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Project summary

Circular economy aims at reducing value loss and avoiding waste, by circulating materials or product parts before they become waste. Today, lack of support for sharing data in a secure, quality assured, and automated way is one of the main obstacles that industry actors point to when creating new circular value networks. Together with using different terminologies and not having explicit definitions of the concepts that appear in data, this makes it very difficult to create new ecosystems of actors in Europe today. This project will address the core challenges of making decentralized data and information understandable and usable for humans as well as machines. The project will leverage open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, as well as a decentralized digital platform that enables collaboration in a secure and privacy-preserving manner.

The project addresses a number of open research problems, including the development of ontologies that need to model a wide range of different materials and products, not only providing vertical interoperability but also horizontal interoperability, for cross-industry value networks. As well as transdisciplinary research on methods to find, analyse and assess new circular value chain configurations opened up by considering resource, information, value and energy flows as an integral part of the same complex system. Three industry use cases, from radically different industry domains, act as drivers for the research and development activities, as well as test beds and demonstrators for the cross-industry applicability of the results. The developed solutions will allow for automation of planning, management, and execution of circular value networks, at a European scale, and beyond. The project thereby supports acceleration of the digital and green transitions, automating the discovery and formation of new collaborations in the circular economy.

Project start date and duration

1st of June 2022, 36 months (Extended until Nov 2025)

Project consortium

No	Partner	Abbreviation	Country
1	Linköping University	LiU	Sweden
2	Interuniversitair Micro-Electronica Centrum	IMEC	Belgium
3	Concular Ug Haftungsbeschrankt	CON	Germany
4	+Impakt Luxembourg Sarl	POS	Luxembourg
5	Circularise Bv	CIRC	The Netherlands
6	Universitaet Hamburg	UHAM	Germany
7	Circular.Fashion Ug (Haftungsbeschrankt)	FAS	Germany
8	Lindner Group Kg	LIN	Germany
9	Ragn-Sells Recycling Ab	RS	Sweden
10	Texon Italia Srl	TEXON	Italy
11	Rare Earths Industry Association	REIA	Belgium
12	Prague University of Economics and Business	VSE	Czech Republic

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0.1	2025-09-25	Karin Wannerberg for guide 1, Ben de Meester and Eva Blomqvist for guide 2	Reviewers	RS, IMEC, LIU
1.0	2025-09-30	Eva Blomqvist	PC	LIU

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Guidebook 1

Guidebook 2

1 Summary

This document represents the compilation of the two guidebooks produced as a result of the training materials task (T7.3) in WP7. The guidebooks will be published on the project website, together with supplementary material, such as links do detailed technical tutorials for setting up and configuring the software deliverables etc. The guidebooks are to be seen as the entry point and overview of how to use the project results, but detailed software and ontologies are available on GitHub and linked from the project website. As this deliverable is not a report, below we simply attach

Guide 1

Value chain design, development & innovation

For a circular and regenerative economy

In collaboration with: Circularity Thinking — Innovating for systemic circular solutions

Funded by the European Union

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Acronyms/ terminology

CE = circular economy
CEON = Circular Economy Ontology Network
MFM = Multi-Flow Method
OCP = Open Circularity Platform

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This guide - how it came to be, who it's for, and how to use it

Why this guide? The Onto-DESIDE project.
The Onto-DESIDE project aimed to accelerate the transition to a circular economy (CE) where materials, components, and products are reused to reduce waste and retain value. At the moment, circular value networks are difficult to design and scale because it is difficult to make sense of such systems as a whole. Second, industries struggle to form circular value networks due to inconsistent terminology, lack of semantic clarity, and limited tools for secure, automated data exchange.

To address this, Onto-DESIDE combined conceptual and technical innovation, by 1) creating innovation capacity for circular value chains, and 2) addressing key technical barriers to data sharing across industries. It developed the Multi-Flow Method (MFM), which integrates resource, energy, value, and information flows into a systemic view of circular value chains, using generative tensions to explore root causes to barriers and find ways to improve functioning and robustness. The project also introduced technical solutions: ontologies to model materials, products, actors and processes, ensuring vertical (within domains) as well as horizontal (across domains) semantic interoperability, together with a decentralised collaboration platform where data can be exchanged. However, a crucial aspect of supporting transformation is to provide guidance in using these new tools - the aim of this guide.

What was done and how
Onto-DESIDE applied a transdisciplinary and iterative methodology to develop tools and technologies for circular value networks. Academia and practice came together, using three diverse real-world industry use cases selected for their diversity and complexity—construction, electronics, and textiles—as testbeds to derive needs and validate the within- as well as cross-sector applicability of the tools and methods.

The project, running from June 2022 to November 2025, was structured into multiple work packages. One focused on the creation of the innovation method, a second on ontology development, and a third on the data-exchange platform. Each used their own methodology and domain-specific expertise, respectively, design science methods, agile ontology engineering practices including eXtreme Design (XD) resulting in the Circular Economy Ontology Network (CEON), and the application of mature open web standards to create a secure and decentralized interoperable data sharing infrastructure dubbed the Open Circularity Platform (OCP)—but collaboration across these tasks makes them comprehensive and integrated. The project combined a top-down approach, analysing CE research and standards, with a bottom-up analysis and generalisation from the project use cases.

Guide 1: *Circular value chain design, development & innovation*

Guide 2: *Decentrally sharing of data & information*

How to use the guides
There are two guides: one which focuses on circular value chain development and innovation, and a second technical guide that is dedicated to setting up a decentrally organised data-sharing infrastructure in such a way the data is interoperable and compatible.

Both guides focus on the practical steps to take towards better functioning circular value chains. Each guide discusses the relationship with the other, so it is clear where they connect. But, depending on your needs and circular maturity level, you can drive straight into the technical parts, or you can first spend a moment thinking about the functioning of your circular value chain and how to design it in the first place. It is up to you, the reader, to decide what you need and where to start. Together, both parts of the Onto-DESIDE project outputs support the planning and automation of management and execution of circular value networks at scale, contributing to Europe's digital and green Twin Transition.

For more details, or more technical descriptions as well as templates, explainer videos, and other supplementary materials go to our website.

Please visit:
www.ontodeside.eu

ONTO-DESIDE

Ontology-based Decentralized Sharing of Industry Data in the European Circular Economy

- 12 partners, 7 countries:
  - Linköping University (SE)
  - *Interuniversitair Micro-Electronica Centrum (BE)*
  - *Concular Ug Haftungsbeschrankt(DE)*
  - *+Impakt Luxembourg Sarl (LU)*
  - *Circularise Bv (NL)*
  - *Universität Hamburg (DE)*
  - *Circular.Fashion Ug (DE)*
  - *Lindner Group Kg (DE)*
  - *Ragn-Sells Recycling Ab (SE)*
  - *Texon Italia Srl (IT)*
  - *Rare Earths Industry Association (BE)*
  - *Prague University of Economics & Business (CZ)*

- June 2022-November 2025
- Funding: Horizon Europe
  - *Grant agreement #101058682*

Three use case domains:
- Textile industry
- Electronics industry
- Construction industry

Funded by the European Union

Who the guides are for
This guide is part of a set of two. Both guides are aimed at anyone who wishes to engage in circular oriented innovation. That is: anyone who wants to explore new or better circular value chains as well as get practical about data and information sharing to enable this in practice. Each guide is meant as an entry point into their respective topics, and they each target different roles - with an emphasis on the role and contribution of these different roles. Mainly these two guides provide an overview and explain what to expect whilst on this journey. In this, we focus on how different roles can work together. To this end at the top of each section, you find an indication of what roles are typically involved or needed to complete a step successfully. Of course, these roles can be different people, or be one and the same.

Guide 1 - *The guide in front of you now:*
Value chain design, development & innovation:

This guide has a strategic focus, and explores what currently shapes the value chain dynamics and how circular strategies can be (better) supported. The following roles are needed to successfully complete the process:

- *Project lead:* Coordinates the overall process in which the method is applied. Ensures the right people are involved, aligns the method with the project's goals, and takes responsibility for follow-up after sessions and working groups.
- *Facilitator:* Guides the group through the Multi-Flow Method. Ensures the process is structured, that flows, tensions, and patterns are captured in a way the group can work with, and that different perspectives are heard.
- *Decision maker(s)*: Stakeholder representatives with the authority to shape the value chain configuration or influence (strategic) decisions. To ensure relevance and actionability, the process should include different perspectives (e.g., suppliers, customers, recyclers, logistics providers).
- *(Flow) Experts:* Bring (technical and practical) knowledge of specific flows (material, information, value, energy). They explain how flows operate in practice and support the group in understanding constraints, dependencies, and opportunities.

Guide 2 - See: www.ontodeside.eu
Decentralised sharing of data & information:

This guide has a technical focus, and explains how to set up a decentralised, secure, and automated data sharing infrastructure, to support a certain value chain configuration and its needed collaborations between actors. The steps involved in setting up this infrastructure needs the involvement of different types of roles in the involved organisations. In this guide we categorise these roles into 4 types:

- *Decision Maker*: May be the value chain manager, coordinating the setup of the whole value chain, or merely the internal manager in charge of ensuring the participation of a specific actor in the value network configuration. Additionally, a decision maker may be a CTO or CIO making decisions about the IT infrastructure setup and investments.
- *Data Steward*: Any role that produces, manages or maintains the data that is to be shared and used in order to make the value chain configuration work.
- *Developer*: Either an information architect/ data modeller, or a software developer/IT specialist. These are the roles that will do the practical work of modelling and transforming the data, as well as setting up the actual infrastructure and configuring it.
- *End-User*: The roles within the value chain organisations that hold the needs for receiving or sharing the data. For instance, this could be a person at a recycling facility, needing the information about incoming used materials in order to make decisions regarding where to dispatch a certain batch or container.

Why, what and how of Circular Economy

"Take-make-use-*lose*"

Our global economy operates largely on a linear model: extract, produce, consume, and dispose - repeat. This system assumes unlimited access to resources and an infinite capacity for waste absorption. But our planet can provide neither: we are rapidly depleting finite resources and overwhelming natural systems with waste and emissions. Even recycling, often seen as a solution, only addresses a very small part of the problem and fails to fundamentally transform how we use resources. What's more, this extractive system entrenches inequality, undermines livelihoods, and worsens living conditions for many.

For example, resource extraction has already more than tripled since 1970 and is projected to rise another 60% by 2060 if the current path is followed, accounting for over 60% of global greenhouse gas emissions and 40% of pollution-linked health impacts[1]. Such scale places enormous pressure on ecosystems and communities. No wonder that the linear economy is sometimes also referred to as "Take-make-use-*lose*"[2].

Instead...

Our economies will have to change their extractive practices to circular and regenerative ones. Circular Economy (CE) offers one path through the application of Re-strategies like rethink, reduce, retain, reuse, repair, refurbish, remanufacture, recycle—and a range of related strategies like composting & industrial symbiosis. The aim is through better taking care of the needs of the different parts of the system (planet, people and businesses) to incentivise dealing differently with waste and resources such that resource conservation, efficiency and productivity are all improved. Or: how can we live comfortably - without costing people and the planet?

CE is no longer optional, but a must-have

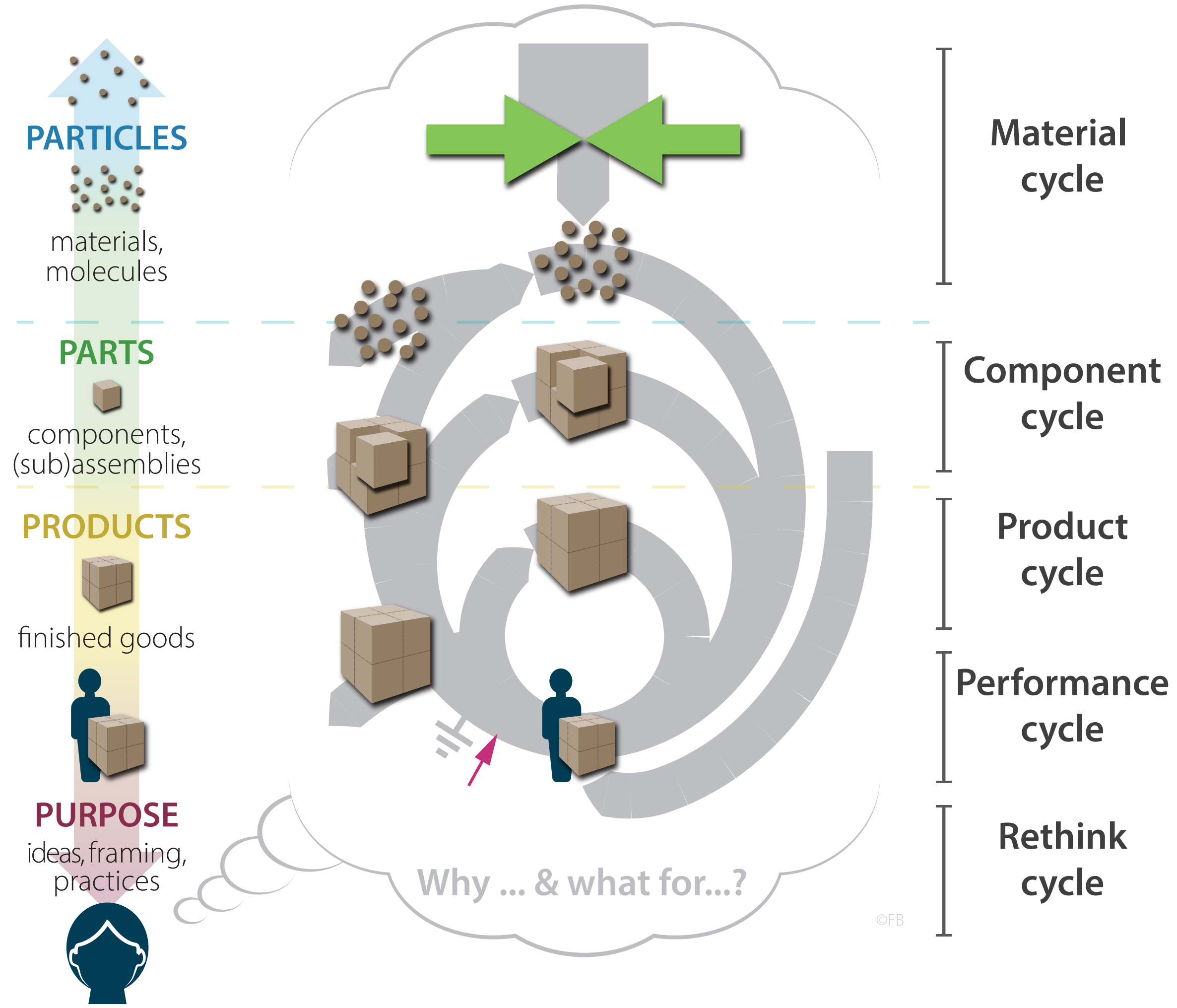
Mounting resource scarcity, increasingly volatile supply chains and resource prices, intensifying legislative and regulatory pressure, and rising stakeholder expectations mean that CE is no longer optional—it's essential for business resilience, compliance, innovation, and competitiveness[3,4,5]. Companies that continue to rely on a take-make-dispose model expose themselves to higher costs, operational disruptions, and reputational risks, while those that adopt circular strategies can secure materials, stabilize supply, and strengthen their license to operate. In short, CE is becoming a key driver of both risk management & value creation.

Likewise, finance and investors are intensifying the shift of capital toward businesses that demonstrate circular strategies, recognizing them as lower-risk, future-fit, and better positioned to deliver long-term value[6]. Capital markets are increasingly embedding sustainability and circularity metrics into lending, investment, and valuation models, rewarding companies that proactively align with emerging standards. Those who fail to adapt may face shrinking access to capital, higher borrowing costs, and reduced investor confidence, while circular leaders stand to attract investment, partnerships, and preferential market positioning.

The Challenge

But... 'going circular' is complex. It requires systems thinking to understand how and why materials flow, where and why waste originates, and how circular strategies interact. It requires moving beyond simplistic models and truly solving problems—not shift them elsewhere or create new ones. And: not all circular strategies work in every context, and some may even compete or create trade-offs. For example, choosing highly durable composites can hinder recyclability, and remanufacturing may initially require more materials—not less. And so on. The challenge is to design and operate sets of circular strategies that resolve, go around or balance these tensions and deliver real benefits. Doing so requires the right mix of competition and collaboration, clear and easily accessible data, and adaptive management across the value entire chain.

For this reason, circular innovation differs fundamentally from linear or 'business-as-usual' innovation. It involves creating virtuous loops—feedback mechanisms where resources re-enter the value chain—and generating emergent properties like sustainability and resilience. These benefits arise not from isolated actions but from how the entire system behaves.



From a linear to a circular mindset

All this means that a different mindset is needed when engaging in circular oriented-innovation. Crucially: it means creating systems where multiple circular strategies operate synergistically - where, through collaboration, all actors benefit. Circularity Thinking helps cultivate this new circular mindset.

1. Flow Structure: One-Way vs. Feedback Loops

- Linear mindset: Resources flow in a straight line—extraction, production, use, disposal—with minimal interaction between these processes.
- Circular mindset: Resources circulate through feedback loops, re-entering the system several times (as products, components, and materials) and influencing upstream and downstream decisions over time.

2. Value Creation: Localized vs. Emergent

- Linear mindset: Value is created and captured at specific points in the chain (e.g. sales, production) - with opposing and conflicting interests, resulting in value conflicts.
- Circular mindset: Value is emergent, arising from how the entire system functions - through resilience, sustainability, and shared innovation. Both the whole and the parts benefit equally.

3. Problem Solving: Fragmented vs. Systemic

- Linear mindset: Problems are solved in isolation, often within departmental or disciplinary silos. This leads to displacement and the creation of new problems.
- Circular mindset: Problems are addressed systemically, considering interdependencies, long-term effects, and cross-sector dynamics.

4. Strategy Use: Selection vs. Configuration

- Linear mindset: Strategies are chosen individually—reuse or recycling, efficiency or durability—as they benefit one actor, often without considering their interactions.
- Circular mindset: Strategies are combined into configurations, designed to work together synergistically and allowed to evolve over time, seeking the addition of more circular strategies through continuous improvement.

5. Innovation Process: Execution vs. Iteration

- Linear mindset: Innovation follows a fixed plan—analyse, design, implement—assuming predictability and with limited flexibility.
- Circular mindset: Multiple innovation modes operate alongside each other, where innovation also incorporates processes that are iterative, involving experimentation, learning, and the ability to pivot when assumptions prove incorrect.

6. Responsibility: Compliance vs. Stewardship

- Linear mindset: Responsibility is often limited to meeting regulations or minimizing costs.
- Circular mindset: Responsibility includes stewardship—ensuring that circular strategies address real problems and no new ones are created elsewhere in the system. And: that the needs of all parts of the system are served.

Value-, resource- & information-flows

Therefore, to design, improve, and operate a circular way of working it is essential to adopt a *value chain* perspective - sometimes also called a *value network*. This is because circularity cannot be achieved in isolation—materials, components, products, as well as benefits and impacts flow across multiple actors and stages. Only by seeing how decisions in one part of the chain affect others can businesses understand how shared benefits can be created and value captured and to design circular strategies that synergistically reinforce each other. This perspective also highlights trade-offs and tensions that must be managed collectively, rather than pushed onto individual actors, if the system is to function. *Data and information* play a critical role in this: they *provide the transparency needed* to track resource flows, identify where waste and inefficiencies occur, and coordinate action across suppliers, partners, and customers. Without accurate, shared and frictionless access to information, circular value chains cannot be designed effectively or operated at scale.

This guide

To help with this, the **Onto-Deside** project created the following guidance and support for:

- *Value chain design, development & innovation:* gaining insight into the root causes of barriers and enablers that shape the behaviour of value chains, and examining how this dynamic can (better) support circular flows.
- *Decentrally sharing of data & information:* understanding data needs and availability, formats, and aligning the data to a shared domain model, the Circular Economy Ontology Network (CEON), setting up an Open Circularity Platform (OCP)—data-sharing such that data becomes interoperable, but where control over what to share with who and when remains with the data owners.

The guide in front of you covers:

- *Decentrally sharing of data & information.*

Please find the other guide at:
>>> www.ontodeside.eu

For all circular strategies - from recycling to repair, from reuse to remanufacturing

To help bring the guidance to life and offer concrete examples to illustrate our methods, here are 4 short examples of different circular strategies that we'll refer back to throughout the guides. All these scenarios (A to D) have the same needs in common. Each actor in the network must be able to selectively share its data, based on ever-changing business needs. Meanwhile, to track resource flows across stakeholders and make appropriate decisions, a common understanding of this shared data is needed.

(A) Beginning-of-life: using recycled input

What: Cross-sector recycling of apparel waste into feedstock for floor tiles.
Why: To unlock circular business models, and help to find the right recycled feedstock through product passports and secure data exchanges.

A *product manufacturer* creates a performance shoe using inputs from various *material suppliers*, each contributing data to a shared platform for product passports using standardized formats. Once the shoe reaches end-of-life, a *recycling operator* disassembles it, guided by digital instructions, and extracts the rubber outsoles and textile laces that are made into bulk materials.

These recovered materials are listed on a *digital marketplace*, enriched with a certificate and metadata including composition, condition, and recycled content. Next, a *materials processor* identifies suitable batches and requests pricing via the platform. After purchase, the recycled inputs are turned into materials that an *interior outfit company* uses for acoustic floor tile layers. Certificates and material data travel along, and a new product passport is generated for the product.

(B) Middle-of-life: repair

What: Repair of an audio system through access to reliable spare parts and instructions.
Why: Automating sustainable asset management through digital tools to enable easier data management, whilst protecting sensitive data.

A *building owner* identifies a malfunction in the installed audio system. Using a data exchange platform they access repair instructions and discover that the *original equipment manufacturer* offers a repair service. The component is sent for repair, and the manufacturer replaces the faulty speaker with a newer model containing a higher amount of recycled content.

The repaired unit is reinstalled, and updated product data is published and added to the *building's digital twin*, including material composition and sustainability attributes. Digital product passports record both original and repaired versions, tracking components and their environmental impact—including recycled content, origin, and certifications—automating the management of building information.

In this guide we focus on this example, but the process applies to all circular strategies

(C) End-of-life: reuse

What: Reuse and resale of a door for use in other building projects.
Why: Linking supply & demand through a digital market place for second-life parts & components.

A *building owner,* preparing for demolition, assesses the reuse potential of installed elements, such as doors, for repurposing through resale. This information is used with the *demolition contractor* to negotiate a fair price for the building's demolition, and sets the frame for what demolition methods will be used.

To find a new use, the building owner lists the components, including the doors, on a *digital marketplace*—provided by an *intermediary* for sale to *construction companies* for reuse in new projects. Metadata such as dimensions, condition, and installation history are shared, and enriched with images, enhancing buyer confidence. Pricing information is managed securely via decentralized data pods, ensuring only authorized parties can access commercial terms and optimising the value for the building owner. Planning considerations are automatically taken into account.

(D) End-of-life: remanufacturing

What: Take-back of the floor tiles by the manufacturer for remanufacturing.
Why: Enabling manufacturers to take-back their products, ensuring access to future feedstock.

At the end-of-life stage of a building, a *building owner* initiates a demolition plan and assesses reuse and recovery options for installed components. Among these, the acoustic floor tiles—originally made with recycled feedstock from apparel waste—are identified as having high reuse potential, but not in their current condition.

The owner contacts the *original tile manufacturer,* who offers a take-back program. Through a data exchange platform—facilitated by an *intermediary*—the manufacturer provides pricing and logistics information for reclaiming the tiles. The tiles are returned, inspected, and remanufactured into new flooring systems, integrating both recovered and new materials. This process reduces raw material demand and preserves embedded value.

Innovating for a circular economy - an overview of the what, why & how of Circularity Thinking

A structured approach to systemic innovation
Circular-oriented innovation touches on many aspects: the material choice, the product design, the business model, business capabilities, customer and supplier relationships as well as other value chain capabilities that may be needed, but cannot facilitate in-house. When juggling all this alongside the daily demands of any organization, it is easy to lose sight of the bigger picture and it can become difficult to make sense of the different interactions. And when — on the rare occasion — there's a moment to engage with these matters, it can be hard enough to navigate the wealth of existing approaches and choose the right tool, card-set, method, framework, or software.

What's often missing is a structured approach that serves as a red thread through this complexity: one that makes it easy to follow a circular mindset by taking a systemic approach, that connects the dots between problems and solutions, and that blends the separate tools into a comprehensive approach. Without this, businesses risk partial solutions, wasted effort, and unintended consequences. Such a method for designing and managing circular innovations provides clarity, focus, and coordination.

Circularity Thinking (CT), is designed to do just this: it is a systematic systems-based method to support CE innovation. It helps organisations move beyond isolated circular strategies by offering a way to understand and address complex resource and waste challenges. CT is designed to support circular oriented innovation by linking the problem space - *what needs to be addressed*, with the solution space - *how circular strategies can be effectively applied*, and to identify and unpack key system dynamics.

A focus on relationships and the i*n-between*
In CE innovation, focusing solely on local optimisation—such as improving the recyclability of a single product or reducing waste in one department—can obscure deeper systemic issues. Waste often originates not at the point where it becomes visible, but elsewhere in the system, driven by decisions made upstream or downstream. For example, designed obsolescence in product development may lead to premature disposal, which also increases manufacturing waste due to replacement purchases. Without a systemic lens, these interdependencies remain hidden, and interventions risk treating symptoms rather than root causes.

The *in-between*—the spaces between processes, departments, companies, and life cycle stages—is often where many obvious and less-obvious wastes reside. Many times, these are overlooked because they fall outside the scope of individual actors or tools. Circularity Thinking helps make these invisible zones visible by mapping flows for complete life cycles and identifying where *waste has a ripple effect*. Or: where waste creates more waste. The method enables seeing how processes interact. This relational view is essential for designing circular configurations that are coherent, scalable, and resilient - and don't lead to circularity for circularity's sake, but enable circular strategies to address real problems.

Moreover, no single actor can implement circularity alone; it requires coordinated action across supply chains, sectors, and communities. By focusing on relationships—who needs to do what, when, and with whom—organisations can identify gaps, align incentives, coordinate processes and build the partnerships necessary for circular systems to function.

Circularity Thinking provides the tools to map actor configurations, explore systemic dynamics and align innovation modes to ensure that circular strategies are not only technically viable but also organisationally feasible.

A red thread, not a replacement of existing tools
Importantly, CT does not replace existing tools. Instead, it acts as a conceptual red thread that connects and enhances them. Whether you're working with product design guidelines, business model tools or lifecycle assessment (LCA) or other tools, CT helps you apply these methods more effectively by clarifying what's at stake and what needs to be achieved. It provides a common language and structure that supports interdisciplinary collaboration and decision-making. For example:

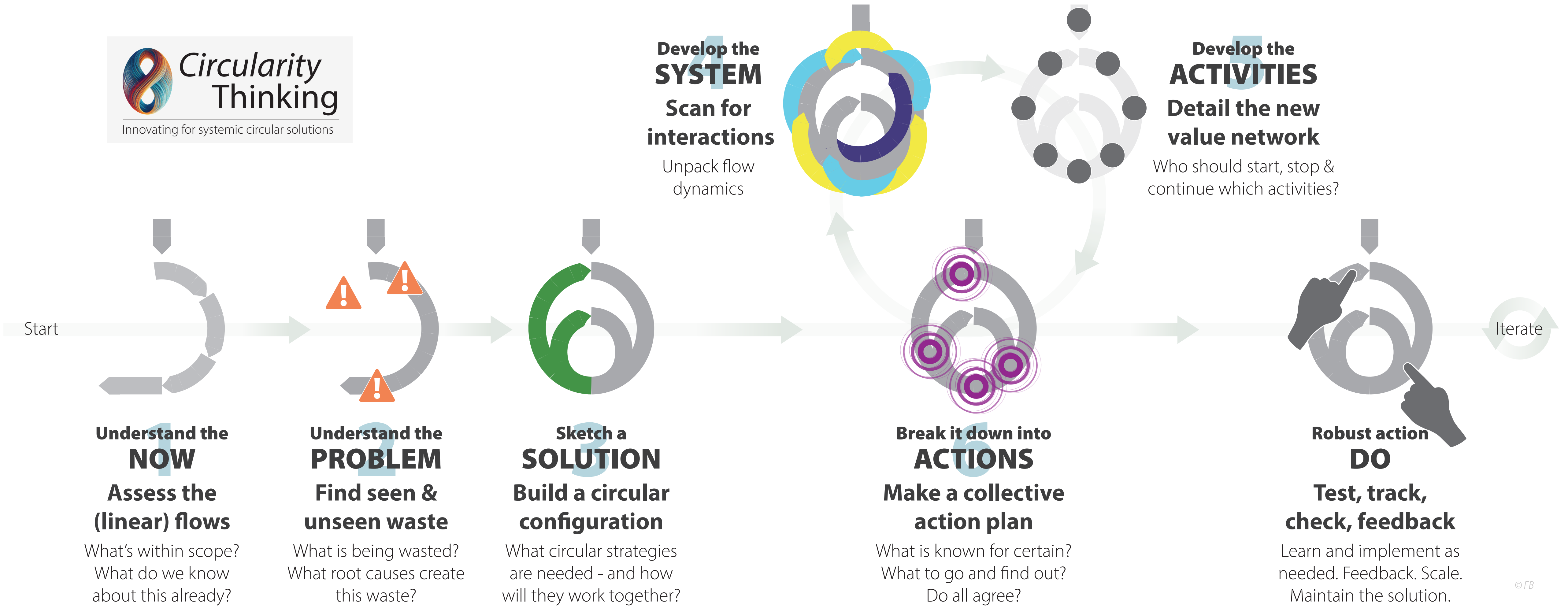
- ***Product Design***
  CT helps design teams understand how circular product features (e.g. modularity, durability, material choices) can support different circular strategies across a resource's life cycle. It enables designers to anticipate how design decisions affect the system as a whole, including downstream processes and user behaviour.

- ***Business Model Development***
  CT distinguishes between anchor strategies (those addressing key structural wastes) and supporting strategies (those enhancing or enabling the anchor). This allows for phased implementation and continuous improvement, helping organisations build circular business models that are both viable and scalable.

- ***Impact Assessment (LCA & others)***
  CT supports the definition of functional units and system boundaries by identifying relevant circular strategies and their implications. It helps organisations assess trade-offs, avoid rebound effects, and interpret LCA results in a way that reflects systemic impact rather than isolated metrics.

Circularity Thinking 'follows the flows' - it always asks: Where does something come from, where does it go next, and what effect does this have? It is built on life-cycle and systems thinking. Each step uses a similar template, but investigates different aspects of the problem- and solution space. It thus provides a suite of tools, each of which was developed in a scientific process, sometimes involving a range of actors, sometimes first exploring the possibilities within a single company. Throughout, CT has seen the involvement of companies of different sizes, maturity levels and from a wide range of sectors: ranging from the built environment to fashion and textile, from electronics to furniture, and from fast-moving consumer goods to capital goods. These companies served both as case studies as well as test beds for different parts of the methodology. This allowed the approach to mature - and it continues to develop still as we learn more about how to bring circular and regenerative practices to scale. To date, Circularity Thinking is used by a wide network of users – ranging from Spain to Norway, from Finland to Germany, from Italy to Romania, and from the Maldives to Japan. CT has also been applied in education, as well as with local, regional and national governments. You can find more about each step in the next pages.

This guide covers Steps 1 to 4 - for the remainder please consult: >>> www.circularitythinking.org



How to use? Always a good starting point.
As Circularity Thinking consists of a suite of tools, you may not need all tools all the time. Depending on the scope, what is investigated and the remit for change, different tools may be used.

However, a good starting point, no matter the project, is to 'understand the now' combined with a 'waste hunt' followed by the 'configuration builder.' The first provides an overview of the life cycle and where different types of waste are located - and how they are related. The second explores the possible set of circular strategies that is needed to address this. This gives you insight into where the problems really lay, and the nature and scope of the solution space that is available. With this foundation, you can further deepen insights & develop solutions in subsequent steps.

Foreground and backstage tools
If you are working with a group of people, inside or outside your organisation, consider how to best use the tools. It may be good to organise a workshop where you convene different actors and use the Circularity Thinking tools to facilitate the conversation. Such *foreground use* helps build a shared picture of what's going on and allows drawing from different types of expertise. But it may not always be needed to organise big workshops. You can also pre-fill the templates and further develop, expand or validate your analysis by asking input from others in 1-on-1 sessions. However, do make sure that before getting a response, that everyone is on the same page regarding the objective, scope of the question and how to navigate the templates. In other cases it may be sufficient to use the tools to structure your own thinking or that of a few key decision makers - and only share the outcomes of this with the group. Such *backstage use* ensures you think through decisions and justify them appropriately.

Use Circularity Thinking to:
Diagnose
- Make hidden wastes visible by mapping flows across the value chain.
- Highlight how waste arises in-between actors, processes, and life-cycle stages.
- Connect the problem space (why waste occurs) with the solution space (what circular strategies to use).

Prioritise
- Distinguish which wastes matter most: large in volume, small but toxic, or strategically critical.
- Compare and weigh different wastes to identify interventions with the highest systemic impact.

Design
- Translate problems into targeted circular solutions (e.g. repair, cascade, recycling).
- Balance interdependencies: account for synergies, trade-offs & competition between strategies.
- Ensure feasibility by considering costs, risks and path dependencies.
- Leave room for continuous improvement and innovation through adaptable system design.

Align
- Clarify roles and responsibilities across actors in the system.
- Identify gaps, overlaps & collaboration opportunities.
- Provide shared understanding and common language across disciplines and organisations.

Justify
- Ground circular strategies in real problems instead of "circularity for circularity's sake."
- Build strong business cases anchored in cost savings, risk reduction, compliance, and sustainability outcomes.

Resources & Waste - Two central concepts

Circular economy is about changing how we handle resources and waste. But what counts as resource and what is waste is not always obvious. Where, how, and why a resource becomes waste shifts with context, use, and perception. Today's waste can become tomorrow's feedstock, and vice versa. This makes it hard to know whether two people mean the same thing when discussing circular strategies. For example, one might say "recycling" when referring to product reuse, while another might say "reuse" to describe recycling. Circularity Thinking offers clarity through a shared language to explore where waste occurs and why. Two frameworks are used: Resource States and Structural Wastes.

What is a *resource*? Introducing *Resource States.*
Simply put, a resource is understood as the *physical "stuff"* that flows through the economy. However, as resources flow they take on different forms during their journey:

- Particles (materials) – elements, substances, molecules or bulk materials (e.g. metal sheets, plastic pellets, cotton bales).
- Parts (components) – intermediate forms created from materials through manufacturing (e.g. gears, motors, casings, zippers).
- Products (finished goods) – fully assembled items that deliver utility to end users (e.g. kettles, phones, cars, clothes).

