital Euro will coexist with cash and commercial bank money. This entails that the financial domain becomes even more decentralized, as now more *Parties* can create and destroy money via several *mechanisms*. A *Rule Set* can contribute to satisfying a *Goal*, which is a desire to fulfill, for which an *Actor* has committed resources. Usually, a number of related *Rules* are needed to reach a *Goal*. Examples of central banks' *Goals* regarding Digital Euro are fostering financial inclusion and ensuring financial stability, and to create a harmonized unified payment infrastructure within Europe. *Objectives* measure satisfaction of a *Goal*.

Measurement of Goal & Objective Realization through Incentives.
While *Goals* are stated qualitatively (e.g., implementation of digital wallets), *Objectives* allow to measuring achievements of the *Goal* (e.g., implement digital wallets free of charge for all citizens by 2024). Multiple parameters *Objectives* need to be achieved for *Goal* satisfaction. Finally, an *Incentive* is a stimulation to achieve *Objectives* and indirectly obey *Rules*. *Actors* can be motivated to strive for reaching *Objectives* and hence *Goal* satisfaction. With the introduction of Digital Euro, the financial domain is becoming decentralized, and value speculation of the Digital Euro versus commercial bank money may occur. A *Reward* is a motivation to achieve *Objectives* and indirectly adhere to *Rules* (e.g., an attractive interest rate to stimulate citizens to adopt Digital Euro, and free of charge to use instead of physical cash). As we see with these examples there is a clash between the several monetary offerings. A *Penalty* is a punishment if *Objectives* are not met and *Rules* are not adhered to (e.g., if a customer's privacy is violated, a *Penalty* can follow for the commercial bank, given by the central bank).

6.3.2 Governance Construct Model

In this section we create governance models using the graphical notation for the case of Digital Euro, next to that, we structure the governance construct with model analysis and decision making structured as a table. To give an observation on how we created the DECENT governance models, using the DECENT software modeling toolkit, we kindly refer to the following video, which demonstrates how governance models can be created. https://www.dise-lab.nl/wp-content/uploads/2023/09/DECENT_Modeling-platform_Example.mp4

We now conceptualize and present the Governance Construct: Goal-Objective, Rule-Set, Incentive and Policy-Mechanism as the Governance Construct Digital Euro Model in Fig. 6.2. The model presents a structure that visualizes the most important governance design decisions. Also, the decentralized structure is visible, as each construct *leads to* another construct and visualizes the governance construct should be *implemented* as well. We remark here, that this governance construct model is just a slice of the Digital Euro domain. What follows now is that we explain and present the DECENT governance models per governance construct hereafter in detail.

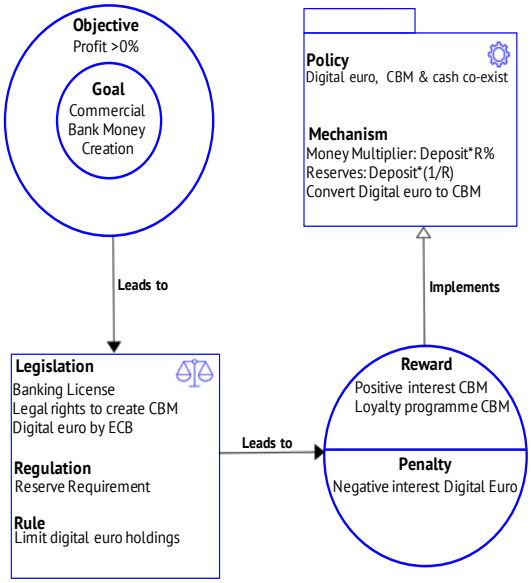


Figure 6.2: Governance Construct Model: Digital Euro

Digital Euro: Group-Actor Conceptualization.
In order to design the governance models, we first have to understand the structures of the concept *Party*, which is either a group or an actor this is identified as the first design decision. Following the Digital Euro case instantiation in Ch. 6.3.1 we construct Table 6.1, in which we identified the relevant *Party* that can either be a group or an actor that will be involved for the introduction of the Digital Euro and consequently how the financial domain of money creation will be impacted. We identified the following *Groups*: European Central Bank, National Central Bank (e.g. De Nederlandse Bank in the Netherlands) and commercial banks. These are groups because all are subjected to comply to the *Legislation* and *Regulation* by European Central Bank and, respectively, the national central bank in which the latter have an important regulating role. We demarcated customers as an *Actor*. As *Actors*, in principle they are solely responsible for their own economic well-being and actions. An *Actor* will interact with the Digital Euro, and commercial bank money creation, since the *Group* commercial banks use the assets of a customer to create commercial bank money. It is expected that the commercial banks will have a decreased access and capability to create commercial bank money, as the Digital Euro, will act as a competing currency. With this identification of the relevant actor and groups we can start by listing the decision making structure in Table 6.1.

Table 6.1: Governance Design Decision: Group-Actor

DECENT Concept	Governance Design Decision
Group	European Central Bank (ECB)
Group	Commercial Bank (CB)
Group	National Central Bank (NCB)
Actor	Customer (C) [Depositor/Borrower]

6.3.3 Goal-Objective Model

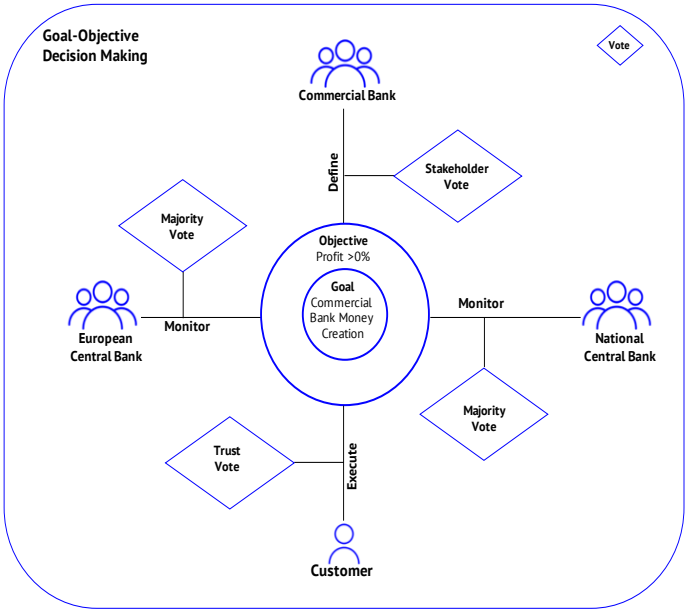


Figure 6.3: Goal-Objective Model: Digital Euro

Goal-Objective Conceptualization.
We identified the relevant *Group-Actor* as presented in Table 6.1. What follows now is the conceptualization of the governance construct: Goal-Objective, which is categorically presented as design decisions in Table 6.2. Based on the governance design decisions we developed a Goal-Objective Model, see Fig. 6.3, it represents the most important constructs and how the Goal-Objective *decision making* is occurring via the voting structure per *Party*. Within the financial domain of Digital Euro, each *Party* has their own (multiple) *Goals*. However, within a decentralized ecosystem a *Goal* and the corresponding *Objective* is not *decided* by just one *Party* as a hierarchical governance structure. Rather, it is decentralized, as the goal-objective model Fig. 6.3 represents. The *Role* and the *Party* structure influences the *Goal-Objective* structures. An important part of the size of an economy is how money is created and distributed. We frame this as Fractional Reserve banking (FRB), as presented in Ch. 4.

The *Group* commercial banks use the money from their customer, which is represented as an *Actor*, to create money via the FRB mechanism. Even within a Digital Euro setting, the *Goal* of the *Group* commercial banks is still to create commercial bank money by using assets from the *Actor* customer. The *Group* commercial bank via *Role* defines the *Goal* of creating commercial bank money, this *Goal* consequently measured by an *objective*. The *Objective* of the *Group* commercial banks is to make profits. Even though the *Group* commercial banks have a defined *Goal-Objective* it is still part of a larger ecosystem, as multiple *Groups* can create commercial bank money. This is subjected to the following governance *Decision making* structures.

The *Group* European Central Bank *Role* is to *monitor* together with the *Group* national central banks to what extent the *Group* commercial bank can create money and this is defined in the governance construct *Rule Set*, which will be discussed in the next section. The *Group* commercial banks can create commercial bank money through the relationship with the *Actor* customer. A customer "votes" in principle with their trust. If trust in a certain commercial bank decreases, the customer will remove their assets in either cash or transferring it to another commercial bank. This can have impact on the total money availability in the economy. A Digital Euro is always backed by the *Group* European Central Bank. The role of *Actor* customer is *execute* as their assets are stored at the commercial bank. If an *Actor*, e.g. a customer, trusts the *group* commercial bank the assets can increase and thus the *goal* of money creation can subsequently grow. It can have a direct-cause effect relationship in trust of the economy. Since the Digital Euro is backed by the group *European Central Bank*, the *Actor* customers have now a decentralized option in where and how to store their assets.

