Enabling Circular Construction: Evaluating ICDD for Effective Deconstruction Processes

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Abstract: The construction industry faces significant challenges related to information loss, from pre-production, assembly and operation through to eventual deconstruction. Furthermore, the urgent need to decarbonise the construction sector demands the reuse of building materials. The use of existing building materials as secondary resources can make a significant contribution to sustainability goals. However, many deconstruction and material reuse initiatives are hindered by insufficient information available from the planning, manufacturing, and operational phases. In response to these challenges and aiming to maximise material reusability, this paper evaluates the Information Container for Linked Document Delivery (ICDD) as a long-term data storage solution for supporting circular construction practices. The study investigates how ICDD can mitigate information loss during transitions from pre-production, on-site assembly, and operation to deconstruction by archiving relevant deconstruction information. It identifies key deconstruction data requirements and information preservation standards. The application of the ICDD framework is demonstrated through a case study on the deconstruction of an assembled steel girder.

Keywords: ICDD, Circular Construction, Linked Data, Information Continuity, Material Reusability

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1 Introduction

The construction industry is characterised by numerous stakeholders and complex projects [1], leading to significant challenges in achieving interoperability among diverse data sources and in linking various process information to the same element. At the same time, there is an increasing demand for material reuse to mitigate rising CO^2 emissions, landfill usage, and material shortages [1], as the construction industry is contributing 5-12 % of the greenhouse gas emissions [2]. Construction materials are typically designed for a lifespan of 50-100 years [3]; nevertheless, they are frequently demolished prematurely. This premature demolition highlights the potential for reusing these materials, thereby addressing challenges related to sustainability and resource efficiency. However, current deconstruction and material reuse efforts often fail due to insufficient information from the planning, manufacturing, and operation phases [4]. In this context, Linked Data provides a robust framework for creating a more connected, accessible and interoperable data environment [5]. Concurrently, the integration and application of Linked Data in construction, as Linked Building Data (LBD) is on the rise. In accordance to these concepts the Information Container for Linked Document Delivery (ICDD) was developed and defined in the DIN EN ISO 21597 [6], [7] to overcome the limitations of existing frameworks for exchanging diverse and distributed building data [8]. This paper assesses the ICDD as a persistent data storage solution for enabling circular construction. It evaluates whether the industry's challenges of information loss from pre-production and on-site assembly to the deconstruction phase can be addressed by archiving all deconstruction-relevant information within the ICDD to support deconstruction processes.

2 State of the Art

2.1 Circular Construction

The demand for circular construction has increased in recent years, aiming to transform materials and components from having an 'end-of-life' to being reused, recycled, or recovered [9]. Benefits of circular construction include waste minimisation, cost efficiency, reduced energy requirements, and lower emissions. However, barriers to its implementation exist, categorised into economic, sociological, environmental, technical, organisational, and political challenges [10]. Transitioning to circularity requires changes in the value chain, early design for disassembly, and recognising waste as a resource, with data availability being crucial for informed decision-making across the life cycle and among stakeholders [4]. Various tools like Life Cycle Assessment (LCA), Energy Certificates, Material Flow Analysis (MFA), and Material Passports (MP) support data-based sustainable construction [11]. Recent studies focus on integrating MP into Building Information Modelling (BIM) to manage building materials throughout their life cycle [12]. Other emphasise the relevance of a total view of the life cycle process (TLCP) of a building. The use of database-based information models (DIM) and the standardised description of the information requirements of the various phases on the basis of the Level of Information Need (LOIN) for the structured recording, exchange and management of project-relevant information is recommended [13]. However, a more holistic approach to storing information about building elements beyond material properties and Information Delivery Manual are essential to address existing challenges in the deconstruction process.

2.2 Semantic Web and Linked Data

The concept of Linked Data originates from the World Wide Web, invented by Tim Berners-Lee and Robert Cailliau at CERN in 1990 [14]. Initially, the web aimed to enhance data exchange among scientists and facilitate the referencing of information regardless of location. Berners-Lee emphasised the need to address distributed information, incompatible file formats, and evolving information requirements [15], leading to the development of the Semantic Web and Linked Data. These principles are highly relevant for the construction industry, characterised by separate systems, multiple stakeholders, and continuous changes. Linked Data can facilitate seamless information exchange, enabling stakeholders to maintain their formats and systems while accessing linked information and referring to the same construction element.

A key component of leveraging Linked Data in construction is the use of ontologies and the standardised description of elements and processes. Ontologies, as formal representations of concepts, their relationships, and attributes [16], are crucial for creating consistent descriptions of construction elements and processes. Recently, developing ontologies for specific domain structures has become increasingly common, particularly in construction, where they address project complexities and enhance interoperability across systems and stakeholders [17].