These states reflect increasing levels of order (organisation of matter) and we can refer to them as three different resource states. The more organised something is, the more effort, technology, and labour has gone into creating it – and therefore the more value is at stake if that order is lost. Value is not just in the raw material itself, but also in the way it is structured. A steel beam, a car engine, and a laptop all contain metals, but dismantling them back into metals destroys much of the invested value in design, precision, assembly and getting it to the user.

Resource states describe what is transformed, but this also corresponds to who does this: the different types of actors, known as tiers. Tiers indicate the position of suppliers relative to the final manufacturer. Materials such as cotton bales or plastic pellets map to Tier 3 suppliers, with expertise in extraction and basic processing. Components like motors or zippers correspond to Tier 2 suppliers, requiring manufacturing skills and technical know-how. Finished products such as clothes or cars align with Tier 1 suppliers or OEMs, act as the brand or final assembler. In this way, resource states also highlight the distinct knowledge and competencies present at each tier.

Circular strategies aim to preserve the order established in each resource state for as long as possible, feasible and desirable. But resources are not static; their value comes from how they are transformed, structured & maintained over time. If we add 'time' to resource states, we get the Circularity Compass - see Figure.

***Why* is something a resource?**
Even more important than *what* it is, is perhaps the question of *why* a resource is even thought of as a resource. Resource-ness is not an inherent property, but emerges when people, organisations, or societies decide it is useful.

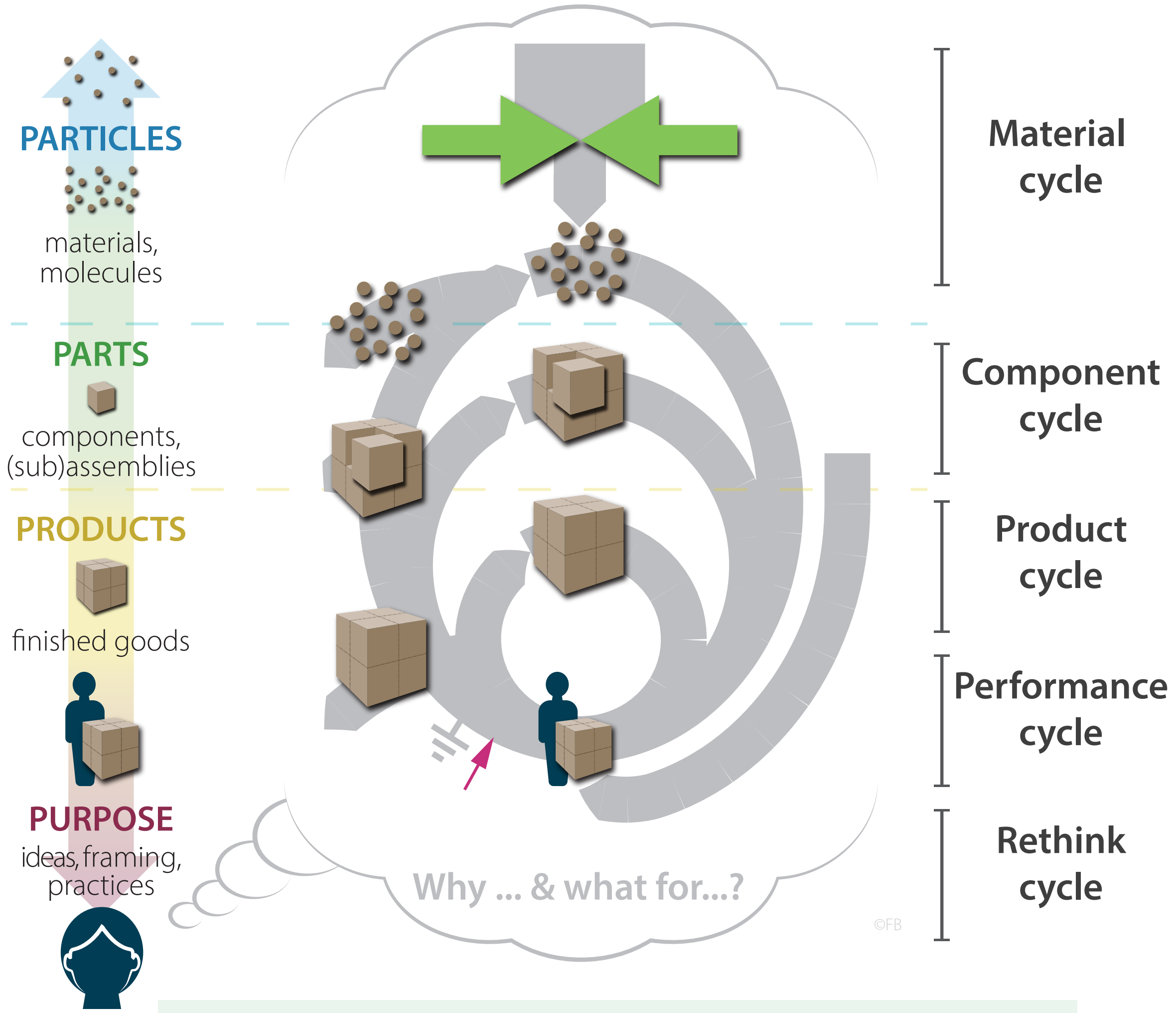
Resource-ness is shaped by:

- Practices (what we do with things).
- Expectations (what we think (will) matter).
- Cultural values (what we all care about).
- Institutional framing (what is allowed, supported, or incentivised).

This means that the same item can be a waste stream in one context and a valuable resource in another — food surplus, CO_2, or old textiles are all familiar examples. Recognising this dynamic also gives leverage: by shifting perceptions, redesigning practices, or changing incentives, it is possible to *turn waste into resources*.

In other words, *resource* is a relational concept: something is only a resource if people attribute value and utility to it. Therefore, making the purpose explicit and reflecting on current practices can allow us to *rethink* how to do things differently. This allows for making more mindful decisions when deciding how to serve needs.

The Circularity Compass (see figure below) combines the three resource states with a fourth interpretive layer on why something is seen as a resource, offering a way to organise discussions.



Further reading:

- *Blomsma and Tennant (2020)*[10]*, and Blomsma, Tennnant & Ozaki (2023)*[11].

What is waste? On *Structural Waste*.
In everyday language, waste is usually understood as what we throw away or is incinerated—the leftovers, scrap, or rubbish that is no longer useful to us. But this narrow view hides a much bigger issue: the *loss or destruction of value*. This type of waste also occurs when products fail too early, when resources are underused, when harmful practices consume more than is necessary or have a toxic effect. To capture these less visible forms of value loss, we use the term *structural waste*. Unlike the colloquial meaning, *structural waste* gives a more technical definition: it highlights recurring patterns in how value leaks out of systems, making it possible to spot and address them systematically through circular strategies. This gives circular strategies a clear 'why' - and prevents circularity for circularity's sake.

How to look for structural waste
To make structural waste actionable, it is grouped into three core categories, each highlighting a distinct way value is lost across systems. These categories are not just technical—they reflect recurring patterns across industries and life cycles. They reveal where resources are discarded too early, left unused, or consumed in ways that cause harm. By naming these patterns—*premature end-of-life*, *premature end-of-use*, and *excess or harm*—and locating them within each resource state, we can better understand the nature of waste and match it with targeted circular strategies that restore, extend, or prevent waste—making circularity purposeful and effective. In doing so, organisations gain clarity on where interventions matter most, how to prioritise them, and unlock value. This reduces blind spots, ensuring strategies address root causes, not just symptoms, and align departments and partners. This structured view shifts ambition into precise action.

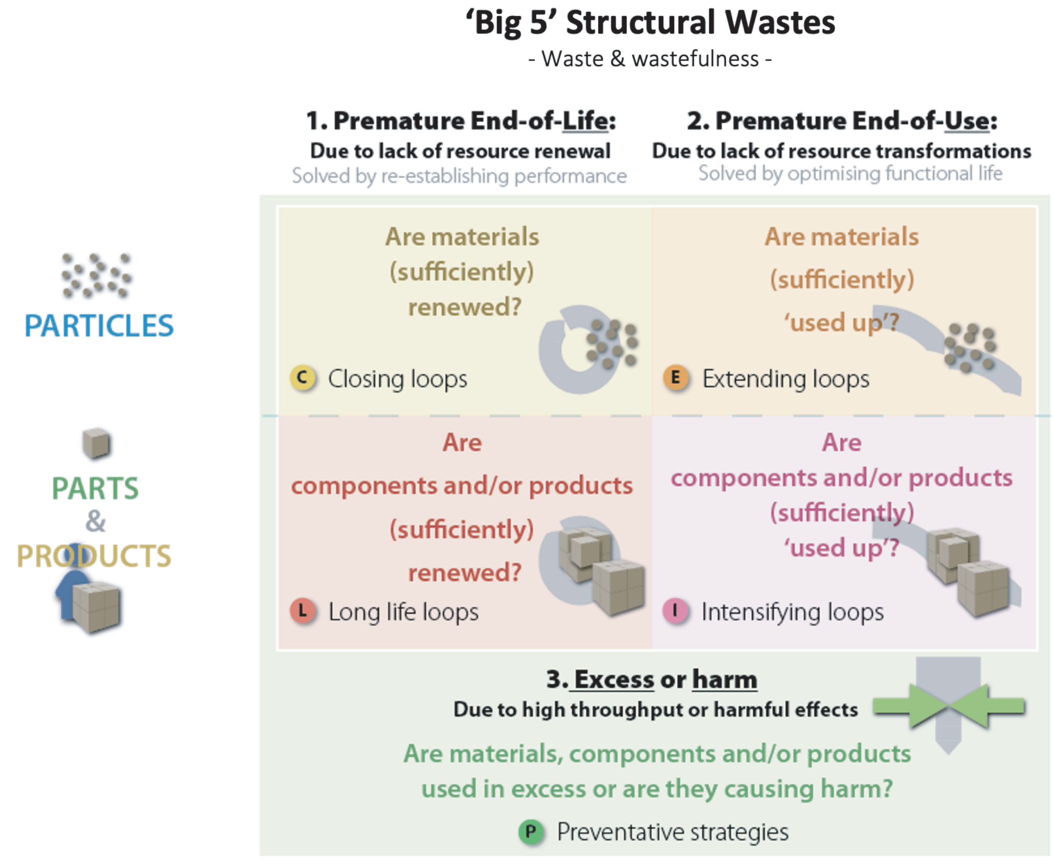
Structural waste patterns

1. Premature End-of-Life
- Problem: A resource stops functioning because its performance is not renewed, even though it could be restored.
- Waste pattern: Life cycles are cut off unnecessarily; value is lost because resources are abandoned instead of rejuvenated.
- Response: *Re-establish performance* by renewing or restoring quality/functionality.

2. Premature End-of-Use
- Problem: A resource's functional capacity is underused; it stops being useful in one context even though it still has value in another.
- Waste pattern: Value is lost due to partial use of resources instead of fully 'used up'.
- Response: *Optimise functional life* by redirecting, cascading, or sharing resources to maximise their use potential.

3. Excess or Harm
- Problem: Resources are consumed unnecessarily, inefficiently, or in ways that cause damage.
- Waste pattern: Overuse, inefficiency, or harmful design choices.
- Response: *Prevent excess or harm* by reducing inputs, choosing benign alternatives, or designing for sufficiency.

Structural waste and resource states
Structural waste patterns span all resource states: premature end-of-life occurs when materials, parts, or products aren't renewed; premature end-of-use arises when their functional capacity remains underused; excess or harm results from unnecessary or damaging consumption, reducing efficiency and sustainability system-wide. We can use these patterns to create a waste-matrix: the *Big 5 Structural Wastes* - see figure next page.



Using the "Big Five"
The Big Five can be used to answer the following questions, which is the foundation for exploring what circular strategies can and should be used:

What waste is found?
Use the Circularity Compass to scan each resource state for structural wastes. This gives an overview of what is going on.

Where does it originate? The "in-between".
Waste often doesn't occur in obvious places: it is hidden in-between processes, departments, and actors when incentives are misaligned, coordination breaks down, data is not shared, or responsibilities are unclear. These gaps, usually invisible to conventional reporting, often represent the biggest untapped opportunities for value creation. Be critical in examining this.

Why does it originate? Purpose & practices.
Similar to what is seen as a "resource" what counts as a "waste" is not fixed but shaped by practices, expectations, cultural values, and institutional framing. What ideas and assumptions around purpose and practices lead to waste?

Which wastes are connected?
Waste in one part of a system often triggers further waste elsewhere. For example, poor design can cause production scraps, difficult repairs & shorter product lives. These connections make that waste multiplies across processes.

The answers to these questions together explain what waste is present and why.

Further reading:
- *See also: Blomsma (2018)[9].*

Why is all this needed?
By now, it may be clear that Circularity Thinking takes a different approach to circular strategies compared to other circular strategy frameworks such as the *waste hierarchy* (“reduce, reuse, recycle”)[, the *9R framework*[or “closing, slowing, narrowing”[. For one, Circularity Thinking avoids a fixed ranking of circular strategies. After all, it may not always be preferable to recycle a material or to reuse a product. For example, recycling low-grade plastics into food packaging can risk contamination, and reusing an old, inefficient refrigerator may waste more energy than replacing it. Instead, Circularity Thinking asks: “How can this whole system be optimised in context?”

<u>A clear language</u>
Other circular strategy frameworks may provide useful shorthand, but they - as already explained - can blur meaning. Resource States (particles, parts, products) gives a clearer language to distinguish what exactly is being preserved (material, component, product), where in the system this is blocked or enabled and what in our thinking makes something a resource or a waste.

<u>A clear ‘why’ for circular strategies</u>
Another shortcoming of other circular strategy frameworks is that circular strategies are presented unconnected to specific underlying problems. This risks creating “circularity for circularity’s sake” by ticking boxes. Instead, using the Big Five critically and examining what waste occurs where in the system allows for focusing on systemic impact. This makes for a shift into a problem-driven rather than solution-driven approach, which grounds circular strategies more firmly in the rationale for doing them. This furthermore supports strategic prioritisation. Instead of asking “Which R should we use?”, Circularity Thinking asks: “Which kinds of waste do we need to address—and how can circular strategies help with this?”

<u>Circular Configuration: a circular strategy portfolio</u>
Another common shortcoming of other circular strategy frameworks is that they tend to present circular strategies as a list of which you, after some reflection, can pick and choose a preferred option. But this ignores a simple fact: circular strategies interact with each other. Some strategies are synergistic with each other: using a bio-waste as an input can also create a compostable material at the end-of-life, whilst others may compete or represent trade-offs: design-for-remanufacturing may mean using more materials for the first cycle.

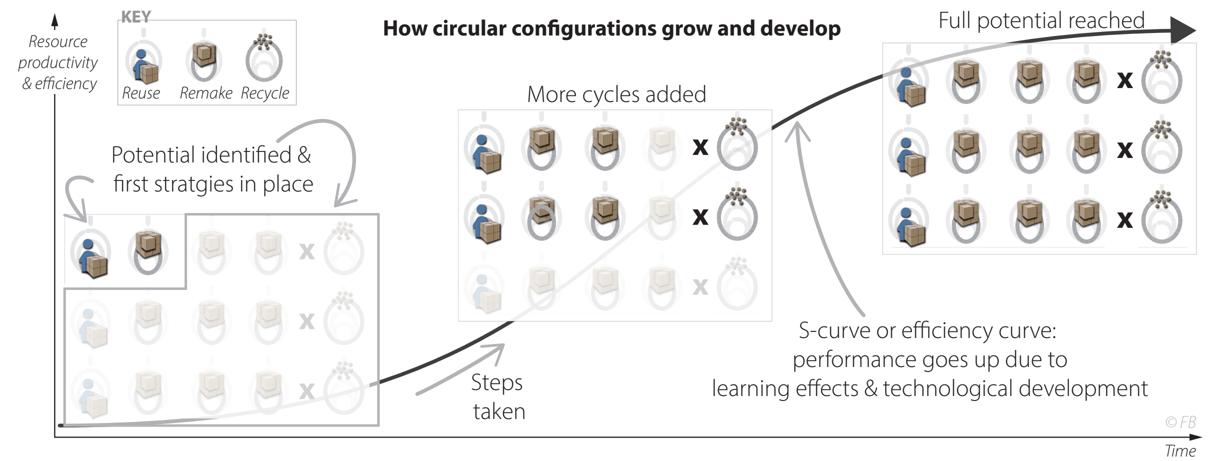
The way Circularity Thinking therefore approaches circular strategies highlights these interactions: acknowledging that such interactions—positive and negative—are common[8]. Therefore, it makes more sense to, instead of speaking of individual circular strategies, to consider *circular configurations:* situations where two or more circular strategies interact with each other in some way. The aim in this, is to create as many positive and synergistic interactions, and to minimise and manage negative ones. Just like in any other portfolio approach, circular strategies should be considered as a set - not in isolation.

Adopting this perspective not only means that it is easier to spot the “in-between” processes, departments and actors discussed earlier, but it also means that already at an early stage effects like displacement—moving impacts to other parts of the system—and rebound—when circular gains trigger extra consumption that cancels out the intended benefits—can be explored by critically examining how the set or portfolio of circular strategies will interact with each other.

<u>Unpack the ‘black-box’ of circular business models</u>
What Circularity Thinking also provides, is a way to unpack what is “in” a circular business model. Whilst on the surface different circular business models may appear similar, such as for example, product-service systems that are based on providing access to products through renting, leasing or pay-as-you-go - we can now unpack what circular strategies they use as part of this offering. Is it just intensification, or is this also supported by maintenance, repair and remanufacturing? In this way, we examine more clearly the degree to which resource conservation, efficiency and productivity are supported by the circular strategies that are part of a circular business model.

<u>Anchor- & support strategies, sequences</u>
Another part of this is how to distinguish between the circular strategies that form the backbone of a business model and those that enhance it. *Anchor strategies* are those directly linked to the most pressing structural wastes a business model seeks to address. They represent the primary intervention and form the foundation of a circular configuration. *Supporting strategies* complement these anchors by enhancing them, or mitigating remaining wastes. A sharing model anchored in intensification, for instance, may first launch as a basic access model, then be reinforced over time with durable design, spare parts provision, and predictive maintenance. Thinking in terms of roll-out sequencing makes circular business models more flexible, adaptive, and capable of continuous improvement.

<u>Continuous improvement</u>
A roll-out mindset also highlights the importance of continuous improvement. Without clarity on the broader set of strategies a business model is working towards, initial choices may unintentionally foreclose later options. For example, selecting composite materials to extend product life might make future recycling impossible, or prioritising downcycling could undermine opportunities for high-quality recycling. Trade-offs and competition between strategies mean that implementing one in isolation can create lock-ins that limit systemic circularity. By sequencing with the bigger picture in mind—see figure, circular business models remain open to adaptation and the integration of additional strategies over time.



Step 1 - Understand the Now: mapping resource flows

Before looking at waste and what (other) circular strategies are needed, it is necessary to understand the current value chain—from start to finish. This may already involve circular strategies or it may not - but chances are, there is plenty to improve and circular strategies can either be strengthened or added.

1.1 Set the scope: your unit-of-analysis

First, set the scope of the analysis. What material, component, product or product group will be examined? The Circularity Compass can accommodate all these different *units-of-analysis*. Just adjust the granularity or resolution of your analysis: if your case encompasses more variety and complexity, you will have to simplify and group smartly.

Are you not certain what to focus on? It may be helpful to make an exploratory draft mapping: as you go through the different life-cycle stages and examine the different flows, you may have a clearer picture afterwards. Also note that, when you go through the different steps, you may need to amend and further clarify your unit-of-analysis later on. It's ok to take an interactive approach.

1.2 Make a resource inventory

Make a *list and description* of what materials are present in a system: what they are, in what quantities they are used, and how important they are for the functioning of the value chain. In the case of rare-earth metals, for example, only a small part of the weight of a product is made up of these materials - but they are incredibly important for the functioning of electronic devices and equipment. Similarly, toxins can be present in small quantities, but have a large impact. However, in the first instance, don't make it too detailed—examining 3-5 different materials or materials groups will already get you a lot of insights. After you've also done a Waste Hunt (Step 2) and Configuration Build (Step 3) it will be clearer where you need more depth and detail—and you can return to this step, if needed.

1.3 Resource flow mapping

Next, map the life-cycle of the resources from beginning to end-of-life: what materials are extracted, how are they processed, where and how do they get to a user, how are they used, and what happens post-use? Essentially, you are making a variation on a formal method that is called a material-flow analysis, or MFA - where, in this version, you do not yet have to worry so much about mass-flow balance or precise quantification. Treat this as a storytelling exercise of the resource journey, capturing the key stages.

<u>Start at the top and move clockwise</u>

Using a different colour for each resource (group), map how the resources flow through the different resource states. Where does *stuff* come from: is a virgin resource being used—and if so, is it a renewable or non-renewable material? Or: is a material already being recycled within this system, or maybe a waste stream from another system is being repurposed here.

Moving on and completing the journey all the way until the end-of-life, make sure to trace how and when these materials are turned into components, and subsequently into products, noting any important intermediate processing steps, such as cutting, glueing, painting, etc.

Along the way, note what comes into the system and what leaves the system. At this stage, we're not yet concerned with identifying what structural waste this represents—the focus is on the flows and the processes. If there are already circular strategies present, include those too.

<u>Get a sense of quantities - where you can</u>

Use rules of thumb (like the "70-fold waste upstream for every unit of finished product") to highlight hidden magnitudes. Find out what these rules of thumb are for the system or industry under examination. At this stage, estimates are enough—the aim is to create visibility, grasp relative scales and hotspots. Indicate this by matching the relative thickness of the lines to each other.

<u>Include everything</u>

Include everything that is bought, sourced, or outsourced, even if a firm does not directly handle it — these activities still shape the system's footprint. This means considering upstream sourcing, manufacturing, logistics, use, and end-of-life. Cutting things out would miss the point of doing this analysis: to get an overview of what impacts are created in the system.

<u>Blind spots and knowledge gaps</u>

Use publicly available sources where needed, even if it just helps to get an initial indication. Mark blind spots and knowledge gaps openly—noting where information is uncertain or unavailable is just as important as mapping what you know. This creates a roadmap for where deeper investigation is needed: maybe a colleague or another value chain partner can help you get answers.

<u>From qualitative to quantitative</u>

Begin qualitatively to capture the system's logic and flows; later, if needed, you can translate this into a formal and quantitative MFA with data, balances, and validation. This first qualitative mapping helps frame the system before committing to detailed (and often time-consuming and costly) data collection—and this initial step often reveals more than expected.

<u>When is it finished?</u>

You have completed your mapping when you have reached the end-of-life for all the (main) flows you have decided to include in your analysis.

How to: Resource-flow mapping

Complexity/ difficulty: can be simple to start with, adding more complexity as your analysis progresses.

Time plan: a rough first version can usually be made in about an hour of brainstorming and consulting publicly available resources. A more detailed version and filling in any blind-spots or knowledge gaps will take longer.

Who to involve: It is helpful to involve different parts of the organisation, as they may have different perspectives and complementary knowledge. Where you can, discuss where it is sufficient to make educated assumptions. Where you feel you cannot do this, involve other parts of the value chain.

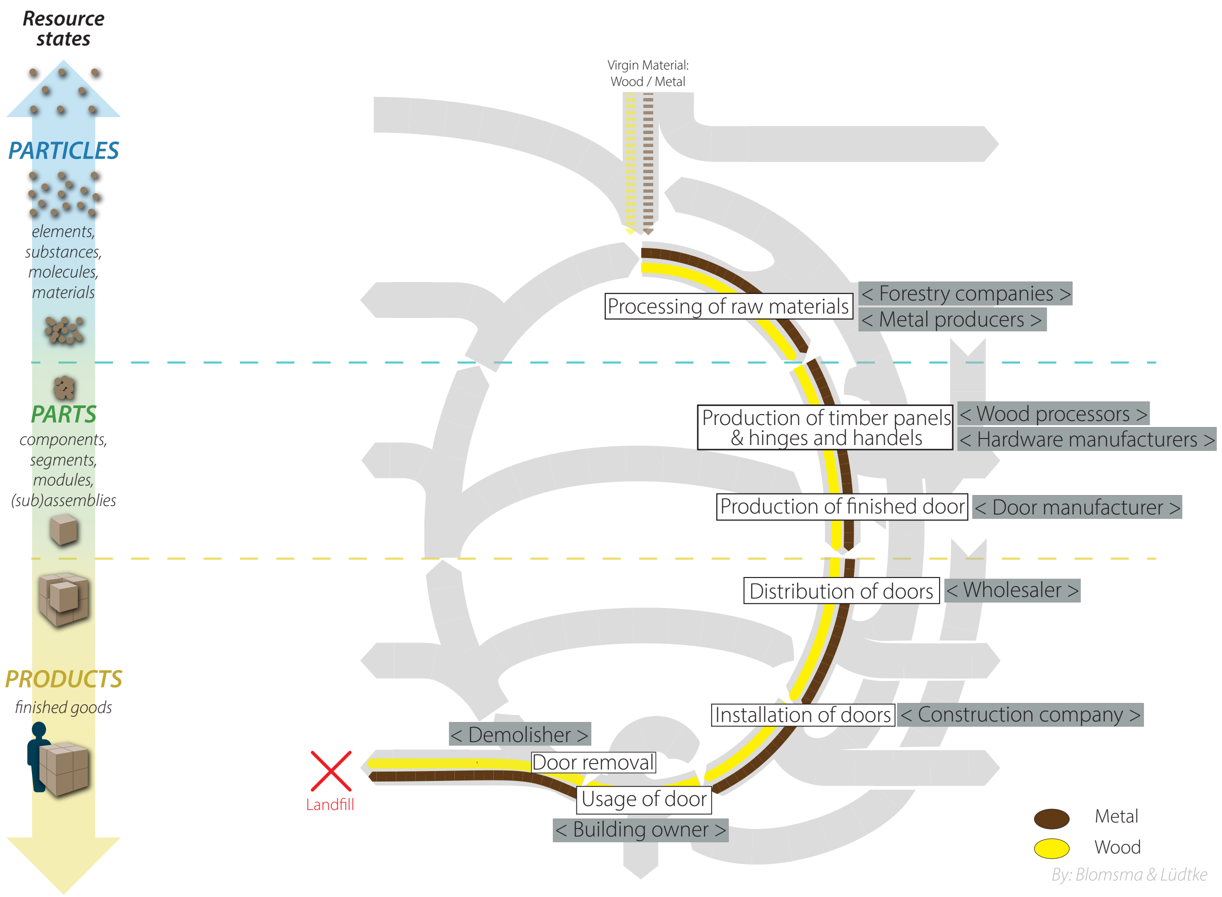
Circularity Thinking materials:

- One the Circularity Compass available as a shared workspace (large print or digital).

Other materials needed:

- Post-its, different coloured pens (if using a pen-and-paper analysis).
- Permissions to edit for contributors (if using a digital workspace).

Building doors – Material Flow Mapping



Example resource flow mapping

In the current resource flows of doors, wood from forestry companies and metal from producers are processed into panels, hinges, and handles by manufacturers, before being assembled into finished doors and distributed via wholesalers to construction companies. These doors are installed and used in buildings until demolition, when the demolisher removes them. At this point, most doors are simply sent to landfill, as this is the cheapest and fastest route. The flows therefore move in a largely linear fashion from virgin input through to disposal, with little effort made to recover or extend the value of materials.

The dominance of landfill stems from cost and convenience: demolition contractors are incentivised to remove doors quickly, rather than dismantle them carefully for reuse, refurbishment, or recycling. To enable alternative outcomes, such as reuse through marketplaces or refurbishment by brokers, the flows would need to include extra steps like assessing door condition, selective dismantling, and arranging logistics. Because these steps are usually skipped, both the material value in wood and metal and the potential for further use are lost, locking the system into a disposal pathway and limiting opportunities for circularity.

Step 2 - “Waste Hunt” - Identify Structural Waste

After mapping the resource flows, the next step is to trace where waste appears in the system. The Waste Hunt uses the BIg Five to make potential value leaks and losses visible on the resource flow mapping, so that you can later decide how to address them. The key is not to measure every gram of waste—some forms of waste will in fact be very hard to quantify and measure, but to identify where in the life cycle resources are p*rematurely lost, underused*, or handled *inefficiently* or *harmfully*.

2.1 *What* waste is found? Scan along the flows.
Take your resource flow map and move step by step through the resource states and the lifecycle stages—from extraction and processing, to use, to end-of-life. At each resource state: consider whether the resources are being renewed (or does premature end-of-life occur?) and fully used (or does premature end-of-use-occur?). Can you detect any excess or harm? Answer the Big Five questions as best you can. This means:

- For every out-flow: What type of waste is this?
- For every arc: is it done in the most efficient way possible? What harm occurs?

But also:
- For every in-flow: Is a waste from a previous life-cycle stage or from another system already being used?

By systematically checking each resource state, you ensure that you don’t only capture visible discards, but also the less obvious inefficiencies in use and design. Name and mark where current flows fall short and identify the types of waste that are present.

A Waste Hunt is best done in dialogue. As you map, check with colleagues or partners: Do we all agree this is a waste point? Is this really a hotspot, or only a minor issue? The aim is to build a shared understanding of where the system is leaking value. Use colour-coding, symbols, or sticky notes to make it clear which waste points belong to which resource flow.

It’s almost inevitable that during the discussion you will already touch upon what circular strategies you may want to use. This is ok, but try and bring it back to discussing what the problems are—e.g. what structural waste exists, until this is fully exhausted, across the value chain.

Of course, other issues, such as biodiversity loss, slave or child-labour, poor health and safety conditions, etc: indicate these too—there’s no reason you cannot strengthen the argument for ‘going circular’ with these elements included

2.2 *Where* does it originate? The “in-between”.
Remember: the *in-between*—the spaces between processes, departments, companies, and life cycle stages—is often where many obvious and less-obvious wastes reside. This means that where waste appears is not necessarily where it originates. For example, a broken component can be the result of design choices. Similarly, a wasted material can be due to the lack of coordination between processes or value chain partners. To understand better where the cause of the waste lies, trace it back to its origin: *where* in the system is it created or caused? Discuss this and note it on the diagram.

2.3 *Which* wastes are connected?
Waste usually doesn’t stand alone. This is because once resources are wasted at one stage (like products being designed to wear out early), it forces more production, more by-products, and more end-of-life disposal—so the waste initially identified is actually part of a part of a chain reaction of wastes, where one form of waste drives others elsewhere in the system.

For this reason it is important to ask: which wastes are connected? Which wastes create more wastes? Identify any chain-reactions and group or cluster these wastes.

2.4 *Why* does it originate? Purpose & practices.
Now that you know *what* wastes originate *where* in the value chain and *which* are connected - critically examine *why* this is the case. Ask, what is it about our expectations and assumptions with regards to the purpose we are using the resource for that makes it a waste at this point? What is the role of our practices, ideas and framing in this? Examining this shifts the focus from symptoms to root causes, enabling smarter and more effective interventions.

2.5 Identify magnitudes and hotspots
At this stage, estimates are enough—you do not need exact figures. Use rough indicators of scale to highlight the biggest issues. The groups or clusters you made earlier help with this. For example, make the icons bigger for large wastes, or use simple tags like “high”, “medium”, “low” on your post-its. Also note where a small flow may still represent a big impact (for example, rare materials or toxic substances). This helps later when you need to prioritise.

2.6 Capture uncertainties
Just as with the resource mapping, do not hide blind spots. If you are unsure about the fate of a certain flow, mark it with a question mark. If you suspect waste occurs but lack data, write it down anyway. These uncertainties are part of the Waste Hunt and create a roadmap for further investigation.

Throughout: challenge, challenge & challenge again
Sometimes, to see something as a waste, a fresh perspective may be needed. Looking in other sectors may help you gain fresh eyes to look at your context anew. After all, a fish takes the water it swims in for granted. For example, cars have become more efficient, but also heavier through the years. This is largely because the current weight has become an accepted norm or standard—largely due car manufacturers not actually carrying the cost for driving and maintaining it. Thus, total-cost-of-ownership is not considered. This means that the weight of cars is really an unseen structural waste. As is the fact that cars only last a decade or so before they often end up in countries with poor end-of-life infrastructure.

The same goes for many situations, but the causes may be different. It may have to do with not being aware of alternative processes (e.g. using closed-cycle CO_2 for dyeing of textiles instead of water, or not machining aluminium parts in protected atmospheres so that the scraps can be directly used in extrusion processes without remelting them. Or: it may have to do with what is considered the ‘core business’ of a company: if the main mission is shifted from producing sugar to ‘making the most of our flows’ it becomes possible to also produce tomatoes in greenhouses using the residual heat and CO_2 from the sugar-refining process. Therefore, critically examine the role of ‘givens’, of assumptions, and of the *but-we-have-always-done-it-this-ways*. Discuss these, how fixed are they, really? For inspiration, it may be helpful to look at other industries or innovative startups. Include in this not only successes, but also failures: after all, the idea may have been sound, but other circumstances may not have been. And: maybe it’s an idea whose time has come.

Don't be tempted to narrow the scope
It may be tempting during the Waste Hunt to focus on the part you, at this time, have control over or influence in. But, because circular strategies impact each other across the value chain, it is important to first establish a complete overview. You may uncover opportunities that are available through collaborations and partnerships. And: having a good overview of the problems will also make the circular configuration you will build (in Step 3) more robust. After all, someone else may soon spot problems that you exclude now - and their solution may make yours obsolete. So, for now, toroughly explore the problems.

When is this step finished?
You have completed the Waste Hunt when your resource flow map clearly shows where waste occurs, both visible and hidden. Waste points are annotated, relative magnitudes are indicated, and uncertainties are marked (which need further investigation). You have thoroughly explored and discussed not only what waste occurs, but also where it really originates and how the wastes—likely you have uncovered quite a few—are connected. Most importantly, the team has reached agreement on the 2–3 most important hotspots to carry forward. These priorities will form the starting point for Step 3, where you will explore which circular strategies could address it. And because you have discussed wastes deeply and thoroughly explored the problem space, you are now ready to build towards an effective circular configuration - knowing *where innovation is most needed*.

How to: Waste-Hunt
Complexity/ difficulty: can be simple to start with, adding more complexity as your analysis progresses.