Table 6.2: Governance Design Decision: Goal-Objective

DECENT Concept	**Governance Design Decision**
Group Role Goal	ECB Define Goal: Creation Digital Euro to maintain trust in euro-currency
Group Role Goal	ECB Define Goal: Efficient, resilient and innovative payment structure. Creation Digital Euro to maintain trust in euro-currency. Prevent data harvesting from Big Tech.
Group Role Goal	NCB Monitor Goal: Maintain trust in euro-currency and payment infrastructure.
Group Role Goal	CB Define Objective: Create commercial bank money
Group Role Goal	CB Define Goal: Profit >0%
Actor Role Goal	C Execute goal: Accumulate asset via loan or deposit
Actor Role Goal	C Execute goal: Accumulate asset via loan or deposit
Group Role Objective	ECB Define Objective: Inflation max 3% in Eurozone
Group Role Objective	NCB Monitor Objective: Reserve requirement 5%
Actor Role Objective	C Execute Objective: Valuation asset + receive or pay interest

6.3.4 Rule-set Model

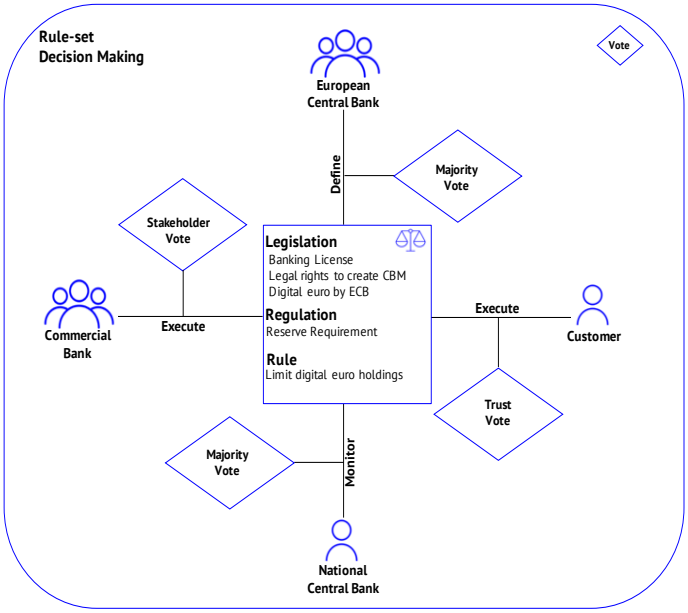


Figure 6.4: Rule-set Model: Digital Euro

Digital Euro: Rule-Set Conceptualization.
We now conceptualize the Rule Set model for the Digital Euro, see Table 6.3 in which the governance design decisions are defined. Based on the design decisions we developed a Rule-Set Model see Fig. 6.4. The Rule-set follows from design decisions about (1) Party structure and (2) Goal-Objective model as discussed in the previous sections. The *Rule-Set* governance construct consists of: Legislation, Regulation and Rules. These hold a formal and legal grounding in the law, which is solidified by *monitoring* the *rules*. When a commercial bank wants to create commercial bank money as a *Goal*, this is consequently subjected to the *Rule-Set*. First, the *Group*, commercial bank needs to obtain a banking license which is *defined* by the *Group*, European Central Bank, and this is defined in *Legislation*. Secondly, the *Group* commercial bank, executes the *legal* right to create commercial bank money, as this is *defined* by the *Group*, European Central Bank. These *Laws* are subjected to change, especially within the financial domain. The current payment financial infrastructure of the European Union is heavily dominated by non-European companies. This poses a risk for the stability, as creation and distribution of money within the euro-zone is in hand of non-European companies, that potentially can use their influence to interfere. Therefore, the *Group* European Central Bank *defined* the intention of a *law* to create a Digital Euro, and the distribution shall be *executed* via the *Group* commercial banks. The *Group* national central banks hold an important *regulating* and *monitoring* role. Each national central bank has to *monitor* the amount of money that is created.

Regulation to *monitor* the commercial bank money is via the reserve requirement, as each *Group* commercial bank is legally obliged to reserve a certain amount of the customers asset at the *Group* National central banks holding account. To prevent speculation of the Digital Euro, there is a *Rule* that limits the total amount of Digital Euro's a customer can hold in their digital wallet. This *Rule* can limit competition between the Digital Euro and the commercial bank money. The Digital Euro will not be a programmable currency as a *Rule*. The Digital Euro will not replace the commercial bank money as a *Rule*. This can be summarized as the decision making structure for the rule-set structure in which the voting per party also plays a significant role. A non-programmable currency is an important *Rule* and also promise to protect the privacy and is in line with the *Rule* of European Data protection and the Digital Operational Resilience Act. The decentralized structure has a provenance in the *Rule* that commercial banks will distribute the Digital Euro. This *Rule* also entails that the anti-money laundering on Digital Euro will be *executed* by the *Group* commercial banks, which consequently will be *monitored* by the *Group* national central banks.

Table 6.3: Governance Design Decision: Rule-Set

DECENT Concept	Governance Design Decision
Group Role Legislation	ECB Define Law: Privacy law and European Data Protection
Group Role Legislation	ECB Define Law: Sole custodian Digital Euro
Group Role Legislation	ECB Define Law: Banking license to create commercial bank money
Group Role Legislation	NCB Execute Law: Issue banking license for commercial banks
Group Role Regulation	ECB Monitor Regulation: Digital Operational Resilience Act (DORA) & European Data Protection
Group Role Regulation	ECB Monitor Regulation: Privacy on personal data processing ACT 2018/1725
Group Role Regulation	ECB Monitor Rule: Data Protection citizens
Group Role Rule	CB Execute Rule: Data Protection Customers
Group Role Rule	NCB Monitor Rule: Reserve requirement dotation from CB
Group Role Rule	NCB Monitor Rule: Total cap on money creation via commercial bank
Group Role Rule	ECB Execute Rule: Max creation Digital Euro to prevent harvesting Digital Euro
Group Role Rule	ECB Define Rule: Money multiplier to create commercial bank money
Group Role Rule	ECB Define Rule: Digital Euro will not replace commercial bank money
Group Role Rule	CB Execute Rule: Creation commercial bank money based on customer asset
Group Role Rule	ECB Define Rule: Digital Euro will not be programmable
Group Role Rule	ECB Define Rule: Digital Euro will be used for retail payments
Group Role Rule	CB Execute Rule: Digital Euro will be distributed via commercial banks
Group Role Rule	CB Execute Rule: Digital Euro will be limited in holdings max 500 €
Group Role Rule	CB Monitor Rule: Anti money laundering

6.3.5 Incentive Model

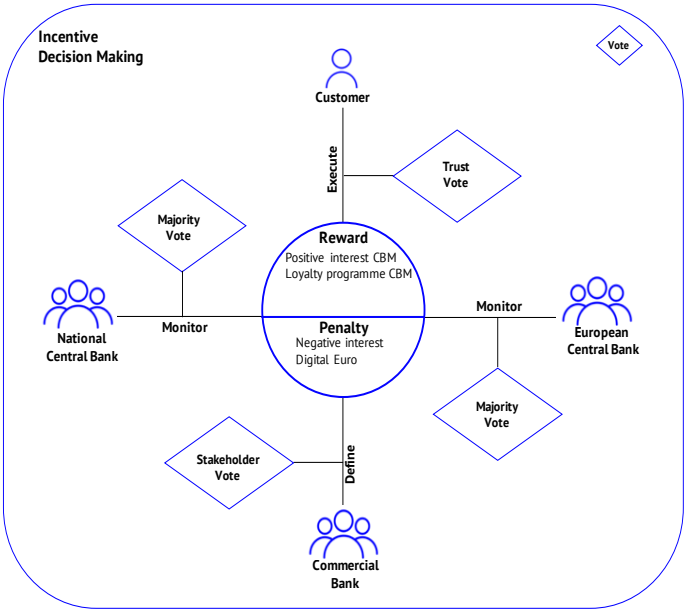


Figure 6.5: Incentive Model: Digital Euro

Digital Euro: Incentive Conceptualization.
We now conceptualize Incentive for the Digital Euro, based on the governance design decisions in Table 6.4, we developed the Incentive Model see Fig. 6.5. We clearly see a realistic clash between the currencies of Digital Euro versus commercial bank money, and how this structure impacts the governance construct *Incentive*. At one hand the Digital Euro will be introduced to unify the European payment infrastructure with as a result decreased dependence on Big Tech companies. However, on the other hand, the Digital Euro is also competing with commercial bank money. To prevent that Digital Euro's would be accumulated as it can be perceived as a stable investment, or even to drive speculation, the *Group* European Central Bank will introduce a *Rule* in place that does not allow an actor to hold more than €500 in their digital wallet per day. This is a structure that is decided by the *monitoring* role of the *Group* European Central Bank. To stimulate the holdings of commercial bank money a positive interest can be accumulated at the digital wallet of *Actor* customers.

