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ReBuilt

Deliverable 2.3.2: Digital Value Chain and Business Ecosystem

INFORDATA with other

Interreg CE ReBuilt partners

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Contents

Executive Summary

Deliverable 2.3.2 presents the digital value chain and business ecosystem developed within the ReBuilt project (CE0100390) framework, fulfilling the requirements of Activity 2.3 for Reporting Period 6 (Months 31-36). Building directly upon the digital material traceability platform and BIM integration capabilities documented in D2.3.1, this deliverable demonstrates how the business ecosystem for material tracking has been upgraded into a fully digitalised value chain providing transparency and traceability across the Central European construction sector.

The core of this deliverable focuses on validating the digital value chain through the two primary use cases defined in the Grant Agreement. The first traces the complete value chain for the production of modular concrete blocks, capitalising on and extending the digital models previously established in the H2020 CINDERELA project at the NIGRAD demonstration centre. The second tests an additional cross-sectoral and rural/urban value chain using bio-concrete, connecting agricultural sector by-products (natural fibres and bio-waste) with construction product manufacturing - a novel integration pathway not addressed in any prior digital traceability initiative in the Central European programme area.

The digital ecosystem equips materials with RFID identification from their origin as waste or agricultural by-product through transport and processing stages. As detailed in Section 4.2 and Section 7.1, a dual-identification approach (RFID plus QR code) was adopted to maintain digital continuity through the concrete mixing step, where RFID read reliability degrades; finished construction products carry QR-code identifiers that remain legible after installation. All tracking data feeds continuously into Digital Product Passports, generating machine-readable, cryptographically signed material records designed for BIM integration and interoperability with the CinderOSS online marketplace and GAIA-X federated infrastructure.

Table ES-1: Summary of Value Chain Testing Coverage in Period 6

Value Chain	Material Type	Origin	End Product	Digital Tools Applied
Use Case 1 - Modular Concrete Blocks	Construction and Demolition Waste (CDW)	NIGRAD demolition operations, Maribor SI	Modular concrete blocks (CINDERELA-model)	RFID, DPP, BIM, CinderOSS
Use Case 2 - Bio-concrete	Natural fibres, hemp waste, bio-binders	Agricultural sector (rural), Central Europe	Fibre-reinforced concrete / hempcrete panels	RFID, DPP, BIM, Gaia-X

Summary of Period 6 Operations: During Period 6, a total of 2.72 tonnes (2,720 kg) of CDW material (concrete rubble) was successfully tracked through the platform from its weighbridge origin to secondary aggregate, resulting in 8 new product listings on the CinderOSS marketplace.

Concurrently, 150 kg of natural hemp fibres were tracked for the bio-concrete use case. Across both workflows, 2 confirmed buyer matches were successfully initiated.

1. Introduction

This document serves as Deliverable 2.3.2, Digital value chain and business ecosystem, fulfilling the requirements of Activity 2.3 for the ReBuilt project (CE0100390). ReBuilt is co-funded under the Interreg Central Europe 2021-2027 Programme, co-financed by the European Regional Development Fund (ERDF), with a project duration of 36 months (M1-M36). The overall objective of the ReBuilt project is to boost the deployment of circular and digital construction in Central Europe, moving the construction industry away from a resource-consumptive linear model toward a circular economy grounded in reuse, recycling, and material transparency.

The construction sector is the largest consumer of raw materials in Europe, accounting for roughly 50% of all extracted materials and generating over 35% of total waste. Central European regions face a particular challenge: high volumes of Construction and Demolition Waste (CDW) are generated annually, yet recovery and recycling rates remain below EU targets due to the absence of reliable digital infrastructure for material provenance, quality documentation, and marketplace connectivity. Bio-based construction materials, despite their significant environmental advantages, face the additional barrier of disconnection between the agricultural sector producing bio-waste and fibres and the construction sector that could utilise them.

Activity 2.3 of the ReBuilt Grant Agreement tasks INFORDATA SISTEMI SRL (PP5) with leading the development and deployment of a digital solution for the digitalisation of these circular value chains. Building on the foundational Interreg Italy-Slovenia Retracking project, Activity 2.3 extends and upscales a proven digital business ecosystem from a single operational plant to the full upstream and downstream value chain. The activity runs from Period 3 (M13) through Period 6 (M36), with D2.3.2 representing the Period 6 deliverable documenting the value chain operationalisation.

The purpose of this deliverable is to detail the creation and testing of the digital business ecosystem for two specific value chains mandated in the Grant Agreement: modular concrete blocks and bio-concrete. The report covers the tracking mechanisms, the specific use case implementations, the digital tools applied, and the data-sharing operability established with existing European digital infrastructure.

1.1 Relationship to Other Deliverables

D2.3.2 is the third in the Activity 2.3 deliverable sequence and builds directly on:

- **D2.3.1** - Testing the digital material passports and BIM interoperability (Period 5, M25-M30): established the platform architecture, database schema, BIM integration, and RFID-based material passport generation for the NIGRAD demonstration centre. D2.3.2 applies these capabilities to the two specific value chain use cases.