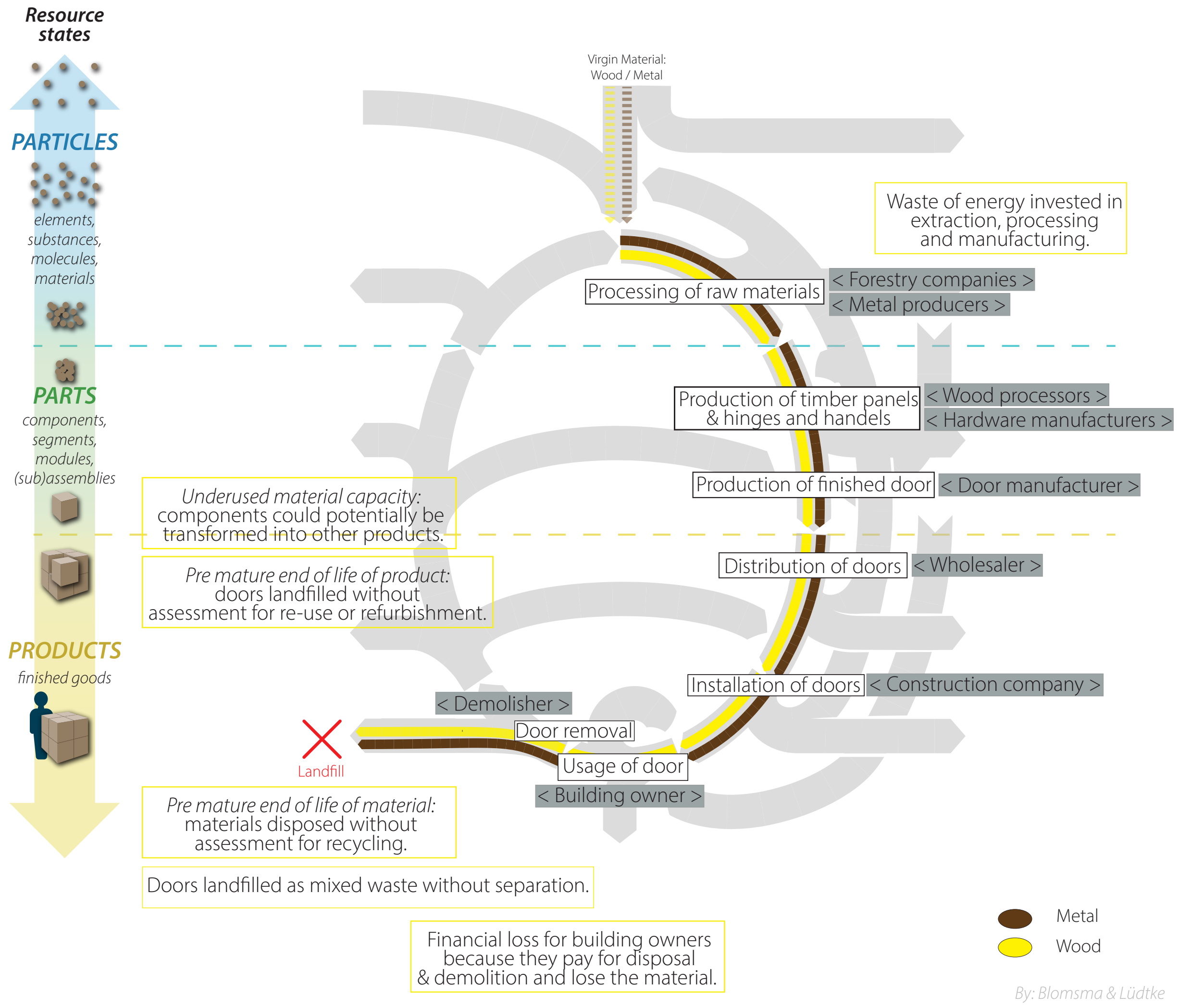
Time plan: a rough first version can usually be made in about an hour of brainstorming and consulting publicly available resources. A more detailed version, incl. the why and which wastes are connected can take longer. Filling in any blind-spots or knowledge gaps can also take additional time.

Who to involve: A Waste Hunt is best done in dialogue. As you map, check with colleagues or partners from the value chain. Consider organising a workshop to gather different perspectives, or consult people 1-on-1.

Circularity Thinking materials:
- One the Circularity Compass available as a shared workspace (large print or digital).

Other materials needed:
- Post-its, different coloured pens (if using a pen-and-paper analysis).
  - Consider using different coloured stickers for the the different wastes (5x different colours).
- Permissions to edit for contributors (if using a digital workspace).
  - Use ready-made icons that can be easily drag-and-dropped onto the workspace

Building doors – Waste Hunt



Step 3 - Configuration Builder - Sketching a set of circular strategies

Once you have identified where waste occurs, the next step is to design possible solutions. A circular configuration is a set of circular strategies that work together and reinforce each other to address the waste hotspots you have identified. Think of them as the circular strategies portfolio of the value chain. The aim of this step is not to arrive at the "final" solution, but to explore and sketch a first configuration that makes sense for your system and that can be refined later. In short: to go from the wide range of circular strategies that are on offer, to a short-list of those that are applicable to the situation under investigation.

3.1 Explore *anchor strategies*

Whilst some circular strategies may have already been discussed in the previous step, here you will explore more systematically which circular strategies make the most sense.

<u>Start from your waste priorities</u>

Look back at and review the 2–3 critical waste hotspots identified in the Waste Hunt. Each one points to an important place in the system where value is leaking out. Start your configuration design by asking: which circular strategies could best address these wastes? For example, if products fail prematurely, repair or refurbishment strategies may be most relevant. If crucial materials are lost, recycling or cascading may play a big role. Keep your focus on the priorities you have chosen—and acknowledge you cannot fix everything at once.

<u>What are central circular strategies?</u>

Many circular strategies fall under the circular economy umbrella: rethink, reuse, repair, remanufacturing, recycling, cascading, redistribution, sharing, performance optimisation, and more. For each hotspot, explore several strategies and ask: what would it look like if we applied this here? At this stage, it is useful to sketch multiple pathways, even if some are not yet feasible. This helps to identify interactions and trade-offs. Which set of strategies would optimise circularity, sustainability and value capture—and do away with the structural wastes you identified?

The set of priority circular strategies that you choose—which address the key structural wastes—these are the *anchor strategies*.

3.3 Combine into a *circular configuration*

Next, consider how different circular strategies could be combined into a set that works together. Be mindful of trade-offs—making a product highly durable may complicate recycling later, or how lightweighting can reduce longevity. Try to design combinations where strategies positively reinforce or support each other. The goal is to create a set that is synergistic rather than fragmented.

<u>Do support strategies need adding?</u>

Once you have a synergistic set of anchor strategies, branch out to identify support strategies. These are strategies that further enhance your anchor strategies. For instance, reuse can be strengthened by repair services, which in turn can make recycling more effective. In addition, support strategies can address remaining structural wastes.

<u>Take the long-view</u>

Envision which circular strategies the value chain would contain when fully mature and operating efficiently. This may not be short- or even medium-term. But the goal is to establish a vision to work towards, and to think about what would be optimal. This is crucial for developing a set of circular strategies that works well together.

3.4 Are any new wastes created?

As all resource transformations require resource inputs, ask if any chosen circular strategies also create new wastes: whether through transport, residual or extra materials, stock, buffers, or other unintended by-products that may undermine circular benefits. Discuss whether these can be managed or addressed—perhaps by adding supporting strategies or redesigning specific steps in the system to avoid unnecessary losses.

<u>Circular rebound</u>

It may be useful as well, to take a moment to consider unintended consequences in the form of circular rebound. Circular strategies can reduce resource demand in one place, but also stimulate additional consumption elsewhere, offsetting or even outweighing the intended benefits[. For example, extending product lifetimes may lower sales volumes in the short term, but can also encourage firms to push more products into the market or consumers to spend their savings on other resource-intensive goods.

All this means circular initiatives should be judged by their net systemic impact, not just immediate efficiency gains. Use this point in the process to surface new wastes and rebound risks, explore side effects, and question assumptions. Even in a qualitative mapping exercise, such reflection can expose hidden dynamics, highlight trade-offs, and reveal leverage points that shape how the new system works in practice and over time.

Considering new wastes and rebound, examine whether the chosen set of circular strategies is truly effective at addressing the structural wastes identified. Iterate the circular configuration accordingly, and remain open to adding, adapting, or combining strategies as new insights and opportunities develop.

3.5 Who and what makes it possible?

Circular strategies require business capabilities and activities to implement them. As you sketch your configuration, ask:

- Do different materials need to be used? Does the product design need to change in some way? Does the user need to be supported differently?
- Do changes to the business model need to be made (e.g. product-as-a-service, take-back schemes)?
- What other activities or capabilities are needed—and which department or which partner can provide them?
- What logistics, infrastructure, or information flows are needed?
- What other relationships need to change? Are new collaborations needed? Is there anyone who will 'lose out'?
- Is there a logical sequence to how the circular strategies will need to be 'rolled-out'?

In other words: what are the practical implications of your proposed circular configuration? The aim is to surface assumptions, dependencies, and enabling conditions early, so you can see what might be required without yet deciding how exactly to deliver it. This reflection is not only about feasibility, but also about timing, priorities, and sequencing—what needs to come first, what can follow later, and where dependencies between actors might create challenges or opportunities. This serves to understand what you are really asking of the partners involved—internal and external.

Use this, again, to iterate the circular configuration accordingly, and remain open to adding, adapting, or combining strategies as new insights and opportunities develop.

When is this step finished?
Keep iterating until the picture feels sufficiently complete for the moment—knowing it will evolve as new insights, partners, and opportunities appear. The aim is not to capture every detail, but to create a sketch that is already useful for reflection, iteration, and discussion. It is “enough for now” when it makes visible the key enabling conditions, assumptions, and gaps—without pretending the picture is final or fixed.

At this stage, these reflections are still exploratory and indicative—meant to sketch possibilities rather than lock in final commitments or detailed plans. Be explicit about the assumptions you are making and the uncertainties that remain: what is still unknown about costs, user behaviour, or technical feasibility? Such uncertainties do not weaken the configuration—they highlight areas for learning, testing, and adaptation. Later steps of Circularity Thinking will help with detailing flows, clarifying actors’ roles and responsibilities, and shaping suitable action plans.

This configuration is not a finished blueprint, but an initial vision of how your system could become more circular. Its value lies in opening pathways for action. In the next stage, this sketch can be deepened into practical plans, partnerships, and pilots.

It is recommended to, after building the initial configuration, allow for time to further develop it. In all likelihood, you have indicated assumptions, uncertainties and questions with regards to certain aspects. If they are crucial enablers or barriers, find out more about them before moving on. But also know: subsequent steps of Circularity Thinking will also help clarify your configuration further and help you to get ready for implementing it.

How to: Configuration Builder

Complexity/ difficulty: can be simple to start with, adding more complexity as your analysis progresses.

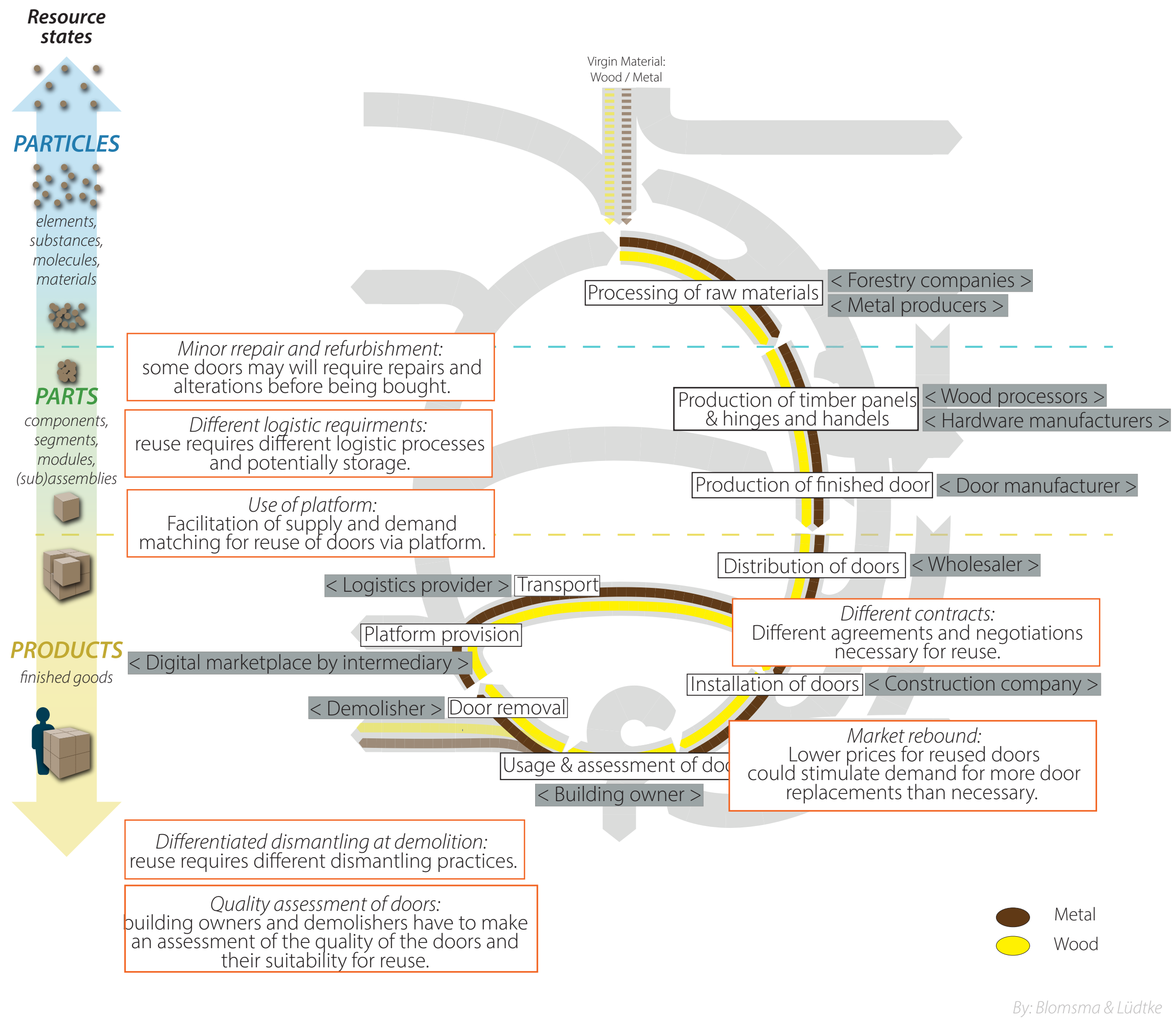
Time plan: a rough first version can usually be made in about an hour of brainstorming and consulting publicly available resources. A more detailed version and filling in any blind-spots or knowledge gaps will take longer.

Who to involve: Same as before: configuration sketch is best developed in dialogue. As you map, check with colleagues or partners from the value chain. Consider organising a workshop to gather different perspectives, or consult people 1-on-1. But also consider: there may not be a place for everyone in the new configuration. For example, if you aim to have a different and more direct contact with customers where dealers or retailers have this at the moment. Involving these stakeholders, or involving too many stakeholders too soon, may block the development of your configuration.

Circularity Thinking materials:
- One the Circularity Compass available as a shared workspace (large print or digital).

Other materials needed:
- Post-its, different coloured pens (if using a pen-and-paper analysis).
- Permissions to edit for contributors (if using a digital workspace).

Building doors – Circular Confrigruation



Step 4 - Multi-Flow Method - what forces shape how all the flows flow?

After sketching a circular configuration, the next step is to explore its feasibility and robustness. Resource flows rarely stand alone—they rely on flows of value, information, and energy. The Multi-Flow Method (MFM) allows you to map these flows and their interactions, and it helps to unpack the forces that shape them. Through this, it uncovers what is important, but usually goes unseen: revealing the systemic shifts that are needed to make a circular configuration work.

Why the Multi-Flow Method matters

Instead of only tracing where materials come from and go, MFM shows how value chains function in practice: recycling, reuse, and repair succeed only if actors are incentivised and the right information is available at the right time. By integrating multiple flows, MFM reveals the structural conditions that enable or block circularity, exposing deeper pressures and interdependencies rather than just listing barriers and enablers. For example, a take-back system may look straightforward on paper, but it depends on financial incentives for users, timely data on product condition, and affordable energy to transport goods back into the loop. Without alignment across these dimensions, even promising strategies stall or collapse in practice.

Traditional approaches to circularity, such as Material Flow Analysis (MFA) or Life Cycle Assessment (LCA), are excellent at quantifying inputs and outputs. They can tell us how much material enters a system, how much is wasted, and what environmental impacts are associated with these flows. However, they stop short of explaining why certain circular opportunities succeed while others fail, and they struggle to capture the complex interactions needed for systemic implementation. This means that numbers alone may give a sense of efficiency and impact, but they cannot reveal the social, economic, and organisational factors that determine whether a strategy is workable.

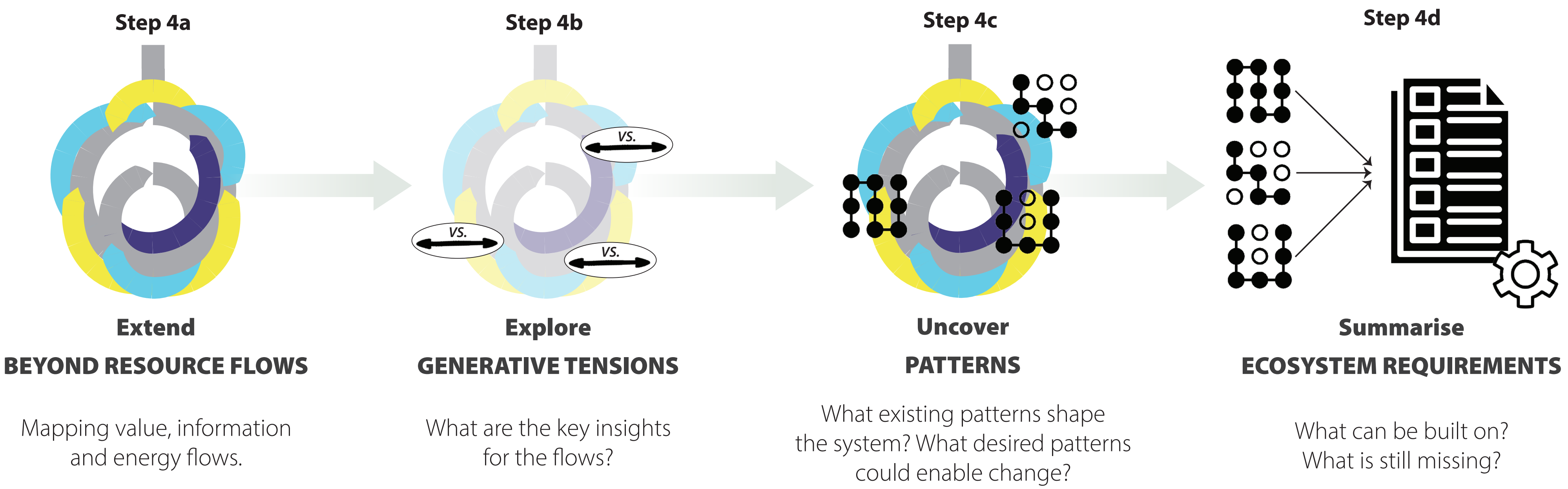
The reason is that materials do not move on their own. They are extracted, processed, used, and disposed of by actors making decisions. Those decisions are shaped by value flows—who gains, who pays, and where profits or losses are created. They are also shaped by information flows—who knows what, and whether actors are able to coordinate effectively. They are further shaped by energy flows, since people decide which processes to use, what sources to rely on, and whether renewables are prioritised. In short: *people make flows flow*—or not.

A recycling process may be technically feasible, but if demolition contractors are paid to landfill rather than recycle, it will not be used. A reuse scheme may be feasible, but if building owners or architects are unaware of it, products will still be discarded. Circular strategies fail not only because of technical limits, but also because of incentives that misalign, knowledge that never reaches the right actors, or energy choices that make one option easier or cheaper than another.

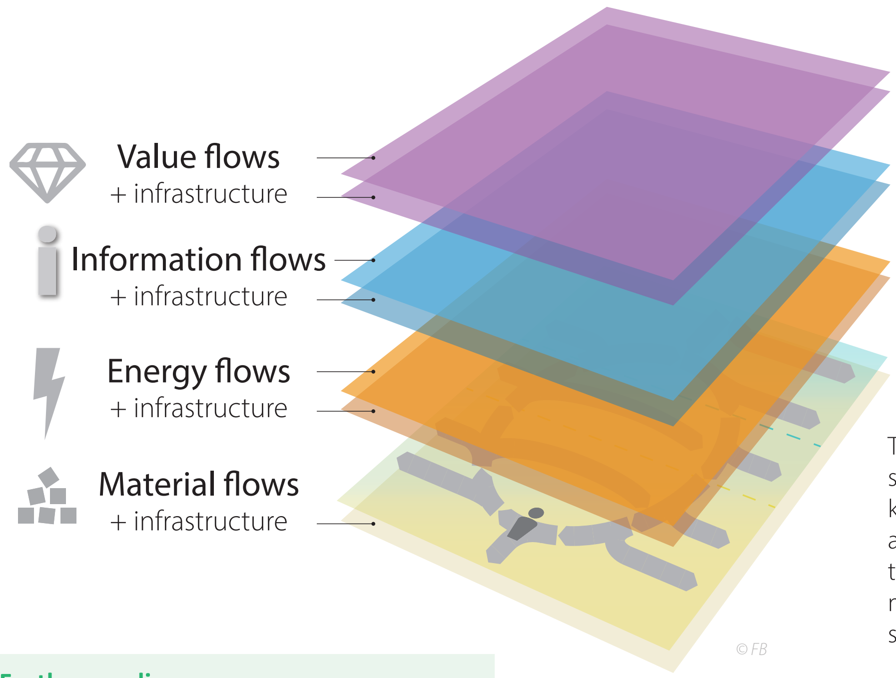
The Multi-Flow Method was developed to make these dynamics visible. It provides a structured way to map not only material flows, but also the financial, informational, and energy relationships that surround them. By doing so, it pinpoints where tensions, bottlenecks, and reinforcing patterns arise, helping to anticipate how the system as a whole behaves and where interventions can be most effective. This means MFM does not just highlight obstacles but also uncovers leverage points—places where small adjustments in incentives, data sharing, or energy sourcing can unlock circular outcomes that can outperform linear solutions.

When to use the MFM

Application of the MFM is most valuable when surface-level tools are not enough—when listing barriers and enablers, or mapping resource flows, leaves the real dynamics unexplained. Its unique contribution is to uncover the tensions and recurring patterns that shape behaviour, helping actors look beyond isolated issues to the deeper forces driving them. This makes it especially useful where collaboration across complex value chains is required, but incentives, power, or roles are misaligned. If the context is simple, actors aligned, or barriers straightforward, the MFM may be unnecessary; but where systemic misalignments dominate, it provides insights other tools cannot. Think of it this way: mapping a flow is like drawing a river system—you see where the water goes, but not why it floods or dries up. The MFM looks deeper, at the underlying forces shaping those flows: weather, terrain, climate, irrigation, etc.



Multi-Flow Metabolism



The 'layers' of the industrial system: each layer depicts a key 'flow' incl. its infrastructure and technology that are vital to transitioning from one metabolsim state (linear) to a second (circular) one.

Further reading:

- *Blomsma, Tennnant and Ozaki (2023)*[12].

Theoretical roots of MFM

The Multi-Flow Method is grounded in several strands of theory. From systems thinking, it takes the insight that behaviours emerge from interactions, not from isolated actors. From complexity theory, it borrows the idea that tensions and paradoxes are generative forces, not obstacles to be removed, and that progress often depends on navigating rather than resolving them. From institutional theory, it highlights the role of rules, norms, and power in shaping flows of value and information. And from socio-technical transitions research, it recognises that industries evolve through the alignment and misalignment of technologies, markets, and institutions. Together, these perspectives make the MFM both a conceptual lens and a practical tool. It translates abstract insights into workable processes where participants can map flows, discuss tensions, and co-create visions of new patterns. It reflects the shared insight that change arises not from isolated actions but from the interplay of structures, relationships, and dynamics across the system. By combining these theoretical perspectives, the method bridges academic insight and practice, enabling systemic thinking to inform practical interventions.

The flows

At the heart of the method are three flows—resources, value, and information—with energy sometimes added as a fourth when it plays a critical role.

- ***Resource flows*** are the most tangible: materials, components, and products moving through their lifecycle. They show where extraction takes place, how processing and manufacturing occur, how products are used, and what happens at the end of life. For example, apparel waste can be recycled into feedstock for acoustic floor tiles. Here the flow of recovered materials runs from one sector to another, extending the lifecycle of resources that would otherwise be discarded. In Step 1 such a resource flow map was already made.

- ***Value flows*** trace the exchange of money, incentives, and costs. They reveal who pays whom, who benefits financially, and where value is lost. These flows often move in the opposite direction to materials. For example, in the reuse of doors from demolition projects, a building owner can negotiate directly with demolition contractors and buyers through a digital marketplace. Value is retained when components are sold for reuse, rather than lost when they are sent to landfill at additional cost.

- ***Information flows*** capture the movement of knowledge, data, and communication. They include location, quantity, and 'health' but also design specifications, contracts, quality standards, or even informal practices and expectations. But also relevant stakeholder information: what capabilities someone has for processing, for example. Without adequate information flows, even technically feasible circular solutions may fail to materialise. For example, repair of a building's audio system depends on reliable data: digital product passports and instructions enable owners and manufacturers to coordinate repair, while updated product information feeds into a building's digital twin, ensuring transparency over recycled content and sustainability attributes.

- ***Energy flows*** become important when energy demand plays a critical role in the system, such as in energy-intensive industries or where energy costs shape decision-making. The type and amount of energy required may determine whether a product is refurbished, remanufactured, or replaced and recycled instead. For example, in the remanufacturing of acoustic floor tiles, energy use in transport, processing, and production determines whether the take-back program is viable, and whether it delivers real environmental gains compared to sourcing new inputs.

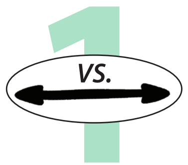
Each flow depends on its own enabling infrastructure—logistics networks to move recovered resources, financial systems and marketplaces for pricing and payment, digital platforms and standards for product information, and energy grids to power processes. Infrastructure sets the conditions for what flows can move, how they move, and at what scale. Together, infrastructure and technology shape the system's possibilities and limits. As they evolve, so do the flows—and it is their interaction that determines whether new solutions can take hold.

When mapped together, the flows and their infrastructure form a more complete picture of the system. Resource flows are the foundation, showing how materials, components, and products move, but on their own they give only a partial view. Adding value, information, and energy flows makes visible the incentives, knowledge, and conditions that ultimately decide whether circular strategies succeed in practice.

More than flows: uncovering patterns
The Multi-Flow Method is not just about mapping flows. While flow mapping reveals how a system operates, it does not explain *why* certain problems persist or why dynamics keep repeating. To address this, the method moves the focus beyond analysing flows or listing persisting barriers and enablers, and instead asks why these dynamics occur. It aims to uncover *patterns*: the recurring dynamics that explain why the value chain functions as it does. Patterns reveal the underlying pressures, trade-offs, and forces that shape behaviour across the system.

To explore such patterns, the method works with three recurring tensions that appear across most value chains. These tensions are not problems to be permanently resolved, but forces that must be balanced, navigated, or worked around. The tensions serve as a lens, a practical tool for uncovering why certain dynamics endure and where opportunities for change lie.

<u>From current to desired ecosystem patterns</u>
Three tensions are used to explore both existing and desired patterns. Existing patterns show how the value chain currently functions—the misalignments, incentives, and structures that hold the system in place and make circular strategies difficult. Desired patterns, by contrast, describe how the system should function for circularity to succeed—for example, through upstream coordination, fairer value distribution, or more adaptive contracts. Examining how existing patterns might be transformed into desired ones reframes tensions and problems as opportunities for redesign. In this way, patterns go beyond barriers and enablers: they reveal the deeper mechanisms and forces that shape behaviour across the value chain as a whole.

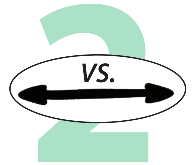


Individual versus Collective interest

- When unmanaged: On the one hand, when individual goals dominate, actors optimise for their own short-term advantage, at the expense of collaboration. On the other hand, when collective goals dominate, the system may neglect the needs and constraints of individual organisations.
- Therefore: Balancing the benefits for individual actors with the shared value of the whole system is essential. In circular value chains, circular strategies can only succeed when all parties are willing to contribute, collaborate, and invest in shared outcomes.

Examples of patterns:

- Existing pattern: Building owners prioritise short-term cost savings (e.g., demolition, disposal) over collective benefits such as reuse, leaving components underutilised.
- Desired pattern: Pricing and incentives align individual gains with collective outcomes, so returning materials (e.g., tiles) becomes financially attractive and supports circular strategies.

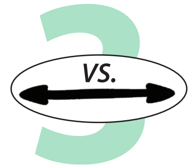


Robustness versus Adaptability

- When unmanaged: Too much robustness creates rigidity and resistance to change; conversely, too much adaptability causes fragility and lack of reliability.
- Therefore: it is necessary to find the right balance between stability and flexibility in value chains. Circular systems depend on stable contracts, processes, and relationships to secure continuity, but also require adaptability to deal with crises, shifting markets, or new technologies. Without adaptability, solutions quickly become outdated. Without robustness, trust and reliability erode.

Examples of patterns:

- Existing pattern: Fixed contracts and rigid processes provide stability but restrict the integration of new data, partners, or recovery options, leaving the system slow to adjust and vulnerable to more innovative competitors.
- Desired pattern: Contracts and data systems combine predictability with flexibility, maintaining trust and continuity while enabling adaptation to changing feedstocks, evolving data standards, and emerging technologies, enabling the solution to remain competitive.



Concentration versus Distribution

- When unmanaged: Too much concentration gives control and benefits to a few dominant players; and too much distribution can lead to fragmentation and weak coordination.
- Therefore: Managing how power, resources, and information are shared across the system is a central challenge. In circular transitions, large players often dominate decision-making and capture most of the value, but broad participation is essential to unlock innovation and ensure fairness. Effective systems balance strong leadership with inclusive collaboration and distributed influence.

Examples of patterns:

- Existing pattern: Large manufacturers and platforms control access to data and value, while smaller actors struggle to participate and benefit equally.
- Desired pattern: Marketplaces distribute access and benefits more widely and fairly, enabling contractors and intermediaries to participate while still ensuring coordination.

From insight to impact: identifying new ecosystem requirements

After examining the current and desired patterns, ecosystem requirements can be defined. These describe what the system must provide to make the desired patterns possible, by asking: what can be built on, and what is still missing? This may involve scaling existing practices, collaborations, capabilities, and infrastructures, or introducing new ones. Making these requirements clear moves the process from analysis to getting ready for planning action.

Ecosystem requirements provide the foundation for concrete steps and interventions, which are developed in a subsequent step of Circularity Thinking. The MFM facilitates moving from flows to patterns—first existing, then desired—and finally to ecosystem requirements, using tensions throughout as a lens to interpret system dynamics. This reveals not only what is technically possible but also what is systemically necessary for circular strategies to succeed.

Working with multiple flows

The following pages present each step of the Multi-Flow Method in detail. Each step is introduced with its overall logic, followed by guiding questions for the different flows. Each step includes guidance for all flows—resource, value, information, and, where relevant, energy—but not all will apply in every case. This structure allows the method to be followed step by step, while focusing only on the flows that are relevant in a given context.

Further reading on the development of MFM:

- *Blomsma and Lüdtke (2023)*[13].
- *Blomsma and Lüdtke (2024)*[14].

How to: Multi-Flow Method

When to use: The Multi-Flow Method is most useful when value chains are complex and traditional tools don't explain why problems persist. Its strength lies in revealing recurring patterns that drive behaviour, making it valuable where incentives, power, or roles are misaligned.

Pre-work: Draw on the outputs from earlier Circularity Thinking. Either a resource flow map of the current system (Steps 1–2) or a configuration sketch from Step 3 can serve as the starting point.

Complexity/ difficulty: The method does not require technical expertise but does demand persistence and tolerance for ambiguity. Participants must move beyond mapping flows to recognising dynamics, patterns, and tensions, which may feel unfamiliar at first. The main challenge lies less in technical detail and more in helping participants think systemically rather than reverting to barrier–enabler lists.

Time: Time requirements vary depending on the complexity of the case, the number of flows explored, and the tensions considered. Workshops with many participants benefit from pre-mapping in a smaller core group to provide a concrete starting point. Allow time for participants to get used to thinking in patterns and for the analysis to move beyond barrier lists.

Who to involve: Ensure the right people are present: at minimum a facilitator, a project lead, and decision makers or stakeholder representatives with relevant perspectives. Flow experts can be invited where technical input on materials, energy, information, or value is needed.

Iterative process: The method works iteratively. While flows are mapped one at a time, new insights will often emerge that require revisiting earlier steps. This back-and-forth is not a distraction but an essential part of connecting across flows.

Practicalities: Use different colours to distinguish flows, patterns, and tensions—whether with post-its and pens in physical workshops or digital equivalents online. We suggest assigning colours to specific flows (e.g. purple for value, blue for information, orange for energy, red for losses), but the key is that participants share a clear understanding of what each colour represents.

Circularity Thinking materials:

- Several Circularity Compasses available as a shared workspace (large print or digital): one for each flow you are examining.

Other materials needed:

- Post-its, different coloured pens (if using a pen-and-paper analysis).
- Permissions to edit for contributors (if using a digital workspace).

See also:
Onto-Deside or Circularity Thinking websites.

Step 4a - Extend beyond resource flows

With a first configuration sketch in place (Step 3), the MFM now extends the focus beyond resource flows. This step builds on the resource flow mappings from the previous steps and expands the view by exploring value, information and energy flows.

Getting started
The mapping created in earlier steps provides the foundation for this stage. If a configuration sketch has already been developed, it is usually best to start there: the MFM can then be directed toward exploring what is needed to realise this specific circular setup. If only a resource flow map of the current situation is available, that can also serve as a starting point. In this case, the MFM analysis will be more exploratory, focusing on what is not working and what possible solutions could address these issues.

Whichever starting point is chosen, additional flows can then be layered step by step—value, information, and, where relevant, energy. Begin with the flow that appears most critical either for realising the new configuration or for deepening understanding of the current situation. Although it is simplest to focus on one flow at a time, expect connections to other flows to surface naturally. Capture these links as you go with brief notes on the corresponding Circularity Compass template so they are not forgotten, but return to examine them in depth later. The method is iterative, and understanding strengthens as flows are revisited and integrated.

If working on paper, use a clean Circularity Compass template for each new flow: sketch the resource flow outline, then add the flow using the mapping steps. Digitally, copy the resource flow template and draw the new flow on top. Keeping flows on separate templates helps maintain clarity, also once patterns & post-its accumulate.

