The Open Circularity Platform: a Decentralized Data Sharing Platform for Circular Value Networks

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Abstract

A Circular Value Network (CVN) is established when connections between actors (e.g. companies and consumers) are exploited to maximally use resources (e.g. by enabling reuse or recycling). Increasing the potential of a CVN requires information flowing between actors, regardless of the domain they operate in, the systems they use, and the data models they adhere to. However, this is currently hindered due to lack of data interoperability, both semantically (i.e. actors adhere to different data models) and technically (i.e. actors share in various formats using various protocols). Knowledge graphs can increase semantic interoperability. Centralization can increase technical interoperability, however, this implies actors lose control (and potentially trust) over their data. In this paper, we present the Open Circularity Platform: a decentralized data sharing platform for CVNs, built on semantic and technical interoperability standards. Specifically, we leverage the RDF Mapping Language (RML) to map existing data to the interoperable Resource Description Framework (RDF), Solid to securely share data across decentralized data pods, and Verifiable Credentials to ensure authenticity and integrity of the information shared on the platform. Furthermore, we complement our platform with a Web application, allowing users to query and verify the information stored across different data pods. We showcase the practical viability and usefulness of the proposed platform's data sharing capabilities in a cross-domain setting through an online demonstrator on which example use cases from the construction, electronics, and textile domains have been applied. We thus highlight how to design an open circularity platform based on the open standards RML, Solid, and Verifiable Credentials to facilitate actors (with different infrastructures and from different domains) to establish CVNs.

Keywords

Circular Value Network, Linked Data, RDF, RML, Solid, Verifiable Credentials

1. Introduction

The Circular Economy (CE) paradigm advocates for the maximal use and reuse of resources by exploiting connections between actors (e.g. companies and consumers) along the value chain

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to establish a Circular Value Network (CVN)) [1]. Increasing the potential of such networks requires information flowing between actors, regardless of the domain they operate in, the systems they use, and the data models they adhere to. However, a network's potential is hindered due to lack of data interoperability [2], both semantically (i.e. actors adhere to different data models) and technically (i.e. actors share in various formats using various protocols).

Knowledge graphs based on Semantic Web technologies is an established method to increase semantic interoperability. A centralized platform can increase technical interoperability by providing infrastructure and services tailored to a common data model and format. However, such centralization shifts control to the authority that governs the platform. Companies are typically reluctant to put their sensitive data on servers beyond their control. Instead, a decentralized approach where each actor is in control of its own data is desirable.

In this paper, we present the Open Circularity Platform: a decentralized data sharing platform, built on semantic and technical interoperability standards, to facilitate the establishment of CVNs. We provide an online demonstrator[1] showcasing the practical viability and usefulness of the proposed platform's data sharing capabilities in a cross-domain setting through the application of example use cases from the construction, electronics, and textile domains.

To provide for an interoperable, transparent, and secure solution, we rely on open Web standards. In particular, we map existing data to the interoperable Resource Description Framework (RDF) using the RDF Mapping Language (RML) [3], allowing actors to complement their existing infrastructure with a component that maps their existing data to an RDF representation that can subsequently be shared through the platform. We leverage Solid – a set of open Web specifications[2] – to establish a decentralized data sharing platform. Specifically, we store each actor's mapped RDF data on their respective Solid pod. We further leverage Solid's authentication and authorization specifications to enable secure and controlled sharing of resources stored on the pod. We employ the W3C Recommendation for Verifiable Credentials to allow users to verify the authenticity and integrity of the information shared on the platform. We provide a Web application that allows users to query and verify the information shared on the proposed platform. To the best of our knowledge, this is a first attempt at bringing together Semantic Web solutions, Solid, and Verifiable Credentials to establish a decentralized data sharing platform to support CVNs across different industry domains.

In section 2, we briefly review state-of-the-art solutions concerning data sharing platforms to facilitate CVNs. In section 3, we describe the design of our platform. In section 4, we describe the implementation of the platform and how it was applied to real-world CVN use cases. In section 5, we conclude and make suggestions for future work.

2. Related work

In this section, we first discuss existing CVN approaches that make use of semantically interoperable data. Then, we introduce Solid and alternatives for decentralized data sharing platforms.