2.3 Collaboration and Storage - ICDD

Currently, Building Information Modelling (BIM) establishes common definitions for construction elements and processes and serves as the leading digital tool for information sharing in the construction industry. While current research focuses on BIM-based information management during the design phase, applying these practices to the construction and maintenance phases can significantly enhance information flow, efficiency, and reusability in circular construction [18]. However, to fully leverage digital tools in the construction industry, it is essential to go beyond BIM by incorporating Linked Data principles. The biggest challenges are the vendor-neutral exchange of heterogeneous, distributed building data as well as the long-term storage and access to the data. The Information Container for Linked Document Delivery (ICDD) was released in 2020 to provide a standardised format for exchanging and sharing of construction-related documents and data. The ISO 21597 provides an open and structured container format for different types of shared information, such as building models, documents and other relevant data and most important, their relationship [6], [7]. In order to guarantee conformity to the container schema and the links between the files within the ICDD, recent research has concentrated on semantic rule checking using Shapes Constraint Language (SHACL) [19]. Moreover, the utilisation of the ICDD can be evidenced as an effective deployment of an exchange platform for diverse stakeholder activites pertaining to asset management during the operational phase [20]. The chapter 3.4 examines the various components of the ICDD structure with regard to the possibility of using the containers as persistent storage of construction data for deconstruction and ensuring access to the data.

3 Linked Data for Circular Construction

3.1 Methodology

This paper evaluates the ICDD as a data storage solution for circular construction by assessing its ability to address knowledge loss in transitions from pre-production, assembly and operation to deconstruction. It focuses on deconstruction data requirements and the information preservation standard, demonstrated through a case study on steel girder deconstruction.

3.2 Construction Requirements

The construction industry is characterised by multiple stakeholders, each with their proprietary systems, and long-lasting project durations encompassing planning, pre-fabrication, on-site assembly, operation, maintenance, and eventual deconstruction. In all phases a variety of data that is produced, requested and enriched throughout the lifecycle of a building. Standardised structuring, effective management and linking of this data is critical to optimising processes and ensuring sustainability. For the planning phase of the deconstruction process, it is of great benefit to categorise the required data according to the specific requirements of different deconstruction activities. Consistent pre-structuring and linking of data will ensure that all necessary information is systematically organised and readily accessible to support efficient and effective deconstruction efforts. Key categories of data required may include:

Table 1: Required data at deconstruction stage

Category	**Data and Usage**
Planning and Design	Material, Structural and Design Data
Carbon Footprint Assessment	Location of Both Sites and Transport Emissions
Testing and Validation	Type and Result of Material Testing
(Robotic) Deconstruction Process	Installation Location, Weight, Size, Assembly Data
Authorisations and Legal Requirements	Deconstruction Authorisations and Legal Documents
Logistics	Assembly, Weight, Structural Data and Transport Data
Time Plan	Detailed Schedule and Structured Workflow with Responsibilities
Technical Equipment	Availability of Necessary Machinery and Equipment
Administration	Responsibility and Contact Data

3.3 Requirements for the Implementation of Information Preservation Standards

Implementing information preservation standards in construction requires a comprehensive approach with the following key requirements:

- Standardised data structure to ensure completeness of required data at deconstruction phase
- Enable proprietary systems but linked data of individual stakeholder at construction project
- Enable the addition of information throughout the lifecycle of the structure
- Enable collaboration during planning, construction and deconstruction phase
- Ensure comprehension of data
- Ensure data availability in 30-50 years
- Overcome current boundaries of data ownership and authorisation

3.4 Application ICDD as Data Storage

The following section evaluates the application of the ICDD as a data storage solution for enabling deconstruction, specifically addressing the key requirements outlined in 3.3. Triple stores as the central data storage facilitate data access and specific querying for information during the construction project. However, it is also crucial to not only have structured individual data, but also to link different documents within a construction project. The ICDD offers a solution for creating these document links. The container comprises three components: an ontology folder containing the file schema, a linkset folder with the links, and a payloads folder containing the documents [6], [7]. Proposing the ICDD for data storage to enable circular construction may extend its use beyond merely publishing the ICDD in the Common Data Environment (CDE) as a virtual repository for collecting and managing construction projects. The concept would follow this procedure:

- **Ensure Completeness of Index File:** It covers the completeness and unique identification of meta-information of the file, e.g. which project information are contained
- **Ensuring Completeness of Ontology Folder:** It covers the structure of the construction and collaboration data of the project, so users (machine and human) can interpret the data at a later point, e.g. using the *dstv* ontology to explain how fabrication data for steel elements is modelled
- **Ensuring Completeness of Linkset Folder:** It includes the consistent and complete link of documents, e.g. link of fabrication data and onsite assembly documentation data
- **Ensuring Holistic Data in Payloads Folder:** It includes all the relevant data and files itself, e.g. the architectural model, delivery notes, quality documents, etc.
- **Exporting ICDD at Point in Time:** Once it is ensured that all relevant data and files are stored within the container, it can be exported as a *Zip file at a specified time, e.g. when the building is handed over to the client
- **Save ICDD File:** The file must be stored in a location that ensures long-term access and availability. Since the container includes all relevant information, incompleteness is not an issue. However, challenges remain regarding storage locations, such as local versus cloud servers (including copies), as well as data ownership and authorisation.