Keep a system-wide perspective
When extending the map, focus on system-wide relationships, not just a single organisation. Look beyond your own operation and ask: Who else needs to be involved for this flow to work? What other actors, processes, or infrastructures interact with it, even if they are outside your immediate suppliers or customers?

4a.1: Mapping value flows
Goal: Make visible how money, incentives and benefits move across the value chain—and who bears the cost or investment.

Why this matters: Circular strategies succeed only when actors are incentivised to participate. Mapping value flows shows who gains, who pays, and where losses occur, revealing whether incentives enable or block circular goals.

To do this, focus on the financial relationships and transactions across the system. Use (purple) post-its to capture payments, costs, or incentives (e.g., “contractor pays for landfill disposal”). For each one, ask: *Who pays or invests—by how much? Who receives or benefits—by how much? What is needed for the value flows to flow—and who provides this?*

Place the notes next to the relevant actor or step in the chain and draw arrows to show the direction of money or incentives. To make the mapping clearer, use two different colours for arrows: one colour (e.g., blue) to indicate value exchanges—where resources are exchanged for money, such as a building owner paying for the purchase of a reusable door—and another colour (e.g., red) to indicate value losses—where resources and financial value are both lost, such as paying for disposal of building material.

Tip: Include both formal mechanisms, such as contractual payments, subsidies, or disposal fees, and informal mechanisms, such as verbal agreements or goodwill-based exchanges. And: financial flows are always a good starting point, but of course other types of value can be added, too, such as easier processes, or environmental and social benefits.

4a.2: Mapping information flows
Goal: Make visible what information needs to move across the value chain for the system to function effectively.

Why this matters: Information connects different parts of the system. Knowing what data is needed, by whom, at what point in time, in what format and what level of detail helps coordinate actions and put the right processes in place.

Focus on the knowledge, data, and communication that move across the system. Use (blue) post-its to capture key pieces of information needed for the value chain to function. For each one, ask: *What information is required? Who needs it? Who is withholding it? When and where in the chain is it needed?*

Place the notes next to the relevant actor or step and draw arrows to indicate where this information comes from or should come from.

Tip: Capture both digital and non-digital exchanges, such as automated sensor data versus a phone call from a supplier.

4a.3: Mapping energy flows
Goal: Make visible where energy is required, consumed, or recovered along the value chain—and indicate the type and quantity.

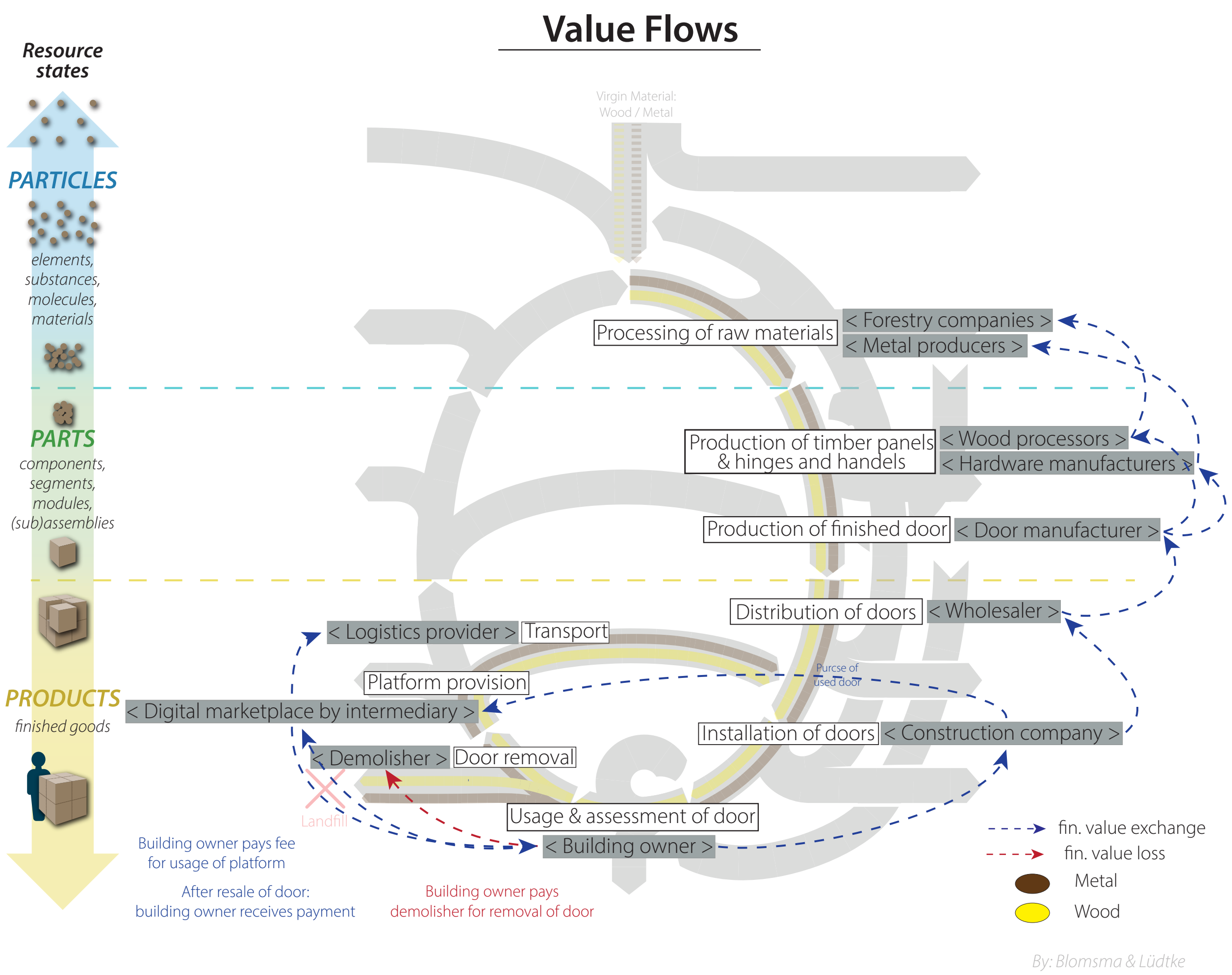
Why this matters: Energy can be a key enabler of circular practices. Mapping energy flows helps identify where demand creates barriers and where opportunities exist for recovery, substitution, efficiency or sustainability gains.

Focus on where energy is needed across the system — at each stage of the value chain, such as processing, transportation, or remanufacturing. Use (orange) post-its to note different types of energy demand and their scale. For each one, ask: *Where is energy required, and for which activity? What type of energy is used (e.g., electricity, heat, fuels)? How much energy is needed — high (H), medium (M), or low (L)? Where does the energy come from? And is any energy wasted, lost, or left unused — and could it be recovered or repurposed?*

Place the notes next to the relevant process or actor and draw arrows to show energy movement or exchanges between stages.

Tip: Where possible, distinguish between different forms of energy (e.g., electricity for machinery vs. heat for drying processes). Noting these differences helps reveal where energy is critical to the system and where alternatives, efficiencies, or substitutions might be possible.

Reuse of building doors – End-of-life example



<u>Value Flows in the reuse of doors - an example</u>
In the case of reusing doors, the mapping shows how value moves between multiple actors: the building owner pays the demolition contractor for removal but can also generate revenue from the marketplace intermediary through the resale of the door. Buyers, such as construction companies, pay for the reused doors, while the marketplace operator earns a commission or service fee. At the same time, disposal fees for doors that cannot be reused or other components represent a value loss for the building owner, as the building owner both pays for landfill and loses the material value. Mapping these exchanges in blue for value creation and red for value loss highlights where incentives align with reuse and where they still push materials toward disposal. While downstream exchanges are relatively straightforward — raw materials, components, or doors are traded for money — the more revealing value dynamics appear in the end-of-life stage, where demolition, reuse, or disposal create sharper contrasts between value gains and value losses.

When is this step finished?
This step is complete when the flow mappings feel sufficiently mature to serve as a basis for exploring patterns. In most cases, at least two flows in addition to the resource map should be included—value and information almost always surface in discussions, while energy can be added when needed. The aim is not to capture every detail but to ensure that all major steps of the process are represented, that there is sufficient detail for critical issues or gaps to become visible, and that the flows reflect system-wide dynamics rather than isolated perspectives.

The maps should be "enough for now": clear enough to inform the next step, but can remain open to refinement later. If discussions risk circling without progress, move on once the major flows and key issues are visible—the following steps will deepen the analysis. Also remember that this is not yet an analysis, just a mapping. Analysis follows in the next step.

Documenting uncertainties or assumptions at this stage is useful, as these will often point to areas for learning or testing in later steps. Remember that this mapping step is not about final answers, but about creating a shared picture that can evolve as new insights and actors come into play.

How to: Step 4a - Extending beyond resource flows
Pre-work: Access the outputs from Steps 1 – 3. Either the resource flow map of the current system or the configuration sketch can be used as a starting point—the configuration sketch provides a more directed discussion, while the resource map allows for a more exploratory one.

Time plan: Mapping additional flows can take 60 to 90 minutes per flow, depending on complexity. All three flows can usually be covered within a half-day workshop, if discussions are kept focused.

Circularity Thinking materials:
- Several Circularity Compasses available as a shared workspace (large print or digital): one for each flow you are examining.

Materials needed:
- Post-its in multiple colours (for resources, value, information, energy).
- Pens or markers, ideally colour-coded according to post-its.

Facilitator tip:
Encourage participants to capture connections to other flows whenever they surface, but keep the active discussion focused on one flow at a time. Emphasise that circling back to refine or add detail later is expected — the method builds through iteration rather than aiming for a perfect map in one go.

Step 4b - Explore tensions - Discuss the influence of opposing forces

Mapping flows alone does not explain why circular systems behave as they do. To fully understand what drives the system, it is necessary to identify patterns—the recurring dynamics that explain why the value chain functions as it does. Patterns highlight the deeper mechanisms, trade-offs and forces that shape behaviour across the system.

How it works
To uncover these patterns, the Multi-Flow Method works with three recurring tensions as interpretive lenses. Tensions are not problems to be permanently solved but forces that must be balanced, navigated, or sometimes worked around. They help explain why certain dynamics persist and where opportunities for change might lie. By using the guiding questions linked to each tension, the discussion explores how opposing forces shape flows, surfaces key insights, and opens up possible explanations for system behaviour. Later, these conversations will be refined into explicit patterns in Step 4c.

Applying tensions as lenses
Goal: The purpose of this step is to create space to explore how the tensions appear in the system and to use them as lenses to spark broader conversation. The step is deliberately divergent: it deepens dialogue and brings forward interdependencies, gaps, and issues, so the outlines of patterns that explain how the system behaves begin to emerge.

Why this matters: Tensions expose pressures and trade-offs—real or perceived— that shape value chains. They move analysis beyond surface issues, revealing forces that enable or block circular strategies, sparking discussion, and clarifying recurring patterns in system behaviour.

Individual versus collective interest
This tension explores how the needs of individual actors relate to the needs of the system as a whole. The key questions are:

- *What is the goal of the individual actors*—and can they reach it*?*
- *What is the goal of the value chain as a whole*—can it be reached*?*
- *Are both individuals and the collective taken care of?*

This lens shows where flows—whether of resources, value, information, or energy—support both the individual and the collective, and where mismatches make circular strategies harder to realise.

4b.1 How to make sense of the flow mappings?
Start by revisiting the flow mappings from Step 4a. The aim now is to unpack these by asking what forces might explain why the flows take their current shape. Begin by choosing one flow where issues surfaced during the mapping or which feels most urgent to explore. Then, with the help of the key questions provided in the boxes above, select one generative tension that seems most pressing to examine. For more detailed questions for each flow, see the table below.

For example, in the case of the reuse of doors, whilst the overall goal may be reuse, demolition contractors may prioritise disposal because it is quicker and cheaper, suggesting a potential misalignment between individual and collective interests. Once a flow and tension have been chosen, turn to the following page and select the respective set of questions to spark discussion. These serve as prompts for reflection, not a checklist—choose only those most relevant to your case.

Robustness versus adaptability
This tension examines how stability and flexibility are balanced in the system. The key questions are:

- *Where is the system robust?*
- *Where is the system adaptable?*
- *Is the balance right?*

This lens helps identify where flows are supported by stability, where flexibility is needed, and where an imbalance undermines circular strategies. It also highlights the trade-offs between reliability and responsiveness that shape how value chains evolve over time.

Concentration versus distribution
This tension looks at how resources, influence, and responsibilities are shared across the system. The key questions are:

- *Where is value/power/information/… concentrated?*
- *Where is it distributed?*
- *Is the balance right?*

This lens helps reveal how flows are governed and accessed, and whether their concentration or distribution supports or hinders circular strategies.

4b.2 What are the key insights?
As you discuss the questions exploring tensions, write down your main takeaways on post-its and place them on the canvas at the point in the flow where they apply. Each post-it should contain one clear insight phrased as a short statement. Avoid simply writing barriers such as “disposal is cheaper than reuse”; instead, reframe it to capture the underlying cause, for example: “current pricing structures make disposal cheaper than reuse.” The goal is to move beyond surface observations and begin to see what drives the system. Therefore, focus on causes rather than symptoms.

Ask yourself:
- What important insights or observations stand out from this discussion?
- What underlying reasons or misalignments seem to explain why flows take their current shape?
- What consequences do these dynamics create for actors or for the system as a whole?

When is this step finished?
This is an intermediary, exploratory step aimed at surfacing the most important underlying forces—in essence a guided brainstorm. The focus is breadth rather than precision: the goal is to open discussion and make visible the different ways tensions shape the system. This step is complete once the main dynamics are surfaced and better understood. It is not necessary to cover every flow under every tension—what matters is to generate meaningful insights about the forces driving behaviour. A good sign is when participants can articulate a handful of key dynamics that explain why the system functions as it does. Remember: tensions are the interpretive lenses that help surface dynamics, while patterns are the recurring dynamics themselves. In the next step, these insights will be organised and refined into explicit patterns. If discussions start circling without new input, move on—the following step will capture patterns more explicitly.

Key insights from the reuse of doors - an example

In the case of value flows for door reuse, several key insights emerged across the three tensions. Under the tension of individual versus collective interest, demolition contractors tend to prioritise fast disposal because it is cheaper for them, even though the system as a whole loses valuable materials. Building owners who might invest in careful dismantling are often undercompensated, since the benefits flow to buyers or brokers instead. Under robustness versus adaptability, standard demolition contracts reinforce this misalignment by locking in fixed prices and timelines, leaving little room to adapt when reuse opportunities arise. Together, these insights show how incentives and rules push behaviour toward disposal rather than recovery.

Other findings highlight how power and trust issues play out under the tension of concentration versus distribution. Buyers hesitate to commit to reused doors because price and supply reliability are uncertain compared to new products, limiting uptake. At the same time, value capture is uneven: large demolition firms dominate recovery because they hold the contracts, have the necessary equipment, and can operate at scale, while smaller refurbishers struggle to access these opportunities. Digital marketplaces add another layer of concentration: they centralise transactions and fees, which can create efficiency but also risk excluding smaller brokers and limiting diversity of access. These insights underline how systemic imbalances across incentives, contracts, and market structures shape whether reuse becomes viable or remains marginal.

How to: Step 4b - Exploring tensions

Pre-work: Flow mappings from Step 4a should be available as a reference. These provide the basis for discussing how tensions shape the system.

Time plan: The time required varies with the level of detail. Covering all tensions for one flow can take around 90 minutes. A focused session of about 3 hours is often sufficient to provide a solid basis for the next step, though not all flows and tensions need to be addressed, and additional time can be added if needed.

Materials needed:
- Post-its to note key insights.
- The guiding questions for each tension.

Facilitator tip:
Encourage the group to treat tensions as interpretive lenses, not checklists. Guide participants to capture concise insights on post-its at the points in the flow where they apply, and to focus on underlying dynamics rather than surface observations.

	Resource Flows	Value Flows	Information Flows	Energy Flows
Individual vs. Collective Interest	• Are actors incentivised to maximise their own short-term use of resources, or to preserve shared long-term availability? • Who benefits from discarding or extracting resources, and who bears the costs of loss or scarcity? • Do current arrangements reward collective recovery of resources, or reinforce individual disposal practices?	• Where do some actors bear costs that benefit others, and how does this affect participation? • Do current value exchanges encourage collaboration across the system, or pull actors in different directions? • When value is created, does it stay with the actor who generated it, or does it spill over to benefit others in the system?	• Are organisations rewarded for keeping information to themselves / sharing information with the value chain? • What are they gaining/ losing by sharing/ not sharing? • What risks emerge from not sharing/ sharing wrong/ unintentionally sharing?	• Do actors optimise energy use mainly for their own operations, or in ways that benefit the system as a whole? • Are savings from efficiency or recovery kept within single firms, or shared across the value chain? • Does competition over energy costs hinder collaboration on shared energy solutions?
Robustness vs. Adaptability	• Do existing supply contracts and standards provide security, or restrict flexibility when resource quality or availability changes? • Can the system adjust when disruptions occur (e.g. shortages, impurities), or is it too dependent on fixed supply chains? • Does stability in resource flows build confidence, or reduce the space to experiment with circular alternatives?	• Do financial arrangements (e.g. contracts, pricing models) provide security, or lock actors into rigid paths? • When conditions change, can value flows adapt — or are they too fixed to respond? • Does stability in value exchange build trust, or prevent experimentation with new circular practices?	• Is the way information moves in this system rigid? Or flexible when things change? • What happens when unexpected things happen? • Does the system rely on fixed routines? Or can it adjust when things change?	• Are energy supply arrangements (e.g. contracts, infrastructure) providing stability, or locking the system into rigid paths? • When disruptions occur, can the system shift to alternative energy sources, or is it too dependent on one option? • Does reliance on stable but carbon-intensive energy provide short-term security at the cost of long-term adaptability?
Concentration vs. Distribution	• Is access to key resources concentrated in a few actors, or spread more widely across the system? • Does concentration create efficiency and control, or vulnerability to bottlenecks and dependency? • Would more distributed access to resources enhance resilience, or complicate coordination?	• Is value capture concentrated in the hands of a few actors, or distributed more widely across the system? • Does concentration of financial power create efficiency, or dependency and exclusion? • Would broader distribution of value strengthen resilience, or complicate coordination?	• Is access to information concentrated among a few actors, or broadly shared across the system? • Who controls the key information needed to make decisions, and who is left dependent on them? • Does concentrating information in a few hands make the system more efficient, or more vulnerable?	• Is access to affordable energy concentrated in a few hands, or distributed fairly across actors? • Does centralised energy provision create efficiencies, or make the system vulnerable to bottlenecks and disruptions? • Would distributed and decentralised energy models increase resilience, or add coordination challenges?

Step 4c - Uncover patterns - Identify the main dynamics

In the previous step, the system was examined through the lens of tensions, surfacing deeper forces that shape how flows behave. Now the focus shifts from broad exploration to convergence: refining and prioritising the key insights and organising them into patterns. Patterns are the recurring dynamics that explain why the system functions as it does. They emerge from the interplay of flows and actor decisions, shaped by the tensions identified earlier, and move the focus beyond isolated issues to reveal the structures, incentives, and behaviours that drive outcomes across the value chain.

Patterns should always describe systemic dynamics, not single actions. For example, instead of writing ‘provide spare parts,’ frame it as ‘repair becomes the default option because spare parts and knowledge are consistently accessible.’ This ensures the discussion captures recurring behaviour, not isolated fixes.

Goal: The aim of this step is to identify and organise the systemic patterns that explain how the system currently functions, while filtering and prioritising the most important ones. These patterns then serve as the basis for imagining how the system could function differently. The step involves making existing patterns explicit and then defining desired patterns that show how tensions could be resolved, worked around, or embraced.

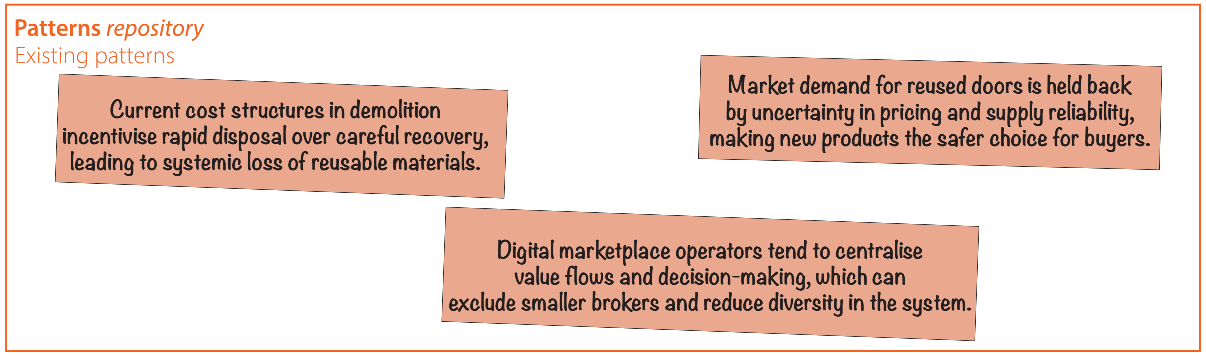
Why this matters: By stepping back to identify and organising patterns, the analysis shifts from listing problems to understanding why they persist. Patterns reveal what is really shaping flows across the system and highlight where change is possible. Distinguishing between existing and desired patterns makes it clear which dynamics currently block circular strategies and what alternative dynamics could support them.

<u>Start from what was discussed</u>
Look back at the post-its developed in Step 4b that highlight where tensions exist in the system. Use the key insights from 4b as the starting point for discussion. You may choose to begin with a particular flow or with an issue that has proven especially pressing.

4c.1. What existing patterns shape the system?
The goal here is to capture what happens across the value chain—not one-off incidents, but recurring behaviours. In the previous step, the focus was on discussing flows to reveal where tensions influence the system. These may have appeared as isolated issues; now the task is to look for common patterns and dynamics that explain how the system functions.

To explore possible patterns, discussions can build on participants’ own reflections or draw on the guiding questions provided for each flow—see table below. These questions are not a checklist to be completed but prompts for reflection—choose the ones most relevant to your case. Capture 2–3 concise statements of recurring dynamics on post-its and place them in a shared repository.

For example, in the case of audio equipment repair, an existing pattern is that repair is discouraged because spare parts are hard to access and manufacturers often push replacement over repair. This reflects the tension between individual versus collective interest, as manufacturers prioritise sales over system-wide value retention. Observing this opens up the possibility of rethinking how the manufacturer can (also) benefit from repair, aligning individual and collective interests.



<u>Existing patterns in the reuse of doors - an example</u>
In the reuse of doors, three systemic patterns stand out. Current cost structures incentivise demolition contractors to prioritise fast disposal over recovery, even though this results in a collective loss of valuable materials. Buyers remain cautious about reused doors, as uncertain prices and supply reliability make new products the safer option. Marketplace operators tend to centralise transactions and fees, which risks excluding smaller brokers and narrowing participation. Together, these patterns highlight how misaligned incentives, demand uncertainty, and platform control combine to hold back reuse at scale.

4c.2. What desired patterns could enable change?
After defining the existing patterns in the previous step, now consider how these could be transformed into desired patterns that support circular strategies. Go through the existing patterns one by one and ask: *what new dynamics would resolve, work around, or embrace the tensions that were identified?* Rephrase barriers into opportunities or describe new dynamics that would enable change.

Use the provided guiding questions as inspiration for your discussions. Desired patterns should be formulated as systemic dynamics rather than single actions, so that they describe how the system could behave differently. Write down each desired pattern as a concise statement on a post-it and add it to the respective repository.

For example, in the case of audio equipment repair, a desired pattern could be that reliable spare parts and clear repair instructions are consistently available. Rather than stating this as a one-off action like “provide spare parts,” it is better phrased as: “repair is the default option because spare parts and knowledge are consistently accessible.” This formulation highlights the systemic shift, showing how new dynamics can reframe repair from an exception to a standard practice.

Patterns *repository*

Desired patterns

- Recovery and reuse are financially and logistically more attractive than disposal, so that material retention can become the default pathway.
- Market mechanisms and standards ensure consistent pricing, quality, and supply of reused doors, giving buyers confidence equal to or greater than for new products.
- Digital marketplaces balance efficiency with inclusivity, enabling both large and small brokers to participate fairly while broadening access to reused materials.

<u>Desired patterns in the reuse of doors - an example</u>

In the reuse of doors, three desired patterns illustrate how the system could function differently. First, recovery and resale need to be financially and logistically more attractive than disposal, making reuse the default pathway rather than the exception. Second, market mechanisms and standards should ensure consistent pricing, quality, and supply, giving buyers the confidence to choose reused doors without hesitation and to plan with them reliably. Third, marketplace structures should combine efficiency with inclusivity, enabling both large and small actors to participate fairly while broadening access to reused materials. Together, these desired patterns highlight how systemic shifts can align incentives, build trust, and open access, creating the conditions for reuse to succeed at scale.

When is this step finished?

This step is complete once a set of existing patterns has been captured and paired with corresponding desired patterns that show how the system could behave differently. It is not necessary to identify patterns for every flow, but there should be enough to explain the key dynamics that block or enable circular strategies.

A good rule of thumb is 2–3 patterns per flow or for the issues that proved most pressing in earlier discussions. At this point, individual barriers and enablers should be understood as connected rather than separate issues, and attention should also be given to patterns that cut across multiple flows.

The patterns should be formulated clearly enough to serve as inputs for the next step, where they will be translated into ecosystem requirements. If discussions risk becoming repetitive, move on once both the main existing dynamics and at least some promising alternatives are visible.

How to: Step 4c - Uncovering patterns

Pre-work: The key insights from Step 4b should be available on post-its, capturing how tensions surfaced in the flows and what dynamics they revealed. These serve as the starting point for identifying recurring patterns.

Time plan: Allow 30 – 60 minutes per flow, though less time may be needed if Step 4b already provided in-depth insights. In total, plan for around 90– 120 minutes.

Materials needed:

- Post-its in two colours (existing vs. desired patterns)
- Repository for clustering existing and desired patterns
- Guiding questions for each flow

Facilitator tip:

Encourage participants to phrase patterns as concise, systemic statements rather than long lists of barriers or enablers. Pair each existing pattern with a desired one to keep the discussion constructive and forward-looking.

	Resource Flows	Value Flows	Information Flows	Energy Flows
Questions to uncover *existing patterns*	● Where are resources consistently wasted, downcycled, or lost from the system? ● How do current sourcing, production, or disposal practices reinforce linear rather than circular use? ● Which dependencies on specific materials, suppliers, or processes repeatedly create risks or bottlenecks?	● How do current incentives and costs shape behaviour across the system? ● Where is value consistently lost, concentrated, or overlooked? ● How do existing financial arrangements (e.g. contracts, subsidies, fees) reinforce or block circular practices?	● Where does information routinely get lost, delayed, or distorted? ● How do current information practices influence trust and coordination? ● Which recurring habits or structures limit access to relevant knowledge?	● Where does energy demand create recurring barriers or dependencies? ● How do current energy practices affect costs, risks, or vulnerabilities in the system? ● Which opportunities for efficiency, recovery, or reuse are repeatedly missed?
Questions to uncover *desired patterns*	● How could design and sourcing practices prioritise reuse, repair, remanufacturing, or recycling? ● What new routines or standards could reduce leakage and keep resources circulating longer? ● How could dependencies on scarce or high-impact materials be reduced through substitution, redesign, or cascading use?	● What incentives or exchanges would make circular practices the preferred option? ● How could contracts, pricing, or financing balance stability with adaptability? ● What would fairer distribution of value look like across different actors in the system?	● How could information sharing be structured to improve reliability and coordination? ● What practices or standards would build trust and transparency across the system? ● How might feedback loops help decisions adapt to real-time information?	● How could energy recovery, reuse, or efficiency become standard practice? ● What role could decentralised or renewable energy provision play in strengthening resilience? ● How might energy use be redesigned to both meet demand and reduce environmental impact?

Step 4d - Summarise ecosystem requirements

Desired patterns describe how the system should behave in the future. The next step is to identify what the ecosystem must provide to make those patterns possible. While patterns describe how the system tends to behave, ecosystem requirements describe the conditions that make such behaviour possible. Think of patterns as 'what should happen' and requirements as 'what the system must provide to allow it to happen.' Ecosystem requirements translate visions into practical conditions by showing both what can already be built upon and what still needs to be created. This step also offers a chance to condense similar desired patterns into broader, system-wide requirements that cut across multiple flows.

<u>Start from your desired patterns</u>
Begin with the set of desired patterns developed in the previous step. Review them one by one and look for overlaps or common themes across different flows. Where several patterns point to the same underlying condition, condense them into a single requirement. Be careful not to oversimplify—similarities can be combined, but important nuances should not be lost.

Goal: Translate desired patterns into clear ecosystem requirements by identifying offerings that can be built upon and needs that must be developed. Offerings and needs are not patterns themselves—they are the systemic conditions, resources, or infrastructures that either already exist (offerings) or still need to be created (needs) to enable the desired patterns.

Why this matters: Systemic change does not always start from scratch. Often, existing resources, infrastructures, and practices can be scaled or adapted rather than reinvented. At the same time, naming what is absent makes gaps visible and actionable. This step is therefore a crucial part of the overall process: it moves the Multi-Flow Method beyond analysis and prepares the ground for concrete action by specifying what the ecosystem must deliver for circular strategies to succeed.

Review desired patterns
Look for overlaps between desired patterns from different flows and condense them where appropriate. Be careful not to oversimplify—the aim is to identify shared requirements without losing important nuances.

4d.1. What can be built on?
Look for offerings—tools, practices, infrastructures, or relationships — that are already in place and can help realise the desired patterns in order to strengthen the system's circularity. Ask: *Which practices or routines already work well? What resources, infrastructures, or partnerships are available to build on? Where does the system already show strengths that can be scaled?*

Ecosystem Requirements *repository*
Offerings

Digital marketplaces for reused construction components already exist and provide a starting point for connecting supply and demand.

Networks of reuse brokers and intermediaries have experience matching supply with buyers, offering expertise that can be scaled.

Established demolition practices sometimes include selective dismantling, showing that recovery for reuse is already feasible in certain cases.

Write down each offering as a concise statement on a post-it and place it in the repository under *Offerings*.

<u>Ecosystem offerings: the reuse of doors - an example</u>
In the reuse of doors, several elements already exist that can be built upon. Digital marketplaces for reused construction components already exist and provide a starting point for connecting supply and demand, even if their scale and adoption vary between regions. Established demolition practices sometimes include selective dismantling, showing that recovery for reuse is already feasible in certain cases, and that practical know-how exists in the industry. Networks of reuse brokers and intermediaries also have experience matching supply with buyers, offering expertise that can be scaled and transferred to new contexts.

Together, these offerings illustrate that reuse is not an entirely new practice but one with a foundation to build on. The challenge is less about invention from scratch and more about strengthening, expanding, and aligning these existing initiatives to make them effective across the system.

4d.2. What is still missing?
Identify the needs—capabilities, infrastructures, or connections—that are currently absent but would be required to make the desired patterns a reality. Ask: *Which capabilities or resources are not yet in place? Where are the gaps or bottlenecks that hold the system back? What critical elements are needed but currently unavailable?*

Capture each need as a concise statement on a post-it and place it in the repository under Needs. Keep requirements specific and actionable.

For example, in the case of audio equipment repair, the desired pattern was that spare parts and clear repair instructions are readily available, in an effort to make repair the default option instead of replacement. To realise this, one offering might already exist in the form of repair manuals for newer product lines. A critical need, however, could be a platform that ensures consistent availability of spare parts across multiple generations of products. Identifying such needs makes clear what additional elements the ecosystem must provide to make the desired pattern work in practice.

<u>Ecosystem needs in the reuse of doors - an example</u>
To make the desired patterns a reality, additional needs must be addressed. Standardised quality and pricing frameworks are essential to ensure reused doors can be trusted and planned for in construction projects, providing consistency for architects, contractors, and clients. Incentive structures or policy support, such as disposal levies or tax breaks, are needed to make recovery and

Ecosystem Requirements *repository*
Needs

Standardised quality and pricing frameworks to ensure reused doors can be trusted and planned for in construction projects.

Incentive structures or policy support to make recovery and resale financially more attractive than disposal.

Established demolition practices sometimes include selective dismantling, showing that recovery for reuse is already feasible in certain cases.

resale financially more attractive than disposal, shifting the economic balance in favour of circular practices. Inclusive platform design and governance must also be ensured, so that smaller brokers and contractors can access marketplace opportunities alongside larger firms. Without these measures, existing efforts risk staying fragmented or being captured by dominant players, rather than enabling a systemic transition.

When is this step finished?
This step is complete when offerings and needs have been defined for the desired patterns. Aim to cover as many patterns as is useful given their number and relevance—the exact breadth depends on how many patterns were identified—while prioritising those that matter most. As a general guideline, the most pressing patterns should each have at least one offering and one need recorded. Requirements should be specific and actionable, clearly linked back to the patterns, yet remain open to refinement. A good sign of maturity is when it's clear what the ecosystem already provides and where the critical gaps are.

This marks the end of the Multi-Flow Method: the process has moved from flows to tensions, from patterns to requirements, leaving a clear picture of what the ecosystem must deliver for circular strategies to succeed. The next steps for translating these requirements into action fall outside the scope of this guide, but you can find more on this in the remainder of the Circularity Thinking process.

How to: Summarising ecosystem requirements
Pre-work: Desired patterns from Step 4c should be available as post-its. These form the basis for defining what the ecosystem must provide.

Time plan: Plan for 60 – 90 minutes, depending on the number of desired patterns carried over from the previous step. Allow extra time if overlaps need to be reviewed and distilled into clear, systemic requirements.

Materials needed:
- Repository divided into "Offerings" and "Needs"
- Post-its in two colours, markers or digital equivalents

Facilitator tip:
Encourage participants to phrase requirements in systemic and actionable terms. Remind them that the aim is not to design detailed solutions but to specify what the ecosystem must provide for circular strategies to succeed. Highlight that this step produces the final result of the Multi-Flow Method — a clear picture of what already exists and what is still missing in the ecosystem.

Closing words

Looking back, this guide has taken you on a journey from understanding flows and resource states, to mapping waste, sketching sets of circular strategies and exploring how structural patterns can be turned into actionable strategies. Along the way, we have shown how tools and frameworks can turn abstract circularity ambitions into practical steps. The key insight is that waste is not inevitable—it can be prevented, reduced, or transformed when organisations see the bigger system and act with intent.

Of course, circularity is not a one-off project but a continuous process. As you learn from the first circular strategies you implement, conditions change, technologies evolve, and partnerships expand, there is always room to refine, adapt, and improve. Keep testing your assumptions, strengthening your practices, and updating your strategies. Each iteration brings you closer to unlocking new value, building resilience, and delivering impact at scale.