[1]https://viewer.onto-deside.ilabt.imec.be
[2]https://solidproject.org/TR

There is a plethora of Circular Economy projects[3] and CVN projects such as DATAPIPE[4] and REPLANIT[5]. Such projects are typically focussed on specific domains[6] or locations and optimize their systems for those specific use cases. To make sure we can address potential cross-domain use cases, we specifically look into generic domain-independent works.

The existing work leveraging Semantic Web technologies in the context of CVNs is limited, and typically involve custom implementations [4, 5] and centralized management [4], hindering interoperability and control.

Solid [6] allows users to manage their personal data on the Web, while being in control of the data they share with whom. To this end, the Solid Protocol leverages a set of open-source Web standards governed by a multitude of W3C working groups, each focusing on different aspects of the ecosystem: i) Semantic interoperability using the Resource Description Framework (RDF); ii) storage operations using the Linked Data Platform LDP [7], which specifies how HTTP requests should be performed to operate on Linked Data resources; iii) identity using the WebID and WebID Profile Documents [8], which links to the Identity Provider (IdP) that can be used to authenticate the user; iv) authentication via Solid-OIDC [9]; and v) authorization using Web Access Control (WAC) [10] and Access Control Policy (ACP) [11]. Both WAC and ACP allow describing the required conditions and granted permissions to a user (or group) for a particular resource (or container).

Solid has been put to use as a means to achieve technical interoperability and control in, for example, SOLIOT [5], which extends an open-source Solid server implementation to support IoT protocol communication. Although SOLIOT relies on similar technical choices, its scope is narrower (i.e. it does not take existing data management systems into account) and the use case imposes different requirements (i.e. support for resource-constrained IoT devices vs. supporting a CVN between existing systems).

To the best of our knowledge, there is no existing work combining Semantic Web technologies, Solid and VCs to establish a decentralized data sharing platform to support CVNs across different industry domains.

3. Architecture

The Open Circularity Platform is completely built on open Web standards and provides four steps for enabling companies to participate and collaborate on the platform (figure 1). Specifically, a company's source data needs to be mapped to an interoperable representation (*Transform*), which can subsequently be shared with others (*Share*) through interoperable interfaces. Then, the interoperable data, spread across the platform's actors, needs to be retrieved (*Query*) and presented to other actors in an accessible and convenient manner (*View*). To establish (cryptographic) trust, additional operations to make the information verifiable are orthogonally integrated in each step.

[3]https://circulareconomy.europa.eu/platform/en/dialogue/existing-eu-platforms
[4]https://www.tudelft.nl/tbm/onderzoek/projecten/datapipe-project
[5]https://www.ams-institute.org/urban-challenges/circularity-urban-regions/circular-resource-planning-for-it-replanit/
[6]E.g. circular economy projects on building data by https://www.bamb2020.eu/, https://madaster.com/, or https://ccbuild.se/.

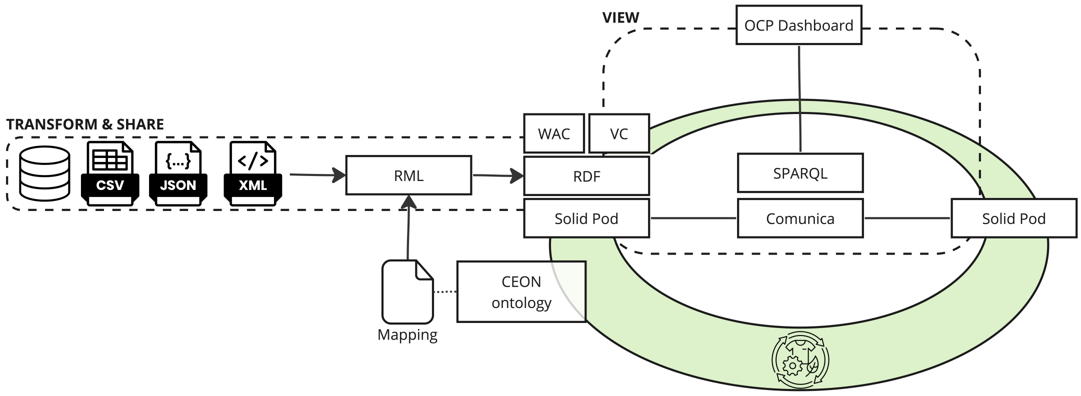

Figure 1: The Open Circularity Platform *transforms* heterogeneous source data to verifiable RDF according to an ontology, through a mapping defined in RML. This data is *shared* securely using Solid specifications, and *queried* using SPARQL in a federated manner. A Proof-of-Concept demonstrator provides an end-user *view*.