The voting structure of the *Actor* customers, which influences trust, is how a customer assets will be stored. Therefore, the *Group* commercial bank introduces a *Reward*, e.g. a loyalty program that will *Reward*, stimulate to convert Digital Euro holdings to commercial bank money. If the *Actor* customers, prefers to hold amounts of Digital Euro, the *Group* commercial bank can *define* a *penalty* of negative interest to discourage large holdings e.g. savings account of the Digital Euro.

The *Role* of the National Central Bank also has an influence. Their *role* within the *incentive* structure is to *monitor* the interest rates on the Digital Euro versus the commercial bank money. Also the *reward* loyalty program and the conversion rates of Digital Euro to commercial bank money and vice versa will be subjected to *monitoring*.

Table 6.4: Governance Design Decision: Incentive

DECENT Concept	**Governance Design Decision**
Group Role Penalty	CB Monitor Penalty: Max transactions per day with Digital Euro
Group Role Reward	ECB Define Reward: Digital Euro free basic use by citizens
Group Role Reward	CB Define Reward: Loyalty program to use commercial bank money over Digital Euro
Group Role Reward	CB Define Reward: Positive interest compound on commercial bank money
Group Role Reward	CB Define Penalty: Negative interest to hold Digital Euro

6.3.6 Policy-Mechanism Model

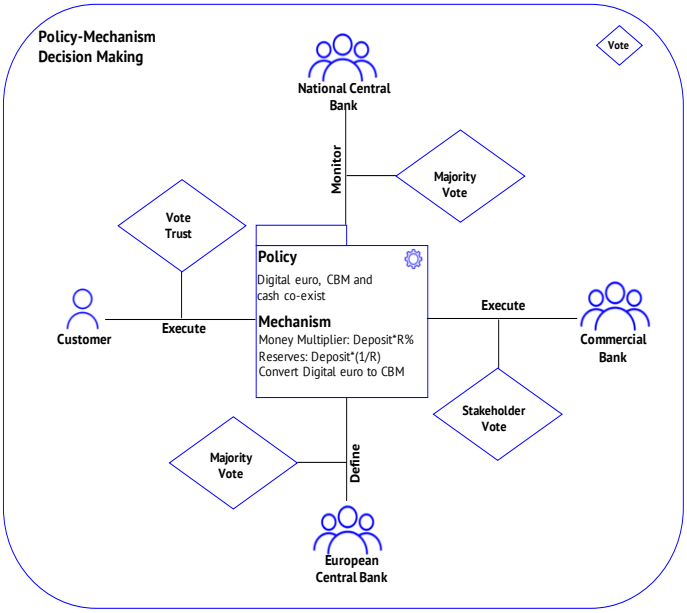


Figure 6.6: Policy-Mechanism Model: Digital Euro

Digital Euro: Policy-Mechanism Conceptualization.
We now conceptualize Policy-Mechanism for the Digital Euro based on the governance design decisions in Table 6.5 we developed the Policy-Mechanism model see Fig. 6.6. A *Policy* is a plan for action, consisting of coherent set of *mechanisms*, to implement a particular *Rule-Set*, *Incentive*, and *Goal-Objective*. The *Policy* that will be *implemented*, are defined in the Rule-Set model see Fig. 6.4. The *Actor* customer has again an influence via *Vote*, even though there are policy and mechanisms in place to create money in the economy, it all ties together via the *vote-trust*. Essentially the *Policy* that will be implemented is that cash (banknotes and coins), Digital Euro and commercial bank money will co-exist. This *Policy* is *defined* by the *Group* European Central Bank, *executed* by the *Group* commercial banks and *monitored* by the national central banks. The *Policy* is implemented by the *Mechanism*.

The *Group* commercial banks are not allowed to create commercial bank money infinitely, thus the *mechanism* reserve requirement is implemented, and *monitored* by the *group* National central bank. The *mechanism* money multiplier is *defined* by the *Group* European Central Bank, depending on the state of inflation and price stability, the money multiplier formula is *defined* and is adjusted over time. There is also tension between the Digital Euro that an *Actor* customers can hold versus the commercial bank money. There needs to be a decision *mechanism* that can determine the conversion between Digital Euro and commercial bank money and vice versa.

The *group* commercial bank will have an increased tension, as the stakeholders of the commercial bank expect profit and growth of their assets portfolio. With the introduction of the Digital Euro the *groups* European and national central bank increase their control on the financial domain and how money is created, stored, exchanged and destroyed.

Table 6.5: Governance Design Decision: Policy-Mechanism

DECENT Concept	**Governance Design Decision**
Group Role Policy	ECB Defines Policy: Cash, Commercial Bank money and Digital Euro will co-exist
Group Role Mechanism	ECB Define Mechanism: Money Multiplier Deposit*R%
Group Role Mechanism	CB Execute Mechanism: Money Multiplier Deposit*R%
Group Role Mechanism	NCB Monitor Mechanism: Money Multiplier Deposit*R%
Group Role Mechanism	CB Execute Mechanism: Reserve Requirement Deposit*(1/R)
Group Role Mechanism	NCB Monitor Mechanism: Reserve Requirement Deposit*R%
Group Role Mechanism	CB Execute Mechanism: Convert rate Digital Euro to commercial bank and vice versa

6.4 Reflection Commercial Bank: ABN AMRO

What follows now is the reflection of our case study partner, the commercial bank ABN AMRO, Market Infrastructure Group in what the value and limitations are of DECENT: A Model-Based Approach to Design Decentralized Governance.

Introduction.
The European Central Bank (ECB) is investigating the development of a Digital Euro and in June 2023 the European Commission (EC) proposed a regulation to establish the Digital Euro. The arrival of Digital Euro, will most likely have profound implications on commercial banks as the Digital Euro offers an alternative to the current means of digital payments offered by banks. However, the actual design implication of the Digital Euro depends on the following groups: (1) European Central Bank (ECB) design choices, (2) European Commission (EC) to design the regulatory framework and (3) Commercial banks, how to shape and design a financial market response with a new disruptive business model. For a proper response those implications should be designed by using models, by also including into the design equation which technology will be used to shape the appropriate governance model. Thus, the commercial banks need to assess a future situation with many unknown variables that asserts subjective interpretation, which calls for a model-based governance design approach.

Value of a Model-Based Approach.
By taking the approach of a model-based design approach allows us to create a powerful baseline for common understanding as the process enforces many groups to determine clear definitions and semantics, and to conceptualize decentralized governance structures. The effort to identify and define each party including governance, roles, goals and intentions creates an improved and consistent understanding of the domain at hand. It enabled us to find an internal understanding and develop a position to define in the governance structures. It enables us to pinpoint the challenges certain design choices will lay upon banks, like the responsibility commercials banks will have on Anti Money Laundering (AML) and funding the digital infrastructure of the Digital Euro wallets, that will eliminate the role of a trusted third party that the commercial bank plays to a certain extent. It also allowed us to explain visually what the written language could not imply or define. The models outcome gave a clear direction to focus on in our worldwide banking lobby as it is only fruitful to lobby if the interest of the party towards the lobby is directed is also served.

Decentralized Governance Design using DECENT.
DECENT Digital Euro models have clearly demonstrated that commercial banks need to ensure their role in Fractional Reserve Banking must be protected as much as possible, this to prevent a centralized role of the European Central Bank. In economics it is generally accepted money has consistently have three functions: store of value, unit of account, and medium of exchange. In case of the Digital Euro the unit of account remains the same as the introduction of the Euro already changed that earlier. We have positioned "function store of value" to issue debt in commercial money only to provide competitive interest. This can be achieved in design with the ECB and EC governance rules to make the function as medium of exchange for the Digital Euro as efficient and innovative as possible, and invest improvements for commercial bank money as medium of exchange.