This guide also sets the stage for the next step: data and information sharing. By identifying flows, and value chain patterns, you have clarified where information matters most. These insights form the foundation for designing data infrastructures, where transparency and interoperability help organisations coordinate more effectively and scale circular practices - see Guide 2 *Decentralised sharing of data & information.*

At the same time, what you have explored here is just part of the pathway into Circularity Thinking. Other steps of the toolkit, but also other methods, and perspectives—whether focused on business models, governance, or cultural change—can further strengthen your approach. Use them to complement what you have learned, and let them inspire new directions. Good luck on your circular journey—we wish you curiosity, persistence, and success in putting these ideas into practice!

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Charis Lüdtke
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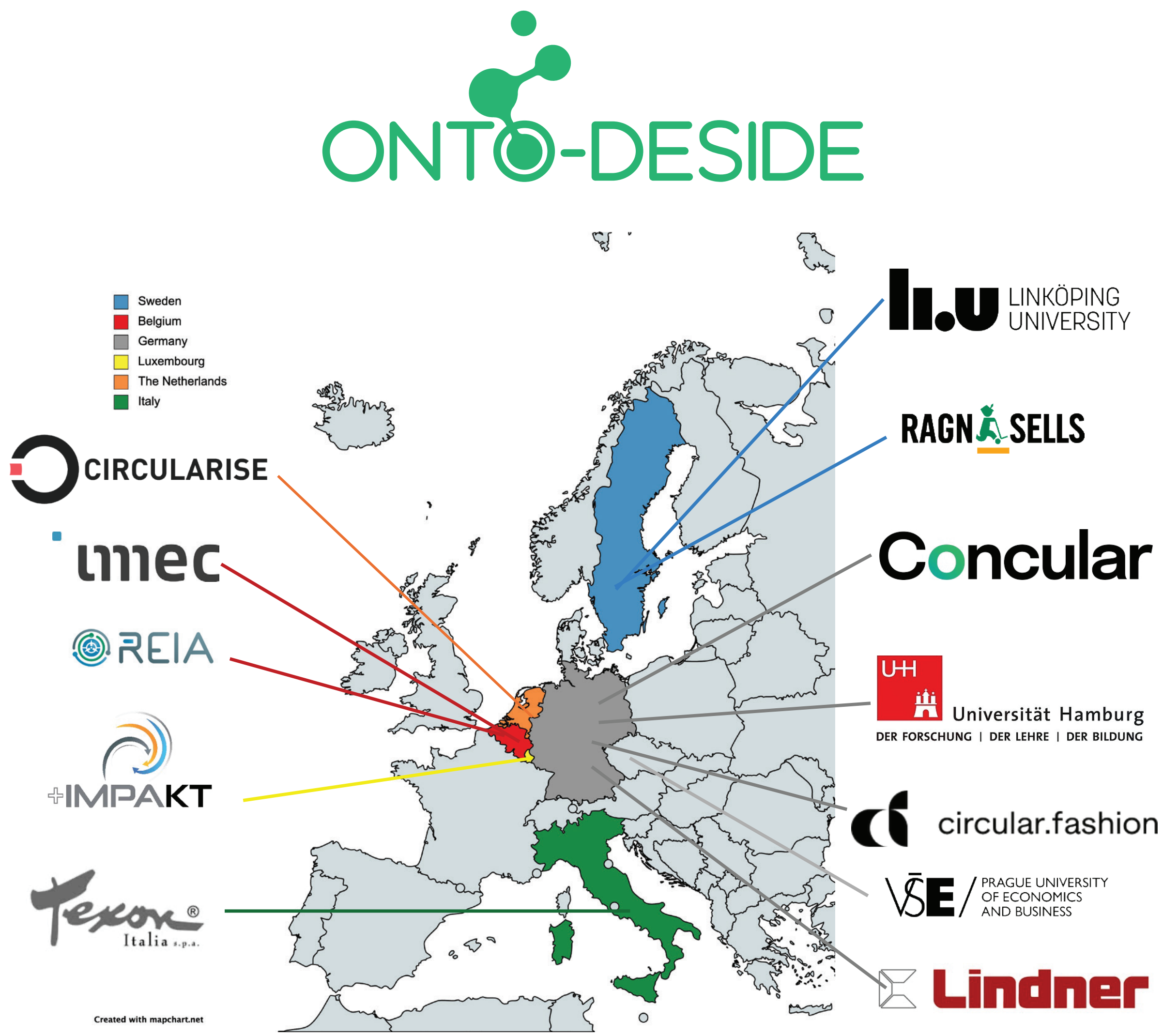

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Guide 2

Decentralised sharing of data & information

For a circular and regenerative economy

Funded by
the European Union

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Acronyms/ terminology

API = Application Programming Interface
CE = circular economy
CEON = Circular Economy Ontology Network
CSV = Comma Separated Values
CQ = Competency Question
DPPO = Digital Product Passport Ontology
JSON = JavaScript Open Notation
JSON-LD = JavaScript Open Notation for Linked Data
LOV = Linked Open Vocabularies
MFM = Multi-Flow Method
OBDA = Ontology Based Data Access
OBO = Open Biomedical Ontologies
OCP = Open Circularity Platform
OWL = Web Ontology Language
R2RML = RDB 2 RDF Mapping Language
RBAC = Role-Based Access Control (RBAC)
RDB = Relational Database
RDF = Resource Description Framework
RML = RDF Mapping Language
SHACL = Shapes Constraint Language
SPARQL = SPARQL Protocol and RDF Query Language
SSSOM = Simple Standard for Sharing Ontological Mappings
URI = Uniform Resource Identifier
W3C = World Wide Web Consortium
XML = eXtensible Markup Language
YARRRML = Yet Another R2RML and RML Language
XD = eXtreme Design

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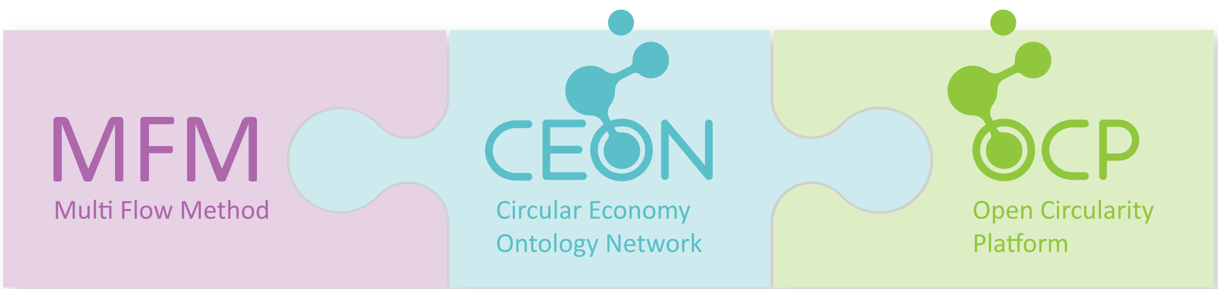
This guide - how it came to be, who it's for, and how to use it

Why this guide? The Onto-DESIDE project.
The Onto-DESIDE project aimed to accelerate the transition to a circular economy (CE) where materials, components, and products are reused to reduce waste and retain value. At the moment, circular value networks are difficult to design and scale because it is difficult to make sense of such systems as a whole. Second, industries struggle to form circular value networks due to inconsistent terminology, lack of semantic clarity, and limited tools for secure, automated data exchange.

To address this, Onto-DESIDE combined conceptual and technical innovation, by 1) creating innovation capacity for circular value chains, and 2) addressing key technical barriers to data sharing across industries. It developed the Multi-Flow Method (MFM), which integrates resource, energy, value, and information flows into a systemic view of circular value chains, using generative tensions to explore root causes to barriers and find ways to improve functioning and robustness. The project also introduced technical solutions: ontologies to model materials, products, actors and processes, ensuring vertical (within domains) as well as horizontal (across domains) semantic interoperability, together with a decentralised collaboration platform where data can be exchanged. However, a crucial aspect of supporting transformation is to provide guidance in using these new tools - the aim of this guide.

What was done and how
Onto-DESIDE applied a transdisciplinary and iterative methodology to develop tools and technologies for circular value networks. Academia and practice came together, using three diverse real-world industry use cases selected for their diversity and complexity—construction, electronics, and textiles—as testbeds to derive needs and validate the within- as well as cross-sector applicability of the tools and methods.

The project, running from June 2022 to November 2025, was structured into multiple work packages. One focused on the creation of the innovation method, a second on ontology development, and a third on the data-exchange platform. Each used their own methodology and domain-specific expertise, respectively, design science methods, agile ontology engineering practices including eXtreme Design (XD) resulting in the Circular Economy Ontology Network (CEON), and the application of mature open web standards to create a secure and decentralized interoperable data sharing infrastructure dubbed the Open Circularity Platform (OCP)—but collaboration across these tasks makes them comprehensive and integrated. The project combined a top-down approach, analysing CE research and standards, with a bottom-up analysis and generalisation from the project use cases.



Guide 1: *Circular value chain design, development & innovation*

Guide 2: *Decentrally sharing of data & information*

How to use the guides
There are two guides: one which focuses on circular value chain development and innovation, and a second technical guide that is dedicated to setting up a decentrally organised data-sharing infrastructure in such a way the data is interoperable and compatible.

Both guides focus on the practical steps to take towards better functioning circular value chains. Each guide discusses the relationship with the other, so it is clear where they connect. But, depending on your needs and circular maturity level, you can drive straight into the technical parts, or you can first spend a moment thinking about the functioning of your circular value chain and how to design it in the first place. It is up to you, the reader, to decide what you need and where to start. Together, both parts of the Onto-DESIDE project outputs support the planning and automation of management and execution of circular value networks at scale, contributing to Europe's digital and green Twin Transition.

For more details, or more technical descriptions as well as templates, explainer videos, and other supplementary materials go to our website.

Please visit:
www.ontodeside.eu

ONTO-DESIDE

Ontology-based Decentralized Sharing of Industry Data in the European Circular Economy

- 12 partners, 7 countries:
  - Linköping University (SE)
  - *Interuniversitair Micro-Electronica Centrum (BE)*
  - *Concular Ug Haftungsbeschrankt(DE)*
  - *+Impakt Luxembourg Sarl (LU)*
  - *Circularise Bv (NL)*
  - *Universität Hamburg (DE)*
  - *Circular.Fashion Ug (DE)*
  - *Lindner Group Kg (DE)*
  - *Ragn-Sells Recycling Ab (SE)*
  - *Texon Italia Srl (IT)*
  - *Rare Earths Industry Association (BE)*
  - *Prague University of Economics & Business (CZ)*

- June 2022-November 2025
- Funding: Horizon Europe
  - *Grant agreement #101058682*

Three use case domains:
- Textile industry
- Electronics industry
- Construction industry

Funded by the European Union

Who the guides are for
This guide is part of a set of two. Both guides are aimed at anyone who wishes to engage in circular oriented innovation. That is: anyone who wants to explore new or better circular value chains as well as get practical about data and information sharing to enable this in practice. Each guide is meant as an entry point into their respective topics, and they each target different roles - with an emphasis on the role and contribution of these different roles. Mainly these two guides provide an overview and explain what to expect whilst on this journey. In this, we focus on how different roles can work together. To this end at the top of each section, you find an indication of what roles are typically involved or needed to complete a step successfully. Of course, these roles can be different people, or be one and the same.

Guide 1 - See: www.ontodeside.eu
Value chain design, development & innovation:

This guide has a strategic focus, and explores what currently shapes the value chain dynamics and how circular strategies can be (better) supported. The following roles are needed to successfully complete the process:

- *Project lead:* Coordinates the overall process in which the method is applied. Ensures the right people are involved, aligns the method with the project's goals, and takes responsibility for follow-up after sessions and working groups.
- *Facilitator:* Guides the group through the Multi-Flow Method. Ensures the process is structured, that flows, tensions, and patterns are captured in a way the group can work with, and that different perspectives are heard.
- *Decision maker(s)*: Stakeholder representatives with the authority to shape the value chain configuration or influence (strategic) decisions. To ensure relevance and actionability, the process should include different perspectives (e.g., suppliers, customers, recyclers, logistics providers).
- *(Flow) Experts:* Bring (technical and practical) knowledge of specific flows (material, information, value, energy). They explain how flows operate in practice and support the group in understanding constraints, dependencies, and opportunities.

Guide 2 - *The guide in front of you now:*
Decentrally sharing of data & information:

This guide has a technical focus, and explains how to set up a decentralised, secure, and automated data sharing infrastructure, to support a certain value chain configuration and its needed collaborations between actors. The steps involved in setting up this infrastructure needs the involvement of different types of roles in the involved organisations. In this guide we categorise these roles into 4 types:

- *Decision Maker:* May be the value chain manager, coordinating the setup of the whole value chain, or merely the internal manager in charge of ensuring the participation of a specific actor in the value network configuration. Additionally, a decision maker may be a CTO or CIO making decisions about the IT infrastructure setup and investments.
- *Data Steward*: Any role that produces, manages or maintains the data that is to be shared and used in order to make the value chain configuration work.
- *Developer*: Either an information architect/ data modeller, or a software developer/IT specialist. These are the roles that will do the practical work of modelling and transforming the data, as well as setting up the actual infrastructure and configuring it.
- *End-User*: The roles within the value chain organisations that hold the needs for receiving or sharing the data. For instance, this could be a person at a recycling facility, needing the information about incoming used materials in order to make decisions regarding where to dispatch a certain batch or container.

Why, what and how of Circular Economy

"Take-make-use-*lose*"
Our global economy operates largely on a linear model: extract, produce, consume, and dispose - repeat. This system assumes unlimited access to resources and an infinite capacity for waste absorption. But our planet can provide neither: we are rapidly depleting finite resources and overwhelming natural systems with waste and emissions. Even recycling, often seen as a solution, only addresses a very small part of the problem and fails to fundamentally transform how we use resources. What's more, this extractive system entrenches inequality, undermines livelihoods, and worsens living conditions for many.

For example, resource extraction has already more than tripled since 1970 and is projected to rise another 60% by 2060 if the current path is followed, accounting for over 60% of global greenhouse gas emissions and 40% of pollution-linked health impacts[1]. Such scale places enormous pressure on ecosystems and communities. No wonder that the linear economy is sometimes also referred to as "Take-make-use-*lose*"[2].

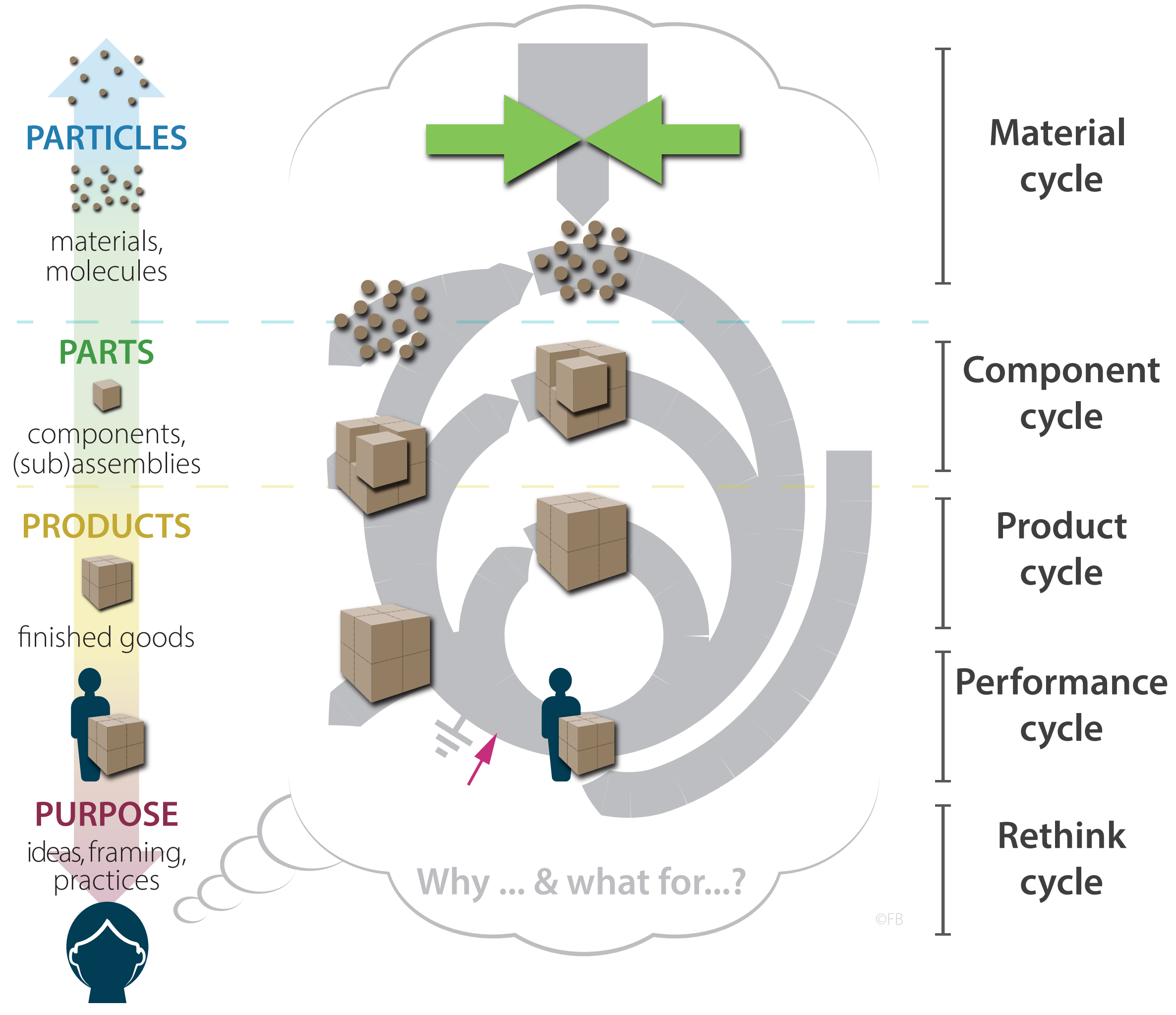
Instead...
Our economies will have to change their extractive practices to <u>circular</u> and <u>regenerative</u> ones. Circular Economy (CE) offers one path through the application of Re-strategies like <u>re</u>think, <u>re</u>duce, <u>re</u>tain, <u>re</u>use, <u>re</u>pair, <u>ref</u>urbish, <u>re</u>manufacture, <u>re</u>cycle—and a range of related strategies like composting & industrial symbiosis. The aim is through better taking care of the needs of the different parts of the system (planet, people and businesses) to incentivise dealing differently with waste and resources such that resource conservation, efficiency and productivity are all improved. Or: how can we live comfortably - without costing people and the planet?

CE is no longer optional, but a must-have
Mounting resource scarcity, increasingly volatile supply chains and resource prices, intensifying legislative and regulatory pressure, and rising stakeholder expectations mean that CE is no longer optional—it's essential for business resilience, compliance, innovation, and competitiveness[3,4,5]. Companies that continue to rely on a take-make-dispose model expose themselves to higher costs, operational disruptions, and reputational risks, while those that adopt circular strategies can secure materials, stabilize supply, and strengthen their license to operate. In short, CE is becoming a key driver of both risk management & value creation.

Likewise, finance and investors are intensifying the shift of capital toward businesses that demonstrate circular strategies, recognizing them as lower-risk, future-fit, and better positioned to deliver long-term value[6]. Capital markets are increasingly embedding sustainability and circularity metrics into lending, investment, and valuation models, rewarding companies that proactively align with emerging standards. Those who fail to adapt may face shrinking access to capital, higher borrowing costs, and reduced investor confidence, while circular leaders stand to attract investment, partnerships, and preferential market positioning.

The Challenge
But... 'going circular' is complex. It requires systems thinking to understand how and why materials flow, where and why waste originates, and how circular strategies interact. It requires moving beyond simplistic models and truly solving problems—not shift them elsewhere or create new ones. And: not all circular strategies work in every context, and some may even compete or create trade-offs. For example, choosing highly durable composites can hinder recyclability, and remanufacturing may initially require more materials—not less. And so on. The challenge is to design and operate sets of circular strategies that resolve, go around or balance these tensions and deliver real benefits. Doing so requires the right mix of competition and collaboration, clear and easily accessible data, and adaptive management across the value entire chain.

For this reason, circular innovation differs fundamentally from linear or 'business-as-usual' innovation. It involves creating virtuous loops—feedback mechanisms where resources re-enter the value chain—and generating emergent properties like sustainability and resilience. These benefits arise not from isolated actions but from how the entire system behaves.



From a linear to a circular mindset

All this means that a different mindset is needed when engaging in circular oriented-innovation. Crucially: it means creating systems where multiple circular strategies operate synergistically - where, through collaboration, all actors benefit. Circularity Thinking helps cultivate this new circular mindset.

1. Flow Structure: One-Way vs. Feedback Loops

- Linear mindset: Resources flow in a straight line—extraction, production, use, disposal—with minimal interaction between these processes.
- Circular mindset: Resources circulate through feedback loops, re-entering the system several times (as products, components, and materials) and influencing upstream and downstream decisions over time.

2. Value Creation: Localized vs. Emergent

- Linear mindset: Value is created and captured at specific points in the chain (e.g. sales, production) - with opposing and conflicting interests, resulting in value conflicts.
- Circular mindset: Value is emergent, arising from how the entire system functions - through resilience, sustainability, and shared innovation. Both the whole and the parts benefit equally.

3. Problem Solving: Fragmented vs. Systemic

- Linear mindset: Problems are solved in isolation, often within departmental or disciplinary silos. This leads to displacement and the creation of new problems.
- Circular mindset: Problems are addressed systemically, considering interdependencies, long-term effects, and cross-sector dynamics.

4. Strategy Use: Selection vs. Configuration

- Linear mindset: Strategies are chosen individually—reuse or recycling, efficiency or durability—as they benefit one actor, often without considering their interactions.
- Circular mindset: Strategies are combined into configurations, designed to work together synergistically and allowed to evolve over time, seeking the addition of more circular strategies through continuous improvement.

5. Innovation Process: Execution vs. Iteration

- Linear mindset: Innovation follows a fixed plan—analyse, design, implement—assuming predictability and with limited flexibility.
- Circular mindset: Multiple innovation modes operate alongside each other, where innovation also incorporates processes that are iterative, involving experimentation, learning, and the ability to pivot when assumptions prove incorrect.

6. Responsibility: Compliance vs. Stewardship

- Linear mindset: Responsibility is often limited to meeting regulations or minimizing costs.
- Circular mindset: Responsibility includes stewardship—ensuring that circular strategies address real problems and no new ones are created elsewhere in the system. And: that the needs of all parts of the system are served.

Value-, resource- & information-flows

Therefore, to design, improve, and operate a circular way of working it is essential to adopt a *value chain* perspective - sometimes also called a *value network*. This is because circularity cannot be achieved in isolation—materials, components, products, as well as benefits and impacts flow across multiple actors and stages. Only by seeing how decisions in one part of the chain affect others can businesses understand how shared benefits can be created and value captured and to design circular strategies that synergistically reinforce each other. This perspective also highlights trade-offs and tensions that must be managed collectively, rather than pushed onto individual actors, if the system is to function. *Data and information* play a critical role in this: they *provide the transparency needed* to track resource flows, identify where waste and inefficiencies occur, and coordinate action across suppliers, partners, and customers. Without accurate, shared and frictionless access to information, circular value chains cannot be designed effectively or operated at scale.

This guide

To help with this, the **Onto-Deside** project created the following guidance and support for:

- *Value chain design, development & innovation:* gaining insight into the root causes of barriers and enablers that shape the behaviour of value chains, and examining how this dynamic can (better) support circular flows.
- *Decentrally sharing of data & information:* understanding data needs and availability, formats, and aligning the data to a shared domain model, the Circular Economy Ontology Network (CEON), setting up an Open Circularity Platform (OCP)—data-sharing such that data becomes interoperable, but where control over what to share with who and when remains with the data owners.

The guide in front of you covers:

- *Decentrally sharing of data & information.*

Please find the other guide at:
>>> www.ontodeside.eu

For all circular strategies - from recycling to repair, from reuse to remanufacturing

To help bring the guidance to life and offer concrete examples to illustrate our methods, here are 4 short examples of different circular strategies that we'll refer back to throughout the guides. All these scenarios (A to D) have the same needs in common. Each actor in the network must be able to selectively share its data, based on ever-changing business needs. Meanwhile, to track resource flows across stakeholders and make appropriate decisions, a common understanding of this shared data is needed.

(A) Beginning-of-life: using recycled input
What: Cross-sector recycling of apparel waste into feedstock for floor tiles.
Why: To unlock circular business models, and help to find the right recycled feedstock through product passports and secure data exchanges.

A *product manufacturer* creates a performance shoe using inputs from various *material suppliers*, each contributing data to a shared platform for product passports using standardized formats. Once the shoe reaches end-of-life, a *recycling operator* disassembles it, guided by digital instructions, and extracts the rubber outsoles and textile laces that are made into bulk materials.

These recovered materials are listed on a *digital marketplace*, enriched with a certificate and metadata including composition, condition, and recycled content. Next, a *materials processor* identifies suitable batches and requests pricing via the platform. After purchase, the recycled inputs are turned into materials that an *interior outfit company* uses for acoustic floor tile layers. Certificates and material data travel along, and a new product passport is generated for the product.

(B) Middle-of-life: repair
What: Repair of an audio system through access to reliable spare parts and instructions.
Why: Automating sustainable asset management through digital tools to enable easier data management, whilst protecting sensitive data.

A *building owner* identifies a malfunction in the installed audio system. Using a data exchange platform they access repair instructions and discover that the *original equipment manufacturer* offers a repair service. The component is sent for repair, and the manufacturer replaces the faulty speaker with a newer model containing a higher amount of recycled content.

The repaired unit is reinstalled, and updated product data is published and added to the *building's digital twin*, including material composition and sustainability attributes. Digital product passports record both original and repaired versions, tracking components and their environmental impact—including recycled content, origin, and certifications—automating the management of building information.

(C) End-of-life: reuse
What: Reuse and resale of a door for use in other building projects.
Why: Linking supply & demand through a digital market place for second-life parts & components.

A *building owner,* preparing for demolition, assesses the reuse potential of installed elements, such as doors, for repurposing through resale. This information is used with the *demolition contractor* to negotiate a fair price for the building's demolition, and sets the frame for what demolition methods will be used.

To find a new use, the building owner lists the components, including the doors, on a *digital marketplace*—provided by an *intermediary* for sale to *construction companies* for reuse in new projects. Metadata such as dimensions, condition, and installation history are shared, and enriched with images, enhancing buyer confidence. Pricing information is managed securely via decentralized data pods, ensuring only authorized parties can access commercial terms and optimising the value for the building owner. Planning considerations are automatically taken into account.

(D) End-of-life: remanufacturing
What: Take-back of the floor tiles by the manufacturer for remanufacturing.
Why: Enabling manufacturers to take-back their products, ensuring access to future feedstock.

At the end-of-life stage of a building, a *building owner* initiates a demolition plan and assesses reuse and recovery options for installed components. Among these, the acoustic floor tiles—originally made with recycled feedstock from apparel waste—are identified as having high reuse potential, but not in their current condition.

The owner contacts the *original tile manufacturer,* who offers a take-back program. Through a data exchange platform—facilitated by an *intermediary*—the manufacturer provides pricing and logistics information for reclaiming the tiles. The tiles are returned, inspected, and remanufactured into new flooring systems, integrating both recovered and new materials. This process reduces raw material demand and preserves embedded value.

Decentrally sharing data - an overview of the what, why and how

Data & information sharing and management
Circular economy innovations along value chains depend on collaboration across multiple actors—from material suppliers to manufacturers, retailers, and recyclers. But collaboration is only effective if it is built on a foundation of reliable, consistent information. This is why data and information sharing is not a side issue but a central enabler of circular value chain innovation.

Every circular practice—whether it is product-as-a-service, reverse logistics, reuse, or high-quality recycling—requires transparency about what resources exist, where they are, and in what condition. If one actor knows the material content of a component but cannot share it in a usable way with others, opportunities for reuse or recovery are lost. Similarly, without trusted information flows, it is hard to coordinate responsibilities, design for reuse, or match supply and demand in secondary markets.

The challenge is that different organisations often use different terms, classifications, and IT systems. What one company calls a "part," another might describe as a "module." And the same term, such as "product", may mean different things depending on the actor's perspective—what is someone's product may be another's material or component. Data that is meaningful in one system may be unreadable or misleading in another. This is why *aligned ontologies*—shared ways of structuring and describing information—are critical. Just as having a shared technical standard makes it possible to plug components together, having a shared information standard with clear semantics makes it possible to plug data together.

A *data-sharing platform* then becomes the infrastructure that operationalises this alignment. It ensures that information about resources, processes, and transactions can flow securely and consistently across the value chain. Platforms can host material passports, product IDs, or usage histories, making them accessible in formats that others can understand, trust and act upon. With such systems, businesses can make informed choices about design, reuse, or recycling, and policymakers can monitor progress without imposing excessive reporting burdens.

Seen this way, data and information sharing is the *bridge* between circular economy ambitions and their practical realisation. Value chain innovations create the demand for shared knowledge; data platforms and ontologies make it possible to meet that demand in ways that are consistent, scalable, and verifiable. Without them, circular strategies risk being isolated pilots. With them, they can be connected into functioning ecosystems where information flows as seamlessly as materials.

This guide contains more information both on:

- Ontologies for CE - and the use of **CEON**, which is a reusable set of core ontology modules that can be extended to fit virtually any CE use case.
- How to set up a decentralised data sharing platform - and how the **OCP**, which is one such platform, allows for sharing data in a secure decentralised manner.

Both CEON and OCP are outputs of the Onto-DESIDE project and are **freely available.** Before going into the process of how to use these two tools, first we explain a little bit more about the foundations these two tools were built on.

Why *decentralised*?
In the Onto-DESIDE project we focused on decentralised data sharing solutions as it has certain benefits over centralised data sharing. Unlike centralised systems, where all information is collected, stored, and managed by one party, decentralised approaches allow each of the participating organisations to retain control and responsibility. This avoids the risks of bottlenecks, single points of failure, or power imbalances where one actor owns or controls the entire dataset. It also increases flexibility to integrate diverse data sources and adjust to evolving technical standards. In practice, decentralised approaches are often more acceptable to diverse actors, making collaboration possible in complex value chains.

This is especially relevant in a circular economy, where no single authority governs the system and collaborations can span multiple value chains, across multiple domains and participant constellations, and involve multiple circular strategies. Each actor brings its own priorities, IT systems, and sensitivities, which makes centralised data systems difficult to accept for many. For reasons of security and confidentiality, organisations also want to retain sovereignty over their data: deciding what to share, with whom, and under what conditions. Decentralised data sharing enables this by allowing data to remain in an organisation's own systems, on their own premises, while still making agreed portions accessible to partners. In this way, sensitive business knowledge is protected, collaboration barriers are reduced, and trust between partners can grow—creating the conditions for more open, yet secure, circular value chain innovation. By distributing control in this way, decentralised systems reflect the distributed and collaborative nature of circular economies themselves.

Scaling through automation and standardization
In order to scale the circular economy to cover virtually all material flows in our society, the information infrastructure needs to focus on automation and be built to scale. Each actor in a circular economy will need to be connected to a multitude of other actors, of different types, and over a large time span – an unmanageable challenge unless current information exchange methods, such as phone calls and e-mails, are to a large extent replaced and automated.

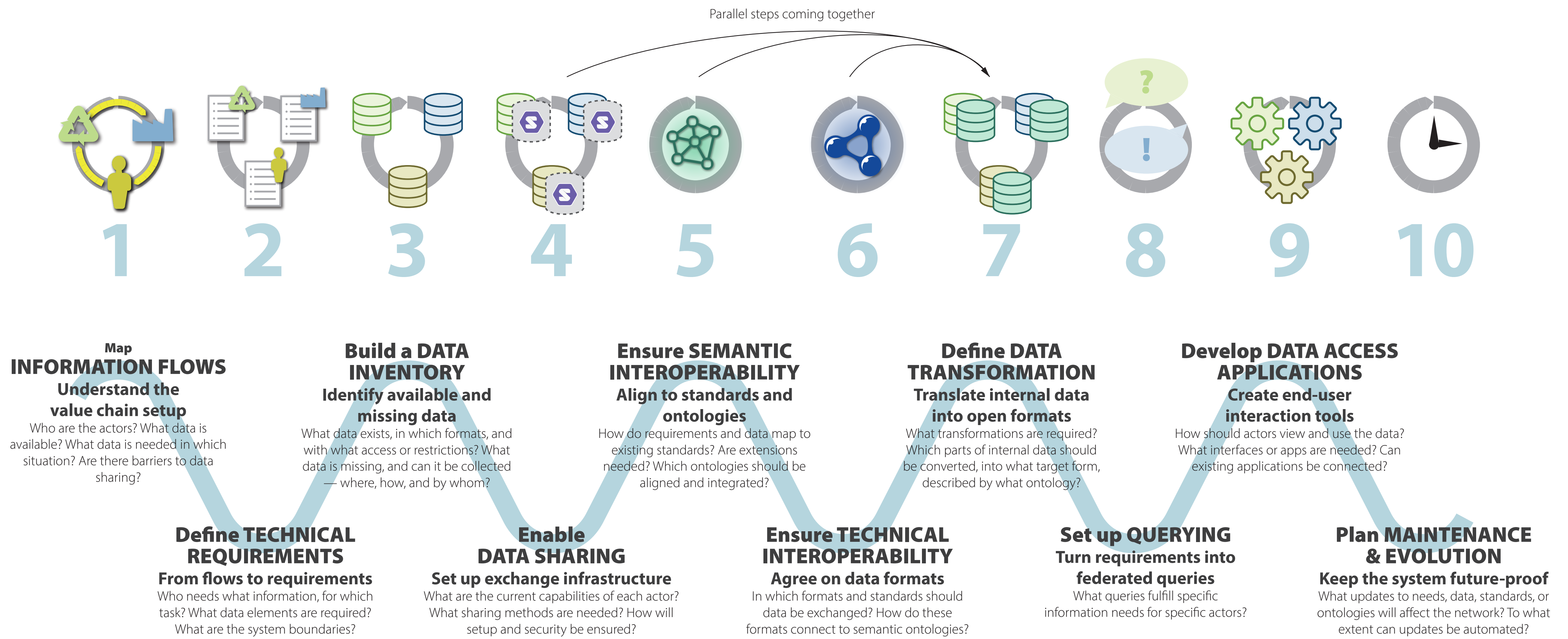
Apart from the technical scalability of the solutions, for instance, being able to handle big data, return query results in a timely manner and so on, this also means that automation needs to increase in all steps of the value chain setup and management. While decision making still needs human oversight, automation should be the target for all the frequent interactions along the value chain. This means that data sharing and access should be automated, with as little manual configuration as possible at setup time, and ideally no human intervention at execution time. For instance, adding new actors and their data sources to the network will likely involve some human mapping and configuration effort, e.g. to set up a sharing endpoint and provide access rights, but at runtime the exchange should be automatic.