Transform To unambiguously convey information between diverse systems that incorporate heterogeneously structured data sources (databases, CSV, JSON, XML, etc.), the Open Circularity Platform provides a mapping component that transforms a company's source data to RDF according to an ontology that is commonly understood by all actors of the platform. To allow consuming actors to verify the integrity and authenticity of an actor's data, the resulting RDF data is complemented with verifiable claims. To this end, we leverage the RDF Mapping Language (RML)[7] [3] to map each company's source data according to the Circular Economy Ontology Network (CEON)[8] [12]. Furthermore, we leverage Verifiable Credentials (VCs) [13] to complement the transformed RDF data with verifiable claims.

Share To provision the (verifiable) RDF data through an infrastructure that enables technical interoperability between diverse systems and allows actors to be in control of their data, the platform leverages several components of the Solid ecosystem. More specifically, the RDF data resulting from the previous step is stored onto a Solid Pod, a decentralized data store that is solely controlled by its corresponding actor. Solid-OIDC (OpenID Connect) allows actors to authenticate using their WebID as an identity mechanism. The WebID serves as a unique identifier that enables the system to verify the identity of each actor attempting to access a private resource. Upon successful authentication, the authorization process determines whether the identified actor has the requisite permissions to access the targeted private resource. This decision is based on access rules defined either in the Web Access Control (WAC) or the Access Control Policy (ACP) framework.

Query As the data is stored decentralized across different Solid pods that belong to different actors, we employ an abstraction layer in which SPARQL queries [14] are executed in a federated

[7]https://rml.io
[8]https://liusemweb.github.io/CEON/

manner. This allows to query data that is distributed across multiple sources, as if it was a single source. Hence, we leverage SPARQL to express which subsets of information to retrieve and/or aggregate (e.g., by computing statistics such as sums or averages) from the platform.

View A Web-based dashboard application (figure 2) allows users to select different views (i.e., different SPARQL query results) over the data they have access to, while being able to check whether data originates from verified sources. For example, a manufacturer should be able to execute views including all details about its materials, components, and products. However, supposing that the manufacturer shared only a subset of its data (e.g., only products) with a reseller, the views executed by that reseller should only include subsets of the data to which the reseller was granted access. The dashboard hides away potential complexities inherent to the decentralized infrastructure (i.e., data being stored across multiple data sources and heterogeneous data structures) by providing the users with a unified, simple, and tabular representation of the query results produced by each data view.

4. Implementation

In this section, we discuss our implementation more in detail (section 4.1), and present a use case to demonstrate the Open Circularity Platform (section 4.2).

4.1. Infrastructure

The Open Circularity Platform covers an end-to-end trustworthy and decentralized data sharing platform that complies to semantic and technical interoperability standards to support CVNs between actors from different industry sectors (figure 1). The source code repositories for the platform[9] and the data viewer[10] are published on GitHub under the permissive MIT License.

To *transform* company data into a semantically and technically interoperable model and format, we map each actor's source data to RDF annotated with the Circular Economy Ontology Network (CEON)[11] using RML mapping rules executed by the RMLMapper [15]. The result is technical (RDF) and semantically (CEON) interoperable data for each actor, generated as a Verifiable Credential.

The resulting RDF is then stored on the actor's Solid Pod, hosted on a Community Solid Server[12] (CSS). By default, all data (except for the public profile) is private to the actor that owns it. The use case's read permissions are configured using WAC rules, so that every actor controls which data to *share* with whom.