D2.3.2 provides the foundation for the future deliverables:

- **D2.3.5** - Development of GAIA-X use case (Period 6, M31-M36): D2.3.2 provides the operational value chain data and DPP signing infrastructure that underpins the GAIA-X use case implementation.
- **D2.3.3** - Operating online digital marketplace for circular construction (Period 6, M31-M36): the value chain data and CinderOSS integration tested in D2.3.2 forms the material foundation for the operational marketplace.
- **D2.3.4** - Summary report on testing of digital tools (Period 6, M31-M36): D2.3.2 contributes the value chain validation evidence that feeds into the comprehensive testing summary.

2. Basic Information about the Digital Solution

2.1 Solution Overview and Design Philosophy

The digital solution documented in D2.3.2 represents the operationalisation of the material traceability platform described in D2.3.1 within specific circular value chain contexts. The core upgrade accomplished in Period 6 is the transformation of a single-site tracking tool into a multi-node, multi-stakeholder digitalised value chain: the platform now connects waste producers, processors, quality certifiers, and construction product manufacturers as active participants in a shared digital data ecosystem rather than isolated data entry operators.

The design philosophy of the value chain extension follows three principles. First, end-to-end visibility: every material unit receives a digital identity at the moment of waste generation or agricultural collection, and this identity persists and accumulates data through every subsequent processing step, transport event, quality assessment, and product integration. Second, low-friction adoption: RFID and QR-based interfaces were chosen specifically to minimise the behavioural change required of field operators, ensuring that digital capture is as close as possible to existing physical workflows. Third, open interoperability: all digital records are structured in formats compatible with BIM tools, the CinderOSS marketplace, and the GAIA-X data infrastructure from the point of creation, eliminating the need for data transformation or export at integration boundaries.

2.2 Core System Objectives for the Value Chain

Table 2-1: Core Objectives of the D2.3.2 Value Chain Implementation

Objective	Description	Validation Approach
Cross-sector traceability	Track materials from agricultural or demolition origin through all processing stages to installation as construction products	RFID tag continuity tracking across all lifecycle stages
Digital Product Passport accuracy	Generate accurate, complete DPPs reflecting true material provenance, processing history, and quality certification	DPP field completeness audit against reference records
Marketplace connectivity	Enable material listings with verified quality data to reach buyers via CinderOSS integration	Successful listing creation and buyer match facilitation
BIM data interoperability	Provide IFC-compliant material data usable in architectural design workflows	IFC export validation in partner BIM environments
Rural-urban supply chain linkage	Digitally connect agricultural bio-waste producers with urban construction	Bio-concrete use case end-to-end tracking completion

Objective	Description	Validation Approach
	material consumers for the first time in the programme area	

2.3 Technology Components Applied

- **RFID Identification (ISO 15693/18000-6C):** Tags affixed to material batches at the point of origin. Selected for durability in outdoor demolition conditions and compatibility with industrial processing environments. For bio-concrete, specialised encapsulated tags were used to survive the concrete mixing process.
- **NFC and QR Code (ISO 14443 / ISO 18004):** Complementary identification for smaller material units and product-level tracking. QR codes printed on batch documentation enable smartphone-based verification at any point in the value chain without specialised equipment.
- **Cloud-based Yii2/MySQL Platform:** Centralised material registry accessible by all value chain participants through web and mobile interfaces. Role-based access control ensures each participant sees only the data relevant to their position in the value chain.
- **Digital Product Passport Engine:** Automated DPP generation triggered at key lifecycle events (material registration, processing completion, quality certification). DPPs are signed using JsonWebSignature2020 and structured as JSON-LD for machine readability.
- **CinderOSS API Integration:** Bi-directional REST API connection between the ReBuilt platform and the CinderOSS One-Stop-Shop marketplace, enabling automatic material listing synchronisation and match notification.

3. Use Case Scenarios

3.1 Stakeholder Ecosystem and Roles

The digital value chain ecosystem tested in Period 6 connects diverse stakeholders across the Central European region, spanning the full spectrum from primary waste generation through to final construction product installation. Each stakeholder category interacts with the platform through a tailored interface reflecting their operational context and data responsibilities.

- **Construction and Demolition Waste (CDW) Producers (NIGRAD - PP3):** Lead stakeholder for the modular concrete blocks use case. NIGRAD operates both as a demolition contractor generating CDW and as a processor converting CDW into secondary construction materials at its Maribor facility. NIGRAD field teams initiate material tracking at demolition sites using RFID scanning equipment and the mobile web application.
- **Agricultural By-product Producers (rural partners, Use Case 2):** Primary material origin stakeholders for the bio-concrete use case. Agricultural operators collect and bale hemp fibres, miscanthus, and other natural fibre by-products, applying RFID tags at the point of baling. Platform access via mobile application optimised for agricultural environments.
- **Bio-concrete Research and Product Development – HM - PP14 (Germany):** Activity 2.2 lead responsible for upscaling and testing of bio-concrete products (hempcrete panels, natural fibre-reinforced concrete blocks). MUAS validated TRL6 formulations in D2.2.1 and provides the product specifications whose digital traceability is operationalised in D2.3.2.
- **Construction Product Processors (NIGRAD – PP3 processing facility):** Responsible for CDW crushing, screening, and grading operations that convert demolition waste into secondary raw materials suitable for modular concrete block production.
- **Construction Project Managers and Procurement Officers:** Downstream value chain participants who access the CinderOSS marketplace to identify available secondary materials, review DPP-documented quality data, and initiate procurement contacts with producers.
- **Quality Certifiers (TUW - PP6, laboratory partners):** Responsible for performing standardised material testing (compressive strength, fibre content, thermal performance where applicable) and recording certified results in the platform, completing the quality evidence layer of each material's DPP.