A Blockchain Technology Led Banking Model.
The outcome of the Digital Euro DECENT models is clear; the bank has determined the main focus on which to develop positions to bring to the financial market and involve stakeholders and integrate design choices. This design approach allowed us to develop a unique position and as such we have a front runner reputation of a bank that wants to collaborate, innovate and bank for better. Furthermore, it also propelled us to make important design decisions how we will have to organize our IT infrastructure as many banks are having to deal with legacy systems that require a lot of (outdated) knowledge and does not contribute towards innovation. DECENT contributes clearly in understanding our role, position and the impact of the Digital Euro, and how the roles of other groups impact the decision making structures. By evaluating the DECENT Governance models, we are solid and confident in taking the decision in building a blockchain based banking model, that is integrated with the governance structures for the Digital Euro.

Implementation.
For a successful implementation of the Digital Euro, there will be an alignment and coordination in which banks and central banks/legislators ideally find each other to achieve an optimal connection and thus allow the Digital Euro and underlying governance structures to function optimally. In our view, this alignment will be done using and applying DECENT. As this model-based approach allows every party to analyze, observe and understand the impact of the governance design. Next to that governance decisions of the digital ecosystem by elaborating choices expressed as models and ultimately in software. Commercial banks are therefore also part of that system as a distributor of money. The system only works properly if all groups are properly connected to each other. This is a completely different approach than the current one in which parties take verbal positions to protect short-term sight and lack of vision. By modeling and demonstrating the software objectively what the result will be, we as a bank can make choices for implementation that will yield the greatest benefit for us and our customers in the long term.

Discussion.
Concretely, the DECENT model-based approach to design the governance structure by developing Digital Euro models allowed us to create a powerful baseline basis for common understanding as it enforces participants to determine clear definitions and semantics, and model the definitions by following and designing the decentralized governance structures. The DECENT governance models allowed us to explain visually what the written language could not imply or define. The creation of a graphical notation seems helpful in designing, structuring and explaining decentralized governance for the case Digital Euro. It enables a team to agree on a common understanding with minimal risk of different interpretations and simplifies explaining the impact which could result in an effective and successful implementation.

Limitation.
This model-based approach demands extensive thinking capabilities of the participants to think and to discuss, it is challenging to define at which granular level which role and processes should be involved. It takes time to get someone not involved in the process up to speed and able to understand the model thus that meaningful feedback can be provided. It is specific knowledge: decentralized governance design and requires a steep learning curve.

Conclusion.
The DECENT governance models outcome gives a clear direction to focus on towards our global positioning on the Digital Euro and determines with whom to collaborate as several groups via the governance structures have to align. DECENT solves asymmetry as with decentralization transparent alignment between groups is crucial for success. Digital Euro modeling has clearly demonstrated that commercial banks need to ensure their role in fraction reserve banking, and this must be protected as much as possible, as Digital Euro will compete with the commercial bank money. This can be achieved to align with the European Central Bank to make the function as medium of exchange for the Digital Euro as efficient and innovative as possible. The models also inspired us to make important design decisions how we will have to organize our infrastructure as many banks are having to deal with legacy systems that require a lot of (outdated) knowledge and do not always prioritize innovation. Evaluating the DECENT governance models, we are sold in our motivation in experimenting with blockchain based banking model, that is integrated with the governance structures that the Digital Euro requires.

6.5 Reflection

We developed the governance system of the Digital Euro by using the DECENT software modeling toolkit, this with the goal of assessing the usefulness of our method. A recap of the work done so far in this dissertation:

- The meta model as a tool to instantiate and describe the governance structures.
- Visualization of the decentralized governance design artifacts.
- Governance models presented from several levels of decentralization.
- Each governance construct presented as a design artifact and is analyzed.
- Design decisions for every governance construct that are traceable and visual.

We did this to learn if we can visualize decentralized governance design artifacts, develop the models and derive governance design decisions. We reflect by subject area and intended user base expressed as observations and lessons learned.

Goal.
The main goal of this dissertation is to develop a model-based approach by conceptualizing decentralized governance. This should serve as an instrument to model, design, and structure decentralized governance for digital ecosystems.
Sub-Goal.
The sub-goal for this chapter is assessing the effectiveness of the DECENT a model-based approach, to do so we develop the case of the Digital Euro to design DECENT governance models with our case study partner.

Subject Area. Assessing to what extent the DECENT graphical notation is helpful in designing, structuring and explaining decentralized governance.
Observations.
O1.1 A granular and precise design approach of the Digital Euro case as this is achieved through case instantiation, design of models, visual presentation of the artifacts and design decisions that are traceable and linked.
O1.2 Each governance construct is designed and linked on several levels of decentralization and this is presented visually as well.
O1.3 The models are exclusively about decentralized governance as we have a consistent design approach using only DECENT, from the meta model as case instantiation and conceptualization of the models by using the software modeling toolkit.
O1.4 Using software to create models allows for a more precise, consistent and accurate modeling and design approach.
Lessons Learned.
L1.1 Design guidelines in how to develop a DECENT governance model would be of value.
L1.2 DECENT software modeling toolkit is a prototype, a web-based cloud tool would encourage others to use it as well. As current software requires local installation.

Modeling. To what extent can our case-study partner, the commercial bank, understand the notion of decentralized governance for the Digital Euro, using exclusively DECENT governance modeling.
Observations.
O2.1 Evaluating the DECENT models has led to the governance design decision that the commercial bank will experiment with a blockchain based banking model, that is integrated with the governance structures the Digital Euro requires.
O2.2 Identification of potential centralized governance structures that might occur with the introduction of the Digital Euro.
O2.3 The Digital Euro can potentially compete with the Fractional Reserve Banking system, which can lead to currency speculation for the Euro.
O2.4 The DECENT governance models allowed the commercial bank to explain visually what the impact is on their positioning but also the design implications for all parties involved through a concise and transparent conceptualization.
Lessons Learned.
L2.1 Decentralized governance design and the ability to develop the models, such as industry consultants requires extensive training and the ability to think from an abstract point of level.
L2.2 Design guidelines in how to use the DECENT software modeling toolkit and how to develop the corresponding governance models would be of value.
L2.3 Dependency (e.g. centralized knowledge) occurring on the academic scholars that developed the Digital Euro governance system, ideally the case-study partner should be able to develop these independently.

7

Discussion

In this chapter, we present original contributions to science. In addition, we critically discuss, assess, and evaluate the limitations of the contributions.

Decentralization is from a societal perspective a response to design digital ecosystems in which (1) value extraction is prevented, (2) economical transparency is offered, (3) to dismantle centralization and (4) to achieve decentralization in terms of operations but also in how decisions are defined, executed and monitored. In summary, the goal is to decentralize power structures and to make it visible which groups are actually in control of the digital ecosystem at hand. In addition, decentralized governance contributes to visualizing which groups have substantial economic influence. An example of value extraction is that certain profit structures are highly concentrated at just a few key players, which in turn drive up the prices from a monopolistic position. Within Europe, we are highly dependent on critical financial and energy infrastructures from parties outside Europe. Take, for example, the energy network. Europe is highly dependent on certain global parties for energy and, as such, decentralization of the energy network and transition should go hand in hand. The payment infrastructure of Europe is also in the hands of powerful Big Tech companies as well. Such centralized structures that aim to influence and harvest personal data are questionable, and this propels the requirement for decentralization in Europe. We also have to develop the energy and financial structures towards self-reliance and decentralization of the payment and energy network from a global perspective. Most crucially, to eliminate the trusted third party to prevent a platform structure in which value extraction can occur. How to organize such (highly critical) complex decentralized digital ecosystems is a governance design decision.

In this dissertation, we present DECENT: A Model-Based Approach in Designing Decentralized Governance. We conceptualized the domain of decentralized governance by presenting the semantics as a meta model. This meta model allows to represent and describe decentralized governance, next to that we created the DECENT graphical notation which is implemented as the DECENT software modeling toolkit. We achieved this by studying the phenomenon of decentralized governance through industry-strength cases: Peer-to-Peer Energy Trading, Fractional Reserve Banking and Digital Euro. These digital ecosystems are characterized by decentralized decision making, and the asset at hand is also decentralized. We structure the discussion based on the academic contribution and critically discuss the limitations. We motivate why our contributions to science are original. In addition, we critically assess the contributions and discuss the limitations.

7.1 Contribution I

Defining and Conceptualizing the Notion of Decentralized Governance in Digital Ecosystems.

How can we critically determine that we did a correct review and analysis of the notion decentralized governance. We reviewed the most known decentralized digital ecosystems Bitcoin and Ethereum, and focused on decentralized governance to conceptualize and understand definitions that are of relevance. Our focus is on understanding and developing a correct notion of decentralized governance. In order to do so, we focus on the definitions and why decentralized governance is different compared to centralized governance structures. We observe that decentralized governance has become a topic of design with the introduction of decentralized digital ecosystems. For a digital system to be positioned as decentralized, the governance, thus the rule-making structures should be equally decentralized over the participants, too. We conducted a model-based analysis approach to understand the governance structures of Bitcoin and Ethereum. We observe that governance structures, in terms of decision-making of Bitcoin and Ethereum, are rather centralized to a certain extent. Although operations are decentralized to execute peer-to-peer transactions, the governance structure is not fully peer-to-peer. We also learned and positioned the governance paradigm model in which decentralized governance is structured with a basic set of semantics, which will be used to construct and conceptualize the domain of decentralized governance as a meta model.