The SPARQL *queries* are executed by Comunica[13]: a meta-query engine designed in a highly modular and configurable manner to deal with the heterogeneous and federated nature of Linked Data on the Web [16]. Comunica is capable of taking Solid's authorization mechanisms

[9]https://github.com/KNowledgeOnWebScale/open-circularity-platform
[10]https://github.com/SolidLabResearch/generic-data-viewer-react-admin
[11]https://liusemweb.github.io/CEON/
[12]https://github.com/CommunitySolidServer/CommunitySolidServer
[13]https://comunica.dev/

into account, so that the query results only include the (subsets of) data for which the consuming actor has been granted access.

We allow data, queried across different sources, to be cryptographically verified by validating the digital signatures bound to each published resource. Each data resource is published together with a Verifiable Credential, signed by the owner of that credential. For this, we first set up each actor with a cryptographic key pair, of which the public key is added to the actor's public profile. Then, we apply the BBS+/BLS12381 cryptographic suite [17] to sign each published resource using the actor's private key. As such, other actors in the network are able to verify the authenticity and integrity of a claim by verifying the claim's digital signatures against the public key published by the issuing actor of the claim.

Our demonstration dashboard application allows actors to explore data across the entire network, i.e. across domains, via a predefined set of configurable views (figure 2). Selecting a view triggers the execution of a particular SPARQL query in the background and provides the user with a tabular representation of the results.

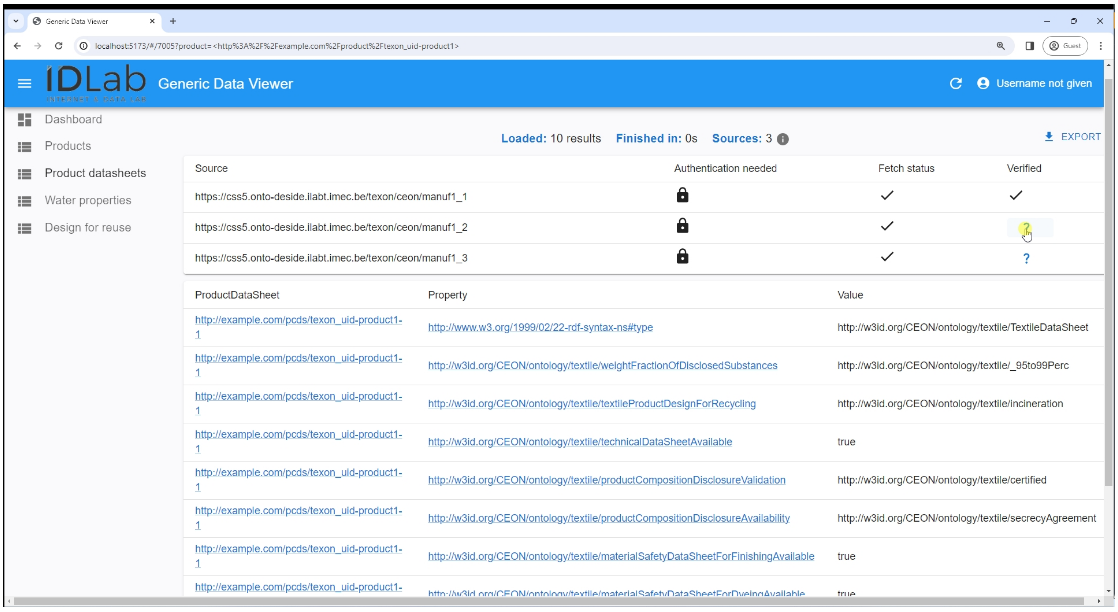

Figure 2: Screenshot demonstrating how the Open Circularity Platform allows to securely query and verify decentralized data sources.

4.2. Textile Use Case: A Visible and Transparent Sustainability Score

Within the Horizon Europe Onto-DESIDE project, we were able to extract multiple scenarios from the textile, construction, and electronics domain, validated by use case partners.

Our example scenario within the textile domain involves three actors: i) a supplier of materials for footwear; ii) a shoe manufacturer that combines different materials that make up the final product (i.e., a shoe); and iii) a brand that sells the shoe. For information to flow across these actors, data about materials and assembled shoes needs to be made available from supplier, to manufacturer, to brand, which we can demonstrate using (the viewer of) the Open Circularity Platform (figure 3).