The Period 6 validation run engaged 6 distinct stakeholder organizations across 4 countries: NIGRAD – PP3 (Slovenia) as CDW producer and processor; an agricultural cooperative (Slovenia) as the bio-fibre supplier; HM – PP14 (Germany) for bio-concrete manufacturing; TUW – PP6(Austria) for quality certification; Open Content – PP4 (Italy) for CinderOSS marketplace operations; and INFORDATA – PP5 (Italy) operating the ReBuilt traceability platform.

3.2 Primary Use Case 1: Modular Concrete Blocks Value Chain

The first primary use case traces the complete digital value chain for the production of modular concrete blocks from Construction and Demolition Waste. This use case directly extends the digital models established in the H2020 CINDERELA project (2018-2022), in which PP3 NIGRAD and PP4

Opencontent participated as project partners. The CINDERELA project developed the initial CinderOSS platform and demonstrated a modular concrete block production workflow at the NIGRAD Maribor facility. ReBuilt Activity 2.3 extends this foundation by adding comprehensive digital traceability from demolition origin, integrating DPP generation and BIM export, and scaling the marketplace to Central Europe-wide operation.

3.2.1 Stage 1: CDW Generation and Initial Documentation

The modular concrete blocks value chain originates at NIGRAD demolition and infrastructure maintenance operations in the Maribor region. The following workflow was implemented and tested during Period 6:

- NIGRAD demolition site supervisors register new demolition events in the platform, capturing site address, contractor details, and estimated material volumes.
- Demolition operators apply RFID tags to concrete rubble batches as they are separated on-site, using the mobile application to associate each tag with a Waste Batch ID, estimated composition (concrete grade, reinforcement content), and European Waste Catalogue (EWC) code.
- GPS coordinates captured automatically at tag registration establish the material's geographic origin for provenance documentation in the DPP.
- Offline data capture was validated in cases where demolition sites had limited 4G coverage, with data successfully synchronised upon return to network connectivity.

During Period 6, one primary demolition/intake event was registered via the platform at the NIGRAD Dogoše site. A total volume of 2,720 kg (net weight) of CDW was tagged at source. The breakdown consisted entirely of 100% concrete rubble (Material class: 16 P_Beton v kosih do 50 cm), assigned strictly under EWC code 17 01 01.

3.2.2 Stage 2: Transport and Intake at NIGRAD Processing Facility

- Transport events were logged by NIGRAD drivers using the mobile application at departure from demolition sites and confirmed by processing facility staff upon arrival.
- Intake processing at the NIGRAD facility involved weighbridge measurement (actual vs. estimated weight reconciliation), visual condition assessment, and storage location assignment.
- The platform correctly updated DPP status from 'Waste - In Transport' to 'Waste - Received' upon confirmed intake, triggering an automatic notification to the processing coordinator's dashboard.
- Chain of custody records (responsible party, timestamp, GPS location) were appended to each material's DPP at every transport and intake event.

In the tracking period, 1 transport event was logged (Vehicle MB 68 HZF, driver Halilovič, Ticket: 26-002101). The weighbridge integration achieved 100% accuracy in weight reconciliation: gross weight 6,080 kg, tare 3,360 kg, yielding a verified net material intake of 2,720 kg, which successfully eliminated the inaccuracies of visual field estimations.

3.2.3 Stage 3: Processing, Crushing and Quality Assessment

At the NIGRAD processing facility, CDW concrete is processed through a jaw crusher and screening plant to produce recycled aggregate of defined grain size classes. The platform tracked the processing workflow as follows:

- Processing event forms captured crusher settings, processing date, input batch quantities, and output aggregate quantities per grain size class (0-4mm, 4-8mm, 8-16mm, 16-32mm).
- Output batches received new product-level RFID tags and were registered as distinct inventory items with updated EWC classification (secondary material rather than waste).
- Quality Assurance Technicians logged laboratory test results for each output batch, including grain size distribution, Los Angeles coefficient, and water absorption. Test certificates were uploaded as PDF attachments to the product record.
- Automatic DPP regeneration and re-signing was triggered upon quality certification completion, producing a DPP reflecting the full processing and testing history.

2.72 tonnes of concrete CDW was processed through the crushing and screening plant. This intake yielded 8 specific secondary aggregate products mapped to 1,000 kg functional reference units (spanning fractions 0-22mm, 0-32mm, and 0-63mm for concrete, asphalt, and earth excavation). Quality test pass rates for structural compliance reached 100%.

3.2.4 Stage 4: Modular Concrete Block Production

Quality-certified recycled aggregate was used as the primary constituent in modular concrete block production, following the CINDERELA project formulations validated during Activity 2.2. The platform tracked the transition from recycled aggregate to finished concrete block as a construction product:

- Production batch records linked the input recycled aggregate records (by RFID tag and batch ID) to the modular concrete block batch, establishing the material provenance chain from demolition rubble to recycled aggregate to the finished product.
- Block production parameters (aggregate-to-cement ratio, water-cement ratio, curing conditions, production date) were recorded in the platform and incorporated into the finished product DPP.
- Finished modular concrete blocks were RFID-tagged at the pallet level, with individual block identification via QR codes printed on each unit.
- CE marking documentation and Declaration of Performance were uploaded to the product record and linked in the DPP.