Summary.

1. Defining and explaining a decentralized digital ecosystem.
2. A model-based analysis of Ethereum and Bitcoin governance structures and the role these systems play in defining decentralized ecosystems.
3. Identification of governance concerns in Bitcoin and Ethereum.
4. Relevance of decentralized governance as a topic of study and the confirming role of decentralization in governance.
5. Conceptualization of the governance paradigm model, as the semantics of this model are used as input to explore the design artifacts for decentralized governance design.
6. We motivate and explain why decentralized governance is an important topic of design in shaping the digital ecosystems that we will study.

Limitation.

We studied the governance structures of Bitcoin and Ethereum and learned that governance, as a design concept, is quite technical and informally organized. The operations of governance structures in Ethereum and Bitcoin are structured via a technical approach, and the organization is via smart contracts. As such, the limitation here is that decentralized governance goes beyond a technical approach as it should be made understandable for every party involved. Studying technical governance structures gives a rather narrow view on conceptualizing and defining governance. Learning from this limitation, we decided to focus on real industry cases of decentralized governance that go beyond the execution of technical operational governance.

7.2 Contribution II

Conceptualization of Decentralized Governance Design by Presenting the Semantics as a Light-weight Informal UML Meta model.
We developed this work as having a (democratic) responsibility in shaping and understanding how the rules of engagement are decided, and more importantly which parties decide, monitor, and execute the decisions for digital ecosystems design, and in society at large. Thus, governance is about relations between design artifacts and how these are influenced by parties and their corresponding roles. To do so we conceptualized decentralized governance by executing a systematic literature review to derive the relevant design artifacts. We assessed the meta model by applying it as a tool to derive, structure and instantiate decentralized governance structures and related decisions for the cases of: P2P Energy Trading, Fractional Reserve Banking, and Digital Euro. By doing so, in developing the governance systems for these digital digital ecosystems, it increases the validity and generalizability of the DECENT meta model.

Summary.

1. Systematic literature review to derive design artifacts for decentralized governance.
2. Conceptualization decentralized governance presented as the DECENT meta model.
3. Meta model construction via: exploration, requirement, knowledge acquisition, conceptualization and assessment.
4. Well-defined semantics and definition of each design artifact for the design of decentralized governance.
5. Design artifact governance construct conceptualizes the meta model as decentralized.
6. Assessment of the meta model by applying it to the industry strength cases of: P2P Energy Trading, Fractional Reserve Banking, and Digital Euro.

Limitation.
To the best of our knowledge, we are the first scholars that developed a model-based approach in designing and conceptualizing decentralized governance; naturally this comes with the following limitations. Even though the meta model is semantically rich and well-contained, it is rather abstract. Our goal is to make decentralized governance understandable for everyone involved and not only to give a rather technical conceptualization of decentralized governance. A hard limitation of the meta model is that we developed it by studying and exploring through the P2P energy trading industry case and the systematic literature review. In the development of real-world industry cases, we did not use it as a visualization method for our case study partners, but rather as a descriptive tool to describe governance structures and relations. The meta model was not usable to present to industry consultants who are business governance orientated. To achieve computational governance, (e.g. on-chain governance) which entails support and implementation of governance structures, the meta model needs to be more detailed e.g. by including LegalRuleML [55], Symboleo [56], and facilities for process modeling, e.g. BPMN [110].

7.3 Contribution III

Assessment and Evaluation if Existing Modeling Techniques [*e*^{3}*value* & BPMN] are suitable to Represent Decentralized Governance Models.
Experimenting with several existing modeling languages proved to be quite valuable, as we were able to generate and represent governance models from the business and process modeling angle. We also learned extensively about the usability of the notations of *e*^{3}*value* and BPMN and to what extent the notation can actually visualize decentralized governance. To extend the usability of the meta model and to represent governance models that are understood by business and technical parties we used the *e*^{3}*value* and BPMN language. We selected *e*^{3}*value* and BPMN because these languages facilitate a multi-actor approach, and governance design occurs at value and process level. The advantage of using *e*^{3}*value* and BPMN is the fact these are well known. We represented a governance model expressed as *e*^{3}*value* and a BPMN model for the case of Fractional Reserve Banking (FRB). To be able to represent it as a governance model we related the design concepts of the meta model to *e*^{3}*value* and BPMN concepts. We were also able to derive governance design decisions based on governance models, by relating the concepts *e*^{3}*value* and BPMN to the concepts of the meta model.

Summary.

1. Using the meta model as a descriptive tool to instantiate, analyze and construct governance structures of the Fractional Reserve Banking case.
2. Representing and analyzing decentralized governance models using *e*^{3}*value* and BPMN.
3. Deriving governance design decisions based on the *e*^{3}*value* and BPMN models.

Limitation.
Using existing languages to represent governance models proved to be challenging and limiting. The BPMN governance model was not deemed useful by our case study partner. BPMN was not used in discussions of the governance structures of the FRB case, as it is quite a detailed model. The many notations of BPMN made it challenging to visualize decentralized governance, and it was also not understood by our case study partner. Next to that, BPMN has an extensive set of notations, and our design goal is a tractable, governance model with a minimum number of concepts of the shared conceptualization of a domain, namely decentralized governance in digital ecosystems. We admit that relating the concepts of *e*^{3}*value* and BPMN proved to be difficult, and challenging to align. Furthermore, expecting that industry consultants that is in charge of designing decentralized governance, to learn three different languages: DECENT, *e*^{3}*value* and BPMN is a knowledge gap difficult to overcome and not realistic. This was a consistent issue in developing the case of Fractional Reserve Banking. To visualize and represent decentralization especially at the level of party and role was not visualized in *e*^{3}*value* and BPMN models, is a hard limitation.

7.4 Contribution IV

DECENT graphical notation to design decentralized governance which is implemented as the DECENT Software Modeling Toolkit to support design of decentralized digital ecosystems.

By evaluating the results of representing decentralized governance models using existing techniques (e^3*value* & BPMN) we are conclusive to develop the DECENT graphical notation implemented as the DECENT software modeling toolkit. This allows for describing, designing, analyzing and visualizing decentralized governance models. Capitalizing and learning from the cases of P2P Energy trading (Ch. 3) and Fractional Reserve Banking (Ch. 4) we developed a vision in how decentralized governance should be designed, visualized and presented. First, we identified the design requirements for the notation. Next, we developed the graphical notation that utilizes the DECENT meta model as a starting point. For each notation we provided a description and how it relates to the meta model. We discuss the design choices, and the governance models are constructed and explained using the DECENT notation. We implemented the DECENT graphical notation in the case tooling of ADOxx. Implementing the notation in a software environment proved to be quite valuable, as we want to study as a long-term goal decentralized governance in the context of computational governance. All documentation and the DECENT software libraries are open source available on Github[1]. The DECENT software modeling toolkit is a viable and stable software environment for future research to develop on-chain computational governance.

Summary.

1. A clear formulated set of design criteria for the graphical notation.
2. Creation of the DECENT graphical notation as an extension of the meta model.
3. Decentralized governance models can be constructed using the DECENT notation.
4. DECENT graphical notation implemented as the DECENT software modeling toolkit in ADOxx.

Limitation.

Learning a new language as we propose takes a serious commitment and a significant time to teach, develop, and explore the appropriate business case. It is crucial to further assess the usefulness of our design approach, in other domains, preferably too. DECENT is a level of abstraction that we propose that can be challenging to understand, however, this is not unique for DECENT only, as this holds as a limitation for other modeling languages as well. The domain of decentralized governance design is an emerging research field and more validation is absolutely necessary. Although we explain each notation, the corresponding governance models with clear examples using the case of the Digital Euro in Ch. 6, we did not provide a manual on how to construct DECENT governance models. This can be challenging for others to use. We see that this can be potentially solved by just looking at the structure of this dissertation and with the multiple cases we developed and created, there is a reasonable amount of governance structures and models available for reference purpose.

[1] https://github.com/DragonGemini/DECENT-Modeling-Toolkit

7.5 Contribution V

DECENT: A Model-Based Approach to Design Decentralized Governance, which is Developed and Assessed with the Cases of P2P Energy Trading, Fractional Reserve Banking and Digital Euro.