This in turn implies that data sharing needs to be based on standards: not require every other actor in the network to adopt yet another technology or data format into their IT infrastructure, but to use what is already available and proven to scale. It also means that data sharing needs to be based on agreed vocabularies, i.e. ontologies, as the language for interchange of information. Ensuring not only technical but also semantic interoperability of the information to be shared.

What is available

The Onto-DESIDE project has developed and showcased one example of how such an infrastructure can be set up, which is decentralised, secure, based on existing and emerging web standards, and allows for a sufficient level of automation in data sharing and access. Specific components could be replaced, e.g. some components may be replaced and new software may emerge for hosting data, however, the overall process of setting up such an infrastructure as described in this guide will still hold. Thus in this guide we focus on the steps that are needed to both make decisions about how to set up such infrastructure and build applications on top of it, as well as giving a brief overview of the work that these steps would entail, in terms of actually setting things up and getting it to work.

The life-cycle process consists of 10 steps, starting from understanding the needs of the value chain configuration, and ending with a maintenance and evolution step, when the infrastructure is up and running, and used by the value chain actors. The guide may be used by decision makers, to simply understand what considerations would have to be taken into account when setting up such infrastructure, or as an overview and high-level checklist for the technical process, when actually implementing this in your organisation or network of organisations.



Responsible role:

Participants:

Step 1 - Map information flows - value chains are more than resource

> See also Guide 1:
Value chain design, development & innovation

Resource flows

Guide 1 introduces a set of tools from the Circularity Thinking innovation methodology to support developing what (set of) circular strategies may be used in a given situation. It is a life-cycle and systems-based approach that "follows the flows": always asking where a resource comes from, where it goes, what forces drive this, what impacts it creates—and how these flows can be improved to become more circular and regenerative. This analysis helps to design how resources should flow in a value chain. But resource flows are only one part of the story: to ensure robust and well-functioning circular systems, the methodology also includes a range of other essential flows.

And also: value-flows…

For circular value chains to function at scale, value flows matter greatly. They determine whether circular strategies make business sense. A product may be recyclable, but unless customers, producers, and/or regulators agree on the value it creates, it may never be adopted. Value includes not just money but also environmental and social benefits. For instance, a take-back scheme for electronics only works if customers see value in returning devices, and businesses can capture value from resale, refurbishment, or recycling.

… energy flows…

Energy flows can be equally critical, as every resource loop consumes or saves energy. Some circular processes are far more energy-intensive than others—for example, melting metals back for recycling requires much more energy than reusing a part. Factoring in these energy costs can therefore be important when choosing which circular strategies make the most sense. At the same time, energy flows can also *enable* circularity: waste heat from one factory can power another, renewable electricity can drive recycling processes, and smart grids can synchronise production with peaks in renewable supply, making processes both more sustainable and cost-effective.

… and information flows!

But without reliable data on resource condition, origin, or composition, resources remain invisible, untrusted, and underused. And likewise, without trustworthy information about the actors involved and the processes they apply, circular collaboration cannot be orchestrated effectively. Companies need to know who potential partners are, which standards they follow, and how their practices align with environmental, social, and economic requirements. Without this visibility, it becomes difficult to discover promising partners, evaluate risks, or configure value chains that are efficient and resilient. In this sense, *information flows are the backbone* of circular systems.

Just as materials, parts, and products circulate through supply chains, the data describing them must also flow—through mechanisms such as digital product passports, certification schemes, or open data platforms—to guarantee traceability, compliance, and quality assurance. Construction firms, for example, rely on material passports to verify that reused doors and windows meet safety standards, while fashion brands depend on accurate fibre content data to enable textile-to-textile recycling at scale. Only when such data travels consistently, transparently, and across organisational boundaries can circular systems expand beyond isolated pilots and mature into trusted, efficient, and resilient networks.

With enabling infrastructure

Each type of flow also requires its own enabling infrastructure. Logistics hubs and processing plants support resource flows; value flows need contractual, accounting, and financial mechanisms that allow costs and benefits to be distributed fairly; energy flows require renewable and smart grids to match supply and demand efficiently; and information flows depend on data standards and digital platforms to ensure that actors can exchange reliable, trusted data.

Truly circular value chains integrate all four flows—resources, value, information, and energy—with infrastructures designed to move them smoothly. To not do so, risks creating bottlenecks.

Understand the whole to set information needs

Guide 1, specifically the Multi-Flow Method, helps circular innovators understand the forces shaping each flow and how their interactions influence the value chain. By using generative tensions, it reveals root causes of barriers and enablers, addressing underlying issues rather than symptoms and highlighting opportunities to make the system more circular and robust.

Working through the method provides a systemic overview that shows where challenges lie and what information is needed to address them. Mapping flows surfaces where data is missing, siloed, or poorly connected, and where sharing is critical for effective collaboration.

Clarifying flows and their interconnections exposes leverage points for greater circularity and shows how information underpins collaboration. This step highlights gaps in transparency, duplication of effort, and weak or misaligned incentives for data sharing, ensuring that technical solutions are grounded in the lived realities of actors across the value chain.

The insights gained—such as identifying actors, clarifying information needs, mapping existing data, highlighting gaps, and exposing barriers—are an essential starting point. Yet at this stage they remain too high-level to guide infrastructure design. Subsequent steps (2 and 3) are therefore required to translate them into detailed technical requirements and system specifications.

Responsible role:

Participants:

Step 2 - Define technical requirements: what do users need data for?

With the systemic insights from step 1 in place, the next task is to translate them into actionable technical requirements (step 2). This involves capturing the identified needs in the form of user stories, which describe in detail how different actors are expected to interact, what information should be exchanged, and under what conditions. These user stories serve as the requirements of the decentralised data-sharing infrastructure and its potential applications. Alongside functional requirements that specify system capabilities, it is equally important to capture non-functional requirements, which relate to aspects such as security, speed, and reliability.

Why user stories?

User stories are a tool used in software development that make complex requirements tangible and easy to communicate. Instead of long technical specifications, they are short, plain-language descriptions of what an end user wants to achieve and why it matters. The format is deliberately simple—*"As a [user], I want to [do something] so that I can [achieve a goal]"*—yet powerful in keeping the focus on outcomes rather than features.

The value of user stories lies in bridging strategy (where Step 1 offered insights) and implementation (from Step 3 onwards). They translate abstract system needs into concrete scenarios that reflect how people will actually interact with the system, ensuring that technical design choices align with business priorities and user expectations. In the context of decentralised data sharing, this could mean expressing requirements around how suppliers, manufacturers, or recyclers access and exchange information in ways that build trust and efficiency across the value chain.

By capturing both what the system should do (functional requirements) and how it should perform in practice (non-functional requirements), user stories provide a structured yet flexible foundation for development. They make it easier for diverse stakeholders—business leaders, technical teams, and end users alike—to work from a shared understanding, reducing the risk of misaligned investments or impractical solutions that hinder instead of help.

How to make user stories

The process of producing user stories needs input in the form of documented value chain information flows as described in step 1. In the previous step concepts such as actors, process, actions, and needs are described on a high level. These are further detailed in user stories as text using a structured format.

Each user story is a specific expression of a distinct need or interaction and will therefore differ from others by focusing on the perspective of a particular actor, a particular task, and/or a particular information requirement. Therefore, creating a broad set of stories is encouraged, since diversity ensures that requirements are captured from all relevant viewpoints and that no critical gaps are overlooked. Documenting these stories also helps to surface assumptions and make implicit expectations explicit, which supports alignment across stakeholders.

But as the number of user stories grows, there will be some stories that make more sense to be implemented before others. Prioritisation is not only about urgency, but also about logical sequencing—some stories may only deliver value once others are in place, while some serve as enablers for multiple others. Such dependencies should be noted in the stories.

Elements of a user story

User stories contain a number of common elements and each story is assigned a unique identifier (such as a number). Below more on the template used.

- ***As a [user]...***

The "As A" part is to be interpreted from the perspective of a certain actor or role that needs to perform an action. For example: you could examine the role of a building owner, a deconstruction company or a recycler, but also detail it further to represent specific roles within those organisations, such as an architect or a purchasing agent.

- ***... I want to [do something]...***

The following "I want", is a detailing of what needs to be done. For example, when dealing with information flows: one actor may be interested in understanding what options for treatment of a broken product exist, another may want to know how to dismantle something, and another may be interested in knowing the composition of a batch of materials. However, actions could also be concrete physical things that should happen, such as shipping a product, or melting a batch of raw materials. The latter may however be less relevant to the information sharing infrastructure, so try to keep the focus.

- ***... so that I can [achieve a goal].***

The "So that" describes the intended result or end state after the action is performed. For example: execute a repair, plan for processing and logistics, or make decisions on purchasing materials and planning production. Again, keep in mind that the focus is here on the value chain setup and execution, so goals should be aligned with the mapped flows from Step 1.

- ***Additional information***

This is a more detailed description of the situation or context that may be added to allow you to understand the conditions under which a user story applies, and potentially any secondary consequences or constraints.

- ***Data need***

Here you place a description or list of the information that the user would need to complete the task described in the above. This can be a list of data sources needed, or if possible a detailed list of data points.

Functional and non-functional requirements

By capturing technical requirements in the form of user stories, the needs from a user perspective are captured together with additional contextual information that further adds to understanding the need and how to address it. These make up the (initial) functional requirements.

But apart from the functional requirements on the system there are also non-functional requirements, such as security, privacy, usability and performance. These should be considered too, as they are also essential for a smooth use and operation of the final system. In Onto-DESIDE we used grouped lists, where requirements were grouped under their respective heading, e.g. "security", "usability" and so on. For example:

<u>Security</u>

- It should not be possible to manipulate source data by an unauthorized actor.
- It should not be possible to manipulate data in transit by an unauthorized actor.
- The platform's source code can be uploaded to a public repository (e.g. GitHub, Bitbucket) under an open-source license.

Who to involve to make user stories
The work of writing user stories is a collaborative process between the stakeholders involved in the value chain and are preferably done together, in person, so that uncertainties and nuances in perspectives are discussed and agreed upon. It is important to make sure that the different user roles appearing under “As a [user]...” are actually involved in this process, so as to validate the needs and the understanding of the context.

User stories would most often be written by a developer or systems engineer, with end users describing their needs and how they should be achieved in the system. Additionally, there needs to be a prioritization in what requirements are most important and in what order they need to be addressed. To do this prioritization architectural needs as well as functionality needs have to be weighted against each other. This prioritization could be done by a senior developer or a systems architect, someone with the authority, overview, and experience to make the correct judgements.

Next steps
Next, these user stories will be the basis for further detailing data needs in Step 3. Step 3 focuses on cataloging what data is needed to meet the needs specified in the user stories. Additionally, the non-functional technical requirements (together with the outcome of Step 3) will be used in step 4 as input to designing a suitable data sharing platform and in Step 5 to derive ontology requirements.

User stories based on the use case examples
Based on the circular strategy examples in section two possible user stories using the Onto-DESIDE template could look like this:

Story: repair-05

Depends on stories:
repair-03, recycling-07, logistics-02

As a *[user]:* Building owner
I want to*:… [do something]*
To be notified when a piece of installed electronic equipment in my building is faulty and needs repair or replacement.
So that I can: *… [achieve a goal]:*
Investigate the status of the faulting equipment and initiate relevant actions to restore it to a fully functional state.

Additional information:
A facility management system is in place and caters for providing information about the building and its health. This system is the primary interface for the building owner in maintaining and acting on data related to the maintenance of the building and its components.

Data need:
- Structural information for locating equipment in a building
- Data on installed equipment/components and contact information to suppliers
- Maintenance and repair information for installed equipment

Story: deconstruction-01

Depends on stories:
recycling-02, logistics-01, manufacturer-07

As a *[user]:* Deconstruction company
I want to*:… [do something]*
To have detailed instructions on how to deconstruct and handle floor tiles so that they can be reused or used as recycled raw material in producing new floor tiles.
So that I can: *… [achieve a goal]:*
I can dismantle floor tiles in the correct way and plan for the correct logistics of them.

Additional information:
A deconstruction company is subcontracted by the building owner and will manage the deconstrution of the building part according to a contract. As part of this contract, different circular strategies will be considered.

Data need:
- Structural information for locating equipment in a building
- Data on installed equipment/components
- Instructions on how to dismantle and handle floor tiles
- Information on circular strategies applicable for the specific floor tile

> See also User Story Template:
www.ontodeside.eu

Responsible role:

Participants:

Step 3 - Build a data Inventory: what data is available or could be collected

Once the information needs are clear, a data inventory is needed. This inventory establishes what data is available, which actor has the needed information, what restrictions on sharing it with others exist, and in case no data exists: could it be collected, how, and by whom? This step may also result in revising the requirements, since some of them may be unrealistic in light of the data collection they entail, or because of restrictions on data access.

What is a data inventory

During the previous step, the data needs surfaced. However, it is hardly ever the case that the information you need perfectly matches the information you already have. To assess this, we first need an overview of the information already available—we need to build a data inventory.

A data inventory is a structured overview of the datasets you have access to and are relevant to address the user stories defined in Step 2 – Technical Requirements. These datasets can be internal or external, private or public, and are typically heterogeneous. That is: they typically encompass a variety of data formats (e.g. JSON, XML, CSV) and data structures (e.g. different database table schemas for different applications), often requiring careful analysis and management to ensure consistency and usability across systems.

This structured overview allows you to understand which informational gaps exist in your organization, and allows you to prioritize: either focussing on filling those gaps to cover all user stories, or focussing on the user stories that can be fulfilled with the existing set of data at your disposal, thereby guiding efficient resource allocation and more informed decision-making throughout the development process.

How to build a data inventory

A data inventory is typically documented in a structured format, such as a spreadsheet as illustrated on the next page, to ensure consistency and ease of use.

The process begins by taking each user story as input and answering the following questions:

- What data is required to resolve a user story?
- And: does this data already exist?

If *the data exists*, a description of the relevant dataset is added to the inventory. For each dataset, the following aspects may be documented:

- Location, format and access—Where is the dataset stored, in which format, and how can it be accessed?
- Ownership and governance—Who owns the dataset, and what usage restrictions or policies are applied?

For each dataset, the data elements (e.g. columns, keys, or references) should also be described:

- Definition: What is the meaning of the element?
- Relevance: For which user story is this element relevant?
- Sensitivity: What is the sensitivity level of the element?
- Access restrictions: What access restrictions apply? Who is allowed to see this data element?
- Data granularity: Can the raw value be shared, or only a derived or aggregated value?

This level of detail ensures that the data inventory not only supports technical implementation but also complies with governance, security, and privacy requirements.

If the required data does *not exist*, the next step is to analyze whether it can be collected and captured, and if doing so would be worthwhile.

A living document

A data inventory is a living document: building it is not a one-time task, but an iterative process that evolves as new information becomes available. Any change in a dataset that is part of the inventory—such as new data elements or revised access policy, but also the creation of new datasets—leads to an update of the data inventory and to potentially revisiting the subsequent steps in this guide. By maintaining this iterative and structured approach, a data inventory remains accurate, useful, and aligned with project goals. In addition, it provides a reliable reference point for all stakeholders, reducing confusion and ensuring that decision-making is consistently based on the most recent information available.

The hard part of building and maintaining such a data inventory is the human factor. That is: finding out which datasets are available to you and reaching a common understanding of what the existing data is about. In some cases also confidentiality of data can be a challenge, e.g. if even the presence of some data elements and their structure is considered confidential. However, the maintenance of such a data inventory can be done using a simple spreadsheet.

Review user stories

During the process, it may become clear that some user stories are not feasible because the necessary data is missing or cannot be accessed. In such cases, the user stories should be revised or marked as unresolved. These unresolved elements can be revisited in future iterations if new datasets become available.

ID	Description	Format	Access	Owner	Remarks
DS1	Building structural info	XML	\\drive1\buildings.xml	facility manager	
DS2	Equipment registry	CSV	\\drive1\equipments.csv	facility manager	Read-only access for rexternal repairers is allowed on equipment level during the period of the repair.
DS3	Supplier contact info	JSON	https://procurement/api/v1/suppliers	procurerment manager	For internal use only
...					

Column	Definition	Sensitivity	Remarks	Linked User Stories
id	id of the equipement	medium		repair_05, deconstruction_01, procurement_07
location	id of location (room, corridor ...) where the equipment is located)	medium		repair_05, deconstruction_01, procurement_07
supplier	supplier of the equipement	medium		repair_05, deconstruction_01, procurement_07
model	id under which the product model is known by the supplier	low		repair_05, deconstruction_01, procurement_07
installation_date	date of the installation of the equipement	medium		repair_05, deconstruction_01, procurement_07
cost	total cost of the equipement at the moment of installation	high	Only cost ranges per 1000 euro may be shared.	procurement_07
...				

Responsible role:

Participants:

Step 4 - Enable data sharing: how and by/with whom?

This step builds on the user stories and the outcomes of the data inventory outlined in the previous steps. That is: now that you know what data is available or will be generated, and you know when and how actors want to exchange this information, and under what conditions—you are ready to decide what kind of data sharing infrastructure is needed. Translating these needs into practice requires more than internal IT systems—it calls for data infrastructure that supports secure, scalable, and standardised sharing across organisational boundaries. Next, we focus on what is needed specifically for *decentralised* data sharing.

Why additional data infrastructure is needed

Data can relatively easily be shared internally using existing organisational deployments, e.g. by providing access to an internal SAP system, or maintaining datasets on an internal FTP server. While sufficient within one company, these approaches break down when collaboration extends to multiple organisations. Getting updates of different datasets—which, as we've seen in Step 3, are likely to encompass various data formats—would require fetching updates via each different protocol and manually integrating those different changes. This is time consuming and easily results in errors.

The web and the Solid protocol

Instead, we can make use of the Solid protocol, which builds directly on the global document sharing infrastructure of the web. By exposing data through web APIs in a controlled manner, information becomes globally accessible while relying on open standards and widely available tools, often at little or no cost. This move from closed systems to web-based infrastructure makes cross-company data exchange feasible at scale. It simplifies technical integration, lowers the barriers for new partners to connect, and creates a more resilient ecosystem where information can flow consistently across organisational boundaries without costly custom solutions. For businesses, this means faster onboarding of new collaborations, reduced IT maintenance, and a clearer path to scaling pilots.

Within the Onto-DESIDE project, the Solid protocols have been applied to support decentralised data sharing. These protocols are a set of open standards (based on the RESTful architecture style for web API design) that specify how secure but granular data sharing can take place on the web. In essence, they define the requirements of a Solid server: how a web server should respond to data updates and request calls, and how this aligns with authentication and authorization protocols so that data can be shared securely. Think of a Solid server as a type of Google Drive or Dropbox, but then for individual data points instead of documents, with sharing across platforms.

In practice, this means that one or more Solid servers, all using the same API, can scalably manage the pieces of data to be shared with other (internal or external) parties. Deploying a Solid server allows to more easily adhere to the same standards, making it easier to integrate your own data with that of your partners—and vice versa. Because each organisation maintains its own Solid server, the approach naturally supports decentralised data sharing: every actor keeps control over its data while still enabling interoperability across the value chain.

Solid is a compelling infrastructure choice because it combines control with openness, aligning technical efficiency with business trust. It provides the foundation for scalable, trustworthy data-sharing ecosystems that transform collaboration into lasting competitive advantage.

Sharing data: servers, workspaces and pods

Within a Solid server, multiple workspaces can be defined. Each workspace is informally called a Solid pod. When you create an account on a Solid server, you receive an account ID in the form of a URI, called a WebID. Access rights are then managed by linking WebIDs to specific data resources and defining the type of access each account has (e.g. read-only, read-and-write, or administrator). Data can be partitioned into resources, giving you full control over storage, grouping, and sharing. The next step is choosing the infrastructure to host your Solid server.

Decide on the infrastructure

To make use of the Solid protocols, a Solid server is needed. As with any Software-as-a-Service, the strategic 'Build, buy, or rent' choice arises:

- ***Build:*** Develop software or technology from scratch, creating a highly customised solution and potential competitive advantage. This requires significant time, skill, and resources but allows full tailoring to specific needs.
- ***Buy:*** Deploy an existing implementation on your own infrastructure. This offers quick setup but limited customisation. Deploying an open-source implementation lowers the cost but comes without commercial support.
- ***Rent:*** Use a cloud or SaaS solution, paying for access and usage. This option provides flexibility, scalability, and reduced upfront investment, but may involve vendor lock-in.

For an initial pilot, we suggest using the MIT-licensed Community Solid Server, as this shows the web service's capabilities without requiring major effort or investment. For setup instructions, see the tutorial linked from our website.

More about Solid

History

Solid servers were initially presented as a way to manage personal data. Solid used to be short for *Social Linked Data*, for connecting personal data across the web. However, the Solid protocols have never been tailored only to personal data. Within Onto-DESIDE, we found that Solid also lends itself very well to industry and governmental data, *making it a strong candidate for supporting the kinds of information exchanges* described in the user stories.

More about Data Spaces

Readers that have heard about *Data Spaces* might wonder how Solid and Data Spaces are connected: the technologies and methods put forward by Data Spaces organizations such as IDSA or Prometheus-X mostly focus on domain-specific governance of data sharing. When going through their documentation, you will notice a lot of emphasis is put on how to create contracts between parties, to make sure data access rules are well established. Solid focuses on the technical protocols needed to let data flow easily between parties, once those data access rules are in place. As such, Solid and Data Spaces are complementary, but not yet fully integrated. Within this training guide, we will not go into detail how data access contracts are put in place, but focus more on how we can technically adhere to these contracts.

Responsible role:

Participants:

Step 5 - Ensure semantic Interoperability and Ontologies

Before data can be shared through data infrastructure, e.g. Solid, it often needs preparation. To achieve true interoperability, data must not only be technically accessible but also semantically consistent. This means describing it with recognised standards and ontologies. We recommend relying on de facto standards within your field, complemented with the Circular Economy Ontology Network (CEON) developed in this project, to ensure cross-domain alignment.

The role of interoperability

Interoperability can exist at different levels, and basically means that entities can work together. In a technical ecosystem, interoperability usually means that a set of systems can operate together without requiring extensive human effort in the day-to-day processing and exchange of data. Achieving this requires looking at both technical and semantic interoperability.

- ***Technical interoperability*** ensures that the *form* (the syntax) of data can be exchanged. For example, agreeing on what file formats a system should import or export, or aligning on the API structure for web-based systems.
- ***Semantic interoperability*** goes further by ensuring that the *meaning* of the exchanged data is shared and understood. Even if two systems agree on a common format—e.g., CSV files or an API with certain parameters—there remains the question of what the data values actually represent. Semantic interoperability means knowing that we use the same meaning for the concepts exchanged, and recognising when data is incompatible.

In general, technical interoperability can be solved by building file format converters and publishing API specifications. Semantic interoperability requires in-depth investigations into not only the data itself but also the processes of using and producing the data. Digital technologies can help to support this process, e.g., by allowing us to describe and capture the meaning of our data in a precise and formal way—understandable by both humans and machines. This is where standards and ontologies become essential.

Achieving semantic interoperability

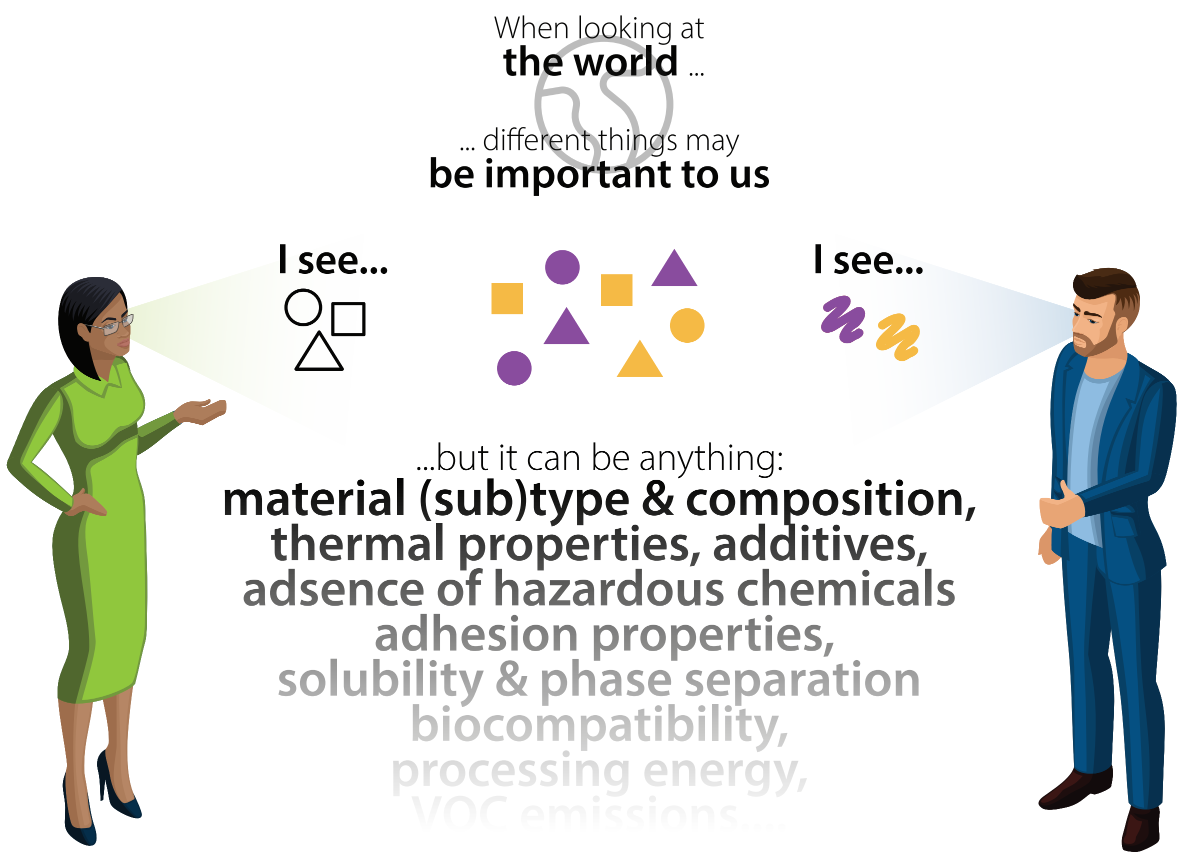
To move from ad-hoc interpretation to shared meaning, data should be described using recognised standards and ontologies. We recommend relying on de facto standards within your field, and complementing them with the Circular Economy Ontology Network (CEON), developed in this project, to support cross-domain alignment. CEON provides a common vocabulary that bridges differences between domains, making collaboration smoother and more reliable.

<u>Ontologies</u>

An *ontology* is a formal model describing a domain of interest. It offers a way of capturing meaning, i.e. defining concepts and relations in the domain that can be used to describe our data, so that we precisely know the semantics of it. Commonly such ontologies are called “domain ontologies”, to separate them from models trying to capture the nature of the whole world, or application ontologies that may be specific to one particular system or type of application.

In order to create and share an ontology, and to make it formal and precise so that it can not only be understood by human users, but also by systems, we need a formal language in which to express the ontology. The most common language used today is a web standard, OWL, developed for expressing and sharing ontologies over the web. The language is based on other common web standards, e.g. using URIs to identify things so that we can point to concepts and relations in the ontology from anywhere on the web. The ontology is stored in a file that should be accessible over the web, so that the URIs identifying its concepts and relations actually resolve. To allow for describing a domain in detail, the language allows to express axioms that can be used for automated reasoning. While reasoning is a powerful feature, it also adds complexity. OWL provides the possibility to derive new fact and check consistency, but it is not a constraint language. For validating data, and verifying constraints, other languages exist, such as SHACL – but this will not be covered in this guide.

To identify and link to ontologies OWL makes use of the namespace notion, which allows us to give an identifier to the ontology as a whole, and then extend that namespace to identify its elements. Normally the URI of the ontology is also its URL, i.e. the location where it can be found, as well as the namespace for its content. A URL can represent a public address on the web, or for instance, a location on an intranet. However, to facilitate a shared model for interoperability between actors, ontologies need to be accessible by the actors that use the data described by the ontology.

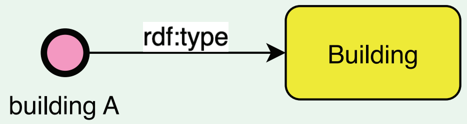


An example of an ontology

To understand and manage the ontologies you need in your value chain, it might be useful to first get a better understanding of what concretely can be expressed using ontologies. In this section we consider a simple example of an ontology consisting of just a few concepts and relations between them, to exemplify some of the constructs in the OWL language. The illustrations here are shown in a notation called Grafoo, though ontologies can also be visualised in other notations. However, an ontology is fundamentally a set of machine readable logical axioms, not merely a graph or diagram. The axioms are stored in an ontology file, using a syntax such as Turtle (see more details in Step 6) to make them understandable and usable by applications.

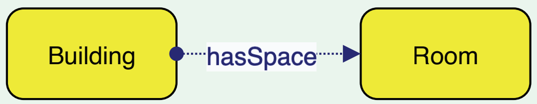
Concepts

The core element of an ontology is the concept. In OWL concepts are called classes, but since this is easily confused with the class notion in programming, we mainly use the term concept. A concept can be viewed as representing a set of things, its instances. So one way to view the concept "Building" is that it represents the set of all buildings. Another point of view is that it represents a type, i.e. it is a category that can be used to classify instances. The example below shows the concept "Building" and an instance of building, i.e. a specific concrete building, which we for the sake of the example have called "building A". The relation rdf:type is a built-in relation, coming from the RDF language (as indicated by the prefix "rdf:"), that is used to connect instances, i.e. data nodes to concepts.



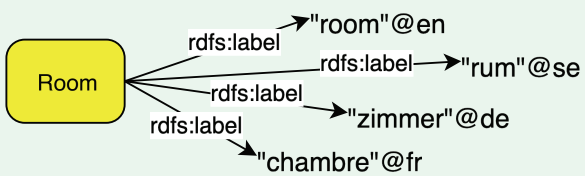
Relations between concepts

In an ontology we also want to express what possible relations may hold between instances of concepts. These are called object properties in OWL. The example below shows two concepts, "Building" and "Room", and a relation "hasSpace" that can connect instances of these concepts. In OWL, properties are first class citizens that can exist independent of any concept, but commonly we express their intended usage through some axioms in the ontology. This could be a restriction on the concept, or domain and range restrictions on the object property, which (in Grafoo) is illustrated by connecting the boxes.



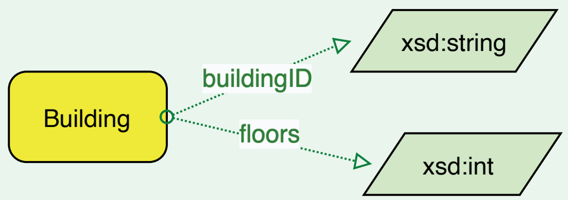
Lexical representations

Ontologies also help us to separate the lexical form of a concept, i.e. the different terms that can be used to refer to a concept or its instances, and the concept itself. Each box and arrow in our figures will have a unique identifier in the ontology file, independent of what label we give it. Thus this separates a concept definition from its naming, allowing us to, for instance, express synonyms, and to represent how different languages name the same concept. It can also be used to express different naming schemes, e.g. how different standards name the same concept differently. Below you see, the "Room" concept translated into English, French, Swedish and German:



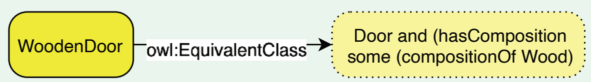
Attributes

Another type of relation is attributes. An attribute connects instances of a concept to literals, i.e.. data values. The actual data values are not part of the ontology, but in the ontology we express what attribute relations (called datatype properties in OWL) exist and the datatypes the data values have. Below we illustrate two datatype properties of a "Building", one that can hold string literals representing a building identifier, and one representing the number of floors as an integer.



Axioms and reasoning

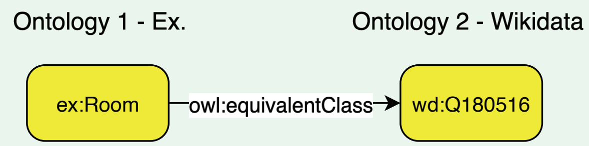
So far we have only seen the features of OWL that allows us to "name things", i.e. to create a vocabulary for types of things and relations in our datasets. However, ontologies can be more than vocabularies. OWL is a logical language, which means that it allows axioms to derive new facts from existing data – a powerful feature, but also complex. For instance, we might want to classify elements in a building as potentially "recyclable" if they meet certain well-defined criteria. In the naïve example below we classify doors as being wooden if they are composed of some wood material, which illustrates such capabilities.



Namespaces and links between ontologies

Agreeing on one single naming scheme, or one single ontology, makes things easier for data exchange within a domain. However, when considering cross-domain scenarios this may simply not be feasible. Each industry doman has its own formats and standards, and in some cases already their own ontologies. So instead ontologies can support mapping between standards and ontologies, because ontology languages, such as OWL, are built for the web. So just as we can create links between web pages, we can also create links between ontologies, and even between single elements and definitions inside the ontologies.

Since all ontologies have unique identifiers, which can be resolved on the web, we can point to any ontology on the web from our data. This means that for instance, the "building A" in our first example on this page, may reside in a dataset on our company server, while the ontology containing the "Building" concept may be published in an entirely different location on the web. To make this work, we need to provide the "address" of each element we introduce, normally a URI. To make things more readable in a file, or an illustration like in this guide, we can shorten the URI to what is called a prefix - a short name for the longer address. In the example below you see two concepts representing a room, from two different ontologies - the "ex:" and the "wd:" are prefixes, which in the ontology file then has to be connected to the correct URIs.



Different uses of an ontology

An ontology is in itself merely a model of some domain, i.e. making it explicit how that domain views the world, how it defines different concepts, and how the concepts are related. This means that an ontology is NOT in itself a data format, it is NOT even a schema for creating data in any format. As such, an ontology does not *prescribe* any format or any structure of the data. It can simply be used as a terminology (or mapping between different terminologies), providing a *description* of the domain. Since ontology elements are uniquely identified by URIs in OWL, this means that descriptions do not have to reside in the same place as the data, but data can link to ontologies published elsewhere.