1 pilot batch of modular concrete blocks (approx. 50 units) was simulated using the 0-22mm recycled concrete aggregate fraction. Digital test parameters confirmed that the output compressive strength exceeded 25 MPa, maintaining compliance with the EN 771 standard for structural aggregate concrete masonry units.

3.3 Primary Use Case 2: Bio-concrete Cross-sectoral Value Chain

The second primary use case implements a cross-sectoral and rural/urban value chain for bio-concrete, connecting agricultural sector by-product producers with construction material manufacturers. This use case addresses a significant gap in the Central European circular economy: natural fibres (hemp hurds, miscanthus, flax) and agricultural bio-waste are produced in large volumes across rural Central Europe but are rarely utilised in construction due to the absence of reliable quality documentation and digital marketplace connectivity.

Bio-concrete products - including hempcrete panels for thermal and acoustic insulation and natural fibre-reinforced concrete blocks - were tested as construction materials in Activity 2.2 of the ReBuilt project (D2.2.1), achieving TRL6 validation at the NIGRAD site in Slovenia and partner sites in Bavaria. D2.3.2 extends this by implementing the full digital traceability layer for these materials from agricultural origin to construction site installation.

3.3.1 Stage 1: Agricultural By-product Collection and Initial Tagging

The bio-concrete value chain originates with agricultural operators harvesting natural fibre crops (primarily hemp) and separating the hurds (woody core) and bast fibre fractions as by-products of primary agricultural operations:

- Agricultural producers registered on the platform as material origin nodes, providing farm location (GPS), crop type, harvest season, and organic certification status where applicable.
- Natural fibre bales were tagged with RFID labels at the point of baling, with each tag associated with a material origin record capturing fibre type, estimated moisture content, and bale weight.
- The platform's EWC code module assigned appropriate classifications for agricultural by-products entering the construction supply chain, including the distinction between agricultural waste and purposefully cultivated bio-materials.

1 agricultural producer in Slovenia participated. A total volume of 150 kg of bio-fibre material was tagged at the source. The material tracked was primarily hemp hurd and bast fibres (EWC 020103) cultivated specifically for construction binder compatibility.

3.3.2 Stage 2: Transport to Bio-concrete Manufacturing Facility

Transport of agricultural fibres to bio-concrete manufacturing facilities was logged using the same transport event workflow as the CDW use case, confirming the platform's cross-sector applicability with minimal configuration change.

Temperature and humidity monitoring data (where IoT sensors were available in transport vehicles) was optionally appended to transport records, as moisture content is a critical quality parameter for natural fibre-based construction materials.

1 cross-border transport event was logged, spanning an estimated distance of 450 km from Slovenia to the testing facility in Bavaria, Germany. Integrated sensors verified that the moisture content of the natural fibres remained safely below the critical 14% threshold during transit.

3.3.3 Stage 3: Bio-concrete Manufacturing and Quality Testing

At partner manufacturing facilities, agricultural fibres were processed into construction-grade bio-concrete products. The platform tracked the bio-concrete manufacturing workflow:

- Manufacturing batch records linked input fibre bale IDs to the production batch, documenting fibre-to-binder ratio, binder type (lime, natural pozzolana, or hybrid), mixing methodology, and curing conditions.
- Quality testing for bio-concrete products was recorded in the platform with reference to the test protocols established in D2.2.1, including density, compressive strength, thermal conductivity (lambda value), and fire reaction classification.
- Hempcrete panel production was tracked at the individual panel level using QR code labelling, enabling per-panel quality documentation and traceability for high-value components.
- Environmental performance data (estimated CO_2 sequestration from hemp cultivation, comparison with conventional insulation products) was incorporated into the DPP as a sustainability disclosure field.

Manufacturing operations produced 10 hempcrete insulation panels (approx. 15 kg each). Quality tests validated a high-efficiency thermal conductivity (lambda value) of 0.07 W/mK and a density of 400 kg/m^3, satisfying TRL6 requirements.

3.3.4 Stage 4: Construction Site Installation and Final DPP

Bio-concrete products were installed at the NIGRAD pilot site in Slovenia and at partner sites in Bavaria (TRL6 validation), completing the value chain from agricultural field to building component:

- Installation events were logged in the platform by construction contractors, capturing installation date, location within building (room, wall/roof designation), and responsible contractor.
- The final DPP for each installed product captured the complete value chain: agricultural origin, transport history, manufacturing parameters, quality test results, and installation location.
- QR codes on installed panels enable future building occupants, renovators, or end-of-life managers to access the complete material passport by scanning with a smartphone.

10 hempcrete panels were successfully installed at the designated pilot site in Bavaria, covering roughly 8 m^2 of wall surface. Post-installation IoT sensors for long-term moisture and thermal monitoring were activated.

4. System Architecture

4.1 Architectural Overview and Value Chain Mapping

The system architecture described in detail in D2.3.1 was applied to the two value chain use cases with specific configuration adjustments to accommodate the distinct operational contexts of CDW processing and agricultural bio-material supply. The four-tier architecture (Physical Interface Layer, Application Layer, Data Management Layer, Integration Layer) proved sufficiently flexible to support both use cases within the same platform instance, with role-based configuration governing which workflow modules were accessible to each stakeholder category.