The central claim of this dissertation is that decentralized governance can designed by taking a model-based approach. This design approach contributes in formulating the right question in design of decentralized governance for digital ecosystems. We assessed and developed the domain by taking real industry-strength cases that focus on decentralized governance for digital ecosystems namely: P2P Energy Trading, Fractional Reserve Banking and Digital Euro. We developed and visualized the decentralized governance design structure and systems for these cases using DECENT. The DECENT model-based design approach for decentralized governance is assessed in detail with the case of the Digital Euro. We structured the Digital Euro case by using the meta model as descriptive tool. Next to that we conceptualized the Digital Euro first at the governance construct model level. Consequently, we modeled the governance constructs separately to visualize a finer grained model that clearly represent decentralized governance between party, role and governance construct, and a decision making as well. This allowed us to describe and model the governance construct precisely and derive the decision making per party and role. The DECENT governance models for Digital Euro present an accurate view of the several decentralized governance constructs. More importantly each model visualizes how the governance construct is influenced, decided, monitored and executed by which party. Our case study partner, the commercial bank also provided a detailed reflection why DECENT a model-based design approach is useful and how it is beneficial to formulating their role and position in the construction of a IT driven financial domain in EU through the development of the Digital Euro.

Summary.

1. We claim that decentralized governance can be designed using the DECENT model-based approach.
2. Conceptualizing decentralized governance design through a model-based approach, presented as the DECENT meta model and DECENT graphical notation implemented as the DECENT software modeling toolkit.
3. DECENT software modeling toolkit is assessed and applied at the case of the Digital Euro. This environment is viable to develop computational governance to implement governance models.
4. DECENT is developed with real industry cases in designing decentralized governance of the following digital ecosystems: P2P energy trading, Fractional Reserve Banking and Digital Euro.

Limitations.

We have taken a model-based approach, to understand if we can design decentralized governance. This redeemed to be possible, however our model-based approach should be replicated and assessed by other scholars as well, to increase (external) validity. The DECENT graphical notation is tested and assessed only with the case of the Digital Euro.

Obviously this is a hard limitation as this affects the generalizability of the notation. The notation should be assessed and addressed with other cases as well to increase generalizability. The work produced in this dissertation is an important step forwards, however the work is by far not done yet, as in this dissertation our focal point is designing decentralized governance. Implementation of decentralized governance models we consider as a topic for computational governance, which is not part of the scope of this dissertation. We provide suggestions for future work in Ch. 8.2.

8

Conclusion

The governance paradigm has been propelled by a response of society to prevent value extraction by designing digital ecosystems that are decentralized. The rise of blockchain technology led to experiments in shaping such digital ecosystems. As governance is a topic of design, there is a clear need for software tooling in shaping decentralized ecosystems. A model-based design is an effective approach to manage and design these complex digital ecosystems. To provide scholars and digital ecosystems designers with an intuitive model-based approach of decentralized governance we propose and developed the DECENT software modeling toolkit. This is a model-based design approach, solidified with the meta model, graphical notation and implemented in the software environment of ADOxx. This allows for design, analysis, description, and evaluation of DECENT governance models for digital ecosystems. This model-based approach has been developed and assessed in with real-industry strength cases of P2P Energy trading, Fractional Reserve Banking and Digital Euro. We answer the research questions and provide a research outlook for future work.

Decentralized governance continues to be a topic of high interest specifically in the domain of decentralizing digital ecosystems. Decentralization as a design instrument to shape a society that is less reliant on centralized structures. The governance paradigm has been propelled by blockchain technology into several experiments in the shaping of digital ecosystems. As this is a topic of design, there is a clear need for tooling in shaping digital ecosystems, in which the DECENT software modeling toolkit is an effective approach to design and manage these complex digital ecosystems. To provide scholars and end-users with an intuitive model-based approach of decentralized governance, we propose the model-based design approach, which is solidified with the meta model, graphical notation and implemented as the DECENT software modeling toolkit. To validate our approach, we first conceptualized decentralized governance design with the meta model which is an informal light-weight UML model. We tested the descriptive capacity of the meta model by formalizing and applying it to three industry-strength cases of: Peer-to-Peer Energy Trading, Fractional Reserve Banking and the Digital Euro. By using the meta model we represented (partly) governance models using existing languages such as e^3*value* and BPMN. This was an important part of this research, as we could sharpen our research direction and as such developed the DECENT graphical notation, which is implemented as the DECENT software modeling toolkit. To validate and assess the approach we designed, we used the case of the Digital Euro to develop, describe and conceptualize governance models using our modeling toolkit.

8.1 Research Questions

In this dissertation we relied on several techniques, which consist of exploring, representing, conceptualizing, developing and implementing the DECENT graphical notation and the DECENT software modeling toolkit. This approach contributes in formulating the answers on our research questions.

RQ1: How do approaches for decentralized governance in digital ecosystems compare?

We analyzed through a model-based approach the most known digital ecosystems that claim to be transparent [28] and decentralized in their decision making (Bitcoin and Ethereum) [22]. Although the decentralization aspect is true for the operational execution of governance, the decision-making structure is still fairly centralized and not transparent. This entails that such digital ecosystems that claim to be decentralized can only be realized if the governance decision-making structure is transparent and decentralized over several parties. We also explored existing digital ecosystems that are inherently decentralized (prior to the emergence of blockchain technology). Hence, we introduced the cases of Peer-to-Peer Energy Trading, Fractional Reserve Banking and the Digital Euro. By studying decentralized governance in digital ecosystems we were able derive the semantics, with the goal to make it explainable for all parties involved in the design of decentralized governance for digital ecosystems. Current decentralized governance approaches are rather operational and technical orientated, which is an occurrence of knowledge concentration.

RQ2: What is a well-founded conceptualization of the notion decentralized governance?
Decentralized governance is about which groups in society affect, define, execute, and monitor governance constructs. We developed the DECENT meta model see Fig. 3.1, which is a semi-formal UML light-weight model that represents classes and defines relationships, structures and more importantly models the behaviors between classes, conceptualized as decentralized governance design. We formulated the design requirements for decentralized governance conceptualization as below:

1. **Exploration.** We focus on digital ecosystems with real industry-strength cases to conceptualize decentralized governance.
2. **Requirement.** We express the requirements regarding meta model construction in terms of: goal, purpose, subject area, and intended user base.
3. **Knowledge acquisition.** Following our requirements and to ensure commitment, e.g., a shared understanding of the domain, we executed a systematic literature search on the concept of decentralized governance in ecosystems, as defined by our purpose requirement.
4. **Conceptualization.** The governance models are conceptualized based on the knowledge and specification phase. We consider the meta model as a semi-formal, explicit specification of a shared conceptualization of a domain, namely decentralized governance in digital ecosystems.
5. **Assessment.** We argue that in order to develop decentralized governance, we have to understand the to-be-developed domain and the related relations within a real-world setting. Therefore, we explored and assessed usability of the DECENT meta model as a tool to describe governance with industry-strength case of P2P Energy Trading, Fractional Reserve Banking, and Digital Euro, this approach increases the usability and generalizability of the meta model.

In the conceptualized meta model we present several design constructs at an abstract level. Although this conceptualization of decentralized governance design is an important step in the domain, we concede that the identified governance design artifacts can be explored further. For example, the governance construct, *Rule-Set* might be expressed and implemented using the technique LegalRuleML [55]. This technique is focused on the notion of legalization. To achieve computational governance, which entails support and implementation of governance models, the meta model needs to be more detailed e.g. by including LegalRuleML, Symboleo, and facilities for process modeling, e.g. BPMN. The attributes of the governance constructs should be assigned to further enrich the domain. The meta model we have developed is an abstract notion of decentralized governance design, hence we positioned it as 'meta'.

RQ3: To what extent can decentralized governance be represented by using existing modeling techniques such as *e³value* and BPMN?
Following our design requirements, which are: purpose, subject area and intended user-base we evaluate it as following. The research idea is to see if through a model-based approach, the intended user base, e.g. industry consultants, understand the notion of decentralized governance through models. Using existing modeling techniques, *e³value* and BPMN, we conceptualized decentralized governance for the digital ecosystems of fractional reserve banking and P2P energy trading, which allowed a model-based approach of decentralized governance design.

As we strive for a visual and conceptualization of decentralized governance, we found that *e³value* and BPMN are capable of representing a number of governance design decisions. Using the meta model, we created governance models represented as e³value and BPMN models. The combination of several design techniques, as each technique has its own design philosophy, was perceived by our academic peers and case study partner as difficult to understand; moreover, the tracing and consistency of the models were not there. Following *e³value* and BPMN as a valid method to design decentralized governance would require stakeholders to learn several complex modeling languages to design decentralized governance, which is a serious knowledge gap. Governance as a topic of design is complex, and to increase that complexity by using several languages to visualize decentralized structures is challenging, and it does not fulfill our design requirements, as our design goal is to minimize complexity.