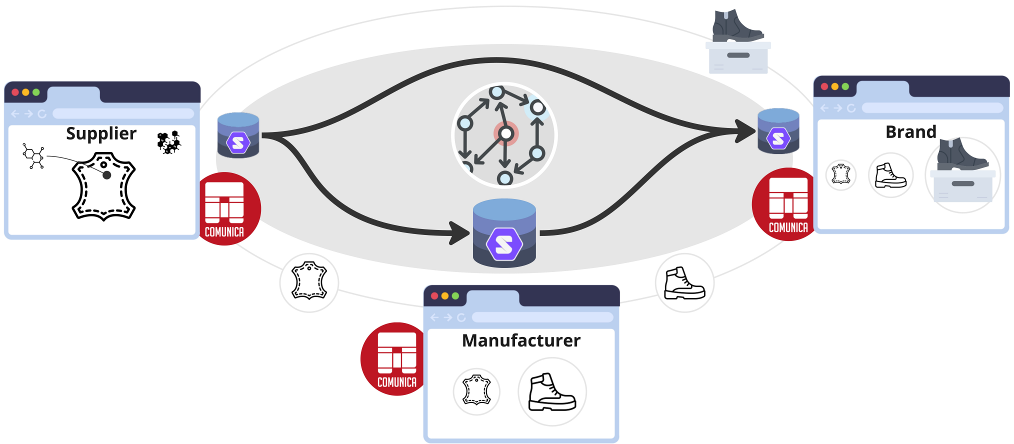

Figure 3: An Open Circularity Platform textile user story: a supplier delivers materials to a shoe manufacturer, which assembles various components to create shoes. Finished shoes are then sold by a brand.

The concrete user story[14] is as follows:

> As a brand, I want to show my sustainability efforts via a visible and transparent score on my product circularity performance.

The user story requires the brand to compute a circularity performance score of the shoes it resells. More specifically, we focus on the average recycled content of each shoe, as brought forward within Onto-DESIDE as a commonly used scenario[15] By means of weight percentage, we can calculate the average recycled content of each product based on which of its components are recycled.

Calculating the average recycled content percentage involves data about products, components, and materials, from different actors in the network. The brand requires read access to the manufacturer's product and component composition data. The component composition data in turn is derived from the supplier's material data.

Transform Each actor in the network (supplier, manufacturer, brand) has data about the materials and components it supplies/manufactures/sells. For example, the manufacturer's data consists of products and their corresponding composition of materials (i.e., their *bill of materials* (BOMs)). RML Mapping rules to map this data to CEON are provided for each actor (see, for

[14] The selected user story, TUS06, is part of the set of agreed-upon use stories within Onto-DESIDE, published at https://ontodeside.eu/wp-content/uploads/2022/12/Onto-DESIDE_Deliverable_D2.1_v1.1_final.pdf.

[15] Similarly, the battery passport includes information about a product's proportion of recycled materials: https://thebatterypass.eu/assets/images/content-guidance/pdf/2023_Battery_Passport_Data_Attributes.xlsx

```
1 prefixes:
2   o: https://www.example/com/textile-ont/
3   d: https://www.example/com/textile-data/
4   ceonproduct: http://w3id.org/CEON/ontology/product/
5
6 mappings:
7   component:
8     source: ["../in/components.csv"~csv]
9     s: d:component-$(ComponentID)
10    po:
11    - [a,                              ceonproduct:Product~iri]
12    - [rdfs:label,                     $(name)]
13    - [o:recycled-content-percentage, $(recycledContentPercentage), xsd:integer]
14    - [ceonproduct:hasComposition,    d:component-bom-$(BoMID)~iri]
```

Listing 1: YARRRML rules (i.e., a developer-friendly syntax for defining RML rules [18]) showing how source data (a CSV file at line 8, of which the columns are referenced via the `$()` construct) is mapped to RDF according to the CEON ontology (cfr., lines 11 and 14).

```
1 @prefix acl: <http://www.w3.org/ns/auth/acl#> .
2
3 <#owner> a           acl:Authorization ;
4          acl:agent    <manufacturer-WebID> ;
5          acl:mode     acl:Read, acl:Write, acl:Control ;
6          acl:accessTo <./boms.ttl> .
7 <#brand> a           acl:Authorization ;
8          acl:agent    <brand-WebID> ;
9          acl:mode     acl:Read ;
10         acl:accessTo <./boms.ttl> .
```

Listing 2: WAC rules granting full access to the manufacturer (lines 3–6), and read access to the brand actor (lines 7–10).

example, the manufacturer's BOM mapping[16], of which a snippet is included in listing 1[17]), taking existing data source systems and data models into account.