Value chain mapping in the platform is implemented through the linked event architecture: each material unit's lifecycle is represented as a sequence of events (origin registration, transport, processing, quality assessment, manufacturing, installation), each of which is timestamped, geolocated, attributed to a responsible operator, and cryptographically signed into the material's DPP. This architecture enables reconstruction of the complete provenance chain from any point in the value chain in both forward (where did this material go?) and reverse (where did this material come from?) directions.

Table 4-1: Value Chain Stage to Platform Module Mapping

Value Chain Stage	Platform Module	Data Captured	DPP Update Triggered
Origin registration	Waste Production / Origin Event	Location, material type, EWC code, quantity, operator	Yes - initial DPP creation
Transport	Transport Event	Vehicle, departure/arrival, weight, GPS track	Yes - chain of custody append
Intake/Receiving	Intake Processing	Weight reconciliation, condition, storage location	Yes - status update
Processing / Manufacturing	Processing Event / Production Batch	Process parameters, input/output quantities, equipment	Yes - material transformation
Quality Assesment	Quality Testing Module	Test type, standard, results, laboratory, certificate	Yes - quality data append
Marketplace Listing	CinderOSS Integration	Availability, price, location, DPP link, contact	No (DPP already complete)
Installation	Installation Event	Building location, contractor, date, component designation	Yes - final DPP completion

4.2 Physical Interface and Data Capture

The physical-to-digital interface layer was the critical technical challenge for both use cases, requiring reliable identification technology in environments ranging from outdoor demolition sites to industrial processing facilities to agricultural storage barns.

- **RFID Tag Selection and Placement (CDW use case):** ISO 15693 HF RFID tags (standard 85.6mm x 54mm credit-card format) were used for concrete rubble batch tracking, applied with industrial-grade epoxy adhesive to concrete rubble containers and recycled aggregate storage bins. Tag performance was validated for read reliability at distances up to 15cm with handheld readers and up to 50cm with fixed portal readers installed at the processing facility entry and exit points.

- **RFID Tag Selection and Placement (Bio-concrete use case):** Encapsulated UHF RFID tags (ISO 18000-6C) were tested for fibre bale tracking, selected for their larger read range and resistance to the high-moisture environments of agricultural storage. A key technical challenge was maintaining tag readability after fibres were incorporated into concrete mix; encapsulated tags survived the mixing process in laboratory tests, though readability degraded and QR codes on finished panels were adopted as the primary identifier for installed products.

For the CDW use case, HID Global IN Tag HF tags (ISO 15693) and Zebra handheld readers were deployed, achieving a 98.5% read reliability rate at a 15-30 cm range despite industrial dust. For the bio-bales, Confidex Survivor encapsulated UHF tags (ISO 18000-6C) were utilised, maintaining a 94% read rate at distances up to 2 meters in high-moisture agricultural storage environments.

5. Integration with External Systems (BIM, Gaia-X, CinderOSS, Marketplaces)

5.1 CinderOSS Marketplace Integration

The ReBuilt digital value chain is deeply integrated with CinderOSS (cindeross.cinderela.eu), the One-Stop-Shop platform initially developed in the H2020 CINDERELA project (2018-2022) and further developed by Open Content (PP4) within the ReBuilt project. CinderOSS serves as the transnational digital marketplace enabling matches between material and waste producers and construction sector buyers across the Central European programme area.

The integration between the ReBuilt traceability platform and CinderOSS was implemented as a bi-directional REST API connection, enabling automated synchronisation of material availability listings from the ReBuilt product registry to the CinderOSS marketplace catalogue. This integration provides CinderOSS buyers with a significant advantage over conventional marketplace listings: every listed material is accompanied by a verifiable, cryptographically signed Digital Product Passport documenting its origin, processing history, and quality certification.

- **Automated Listing Synchronisation:** When a material batch in the ReBuilt platform achieves 'Available for Sale' status following quality certification, the CinderOSS integration module automatically generates a formatted listing in the CinderOSS catalogue, including material type, EWC classification, available quantity, quality parameters, location, minimum order quantity, and a direct link to the material's public DPP.
- **Circular Value Chain and Business Model Upload:** Beyond individual material listings, the documented value chain processes for both the modular concrete blocks and bio-concrete use cases were formatted as replicable business model templates and uploaded to the CinderOSS platform, enabling other Central European operators to adopt similar approaches.
- **Match Facilitation Workflow:** When a CinderOSS buyer expresses interest in a listed material, the platform routes the enquiry to the relevant NIGRAD or partner contact. Confirmed matches (minimum: buyer and seller have exchanged contact details and initiated commercial discussion) are logged in the platform as verified transactions.

8 distinct material listings were successfully published from the ReBuilt platform directly to the CinderOSS catalogue. These listings generated 4 unique buyer enquiries and resulted in 2 confirmed matches, progressing steadily toward the >=20 matches target by the end of the project.

5.2 Building Information Modelling (BIM) Integration

Digital Product Passports generated for both value chain use cases were tested for integration into BIM workflows, fulfilling the requirement of D2.3.1 for the specific material types addressed in D2.3.2. BIM integration is of particular relevance for the bio-concrete use case, as hempcrete panels and natural fibre concrete blocks are novel material types for which standardised BIM material libraries do not yet exist in major BIM authoring tools.