Using an ontology as a vocabulary

An example of this usage could be to apply an ontology to define the keys (names of attributes) in a JSON structure, using the JSON-LD syntax. In this example, see image below, the @context key identifies that it is the GS1 Web Vocabulary (an ontology, available under URI https://ref.gs1.org/voc/) that contains the definitions of the attributes “globalLocationNumber” and “organizationName” that are used to describe the entity identified by the @id URI, which this JSON document is about.

```
{
  "@context": "https://ref.gs1.org/voc/",
  "@id": "http://example.org/my_org",
  "globalLocationNumber": "7350038721075",
  "organizationName": "Ragn-Sells AB"
}
```

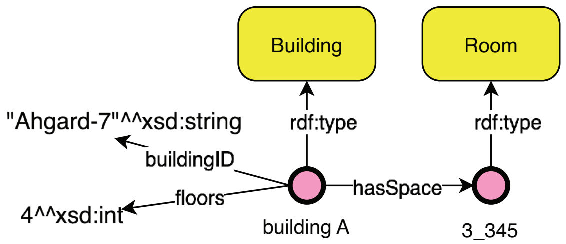
Using an ontology for data access

Another use of an ontology is to express queries over data. As you will read about in step 8 of this guide, expressing queries over data needs to be done using some vocabulary, i.e. we need to know what we can ask for. In this guide we assume that all datasets are actually transformed into RDF (as discussed in step 7), but even if this was not the case we could express queries based on the ontology and then create a mapping to the data sources using their own specific schemas.

Using an ontology as a data schema

An ontology can also be used as a schema for expressing data, i.e. as the structure of a graph dataset. If we would like to create an integrated knowledge graph, for instance, containing data from different data sources. Then the ontology could be used as the schema of that knowledge graph. But it is important to keep in mind that this is just one possible use of the ontology, and which use is right for you depends on the decisions made in the other steps of this guide.

Example data, illustrated as a graph (knowledge graph) with individuals as dots, representing instances of the building and room concepts illustrated earlier, and values for the two datatype properties in the previous example can be seen below:



Why does CE need ontologies?

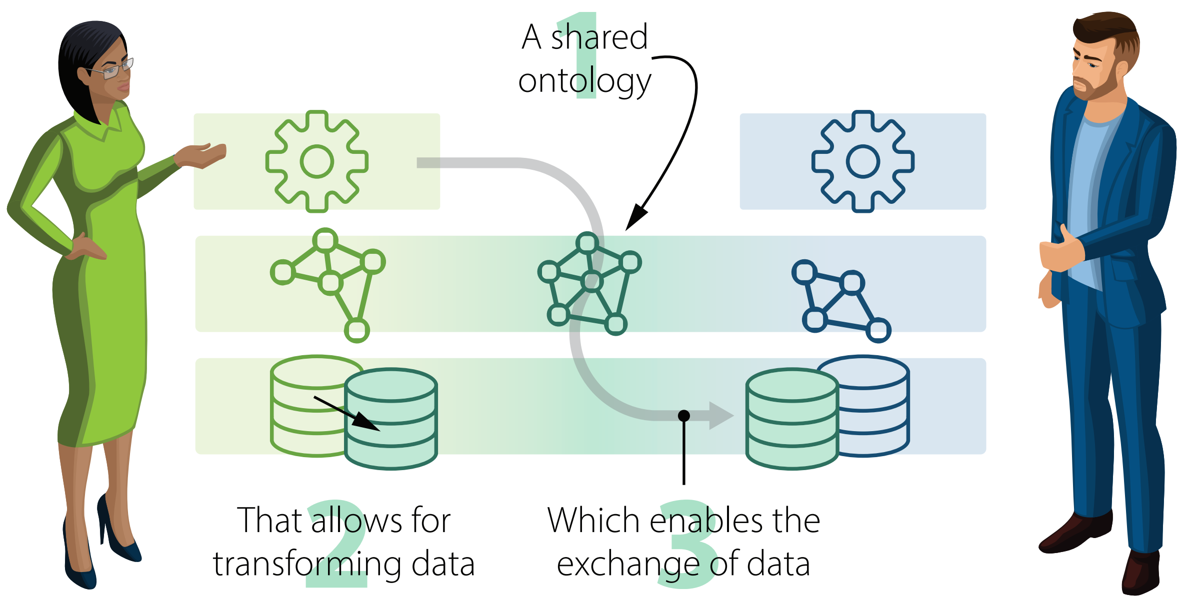
CE inherently means collaboration, and collaboration means the need to understand each other. CE also implies complexity—complex systems that need to scale across organisations, material flows, and time. Most of our current IT systems have not been built for such scenarios, but targets the internal processes of the organisation. Many also have implicit information models and system-specific data formats that are hard to explain and share with others. To some extent standardisation has aimed to alleviate this problem, but usually on a per-industry domain basis, whereas CE goes across domains. In such a scenario it is important to make definitions and assumptions explicit, and to be able to map between a plethora of different standards, formats, and models, and make domain assumptions explicit to others—also to other technical systems. This is where ontologies play a crucial role!

Next steps in ontology support

With semantic interoperability understood, the task is to assess needs and determine ontology support in your case.

- ***Ontology requirements and inventory (5a):*** Identify technical requirements and review existing ontologies, including CEON from Onto-DESIDE. Carefully assess their coverage and fit for purpose.
- ***Ontology extension (5b):*** If CEON or other ontologies do not cover all requirements, extend them to meet specific needs.
- ***Ontology alignment (5c):*** Where multiple ontologies are in use, connect and align them to ensure consistency and interoperability.

Outcome: Step 5 delivers an ontology requirements specification, together with a network of extended and aligned ontologies, designed to support your value chain’s data sharing infrastructure effectively.



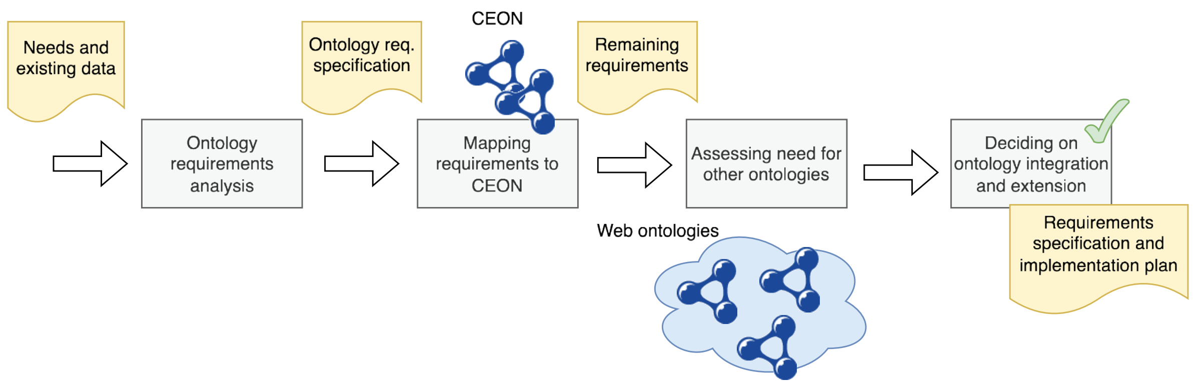
Step 5a - Ontology Requirements and Inventory

It is time to figure out what ontology (or ontologies) we need in the setup of our particular value chain collaboration. Based on the output of steps 1-3, i.e. an understanding of the value chain, its actors, needs, and the data required to make the intended flows happen, as well as the inventory of what data exists and where, it is now time to see how all this maps to an ontology. To have more detailed guidance in the following steps, you may want to look further into a specific ontology engineering methodology, such as LOT[7], and also think about how these steps will interface with your existing information management and systems development practices.

Ontology requirements

In step 2 we determined the overall system requirements of the data sharing infrastructure of the value chain, and in this step we figure out what this means in terms of ontology requirements. Ontology requirements are often expressed as Competency Questions. Competency Questions (CQs) are questions that should be possible to answer using the ontology, or data described using that ontology, and should be based on the information needs of the actors in the user stories. You could view it as listing what questions different users and actors in the value chain would be asking the overall distributed data of the value chain in specific situations. It is usually a good idea to express CQs in generic manner, i.e. without mentioning explicit data examples, but rather types or categories of data. For instance, while "What is the percentage of ALU content of this window construction?" would be a valid CQ, a better one, making the scope and level of detail of the intended ontology more clear, would be "What is the weight percentage of a specific substance in a certain building element?" for an ontology targeted at the construction sector, or even "What is the fraction of a specific substance in a specific physical object?" for a more generic ontology about materials. If expressing questions feels awkward, the requirements can also be expressed as simple sentences, specifying what the ontology needs to cover, such as "Physical objects and their material content, expressed using different metrics with associated units of measure."

In addition, CQs may represent reasoning requirements, i.e. things that should be derivable based on the ontology or its associated data, rather than merely "retrieval questions". For instance, a CQ like "What is the best end of life scenario for a certain used product?" will probably not imply a "lookup" of this in a database, but rather deriving different suggestions for end-of-life scenarios based on a set of parameters of the product in question. Such CQs may spark valuable discussions on the scope and task of the ontology. To what extent should this be derivable through "rules" expressed using the ontology, and to what extent should this be a manual task, or a task of an associated recommender system perhaps? Thus in some cases you will encounter needs that first seem to be ontology requirements, but in the end may result in other kinds of requirements, that may not be solvable by the ontology itself but rather requires a certain software solution or application to be built on top of the data. Adding lots of axioms in your ontology will make it complex, both for humans and machines. So be aware that this should be clarified before starting to build extensions to the ontologies, to avoid having overly complicated models that in the end still may not solve the need you actually had—ontologies do not do magic, they are merely models of the domain, and documentation for your data!



Requirements can also be based on data that is already available, and processes that are already in place, e.g. as discovered in the data inventory step. Studying such existing data may yield additional CQs representing typical queries that are already today used to retrieve the data. Or you may simply use sentences to list the "entities" that exist in those datasets, and their associated attributes. But also make sure to capture any hidden assumptions, e.g. units of measure that are not explicit, or whether there is a need to also capture the provenance of the data, apply change tracking or not, etc.

The output of the ontology requirements engineering process should be an ontology requirements specification document. Take care to give CQs identifiers so that it is easier to refer to them, and to indicate when they potentially change. CQs should also be verified with the actors identified as holding those needs, and may have to be prioritised if there is a long list of them.

Understanding CEON

Once requirements are in place, the next step is to identify to what extent these are already solved in existing ontologies. In the Onto-DESIDE project we have developed an ontology network specific to CE needs, called **CEON**. It is modular, to allow reuse and extension of the single modules, and to make it more flexible to varying needs.

To map the CQs to the **CEON** ontology network, the ontologies can be loaded into a tool for visualisation and editing (such as Protégé), or the online documentation can be used. Entering the URI of the ontology module in a browser window will normally take you directly to the documentation page, where you can see a visualisation of the ontology, as well as lists of all its classes (concepts), properties (relations) and their natural language representations (labels) and definitions (comments). For each CQ you can search for the specific terms included in the CQ to check whether they are actually present in the documentation, and may map to classes or properties. However, in most cases the terminology of your specific requirements may be too specific compared to the one used in the ontology modules, hence, you will need to either search for broader terms, or make a manual assessment by reading through the lists of concepts and relations and their definitions.

In some cases, the ontology may need to be studied more in detail to make sure that a CQ is fulfilled, e.g. checking whether there are also sufficient properties connecting the concepts found, and that their definition (also in terms of domain and range) match the usage you have in mind. This can be done through the ontology visualisation, or by opening the actual ontology file in a tool of your choice.

For example, consider the case where you are the manufacturer of a floor tile systems, and your CQ reads “What is the material composition of a specific floor tile?”. “Material composition” can be found in the ontology documentation of the materials module of **CEON**, while there is no concept representing “floor tiles” in any module. Instead, there is a general concept representing “products”, where in this case the “floor tile” is your specialisation of this concept. Additionally, you check the ontology visualisation to make sure there is a connection between products, and materials. Hence, the conclusion would be that parts of the CQ is directly modelled through the materials module, while another part requires a specialisation of the products module, but it is possible to express their connection through existing classes and properties.

After completing this, you will have an assessment for each CQ, stating whether they are (a) directly modeled by **CEON** already, (b) need a specialisation or extension of **CEON** to be satisfactorily modelled, or (c) seems to be completely out of scope of **CEON**, or are modelled or defined in an incompatible way in **CEON**.

<u>Other ontologies?</u>

In some cases you may already be using other ontologies, or there are other ontologies already built for a specific concept that goes beyond **CEON**. In this case, it is good to first check whether **CEON** also already provides an alignment to such ontologies. In many cases, this may actually have been considered already. For instance, **CEON** contains references to GS1 Web Vocabulary, as well as the EMMO upper ontology for materials modelling. To allow flexibility these links are mainly included as “see also” references in the ontology modules, rather than explicit relations, while also a number of alignment modules are available. When checking if **CEON** already aligns with your ontology of choice, check for “see also” annotations, and review the alignment files available in GitHub.

<u>Decision point - Is the ontology sufficient?</u>

After this step, you should now make a decision how to proceed, depending on your assessment of on one hand the coverage of **CEON** and related ontologies over your CQs, and on the other hand if there are additional ontologies you need to align to.

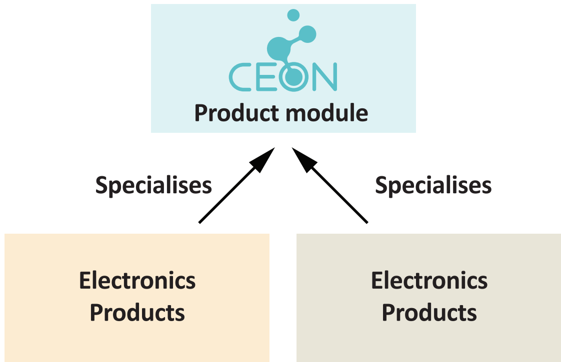
If all your CQs are sufficiently covered by **CEON**, or **CEON** and ontologies where alignments are already provided, then you can proceed to step 6. If there are parts of your CQs that are not sufficiently covered, and you think extensions to **CEON**, such as adding more specific concepts, or extending the scope, are needed, then you should consider step 5 b – ontology extension. If you also would like to connect additional ontologies to **CEON**, or your extensions, that are at the moment not aligned with **CEON**, then consider also Step 5 c – ontology alignment.

Step 5b - Ontology Extension

Given that the assessment of CEON and other existing ontologies resulted in the conclusion that some extensions are needed, a structured approach to such extensions is necessary. In this guide we only briefly describe the steps needed to create an extension of a CEON module. If a completely new ontology has to be created, from scratch, we recommend to study ontology engineering methodologies more in detail, and set up a suitable plan for performing the ontology development project based on that.

<u>Why specialising an ontology?</u>
Our focus here is on ontology extension, i.e. specialising and potentially slightly extending a specific CEON module, based on requirements identified in the previous steps. Specialisation means to add more specific concepts and relations that better describe our data, i.e. adding domain-specific modules as illustrated in the figure to the right, rather than the generic cross-domain concepts in the core CEON modules. The motivation for adding such concepts and relations can be both purely technical, i.e. the need to further specify the concepts so that certain consistency checking or inferences can be made, or also a matter of communication.

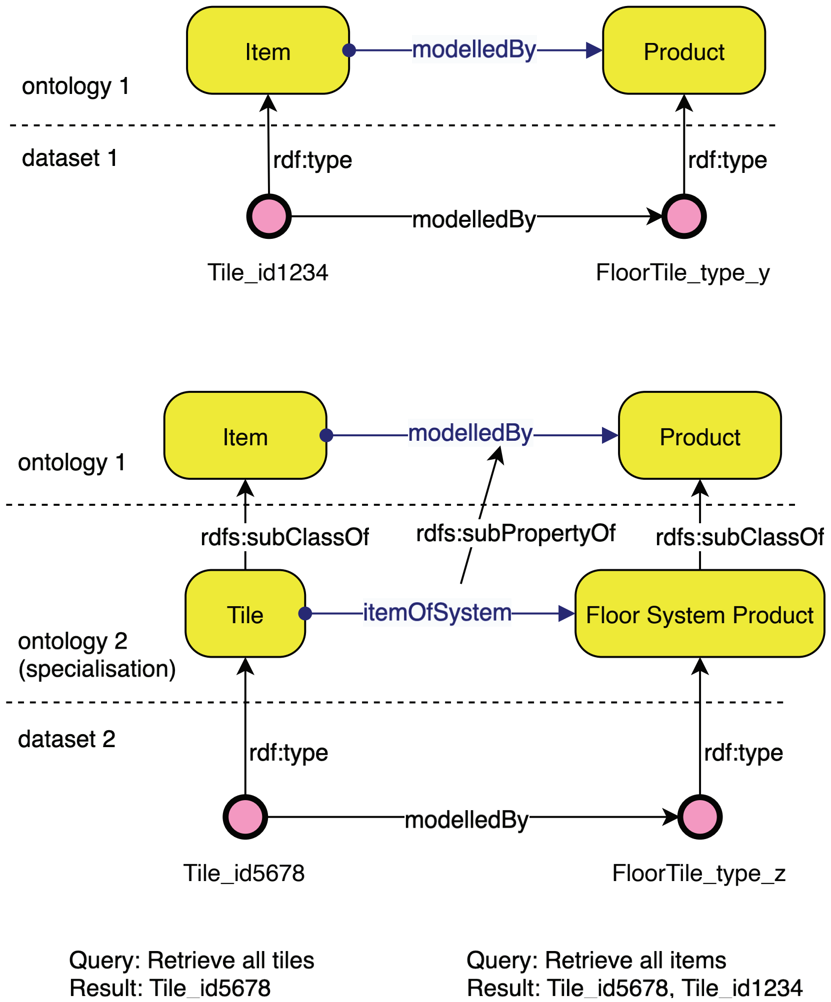
Consider CEON concepts such as "product" and “component”, which can include multiple kinds of things depending on the industry domain, and also the perspective of the organisation where the data originates. In the case of our running examples (A-D), we would rather like to have a more detailed taxonomy of products, such as “building element”, “door” and “floor system”, as well as more detailed component concepts, such as “floor panel” and “floor pedestal” as components of a floor system. The key idea of specialisation is that the new concepts and relations are added



mainly as subconcepts or sub-relations of already existing concepts and relations. While a general extension may also add concepts and relations completely independent of existing concepts and relations in the extended modules.

The benefits of an extension, rather than modelling something from scratch, is that the taxonomy can be used to reason over and query data regardless of at what level in the taxonomy it is described. Consider a dataset that is described using the core CEON module, describing a certain object as an item of a certain product type (see top of the figure to the right). Another dataset may use a more specific ontology that describes another object as a tile of a certain floor system product (middle part of the figure). When querying over both these datasets, asking for all tiles will only return the data tagged with the more detailed concept, i.e. only the result from dataset 2, while asking for all items will return both the items described using the generic concept, but also everything tagged with the subconcepts, such as “tile” (bottom of the figure). Hence, we use the semantics of the subclass relation between concepts, to allow us to seamlessly integrate data that is described with ontologies at different levels of detail and granularity – as long as they both rely on the same core concepts.

Other benefits include the possibility to include more specific relations or restrictions that apply only to the subconcepts. For instance, some characteristics, such as length, width, height, and material composition, may be relevant for almost all items, while other aspects, such as the maximum point load a tile can withstand makes much more sense to model at the tile level (or a potential intermediate level of built elements).



Specialisation

In order to create appropriate specialisations, consider the ontological requirements (e.g. CQs) that were identified as not immediately covered by **CEON** or other existing ontologies. If the matching process in step 5a, understanding **CEON**, resulted in a number of identified connections to CEON, these can now be used to add subconcepts representing the missing specific concepts.

Start by creating a new ontology file, i.e. do not modify the **CEON** files directly, but create your own ontology file with a new identifier and then import the **CEON** module you want to specialise. The new file should have its own identifier, using a URI that can be resolved (whether externally or on your intranet) when you publish the ontology. Then add the specialisations in this file. Commonly a modelling tool, such as Protégé, would be used to allow for graphical modelling. In Protégé, imports can be added using the user interface, and then subclasses, subproperties, and additional axioms can be added, before the file is saved and published.

Where to actually "attach" your extension is not always straightforward. As mentioned above, you should have identified some connections between your requirements and **CEON**, or any other ontology you are extending. However, even if you have identified two concepts that you will specialise by creating subclasses of them, understanding how they are to be "connected" is not always obvious. In this context, it is important to remember the fact that OWL treats relations as first class citizens, i.e. properties exist in their own right, and not only as something "attached" to a concept. This is a great flexibility, but also a usability challenge as it may be hard to understand the intended usage of a relation, and thus also how to specialise it. Usually, some axioms are added to the ontology to prevent misuse of the relations, and to show the intended usage. This can be through domain and range restrictions on the relations themselves, or by setting a restriction on the class. Logically these have very different meanings (semantics), but unless you are going to use a reasoning engine (see more on this below) you can view this as cues about the intended use.

Another issue that may arise is that you seemingly cannot find any direct relation between the concepts you are adding subconcepts to. In some cases, this may of course be because they are not actually connected in the model. But in many cases this may simply be because the connection is not direct. In OWL only binary relations exist, which creates a challenge when we need to connect multiple pieces of information that depend on each other. This could be for instance when we want to express material content of an item, and need to specify both the matter involved, the amount of it, and a unit of measure. For example, saying that "my tile contains 70% calcium sulfate" means connecting a specific tile ("my tile"), a material (calcium sulfate), a number (70), and a unit of measure (%). This cannot be expressed through a direct relation. Instead we have to use a technique known as reification, i.e. we treat the relation itself as a "thing". This can be done by adding a class to the ontology representing the relation, e.g. in this case a MatterComposition class, that then relates to the item, the matter, the value and the unit. CEON is actually full of these reifications, in order to allow for very flexible modelling, and also to enable to track metadata on these kinds of statements.

Design choices and tradeoffs

To make your additions reusable and maintainable also keep in mind that *modularisation* is beneficial. Hence, adding too many new concepts and relations into the same extension module may not be the best choice. Consider to divide the extensions into subsets, either by criteria that make sense to users, such as extensions that will be used for certain queries or certain applications, or layer the extensions so that their granularity fits certain datasets to be described by the ontologies.

Other things to keep in mind is the tradeoff between being very *detailed* versus sticking with less detail but instead being more reusable. Look at the technical requirements defined in step 2 and think about how your module might need to generalise in the future, or whether it can be designed in a way that can cover more than one requirement (e.g. a broader set of CQs and/or more of the user stories) at once. There is no right or wrong here, but this needs to be a decision made by the developers, in close collaboration with data stewards and end users, who may be the ones knowing what to expect in the future in terms of changes to the data or new uses planned.

Another design choice involves what *level of axiomatisation* to add to the ontology. We actually already saw an example of inferences on the previous page, where we used the semantics of the rdfs:subClassOf axioms to infer that the instance of a subclass is also an instance of the superclass, i.e. the tile is both a tile and an item in the case of the extended ontology. OWL also allows for much more complex axioms than this. What is important to remember is that reasoning is a powerful tool, and can be very valuable to both check the consistency of the domain model, as well as infer new information. However, these complex axioms also add complexity to the model. Both complexity in terms of understanding the model, so it becomes harder to use, extend and modify in the future—it is easy to accidentally introduce conflicts and unintended consequences in an ontology with many complex axioms. But also complexity in terms of the computations that are done using the ontology.

For reasoning there are OWL inference engines already available, as general purpose software that allow you to derive the conclusions that you can draw based on the model and associated data. However, these reasoning engines will be slower the more complex the model is, and in some cases there may not even be guarantees on their termination. The same goes for queries that use inferencing as a pre-processing step, such as was the case of the tile example, where we first have to derive the full set of types (concepts) the tile belongs to, before the actual retrieval takes place. This is powerful, but time consuming. So carefully assess the need for such reasoning to take place, before adding too many axioms to your ontology extension.

Documentation and publishing

Once you finish your extension, make sure to properly document all the new elements by using rdfs:label for human readable labels, and rdfs:comment for human readable definitions and explanations of the concepts and relations added. Also document the ontology itself, by adding metadata to it, such as a version number (for keeping track of new versions when changes are made), author, and publisher etc. If the ontology is to be made publicly available, also include licensing information, for enabling its reuse by others.

Testing

As hinted previously, sometimes the models become large and complex, even when split up into a set of modules. So another piece of advice is not to underestimate the need for testing of your ontology. Most ontology engineering methodologies include some evaluation or testing step, but they are sometimes not explained in detail. A minimal set of testing methods may include at least:

- Verifying the syntax by loading the ontology into a tool, and checking consistency of the model using an OWL reasoning engine.
- Checking for structural errors using a validator tool, such as the OOPS! and FOOPS! services.
- Testing your requirements fulfilment by expressing test data according to the ontology structure, and expressing some CQs (or existing queries) as queries over the test data, to verify that expected results are returned.
- Verifying that expected inferences are made over the test data using a reasoning engine, and provoking errors by adding erroneous data that should not cause issues when encountered by the reasoning engine.

Ontology Engineering Methodology

Several well established ontology engineering ethodologies exist, and a useful summary and overview of typical steps and activities can be found in the description of the Linked Open Terms approach[8]. However, other types of approaches and methodologies also exist, such as the eXtreme Design (XD)[9], which is more suitable for modular ontology development and rapid prototyping of ontologies. More concrete, detailed advice on actual modelling can also be found in the tutorial from Stanford University[10].

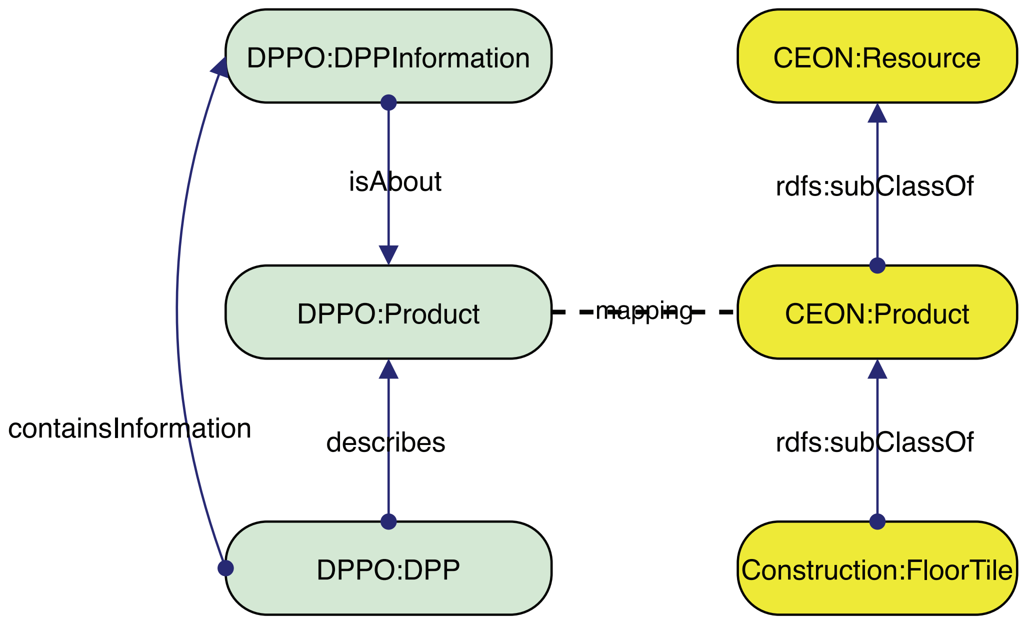
Step 5c - Ontology Alignment

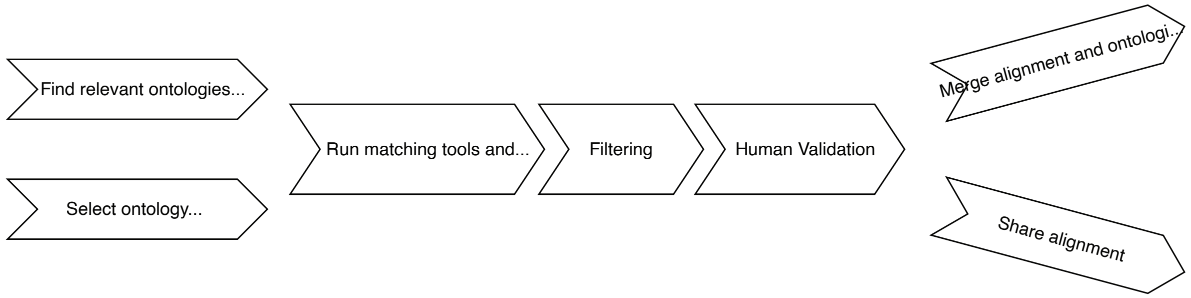
In some cases, you may want to reuse concepts or relationships from other domain ontologies that are not yet represented in CEON or that are more detailed than CEON. Ontology alignment, also called ontology matching, is thus a key technique for enabling semantic interoperability[11].

Why ontology alignment?
In some cases, the ontologies you are working with does not cover all your needs. For example, you might need more detailed categories of engineering materials in your application, but CEON does not currently model them. If you identify another ontology that provides such detailed categories, you will need ontology alignment to integrate it with CEON. Ontology alignment establishes mappings between common concepts and relationships across different ontologies. These mappings can capture equivalence (e.g. two concepts representing the same meaning), hierarchical relationships (e.g. one concept being more specific, a subclass, of another), or even more complex relations than that. For instance, both CEON and the Digital Product Passport Ontology (DPPO) have *Product* concept definitions. If we establish an equivalence mapping or sub-relation mapping (CEON:Product is a DPPO:Product), we make it possible to utilize more semantics in DPPO, as graphically illustrated below.

What is ontology alignment?
Ontology alignment takes two ontologies as input and produces an *alignment* as output, that is, a set of mappings between entities from the input ontologies. These entities may include classes, object properties, data properties, or individuals.

In our project, we established a pipeline for generating alignments between CEON and other relevant ontologies. As illustrated in the figure to the right, once you have relevant ontologies, you can start with using one or more ontology





matching tools to generate candidate mappings. These candidates then undergo an optional filtering step and a validation step to produce the final alignment. Filtering might mean that mappings generated by fewer than half tools are excluded to improve precision, if you use several ontology matching tools to produce candidate mappings. Then validation is a manual step, where a domain expert should check the output of the matching system, to make sure that no errors are introduced (since no such system is 100% accurate).

In our project, we have already provided sets of mappings between CEON and several relevant domain ontologies in the fields of materials, manufacturing, and products. If these ontologies are of interest, you can directly reuse the existing mappings.

Alternatively, if you are working with your own ontology or have identified another ontology that you wish to integrate with CEON, you can follow the alignment pipeline to generate new mappings. This process enables the creation of an ontology network that includes CEON, your ontology, and the "connections" (mappings) between them. In this case, the first step is to select a relevant ontology matching tool and use it to generate candidate mappings.

How to find other related ontologies?
There are several public repositories where you can search for relevant ontologies. Examples include *DBpedia Archivo*[12], *BioPortal*[13], *Linked Open Vocabularies*[14] *(LOV)*, and the *GitHub repository maintained by our project*[15]. These repositories allow you to search for ontologies by concept or relationship names and to download them in various formats. Such repositories provide an important starting point for identifying ontologies that can be aligned with CEON, or any other ontology.

Ontology matching tools and what they do
A variety of ontology matching tools are available to generate candidate mappings. For example, *LogMap*[16] is a well-known tool designed for scalability, i.e. working with large scale ontologies. It applies both lexical and structural matching strategies and includes unsatisfiability detection to ensure that the resulting ontology network (ontologies plus alignments) does not contain inconsistent concepts. This feature is crucial, as it helps to verify whether the integrated network is logically consistent. Another widely used tool is *MATCHA*[17], which also employs matching strategies based on lexical and structural information contained in the ontologies. You can of course also select another matching tool of your choice, and apply it using the same principles. However, take care to ensure you can use the output of the tool for further validation, and be aware that different tools have different benefits and drawbacks and no tool is perfect—see them as an assistant, but not as providing the actual truth.

Validating and merging

Once you run an ontology matching tool, it is necessary to involve human validation to check the alignment output. Then, depending on the application, you may either require ontology alignments to demonstrate semantic interoperability between two ontologies, or you may need to integrate the alignments with the ontologies themselves—for example, when creating semantic mappings to transform data into RDF. In the latter case, a merging tool is required.

There are many ways of merging. Two common approaches to ontology merging (where an alignment can also be considered an ontology) are the following: (i) use *Protégé*[18], which provides a merging function accessible directly through its user interface; (ii) use *ROBOT*[19], a widely adopted tool in the Open Biomedical Ontologies (OBO) Foundry. ROBOT can be used as a command-line tool or as a library for any language running on the Java Virtual Machine. The result of this step (in case you decide to perform the merging) is an integrated ontology that includes the input ontologies, together with the alignment.

Sharing ontology alignments

Whether you decide to merge your ontologies or not, you may also want to publish the alignment you arrived at, for others to benefit from. For instance, this could be so that your business partners can also use the same alignments, and thus the same set of interconnected ontologies as you do.

Most ontology matching tools follow a common practice of representing mappings in the *RDF format*. A mapping is typically expressed as a four-element tuple consisting of two entities, the relationship between them, and a confidence score indicating the strength of that relationship. In our project, we further explored the use of the *Simple Standard for Sharing Ontological Mappings (SSSOM)*[20], which extends this practice by supporting richer metadata for describing entity mappings. To facilitate this, we provide a program that converts mappings from RDF format into an SSSOM-compliant CSV format. The figure below shows how to represent a mapping with basic metadata supported in the RDF format and additional metadata supported by SSSOM. The following figure shows the previous mapping example in the tabular format, where the metadata contains basic RDF format-based metadata and additional metadata supported by SSSOM.

We suggest that you share your mappings together with any ontologies you have created, or want to make available, and publish them with a dereferenceable URI at your website.

A detailed tutorial on using an ontology matching tool (e.g., LogMap) to generate candidate mappings, with an optional step for converting them into the SSSOM format, is linked from our website.