Share The user story requires the brand to query material, component, and product data from the supplier's and the manufacturer's data stores in order to compute the average recycled content of a product. Hence, the brand requires read access to the manufacturer's BOM data (listing 2).

[16] https://github.com/KNowledgeOnWebScale/open-circularity-platform/blob/v0.2.1/actors/manufacturer/pod-template/base/data/dt/mapping/boms.yml

[17] Only newly introduced prefixes are included, others can be retrieved via https://prefix.cc.

```
1 SELECT ?product ?productName (SUM(?partialRecycledContentPercentage) as ?
     productRecycledContentPercentage)
2 WHERE {
3   VALUES ?product { <https://www.example/com/textile-data/product-p01> }
4   ?product a ceonproduct:Product ;
5     rdfs:label ?productName ;
6     ceonproduct:hasComposition [
7       ceonproduct:associatedWithProductModel [
8         o:percentage ?percentage ;
9         ceonproduct:hasComposition [
10          ceonproduct:associatedWithProductModel [
11            o:recycled-content-percentage ?recycledContentPercentage ;
12          ]
13        ]
14      ]
15    ]
16  BIND (?percentage * ?recycledContentPercentage / 100 AS ?partialRecycledContentPercentage)
17 }
18 GROUP BY ?product ?productName
```

Listing 3: SPARQL query for computing the average recycled content of a product by retrieving all composed materials (lines 6–15).

Query The brand needs to query data about materials, components, and products from the supplier and the manufacturer's data stores to calculate the average recycled content[18] (listing 3).

Demonstrator We showcase the data sharing capabilities of the Open Circularity Platform through an online demonstrator, made available at: https://viewer.onto-deside.ilabt.imec.be. The demonstrator is set up according to three example user stories from three different industry domains (construction, electronics, and textile) – including the user story discussed in this paper and shown in Figure 3 – and allows for exploring the CVN from the perspectives of different actors (Figure 2). Screencasts can be found at https://youtu.be/o3acUKJO7K8. For the public demonstrator, multiple pods are set up with dummy data and accounts[19].

5. Concluding Remarks

In this paper, we presented the Open Circularity Platform: a first attempt at bringing together Semantic Web technologies and the CVN domain as a semantic and technical interoperable solution. We highlighted the synergetic potential of RML, Solid, and Verifiable Credentials to facilitate actors to establish CVNs. By applying CVN user stories from the construction, electronics, and textile domains, gathered within the Horizon Europe Onto-DESIDE project[20],

[18] https://github.com/KNowledgeOnWebScale/open-circularity-platform/blob/v0.2.1/scripts/comunica/queries/brand-recycled-content-of-product.sparql.template

[19] For demo account details, see https://github.com/KNowledgeOnWebScale/open-circularity-platform/tree/master/actors

[20] https://ontodeside.eu/

we showcase the usefulness of such CVN data sharing capabilities, and how this can be applied between actors from different domains.

For future work, we will further integrate the Open Circularity Platform with existing real-world data and use cases, and more closely align it with actionable CVNs (i.e. measuring the impact of data exchange on a CVN). For this, we have ongoing validation by the Onto-DESIDE industry partners, the results of which will be reported within the public Onto-DESIDE deliverables[21].

Scaling up towards real-world data size will further allow us to measure the performance of the decentralized querying, benchmarking the underlying Comunica engine and comparing its benchmark results with real-world use cases[22].

Furthermore, we will continue integrating our existing research on scalable access management via policy engines to manage an ever-growing network of actors without requiring each actor to manually and individually grant access to other actors, but rather provide access based on, e.g. certifications or profile data [19].

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