3.5 Use Case

Referring to Table 1 and the proposed ICDD procedure, the following use case demonstrates the theoretical application of ICDD as a data repository for the deconstruction of an assembled steel girder (see Figure 1).

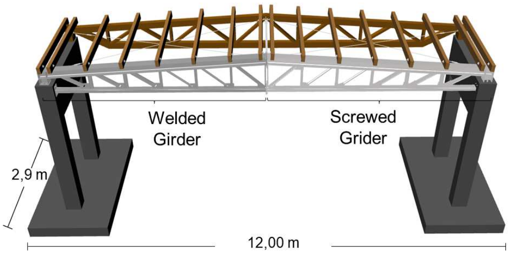

Figure 1: Assembled steel girder, Reference to IoC demonstator [21]

Within Linked Data, ontologies ensure a standardised data structure tailored to each specific domain. For construction, and specifically the reuse of a steel girder, initial approaches for an ontology in steel construction have been developed [22]. This allows for the storage and linking of domain-specific information, such as holistic and unified manufacturing details (e.g. the diameter or position of a hole) and process feedback (e.g. the machine used and time of manufacture). Defining a Uniform Resource Identifier (URI) at the project's outset ensures that all information added by different stakeholders, using their specific software, links to the same element. This unique connection and collaboration are maintained throughout the life cycle, whether in manufacturing, logistics, or on-site assembly.

For evaluating the theoretical application of ICDD as a data repository, it is assumed that the steel girder will be robotically deconstructed following its initial use in a building. The deconstruction process necessitates several essential pieces of information: the girder's location within the building for accurate robot positioning, the weight of the girder to ensure machine capacity and availability, detailed specifications for effective gripper placement, and the type of connections and assembly details to enable the robot to disassemble the components accurately.

One of the key advantages of Linked Data is that it is both human-readable and machine-readable. This requires that information is explicitly defined to cater to different uses and interpretations. For example, while a human can intuitively understand that a part of the steel beam is screwed and thus easier to dismantle, a robot requires this information to be clearly encoded to interpret and execute the task effectively.

Referring to the ICDD, all required information for the deconstruction process should be contained in the *Zip file. In this case, the ontology folder contains the *dstv* ontology, which maps the fabrication processes in steel construction. The robot can retrieve information about the different elements, their connections, and assembly details to disconnect the screwed parts. From the payloads folder, the robot can determine the screws' locations and the force with which they are tightened, enabling it to separate the elements. The linkset folder integrates two distinct documents—fabrication information, which specifies the placement of the threaded hole on the beam, and on-site assembly documentation, which records the final position and force used to tighten the screws—facilitating the deconstruction process.

4 Results and Outlook

The paper introduced an approach utilising Linked Data concepts and ICDD as storage for preserving information, enabling deconstruction processes and Circular Construction. As demonstrated in 3.5, the structured ICDD and Linked Data can address the necessary information outlined in 3.2, providing a comprehensive database for accessing relevant data. However, further research is required to validate the approach and apply it to real-world scenarios. One significant challenge arises when utilising the ICDD file exported at a single point in time, particularly in managing information related to building operation and maintenance. This challenge encompasses determining how to add new data to the container and ensuring the completeness of information, along with addressing issues of data ownership, responsibility, and access authority.

The current methodology primarily focuses on newly constructed buildings for information preservation, overlooking challenges related to accessing information from existing structures for secondary material resources. Solutions can be drawn from recent research on data preservation, maintenance, and digitisation of built cultural heritage [23]. Like built cultural heritage, construction projects face challenges of heterogeneous data, diverse domain experts, and standards. Storing 3D point cloud data representing the built environment and linking it to new data for deconstruction processes can address this challenge.

Linked Data enables collaboration, information querying, process optimisation, and preserves process and project knowledge, benefiting future projects by promoting the reuse of processes and information across similar endeavors. This approach ensures that construction projects are not seen as singular efforts but as part of a continuum, enhancing efficiency and continuity. Moreover, this approach is applicable beyond steel construction and can be extended to various construction processes and projects, including concrete and timber production, infrastructure, and special engineering projects.

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