- **IFC Export for CDW Secondary Aggregates and Modular Blocks:** Processed secondary aggregate batches and finished modular concrete blocks were exported as IFC 2x3 and IFC 4 compliant datasets, with material properties (grain size distribution, compressive strength, density, EWC classification, and DPP URL) embedded in IfcPropertySets on the corresponding IfcBuildingElementProxy entities.
- **IFC Export for Bio-concrete Products:** Hempcrete panels and natural fibre concrete blocks were exported with extended property sets including thermal conductivity (lambda value), fire reaction classification, CO2 sequestration estimate, and agricultural origin data. These property sets were defined in consultation with CZGBC (PP13) to ensure compatibility with their BIM LogBook implementation.
- **Digital LogBook Integration (CZGBC, PP13):** The material DPPs generated for installed bio-concrete products were linked to the digital building LogBook implementation being developed by CZGBC, providing a proof-of-concept for how ReBuilt material traceability data can populate EU Digital Building Logbook records for future regulatory compliance.

IFC 2x3 and IFC 4 datasets were successfully exported and validated in Autodesk Revit 2024 and Graphisoft Archicad 27. Property mapping issues regarding EWC classifications and live DPP URLs were successfully resolved by binding them to custom **IfcPropertySets** without geometry loss.

5.3 Gaia-X Federated Infrastructure Integration

The digital value chain data generated in D2.3.2 forms the operational dataset that underlies the GAIA-X use case developed in D2.3.5. During Period 6, the GAIA-X integration work focused on establishing the federated identity infrastructure and executing DPP signing for full validation in this period.

- **DID Infrastructure Establishment:** The did:web Decentralised Identifier for the ReBuilt platform (did:web:rebuilt.infordata.eu) was established and validated for public resolution during Period 6, providing the trust anchor for all DPPs generated for the value chain use cases.
- **DPP Signing for Value Chain Materials:** Digital Product Passports generated for both use cases were signed using JsonWebSignature2020 from the initial registration phase, establishing a chain of signed evidence from material origin through all processing stages. This signing approach ensures that DPPs circulated on the CinderOSS marketplace and BIM platforms carry verifiable provenance guarantees.
- **GAIA-X Compliance Preparation:** The Gaia-X Participant Credential application process was advanced during Period 6 through the official Gaia-X onboarding wizard, with formal Participant Credential issuance completed concurrently and documented in D2.3.5.

6. Platform Functionalities

6.1 Material Traceability Workflows

The operational implementation of the material traceability workflows for both use cases built upon the platform functionalities documented in D2.3.1, with use-case-specific configuration and workflow adaptations introduced during Period 6:

- **Waste Type Configuration for CDW and Bio-materials:** The Waste Type Index was extended with specific entries for the CDW categories encountered at NIGRAD (reinforced concrete rubble, brick rubble, mixed CDW, secondary aggregate by grain class) and for the agricultural bio-materials in Use Case 2 (hemp hurds bales, miscanthus fibre, flax fibre, bio-concrete paste). EWC code mappings were configured for each waste type, with validation rules ensuring correct classification.
- **Production Batch Linking:** A key workflow addition for D2.3.2 was the implementation of the production batch record linking input waste/raw material records to output product records. This parent-child data relationship enables the platform to trace a finished modular concrete block or hempcrete panel back to the specific demolition rubble batch or agricultural fibre bale from which it was derived - the core value chain transparency claim of Activity 2.3.
- **Cross-sector Operator Interfaces:** Separate mobile application workflow configurations were deployed for agricultural operators (optimised for bale-level tracking with minimal form complexity) and for construction processors (detailed processing event forms with quality testing integration). Both configurations share the same underlying data model, ensuring compatibility without exposing unnecessary complexity to each user group.

During Period 6, the platform processed 2 material registration events, 2 transport events, 2 processing events, 2 quality assessments, and generated 10 unique Digital Product Passports (DPPs) across the two value chains.

6.2 Digital Product Passport Management

As materials progressed through the value chains documented in D2.3.2, the platform continuously aggregated data into growing Digital Product Passports. The DPP for a finished modular concrete block or bio-concrete panel generated through these value chains contains the following information architecture:

Table 6-1: DPP Data Structure for D2.3.2 Value Chain Materials

DPP Section	Data Fields	Source
Material Identity	Unique ID, material type, EWC classification, product name, quantity unit	Platform registration

DPP Section	Data Fields	Source
Geographic Provenance	Origin GPS coordinates, country, demolition site / farm name, urban/rural classification	RFID tag registration event
Material Composition	Primary material (CDW concrete or bio-fibre type), binder type, mix ratio, secondary components	Processing batch record
Processing History	Processing stages, equipment used, processing dates, facility name and location	Processing event records
Quality Certification	Test standard, test results (strength, granulometry, thermal performance), laboratory, certificate ID	Quality testing module + PDF upload
Environmental Data	Estimated CO2 vs. primary material, LCA reference (for bio-concrete), reuse factor	Activity 2.2 data + platform calculation
BIM Reference	IFC entity GUID, BIM project reference (if installed), digital logbook link	BIM integration module
Marketplace Status	CinderOSS listing ID, listing date, availability status, match history	CinderOSS integration
Cryptographic Proof	JsonWebSignature2020, signing key DID reference, signature timestamp, URDNA2015 canonicalisation	DPP signing engine (Gaia-X infrastructure)

Field data populated during this period includes the following structural examples:

- Example 1 (CDW): UID: REB-NIG-001; Product: Recycled concrete aggregate 0-22; EWC: 170101; Origin: NIGRAD Dogoše weighbridge (Net weight: 2,720 kg, Ticket: 26-002101).
- Example 2 (Bio-concrete): UID: REB-BIO-001; Material: Hempcrete Panel; Origin: Slovenian Farm; Biobased Input Weight: 15 kg; Lambda: 0.07 W/mK; CO2 Sequestration: -35 kg CO2e.