Representing decentralized governance using existing languages is not sound and not convenient, to design and to explain to e.g. industry consultants. As a design goal, ideally, a model should be understood and explained in a few minutes. BPMN presents a granular level of abstraction that is too complex for our purpose. Although we explored and related the meta model with the *e³value* and BPMN language, it deemed not to be tractable. Also by relating the meta model concepts to the *e³value* and BPMN language, we observed that the consistency was not there, and we are coupling several design philosophies together which simply does not work. Next to that, we observed that we could not formulate each governance construct precisely and separately as it was all concentrated in just one model. Using existing languages we could not model decentralization between the governance construct and the party, which is a solid concern we identified.

RQ4: How can decentralized governance be conceptualized by a graphical notation and supported by software tooling?
We experimented with existing modeling techniques as discussed and we are conclusive that it does not fulfill our design requirements to visualize and design decentralized governance models. Therefore, we developed the DECENT graphical notation, following the conceptualization of decentralized governance design presented as the meta model. The graphical notation is implemented as the DECENT software modeling toolkit. This modeling toolkit allows for design, analyze, and assessment of decentralized governance models for digital ecosystem design. The DECENT software modeling toolkit is an important contribution towards operationalizing and implementing governance. The DECENT software modeling toolkit can serve as the starting point to develop computational governance and facilitate on-chain governance execution, which is our long-term research goal.

RQ5: Is a dedicated graphical notation helpful in designing, structuring and explaining decentralized governance?
We developed the DECENT graphical notation for decentralized governance design which allows us to create, assess and analyze governance models. To assess the usability of the graphical notation we applied the DECENT software modeling toolkit to design the governance system of the Digital Euro case. This is about the design and exploration of governance structures of the Digital Euro system. Comparing using our graphical notation with existing languages, we observed the following. Using the DECENT graphical notation, the level of granularity is more precise and consistent comparing it by using existing languages. We were able to design and formulate this as a decentralized governance construct. This allows for a precise definition in defining the party and the role and how this affects the governance constructs. This granularity of decentralization and transparency in which the party takes the decision is simply not possible with existing modeling languages. Next to that, we applied the meta model as a tool to describe, design, and analyze governance models for the cases of P2P Energy Trading, Fractional Reserve Banking, and Digital Euro.

8.2 Future Work

The achieved results in conceptualizing and formalizing decentralized governance design are encouraging, but much more research is required, there are a number of steps for future work that are of relevance.

Computational Governance.
Our contribution to science is a model-based approach to design decentralized governance. The logical next step would be to implement and execute the DECENT governance models computationally. Ideally, this should be executed via on-chain governance, which may be supported by blockchain technology. As we have identified the governance concerns in Bitcoin and Ethereum, the decision making is to a large extent centralized and is facilitated via off-chain governance discussion forums. Ideally, computational governance software should allow for implementing and also executing the governance constructs following the design of decentralized governance models. A next step would be developing software that can actually implement and execute the governance models computationally. To mature the domain of decentralized governance, developing software to support computational governance would be of value. A computational approach will help to implement the proposed governance models. This will lead to increased transparency and might contribute towards solidifying the decentralized aspect stronger. An example of computational governance is the following. Within P2P energy trading, to prevent centralization and manipulation of price and demand, a (daily) cap of energy trading can be introduced. This means that every party can only trade for a pre-defined cap kWh per day. To implement this rule-set, the smart contract that facilitates trading will automatically block a trade when a group/actor has reached their max kWh trade for the day. The governance construct in this example of computational governance has the goal of preventing centralization and inferring transparency.

Measurement of Decentralization through a Metrics Sheet.
In this dissertation, the focal point is on decentralized governance design, the implementation of the governance models should occur ideally on-chain and this might be facilitated by blockchain technology. We consider that computational governance can allow for measurement to which extent governance design of a digital ecosystem is decentralized. Developing models is one thing, and the implementation of governance models is an important measurement and indication of true decentralization. The meta model is formalized, please see [111], we consider this as a starting point to explore a numerical approach in measuring decentralization of governance models. Ideally the design and implementation of the governance models should be traceable and linked to each governance construct as we proposed in the meta model. To develop computational governance, we suggest that the DECENT software modeling toolkit is a starting point to do so. Ideally computational governance should be generated based on the DECENT governance models to achieve consistency, transparency, and rigor. This should allow to measure to what extent a governance model design of a digital ecosystem is decentralized. We consider that the meta model gives pointers as a starting point to develop the numerical metrics to measure decentralization.

Decentralized Internet Web3.
Recently, Tim Berners-Lee announced his new start-up that focuses on decentralization of the world wide web. Moreover, he clearly stated that the current formation of the internet, with a few dominant players is not how he envisioned the design of the Web initially[1]. Instead, his idea was a much more equal level (peer-to-peer) playing field. The question is how to arrive at such a situation without centralized power concentrations as we currently have. For example, storage and exchange of data is occurring via centralized structures, e.g. cloud, which is again dominated by Big Tech firms. We argue that an important requirement for arriving at a level playing field is that governance of such systems should be designed decentralized, hence preventing the emergence of power concentrations that can control and extract value from the infrastructures, as currently data are increasingly stored at the cloud, which is controlled by Big Tech firms.

Decentralized Value & Data Creation.
If we want to design truly decentralized digital ecosystems, value creation should occur ideally decentralized as well, and not designed for the benefit of the centralized structure. The digital infrastructures are asymmetric, as the world wide web is dominated by the Big Tech firms. We state and believe that blockchain technology is here to stay, particularly in the domain of decentralized web and decentralized finance (DeFi). We see that data ownership and designing the crypto-economy are inherently linked with each other, as we have seen with the initiative on the Digital Euro, with the purpose of building an accompanying digital infrastructure which is native of Europe. We observe that the decentralized Web3 is the next evolutionary step of the internet, and it is defined by a focus on end-user sovereignty which translates in decentralized value creation occurring peer-to-peer. This is for example data ownership and this development goes hand in hand by entering the age of computational trust, in which network regulation and federation is possible without a centralized party.

Decentralized Participatory Economics.
Without a centralized actor, a self-organizing digital ecosystem logically requires a decentralized design approach, as we refer to that as a decentralized governance design. The World Wide Web should enable participants to create, read, write, and own content in a decentralized approach. This will also contribute to decentralized decision making [112], which will also contribute to decentralized governance structures, to prevent value extraction. Using the DECENT software modeling toolkit to explore the semantics of the decentralized web could be of value.

[1] https://www.nytimes.com/2021/01/10/technology/tim-berners-lee-privacy-internet.html

Academic Contribution

We present and discuss the peer reviewed publications that are part of this dissertation, with a clear distinction and reference to the corresponding chapters as well.

1. **Governance in Peer-to-Peer Networks is a Design Problem.**
   Lead Author, Value Modeling and Business Ontologies, 2020 [5].
   Positioning paper as we discuss that Peer-to-Peer (P2P) networks are gaining momentum, and its revolution is accelerating. Examples of P2P networks are the Bitcoin and Ethereum which are enabled by blockchain technology. Governance design can be done from the start of a project, or can gradually emerge (Bitcoin). We argue that developing an appropriate governance structure is a design problem, and observe that (1) governance is a serious issue in blockchain networks that (2) has to be designed.

2. **Exploring Governance in a Decentralized Energy trading Ecosystem.**
   Lead Author, BLED, 2020 [1].
   Exploration and positioning paper to what extent a governance model can be represented by an e^3*value* model, and if a model-based approach can lead to governance design decisions. We experiment, conceptualize and analyze design artifacts that could be of relevance for decentralized governance. Assessment of the model-based approach by using a real-industry strength case of Peer-to-Peer energy trading Ch.3). We define value extraction and why this is an important motivation for decentralized governance, this work is covered in Ch. 1.

3. **DECENT: An Ontology for Decentralized Governance in the Renewable Energy Sector.**
   Lead Author, IEEE CBI, 2021 [7].
   A key question is how to design the decentralized governance structure of digital ecosystem that formulated the goal of decentralization in terms of operation and also decision making. To do so, we propose the DECENT (decentralized) meta model which results from an extensive literature study in the field of decentralized governance in the energy sector, which allows to describe governance in digital ecosystem in a structured approach. The meta model provides the terminology to represent and analyze decentralized governance constructs. We demonstrate the practical use of the meta model by means of a case study about P2P Energy Trading, this is covered in Ch. 3.