RDF format-based metadata				Additional SSSOM format-based metadata		
entity1	**enity2**	**measure**	**relation**	**justification**	**tool**	**Reviewer**
CEON:Product	DPPO:Product	1.0	Equivalence Mapping	LexicalMatching	LogMap	Reviewer1

Responsible role:

Participants:

Step 6 - Ensure technical interoperability - Data formats

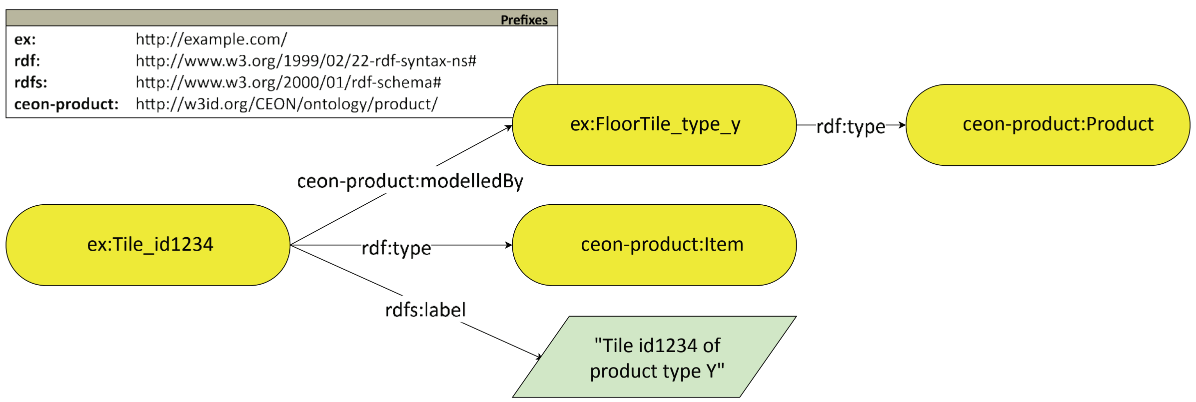
In the previous step, we introduced semantic interoperability and an ontology network to describe a data model to create a common understanding of what kinds of data we want to exchange across parties (Step 5). However, to achieve true data interoperability, we need to map existing datasets onto that ontology. The next step introduces some technical best practices of how to achieve that, but in this step, Step 6, we first introduce some background technical information: interoperable data formats.

Graph data
Existing tabular or tree-based data structures inherently have limited flexibility: changing a database schema typically requires a database migration, and creating new combinations of data within a database introduces the need for joins and join tables. To make sure we can map our data in such a way that it becomes interoperable for many different parties and their use cases, we would benefit from a more flexible data model.

We therefore recommend a *graph-based datamodel*, with its primitives only consisting of nodes and edges. By only using nodes and edges, we have a *very flexible means of introducing new structures* ("it's just adding a new edge and node to the existing graph") *and introducing new links* ("it's just adding a new edge between two existing nodes in a graph").

Labeled property graphs and companies such as Neo4J use a similar graph-based datamodel. However, labeled property graphs are stored in a centralized database. The graph-based datamodel makes it easier to introduce new data and new data links in the existing (centralized) graph, however, the problem of introducing new data stores and new cross-party data links is NOT solved.

The Resource Description Framework (RDF)
We apply a different graph-based datamodel, called the Resource Description Framework (RDF). This framework allows structuring data in a graph, but further introduces *global identifiers, i.e. web identifiers, URIs*. In RDF, data is structured as *triples*: a subject (node), a predicate (edge), and an object (node), where subjects and predicates are URIs (thus, becoming globally identifiable), and each object can be either a literal (value) or a URI. Since OWL is based on RDF, the ontology described in Step 5 can also be encoded as an RDF graph, and thus allow instance data to be linked to other instance data or to ontologies.



RDF data can be represented in many different (syntactic) formats: you can represent an RDF graph in JSON using the JSON-LD specification, in XML using the RDF/XML specification, and others, such as Turtle: a dedicated format to represent RDF data. Turtle is specifically designed to be human readable and compact, so that it is relatively easy to understand an RDF file in this syntax, even when inspecting it using a text editor.

Below, we see a piece of RDF data that represents a specific type of product: a subject (URI, noted with angle brackets <URI>) links via a predicate (URI) to an object (URI).

```
<http://example.com/FloorTile_type_y>
<http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
 <http://w3id.org/CEON/ontology/product/Product> .
```

Turtle provides a couple of shortcut mechanisms to make the data more easy to read, as seen in the next example. First, we see some prefix declarations, to make URIs shorter to write. The next triple links a tile's identifier to its type (Item) via the rdf:type ontology term), and via the rdfs:label predicate to its name (literal, noted with double quotes ""). The final triple specifies after which Product is modelled by. As all triples describe the same subject, we can use a shortcut via the semi-colon.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX ceon-product: <http://w3id.org/CEON/ontology/product/>
PREFIX ex: <http://example.com/>
ex:Tile_id1234 rdf:type   ceon-product:Item;
   rdfs:label "Tile id1234 of product type Y" ;
   ceon-product:modelledBy ex:FloorTile_type_y.
```

These triples could be illustrated in the graphical notation (Grafoo) that you have seen earlier in this guide: see figure to the left.

More about RDF and knowledge graphs
RDF was developed by the World Wide Web Consortium (W3C) in the late 1990s as part of the effort to create a "semantic web" where web data can be understood and processed by machines. RDF became a W3C Recommendation in 1999, marking its official adoption as a standard for describing web resources. RDF is the backbone of linked data on the web, which encourages the interlinking of web resources to create a web of data, rather than isolated documents. What is nowadays called knowledge graphs is commonly seen as an extension of the linked data concept. RDF is one of the most common formats for knowledge graphs.

Responsible role:

Participants:

Step 7 - Define data transformation - connecting data and ontologies

Once relevant data, required to solve the user stories (Step 2), has been identified in the data inventory (Step 3) and the infrastructure to share the data has been set up (Step 4), the next step is to ensure that heterogeneous datasets, each with their own formats (e.g. databases, CSV, JSON, XML) and model (e.g. product, item, resource or material as term to express the same thing), can be represented in a uniform way that is semantically meaningful across all actors. Within the Open Circularity Platform, this is achieved by mapping company-specific data sources into RDF according to the Circular Economy Ontology Network (CEON) (Step 5), which serves as the global schema.

Data mappings
At the core of this process is the mapping component, which defines how data from a source schema is translated into RDF resources that follow the ontology. To describe these mappings, we use the RDF Mapping Language (RML), an extension of the W3C standard R2RML. Unlike R2RML, which is restricted to relational databases, RML supports a variety of data sources, making it well-suited for real-world scenarios where companies rely on diverse legacy systems. To make RML easier to configure, we use YARRRML, a human-friendly syntax that is converted into machine-readable RML rules by the YARRRML Parser.

The mapping files created by each actor specify:

- Which data is shared,
- How it is translated to RDF aligned with CEON,
- How the data is split across resources,
- How it is stored on a Solid Pod, and:
- Which access control rules apply.

A detailed tutorial explaining how to write these mapping files in YARRRML is linked from our website.

In its essence, creating and managing mapping files goes as follows. First, specify the globally unique and permanent identification schema you will apply, i.e. specify how to go from your local identifiers to URIs. A simple URI scheme could be https://[organization domain]/data/[element concept type]/[element local id]. This URI scheme includes semantics in the identifier. Such a human-readable URI makes debugging your setup-up much easier. However, this is not deemed a best practice: in this case, encoding the type of the element within your URI makes it confusing later if the type of the element changes (and global identifiers should not change). Just using generic identifiers such as UUIDs is preferred.

Second, the internal data is iterated upon. In a CSV file, this means going over every row of the file. In a relational database, this means executing a query and going over every query result. For a JSON file a JSONPath expression, e.g. $.items[*], can be defined to iterate over each item entry individually. Depending on which data source you are accessing, different query languages are applicable (e.g., SQL for a relational database, JSONPath for JSON files, XPath for XML files).

Third, for each iteration, the mapping from the relevant data fields to an RDF representation is described, e.g. the internal column 'name' is mapped to ontology term dcterms:title, etc.

Generating RDF data
Once a mapping file is done, this can be used to instruct a mapping engine to perform the actual data transformations. The RMLMapper is a mature mapping engine.

During execution, the RMLMapper processes the mapping rules, generates RDF data, and stores this data on the Solid Pod.

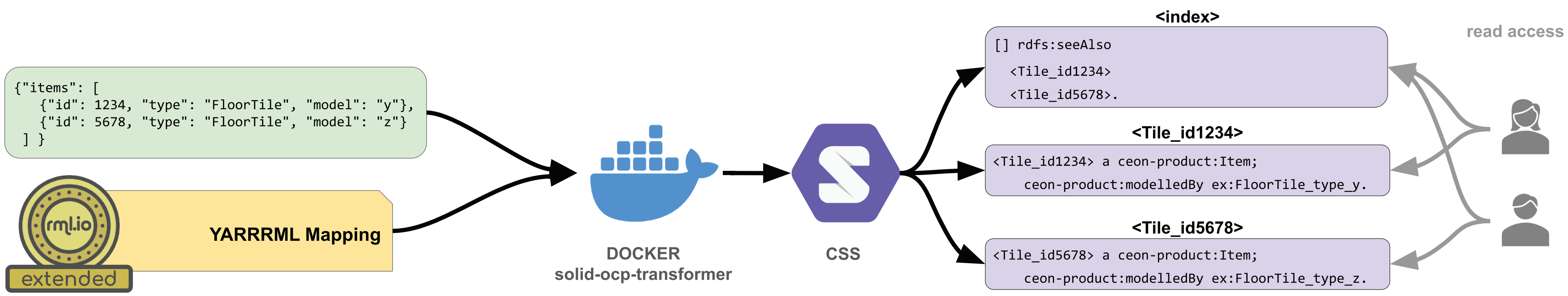
Optionally, the data can be wrapped in a Verifiable Credential (VC) envelope. This additional step ensures that data consumers can verify the authenticity and integrity of shared resources using standard VC mechanisms.

Finally, also data lifecycle events must be handled. Updates to the source must trigger a re-execution of the mapping, automatically replacing outdated RDF resources. When source data is deleted, obsolete RDF resources must be removed from the Solid Pod, maintaining consistency between the source and the published data.

Mapping pipeline
In Onto-DESIDE, we have built a Docker image, available as *rmlio/solid-ocp-transformer* on Docker Hub, that encapsulates a complete pipeline—from source data to CEON-aligned RDF with access control and verifiable claims. This simplifies deployment and guarantees reproducibility. With one command, a system administrator can run the full process:

1. Transform heterogeneous data into RDF,
2. Split it into subsets,
3. Add Verifiable Credentials,
4. Upload resources to the Solid Pod,
5. Configure access control rules, and:
6. Delete obsolete data.

By following this transformation step, all actors in the OCP can share interoperable, trustworthy, and access-controlled data, while still maintaining full control over their own systems and sources. This approach ensures that the platform not only integrates heterogeneous datasets but also establishes a secure and verifiable foundation for data exchange within the circular economy.



Responsible role:

Participants:

Step 8 - Set up querying - Federated querying with SPARQL

Once data has been described by ontologies and expressed in a standard format, Steps 8 and 9 are about putting the data into use. First, given that your data is now in RDF form, it is time to create the SPARQL queries that are to be used for accessing the data from an application point of view.

The SPARQL query language

Now that we have all data in the standardised RDF format, integrating data becomes a matter of sending queries to all relevant data sources. SPARQL is a query language to select specific data from RDF datasets. By querying the relevant datasets via SPARQL, data can be integrated on the fly, and the right answers are generated dynamically.

A SELECT query is a typical SPARQL query to find values that satisfy conditions. The syntax can be seen as a combination of Turtle and SQL. RDF data is selected using triple patterns: a triple pattern is a triple in which each of the components can be a variable. Further processing or filtering of the selected RDF data is done using additional SPARQL modifiers, e.g. LIMIT (returns only the first n results), OPTIONAL (specifies a left join, i.e. includes extra information in your results if it exists, but it won’t remove a result if that information is missing), FILTER (selects based on an expression), and ORDER BY (sorts results based on an expression).

Consider again the example of a specific floor tile, linked to its type, that was illustrated in Step 5b. The query at the bottom of this page is an example to find all items modelled by a certain type of product, in this case "floor tile type y", and to return both the item itself and its label.

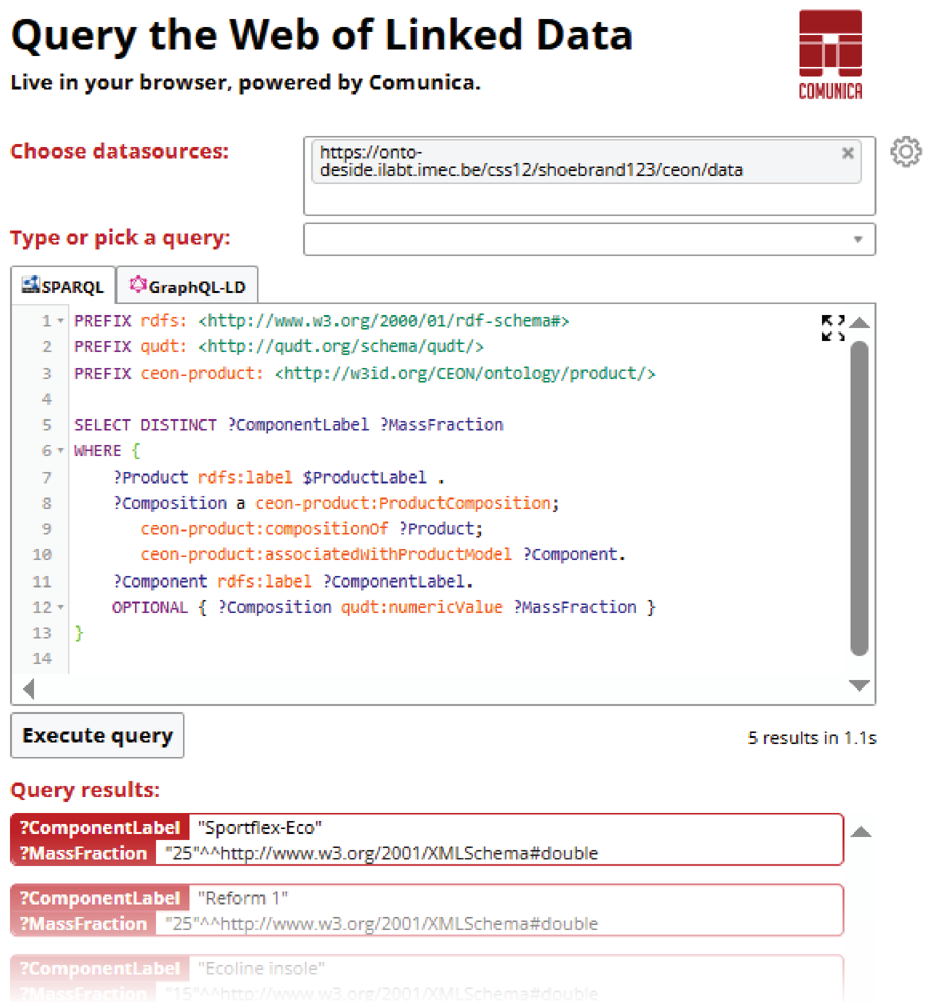
The first three lines declare *prefixes*, which are shortcuts so we don't have to repeat long URIs. The next line *selects* what information the query should return, using variables which start with a question mark. In this case, we want two data elements: ?item, i.e. the item itself, and ?label, i.e. the human-readable name of that item.
The last five lines, the *where* block, describes the *pattern* the query looks for in the RDF data. In this case, each query result must satisfy the following three conditions: anything bound to the variable ?item must (i) be of the type <http://w3id.org/CEON/ontology/product/Item>, (ii) must have a label, where this label will be bound to the variable ?label, and (iii) must be modelled by the product with URI <http://example.com/FloorTile_type>.

```
PREFIX  ceon-product: <http://w3id.org/CEON/ontology/product/>
PREFIX  rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX  ex:   <http://example.com/>
SELECT  ?item ?label
WHERE
          { ?item  a ceon-product:Item;
      rdfs:label ?label;
      ceon-product:modelledBy ex:FloorTile_type_y.
          }
```

Federated querying

A *SPARQL engine executes the query,* running it against RDF data. Many established SPARQL engines – such as those built in triple stores such as Virtuoso, GraphDB, or QLever – are optimized for querying their own triple store, but cannot easily perform federated queries, especially in cases where the data sources are dynamic.

Comunica is a special kind of SPARQL engine, capable of processing such SPARQL queries over a (dynamic) set of data sources (so-called *federated querying*): the SPARQL query above could be asked to multiple resources, over multiple pods, and Comunica will be able to correctly combine the information coming for all different resources and integrate them on the fly.



Responsible role:

Participants:

Step 9 - Develop data access applications

Although SPARQL (as presented in the previous step) is a mature standard to query data from RDF-based data storage, it is for technical purposes and application access to data. End-users of the data need to access data in a different way. In this step, we describe how applications can access the data, and exemplify this through a data viewer built in the project. This could be seen as the starting point for building your own applications on top of the data sharing infrastructure, or for connecting your existing applications to the platform.

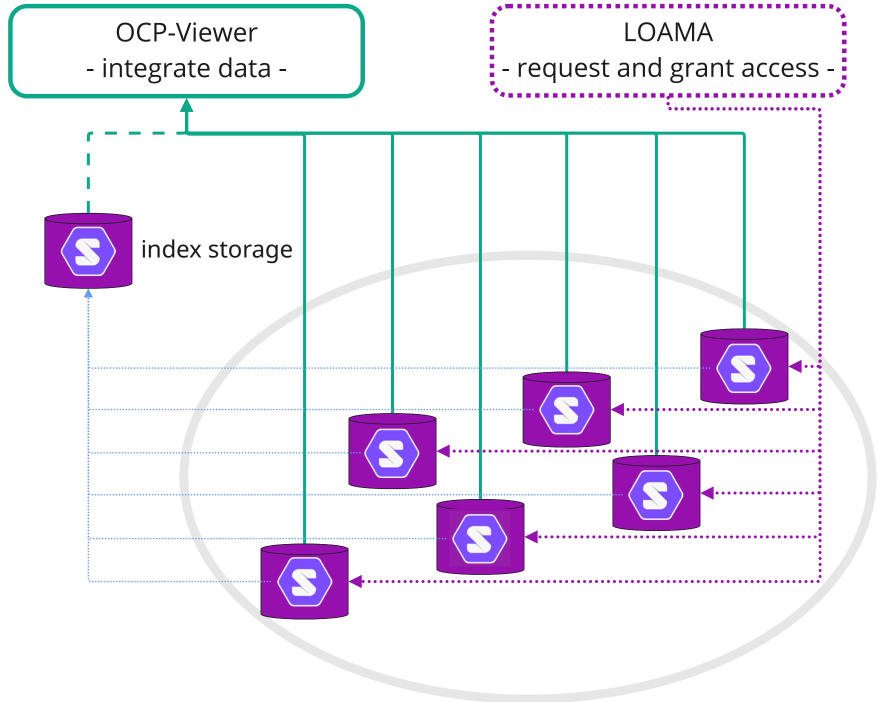
From backend to user-facing solutions
Up till now, we mostly introduced the backend solutions needed to easily share and integrate data for and from multiple stakeholders in a network. However, there are some additional steps to be taken. First, some governance framework needs to be set up, to make sure that the shared data is discoverable by the relevant partners in the network, e.g. managing the configuration of the value network, and its data sources. Second, data sharing contracts should be set so that access to the right data is agreed upon. Third, user-facing applications are needed to make sure that end users experience the benefits of easily integrated data from these backend solutions in an intuïtively understandable way.

Governance
First, concerning governance, existing initiatives such as dataspaces can be applied. These initiatives introduce the concept of a data catalogue: a registry where all data that may be discovered by the network is described. Note that this catalogue does not contain the actual data, but only the metadata. Within this step, we propose a source index, managed by a network administrator. Such a source index contains pointers to the location of the data of all included actors within the network, as a starting point for queries. Every change, e.g. every time a resource is added or removed, should be reflected in the source index. For the Onto-DESIDE demonstrators, we have maintained domain-specific source indexes, i.e. containing the URIs of data sources from resp. for the construction, electronics and textile domain, and a cross-domain index, covering these three domains.

Access control
Second, concerning access control, the Solid specifications provide a way to set access control rules on specific user accounts, or user account groups, thus providing role-based access control (RBAC). Granting or denying read or write access can be made simple via dedicated user-facing applications. We provided LOAMA as a demonstrator of how such an access management application could look like. A link to this application is available on the project website. Considering the resale of doors, a building owner can use LOAMA to grant read access to the resources with commercially sensitive data such as pricing with a specific buyer, without disclosing this information to other interested parties.

Frontend applications
Third, end users experience the benefits of these backend solutions through frontend applications, which can present the integrated data (i.e. the query results) to the end user in an intuïtively understandable way. Within the next section, we introduce such a demonstrator frontend application.

Using Miravi
Miravi is an exemplary application on top of the technically and semanticly interoperable open



and access controlled data. Applications like Miravi showcase the potential of combined data to enable resource flows and accelerate circular economy.

Miravi allows you to configure a data dashboard customized to a specific use case, integrating data from decentralized open and access controlled data sources, including but not limited to Solid pods. During usage, an end user browses the user-friendly web UI which provides access to the Solid-based decentralized data-sharing platform via predefined SPARQL queries. The predefined queries can start from an index to traverse an evolving set of query sources and can make use of variables to be filled in by the end user for more flexible querying. Miravi also allows the end user to export the query results, and to create, save, and load custom queries. Miravi can be easily set up, independent of the networks the Solid pods reside in, following the instructions of the extensive readme of Miravi's GitHub repository.

As a demonstrator for the Onto-DESIDE project an Open Circularity Platform Viewer was configured using Miravi. The Viewer provides a set of predefined queries the user can execute over the Solid pods with example data from the three domains under focus in the project, i.e. the textile, electronics, and construction domain. The predefined queries provide the needed data to resolve the domain specific and cross-domain use cases defined to evaluate the project, e.g., for the repair of an audio system, a building owner can discover repair instructions and track the digital product passport information of the original and repaired product in OCP Viewer.

Responsible role:

Participants: various

Step 10 - Plan for maintenance and evolution

Finally, this step describes various scenarios for maintenance and evolution of the data sharing infrastructure, such as extending the value chain configuration with new actors, including new data sources, adapting to changes in models, data and formats, as well as transforming data into new structural patterns, to adopt new or alternative ontologies. This step does not cover all possible scenarios, but gives a hint as to what will be necessary to keep the infrastructure up to date.

After concluding the previous steps, you have a robust set of technologies to create more interoperable data exchange in the Circular Economy domain. Every subsequent change is incremental. Depending on where the change happens, subsequent steps in this guide also must be reviewed. In the following paragraphs we discuss how changes to the context, requirements or certain artefacts will affect what was done in other steps.

Changes in the Circular Value Chain - Step 1
If changes appear in the context where the data sharing infrastructure is used, i.e. the value chain collaboration, then the mapping of flows may need to be updated and the subsequent steps may have to be revisited. For instance, it could involve adding new possible resource paths, involve new types of actors in the collaboration, or update the information needs and barriers.

Changes in requirements - Step 2
When a new user need is identified, this must be added to the list of requirements. Or if a change of requirements is identified based on, for instance, a change in the value chain context then the solutions and decisions made in subsequent steps will have to be revisited. Perhaps some solutions are no longer relevant.

Updating the data inventory - Step 3
When the requirements are updated, the data inventory needs to be reviewed to identify whether you can cover this requirement with your existing data inventory or you need to look for additional data sources (or data collection opportunities). On the other hand, when the set of data sources changes (e.g. a new data source is identified, or an existing data source is updated), the data inventory must be reviewed and updated to reflect that. Such a change may in some cases be an opportunity, but may in some cases instead lead to that a data source no longer matches the information need it was previously used to fulfill.

New previously unseen data may result in needs to update ontologies and queries, as well as applications, while removal of data element usually does not affect the models in the same way. However, queries can of course no longer ask for data that is not available.

Changes in data sharing setup - Step 4
When a new actor enters the network, a new data sharing web service must be set up. However, this should not affect the other actors in the network, regarding their data sharing setup.

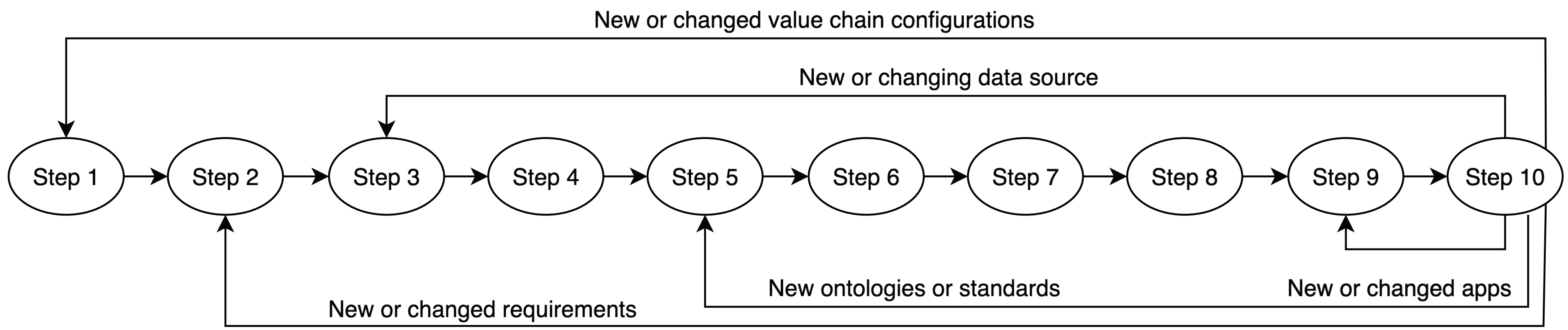
Changes in ontologies - Step 5
As mentioned previously, ontologies may need to be updated, based on new information needs, technical requirements, new or changing data sources. However, changes could also be initiated by an update to an ontology the network relies on, potentially beyond the control of the value chanin actors. Relying on standards and frequently used ontologies is a good practice, since this increases interoperability also across value chain collaborations, but it also means that some ontologies may be outside the control of the involved actors. Updates to such ontologies may then result in the need for updating the data transformations, queries and potentially slightly modify applications using the ontologies and data.

Changes in data formats - Step 6
The standards we recommend are mature and stable, and no direct impact onto or from this step is expected. In fact, one of the benefits of applying our approach is that the data formats are generic, and not specifically tailored to any industry domain or use case, which makes them particularly robust and unlikely to change.

Changes in data transformation - Step 7
Changes in the mappings of data to the ontologies will not appear by themselves, but are always consequences of other changes. For instance, when the data inventory is updated or ontologies change, the data transformations must be reviewed to identify if there are user needs that are no longer met, if new user needs can be met, and assess the need of changes in the mappings or whether it is merely enough to update the mappings to a new ontology vocabulary.

Changes in queries - Step 8
Similarly to step 6 the standards we work with are mature and stable, and no direct impact onto or from this step are expected. While still consequences of other changes may have to be reflected in the queries, e.g. using new vocabulary in the queries if the ontologies are changed, or querying over new data sources if such become available.

Changes in applications - Step 9
The use of standard languages, and by separating the models and queries from the applications, make applications built on top of this kind of



infrastructure surprisingly robust. While changes in data availability and requirements may certainly result in new or modified data visualisations, all the formats and data access components remain the same. Hence, no major changes in applications will most likely be required based on changes in any of the previous steps.

Below, we give an overview of how the steps are dependent on each other. Note how Steps 4, 6, and 9 are deemed to be independent of changes happening in the other steps.

Change in scenario A - Adding a new actor to the value network

In the context of our scenario 1, using recycling material, as time passes new recycling methods will appear, and new actors become interested in the recycled feedstock. In such a marketplace scenario, there will constantly be new suppliers of recycled material, and new actors interested in purchasing batches of materials, hence the concrete set of actors will change, and new material flows (step 1) will be added (and others removed).

In this case, the business case is still selling and buying recycled materials as feedstock for new products, hence, requirements (step 2) of the value network remain more or less the same. While the data inventory (step 3) is constantly changing, including data of new suppliers, and removing actors that no longer provide any materials for the marketplace. Each new actor that desires to participate in the material, and data, exchange needs to set up their data sharing service (step 4), e.g. contract a Solid pod service.

In case the new flows require new data points about the recycled materials, the ontologies may need to be specialised (step 5), however, given that the requirements remain more or less the same no extensions to the core ontologies would be needed. Next, the data source of the new actors need to be mapped to these ontologies (step 7), but if the new data is described by a specialisation of the previous ontologies, then it may even be possible to use the previous queries unchanged, simply adding new sources to the source index used as starting point for the query. And thus the marketplace application, if built based on the core ontologies, should remain more or less unchanged.

Change in scenario B - Adding a new data source to the infrastructure

In the context of our scenario 2, reuse of building elements, we may consider the addition of a BIM system, providing a digital twin view of the building, by the building owner. Such a system provides a new source of information about the used building elements, i.e. also including usage and repair data about the elements, in addition to the manufacturing data, product retail data etc.

Adding such a new data source does not change the flows, or requirements, nor the way the building owner will share data with others. However, the data inventory (step 3) is updated, by adding the new data source. Then this new data source is compared with the current ontologies, to see if they already cover all the needed data points. In this case, it may be the case that extensions are needed, if usage data for instance was not previously covered by the ontologies. Thus, an ontology extension is needed, where external ontology models for BIM can be reused, through adding an alignment (step 5c) to the CEON core modules.

Subsequently, a mapping of the data source (step 7) is needed, to these new ontology extensions, and formulation of new queries (step 8) that include these data, to complement previous reuse queries. If the applications (step 9) for mediating and marketing reused building elements are not able to take into account usage data aspects in their presentation of the available elements, they may need to be updated. For instance, consider the case of adding a way to search and filter used doors based on the type of usage of the rooms they have been mounted in, or based on the usage frequency.

Changes across scenarios - Modifying an ontology

We have previously described the flexibility of the graph data model in adapting to different situations that may occur in the real world (especially, in a complex domain such as that of CE value chains) that is to be modelled. Yet, even if ontological data schemas are less rigorous than most other schema types, sometimes we need to reshape the data in such a way that even the ontology itself needs to be modified. This may hold even though the world itself has not changed. The motivation for such a change would typically be the need for greater conciseness of the data graph, but sometimes also, a bit opposite, putting some (previously tiny or implicit) parts of the graph into the spotlight. The ontology should then undergo what we label as *transformation*.

A simple example of ontology transformation is de-reification. Remember the material content modeling problem: in the reification style of modeling, CEON contains a MatterComposition class, connected with relations possibly called “item”, “matter”, “value” and “unit” . Then we find out that reaching from the item (such as “tile”) to the matter (such as “calcium sulfate”) is cumbersome for some applications, because of the intermediate hops in the graph. For example: a data diagram in a visualization tool would be too cluttered, or some large-scale data analytics tasks would have to search in an unnecessarily large space.

An ontology transformation tool, such as PatOMat2 developed in the Onto-DESIDE project (see further information on our website), can then help us identify the possible “shortcut” (leading directly from the item to the matter), and introduce it into the ontology. Moreover, it can suggest, through a call to a pre-trained language model, a possible label for the new “shortcut” relation, for example, “contains matter”.

Closing words

To scale the Circular Economy, we need to scale the information flows that underlie a well-functioning value network. Luckily most IT infrastructure and standards we need are already in place, in some cases since many years - it is just about using them in a new way, and developing the necessary models and tools that guide the users specifically when developing CE solutions.

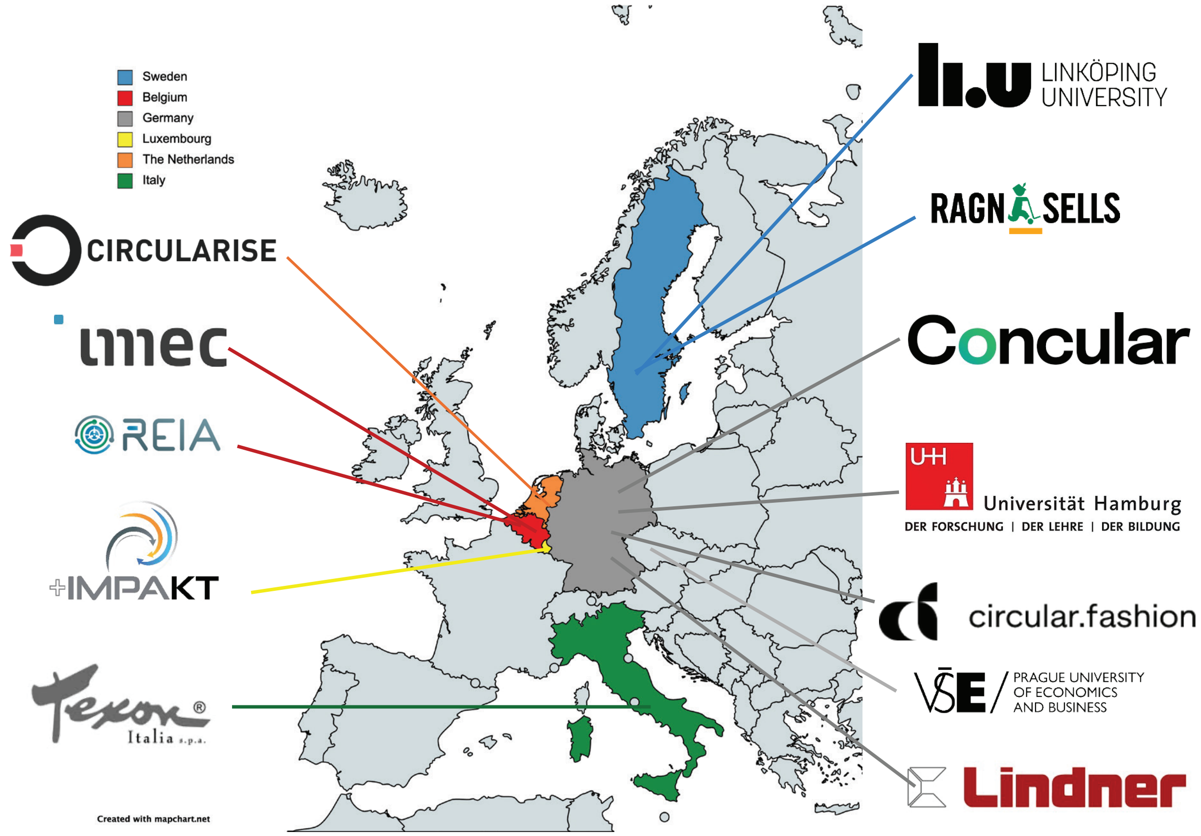
It is most likely the case that you as an organisation already have most of the basic prerequisites in place. For instance most organisations have a web server, either as part of their in-house IT infrastructure or as a hosted service, with security and access control as part of its basic setup. URI lookup and linking are also things already supported by our web application and browsers. Hence, the step is not too far, to extend this to linking also our data!

The challenge is to accept and embrace diversity instead of attempting to create (yet another) standard or data template to fit all scenarios. And to avoid lock-in through commercial APIs and formats, but rather focus on open standards and shared agreements. Technologies, such as ontologies, can be used to manage this diversity, create data descriptions and mappings, and allow for navigating and making use of the diverse data landscape.

On behalf of all Onto-DESIDE contributors,

Prof Dr Eva Blomqvist
Project coordinator

ONTO-DESIDE



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16 https://github.com/ernestojimenezruiz/logmap-matcher
17 https://github.com/liseda-lab/Matcha-DL
18 https://protege.stanford.edu/
19 https://robot.obolibrary.org/
20 https://github.com/mapping-commons/sssom

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