7. Challenges and Lessons Learned

7.1 Technical Implementation Challenges

- **Cross-sectoral Tracking System Configuration:** Implementing a single platform instance that satisfies the data capture requirements of both the CDW construction sector context and the agricultural bio-material supply context required significant configuration work. The EWC code taxonomy, while comprehensive for construction and demolition waste, required extension with agricultural by-product classifications not originally anticipated in the platform design. Additionally, the data entry form logic designed for construction operators (accustomed to batch-level records with precise quantities) required redesign for agricultural users, who operate at bale level with higher variability in individual unit weight and moisture content.

- **RFID Tag Durability in Concrete Processing:** The most significant technical challenge specific to the bio-concrete use case was maintaining RFID tag readability when agricultural fibres were incorporated into concrete mix batches. Standard ISO 15693 HF RFID tags failed to survive the high-shear mixing process in laboratory tests. Encapsulated UHF tags showed improved survivability but with reduced read reliability after curing. The practical solution adopted for Period 6 was a dual-identification approach: UHF RFID tags for fibre bale tracking prior to mixing, transitioning to QR code identification on finished panels post-curing. This approach maintains digital continuity through a software linkage between the input fibre record and the output panel record in the platform.

- **Data Model Integrity for Production Batch Linking:** Implementing the parent-child data relationship between input waste/raw material records and output product records exposed edge cases in the platform's data model not anticipated in D2.3.1's single-site tracking design. Specifically, processing events where a single input batch is split into multiple output batches of different grades (as occurs in CDW aggregate screening) required a one-to-many batch split architecture. This was implemented during Period 6 with corresponding DPP version branching to maintain accurate provenance for each output batch.

A key technical challenge was standardising bulk aggregate entries into the CinderOSS API. Because bulk materials lack standard geometric dimensions, the platform parsing logic was adapted to utilize 'width' and 'height' fields to capture the nominal maximum fraction sizes (e.g., 22mm, 63mm) mapped to a fixed 1,000 kg functional reference unit.

7.2 Operational and User Adoption Challenges

- **Agricultural Operator Engagement:** Agricultural producers have limited prior exposure to digital material tracking systems and were generally motivated by environmental certification and market access benefits rather than by intrinsic interest in data management. The onboarding process required simplification of the mobile application workflow to the absolute minimum viable steps (scan tag, confirm bale weight, submit) to achieve field adoption. Dedicated on-site training sessions delivered in local languages by partner organisations were more effective than remote digital onboarding.

- **Quantity Estimation Inconsistencies at Origin:** Both use cases encountered the common challenge of imprecise quantity estimation at the point of initial material tagging. CDW demolition operators typically estimate concrete volumes visually rather than by weighing, leading to systematic underestimation that required correction at weighbridge intake. Agricultural fibre bale weights vary by 10-25% depending on moisture content and baling pressure. The platform was updated with explicit quantity verification steps at intake and processing stages, and DPPs were configured to display both estimated origin quantities and verified processed quantities with explicit source attribution.

- **Coordination Across Value Chain Nodes:** The multi-stakeholder nature of both value chains - spanning agricultural producers, transport operators, processors, quality laboratories, and construction companies in multiple countries - created coordination overhead that a single-organisation deployment would not face. Agreed data handover protocols between value chain nodes were documented and shared with all participants, specifying the minimum data required from each party before the next stage of tracking could proceed. This formalisation of data responsibilities was essential for maintaining DPP completeness across the full chain.

Field operators found it time-consuming to manually type repetitive European Waste Codes (EWC) and fractional granular data on mobile devices. The resolution involved utilizing a Platform-assisted data entry approach (Option B), where raw bulk CSV data and weighbridge tickets were centrally injected into the platform backend, circumventing the field data-entry bottleneck. (Added to "Quantity Estimation Inconsistencies at Origin" paragraph): The platform was updated with explicit quantity verification steps at intake and processing stages, and DPPs were configured to display both estimated origin quantities and verified processed quantities with explicit source attribution.

8. Conclusions and Next Steps

8.1 Summary of Value Chain Achievements

Deliverable 2.3.2 successfully demonstrates the operability of a fully digitalised value chain and business ecosystem for circular construction across two distinct material pathways. By tracing both modular concrete blocks (from CDW demolition origin through processing and production) and bio-concrete products (from agricultural by-product origin through manufacturing to building installation), the platform validates the feasibility of cross-sector and cross-border digital material traceability in the Central European context.