4. **DECENT: A Domain Specific Language to Design Governance Decisions. Lead Author, RCIS, 2023 [12].**
   In this paper we assess the following: (1) if we can use the meta model as a tool to instantiate governance structures, and (2) to what extent governance models can be represented by using existing techniques such as *e*^{3}*value* and BPMN. Next to that, we derive governance design decisions based on the governance models and BPMN. We do so by taking the case of Fractional Reserve Banking (FRB), which is about governance rules for commercial banks to create and destroy money, this is covered in Ch. 4.

5. **An Ontological Exploration of Central Bank Digital Currency Design. Lead Author, BLED, 2022 [98]**.
   This work discusses the emergence of unregulated cryptocurrencies and the increased reliance on Big Tech regarding critical financial infrastructures in the European Union (EU). This is formulated by the EU as a critical governance concern for the privacy and data safety of the EU citizens. This motivates the EU to investigate alternatives, such as the Digital Euro that can be subjected to governance and rules. In this paper, we explore the key question of how to design a governance structure, we do that by applying the meta model and develop models of the Digital Euro, this work is partly covered in Ch. 6.

6. **A Call for Decentralized Governance of fair Ecosystems. Co-Author, Journal of Service Management Research, 2021 [28].**
   This paper contributes and states that a blockchain enabled digital ecosystem can only succeed if the governance is decentralized as well. We provide a critical viewpoint on the dominance of centrally governed platform ecosystem, stressing the resulting negative economic and social effects such as value extraction. A digital ecosystem should be designed in a fair and transparent approach, by motivating that blockchain technology could be a potential tool to achieve transparent and digital ecosystem. We propose in this paper a model-based approach that allows to develop governance models with that is discussed in Ch. 2. As co-author my contribution was reviewing, giving feedback and editing the paper.

7. **Knowledge Engineering: Formalizing DECENT Meta Model. Co-Author, CAiSE Workshop: Knowledge Graphs for Semantics-Driven Systems Engineering, 2023 [111].**
   We formalized the DECENT meta model, to gain a deeper understanding as a baseline to develop a coherent and logical graphical notation, this paper lead to inspiration to design the notation, this work is covered partly in Ch. 5. As supervisor for the paper I proposed the idea to formalize the meta model, to position our contribution as knowledge engineering and why this is of relevance for the domain of decentralized governance. I created the structure of the paper, and as such written the sections except for the formalization part. I reviewed the formalization together with my other co-author, and provided input for changes.

8. **Blockchain Governance Design: A Computer Science Perspective. Co-Author, CAiSE Workshop: Blockchain for Information Systems, 2023 [31].**
   We discuss and motivate why decentralized governance is a relevance topic of design in research. We analyze the design flaws and governance concerns of decentralized governed digital ecosystems. As supervisor and co-author, I positioned the paper, created the structure and designed the Systematic Literature review methodology following PRISMA, and I co-wrote sections. Next to that I revised the full paper. This work is covered in Ch. 1 and Ch. 2.

9. **Decentralized Fair Governance Model for Permissionless Blockchain Systems. Co-Author, Value Modeling and Business Ontologies 2021 [22].**
   In this paper, we analyze, in a model-based approach, well-known blockchain systems (Bitcoin, Ethereum, Tezos). We create governance models of the existing governance protocols of these blockchain systems and concluded that while the operations are decentralized, the decision making is centralized, which is an important finding that is reflected throughout this dissertation. As co-author I participated in the research discussion and evaluated the developed governance models. This work is covered in Ch. 2.

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List of Publications

Included in this dissertation.

1. DECENT: An Ontology for Decentralized Governance in the Renewable Energy Sector.
   F Kaya, J Gordijn, IEEE Conference on Business Informatics, 2021.

2. DECENT: A Domain Specific Language to Design Governance Decisions.
   F Kaya, F Perez, J Dekker, J Gordijn, International Conference on Research Challenges in Information Science, 2023.

3. Knowledge Engineering: Formalizing DECENT Meta Model.
   A Fiorentino, **F Kaya**, P Johanesson, International Conference on Advanced Information Systems Engineering Workshop, 2023.

5. An Ontological Exploration of Central Bank Digital Currency Design.
   F Kaya, G Amaral, M Makkes, J Gordijn, Bled eConference: Digital Restructuring, 2022.

6. Exploring Governance in a Decentralized Energy trading Ecosystem.
   F Kaya, M Makkes, R Wieringa, J Gordijn, Bled eConference: Digital Restructuring, 2020.

7. A Call for Decentralized Governance of fair Ecosystems.
   J Gordijn, **F Kaya**, R Wieringa, Journal of Service Management Research, 2021.

4. Blockchain Governance Design: A Computer Science Perspective.
   Y Wang, **F Kaya**, J Gordijn, International Conference on Advanced Information Systems Engineering Workshop, 2023.

8. Governance in peer-to-peer networks is a design problem.
   F Kaya, M Makkes, R Wieringa, J Gordijn, Value Modelling and Business Ontologies, 2020.

9. Decentralized Fair Governance Model for Permissionless Blockchain Systems.
   S Jairam, J Gordijn, I Torres, **F Kaya**, Marc Makkes, Value Modelling and Business Ontologies, 2021.

10. Early Identification of Potential Distributed Ledger Technology Business Cases Using e^3*value* Models.
    G Poels, **F Kaya**, M Verdonck, Conference on Conceptual Modeling, Workshop, 2019.

11. A Minimalistic Decision Tree for Blockchain Business Cases in Healthcare.
    F Kaya, R Wieringa, J Gordijn, Practice of Enterprise Modeling Forum, 2019.

12. Decentralized Trading with Optimal P2P Energy Exchange using Blockchain Technology.
    F Kaya, R Wieringa, J Gordijn, ICT-OPEN, 2020.

13. The Banking Industry Underestimates Costs of Cloud Migrations.
F Kaya, M van den Berg, R Wieringa, M Makkes, IEEE Conference on Business Informatics, 2020.

14. Towards a Sustainable Blockchain Use Case.
J Gordijn, R Wieringa, **F Kaya**, Value Modeling and Business Ontologies, 2019.

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In gratitude for the love and support I have received, here are words of wisdom from the people I love.

The wind carriers her as seeds to unknown lands. She is no longer dependent on its native soil.
It has taken possession of a new realm of which it has become the master. It grows and it sculpts
its kingdom as it pleases, far away in time and space. She is life now and here.
Observe and name it.

In the banquet of academia, let them eat cake if they must you bring your own fest to share
with the like-minded, and always remember, if you can be anything in this world, be kind.

What is true is that nobody knows, so let us be humble, but what is good and right is entirely up to us.

All models are wrong. Some are useful. Mostly to the rich.

Science provides an effective way of attaining your goals but not of choosing them,
as that requires idealism and courage.

How futile it is to try to find the perfect model, but how rewarding it is to believe you have found it.

You cannot save the world, but you might save the man in front of you, if you work fast enough.

Your education is the one thing no one can take away from you.

Bienheureux ceux qui savent rire d'eux-mêmes : Ils n'ont pas fini de s'amuser.

Our greatest weakness lies in giving up, the most certain way to succeed is always to try just one more time.

Love in its purest form whispers and is how souls meet.

Mijn paper is afgewezen. BFF: Wat een klootzakken, ik voelde zonder gekkigheid mijn ballen letterlijk zakken.

Quitters never win.

When are we going to realize that our ineffective, slave and carbon driven, material wealth
of the world, is still relative poverty when comparing to the decision-making capita?

I hereby declare the death of monkey see, monkey do.

Light creates shadow, and shadow demands light. So it is with pleasure and suffering.

The other distracts us from ourselves, the other is indispensable to our being, it's a fragile balance.

Her PhD journey was like a pink dolphin: legendary.

When in doubt, seek refuge in books.

Thus spoke your personal Dalai Lama.

We know that we all have knowledge. Knowledge puffs up, but love edifies.

There is nothing either good or bad, but thinking makes it so.

It is called a deadline cause you are f*cking d**d at that time.

Not invented here, jalousie de métier?

Met vallen en opstaan? Nee, gewoon gaan met die banaan.

Knowledge and fine cuisine are the essence of a fulfilling life.

Technology can be a blessing or a curse, it all depends on how we use it.

Meedogenloos structureren.

Continue to dance and enjoy life.

The wings of knowledge what you were looking for - you found them and you spread your wings.

You will keep flying and keep discovering, there is still so much more out there.

Lasting peace comes from understanding the innate unity of all life.

We lead a parasitic existence.

Come up, fly to me, through darkness, through light, you can reach me for I am everywhere.

Zonder communicatie is er geen wetenschap.

The Invisible controls the visible.

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