The key achievements of the Period 6 value chain implementation are:

- End-to-end digital traceability demonstrated for both CDW and bio-material value chains, from primary origin to construction site installation.
- Dual-identification solution (RFID plus QR code) proven for maintaining digital continuity through the challenging processing step of concrete mixing.
- Production batch linking architecture implemented, enabling verifiable provenance tracing from a finished construction product back to its specific waste or bio-material origin.
- CinderOSS marketplace integration operational, with verified material listings accompanied by DPP links enabling buyers to access authenticated quality documentation before purchase.
- BIM interoperability confirmed for both conventional secondary aggregate materials and novel bio-concrete product types, extending IFC property sets to cover bio-material-specific properties.
- GAIA-X DID infrastructure established and DPP signing operational, providing the trust foundation for the full Gaia-X use case documented in D2.3.5.
- Rural-urban supply chain integration achieved: the bio-concrete use case successfully connects agricultural sector operators with construction product manufacturers through a shared digital platform for the first time in the programme area.

8.2 Contribution to ReBuilt Objectives

Deliverable 2.3.2 directly contributes to the following ReBuilt project outputs and objectives:

Table 8-1: D2.3.2 Contribution to ReBuilt Project Outputs

Output	Output Title	Contribution from D2.3.2
O2.2	Circular construction digital pilots	Operational digital pilot for two material value chains at NIGRAD and partner sites

Output	Output Title	Contribution from D2.3.2
O2.4	Digital solutions for circular construction	Validated digital value chain solution ready for SaaS deployment through Hubs
O3.3	Regional Circular and Digital Construction Hubs	Provides replicable value chain model and business ecosystem template for Hub operators
O2.3	Circular construction products	Digital DPP and quality documentation for CDW-derived and bio-concrete products produced in Activity 2.2

The deliverable directly contributes to Output 2.4 (Digital solutions for circular construction) by establishing the operational data pathways required for the project. It bridges the gap between physical material recovery and digital procurement, increasing transparency and trust in secondary raw materials. The bio-concrete use case further supports the project's cross-sectoral objectives by demonstrating that digital circular economy infrastructure can connect traditionally siloed sectors - agriculture and construction - into a coherent material flow ecosystem.

8.3 Next Steps and Recommendations

8.3.1 Immediate Next Steps (M31-M36)

- **D2.3.3 Marketplace Operationalisation:** The value chain data and CinderOSS integration validated in D2.3.2 forms the active material inventory for the full marketplace deployment documented in D2.3.3, targeting at least 20 confirmed matches between material producers and buyers by Period 6 end.
- **D2.3.5 GAIA-X Credential Completion:** The DID infrastructure and DPP signing approach established in D2.3.2 will be extended to full Gaia-X Participant Credential status and independent third-party DPP verification in Period 6.
- **Value Chain Expansion: Based on operational learnings, onboard additional material streams and agricultural partners to the bio-concrete value chain, and extend the modular concrete block use case to include reinforced concrete deconstruction scenarios not fully addressed in the initial validation runs.**

Month 31: Onboard two additional agricultural partners to scale bio-concrete material supply (including flax tracking).

Month 32: Expand the CDW tracking workflow to include wood waste streams (EWC 170201).

Month 33: Fully link multi-output CDW processing workflows (e.g., separating reinforcement steel from concrete).

8.3.2 Medium and Long-term Scaling

- **SaaS Deployment via Regional Hubs:** The value chain configurations developed in D2.3.2 (CDW tracking workflow, bio-material agricultural interface, production batch linking, DPP templates) will be packaged as replicable modules offered as part of the SaaS deployment through the network of Regional Circular and Digital Construction Hubs (Output 3.3), enabling partner regions across Central Europe to adopt comparable value chain digitalisation without requiring custom development.

- **EU Digital Product Passport Regulatory Alignment:** The DPP data models developed for modular concrete blocks and bio-concrete products will be reviewed and updated to align with the final sector-specific implementing acts under the EU Ecodesign for Sustainable Products Regulation (ESPR) as they are adopted for construction materials.
- **Cross-border Value Chain Extension:** The rural-urban supply chain model demonstrated in the bio-concrete use case should be extended to cross-border supply chains, connecting agricultural producers in one partner country with construction manufacturers in another. The Gaia-X federated infrastructure established in Activity 2.3 provides the data sovereignty framework for such cross-border exchanges.

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List of Acronyms

Acronym	Full Term	Context
BIM	Building Information Modelling	Digital 3D model-based process for construction
CDW	Construction and Demolition Waste	Waste generated by construction/demolition activities
DID	Decentralised Identifier	W3C standard for verifiable digital identity
DPP	Digital Product Passport	Digital record of a product's lifecycle and material data
ERDF	European Regional Development Fund	EU fund co-financing the Interreg programme
EWC	European Waste Catalogue	EU standard waste classification system (2002/532/EC)
GAIA-X	European federated data infrastructure	EU initiative for data sovereignty in digital services
IFC	Industry Foundation Classes	Open BIM data exchange standard (ISO 16739)
NFC	Near Field Communication	Short-range wireless communication (ISO 14443)
NIGRAD	Nigrad komunalno podjetje d.o.o.	PP3 - demonstration centre operator, Maribor, SI
RFID	Radio Frequency Identification	Wireless material tracking technology
SaaS	Software as a Service	Cloud-based software delivery model
SRM	Secondary Raw Material	Material recovered and processed from waste streams
TRL	Technology Readiness Level	EU standard scale for technology maturity (1-9)
WPI	Waste Production Item	Individual material item within a waste production batch