# Defining a Workflow For Semantic Enhancement of Cultural Heritage Metadata

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### Abstract
This paper introduces a workflow for the semantic enhancement of Cultural Heritage metadata, focusing on the conversion of tabular data into Resource Description Framework (RDF) serialisations. The literature review presents the landscape of approaches and motivates the choice of Morph-KGC, an RML-based engine. The iterative approach defining the workflow is introduced in the methodology and further contextualised through the case studies, which helped identify the major procedural pitfalls. The entire workflow is presented as a research result, delving into the technical details of the developed Morph-KGC extension based on Chad-AP (Morph-KGChad). Future works include finalising the development of Chad-Ask to formalise domain knowledge through questionnaires and adapting the orchestrating tool MITAO to define reproducible visual workflows embedding automatic operations.

### Keywords
Semantic Web, Cultural Heritage Metadata, Morph-KGC, RDF Mapping Language, Workflow



## 1. Introduction

In the Humanities domain, the concept of data can assume several nuances, as it is naturally rich in unstructured and semi-structured information [1]. Preserving domain-specific content can prevent proper data formalisation when informative richness is prioritised over machine-readability. Nonetheless, data structuring practices increase opportunities for data integration and discovery. In detail, the adoption of Open Science approaches in the Galleries, Libraries, Archives and Museums (GLAM) domain boosts transparency and reinforces data and pipeline trustworthiness through seeking Findability, Accessibility, Interoperability and Reusability (FAIRness) [2, 3]. The procedure requires knowledge of standards and good practices, and relevant outcomes depend on the shared understanding of the advantages resulting from the effort.

This paper introduces a research workflow for structuring GLAM and Cultural Heritage (CH) knowledge [4], converting tabular spreadsheets into Linked Data [5] by adopting Resource Description Framework (RDF) serialisations [6, 7]. The target format allows for representing the semantics embedded in the data by expressing relationships among the entities in the shape of triples involving a subject and an object, connected by a predicate. This enables leveraging Semantic Web Technologies [8] on CH data, including SPARQL query functionality[1].

## 2. Context And Research Questions

The variety in CH data results in a multitude of data models. Attempts at reconciliation are performed through metadata crosswalks, *i.e.*, procedures for converting data from one formalisation model to another without losing informative content. The ideal goal of addressing any-to-any crosswalks is limited in this paper to the scope of tabular-to-RDF conversions. While the target format was selected

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[1]https://www.w3.org/TR/sparql11-query/

to maximise the data reuse potential, the input was chosen for its widespread adoption among CH non-technical users. The aims of the research include extending existing technologies for CSV to RDF crosswalks, defining a FAIR executable workflow, and integrating open-source tools to enhance RDF data access. The research questions to be addressed are:

1. Which gaps prevent conversion pipelines from being accessible to non-technical users?
2. What are the workflow core steps, and which are the best tools to perform them?
3. Is the workflow effective in different case studies?

## 3. Literature Review

In recent decades, the task of formalising CH tabular data into RDF has been addressed with several approaches. Building on previous reviews of conversion engines [9, 10], and analyses of good practices [11], a survey was performed on the state of the art [12]. The scope was then extended to full methodologies for addressing this task in Humanities projects. Among these, the methodology proposed by Stolpe and Skjæveland [13] and tested on the Yellow List used bounded RDF homomorphism to preserve data integrity. The same purpose was pursued in the conversion of the Amsterdam Museum metadata [14], defining a methodology based on RDF/XML, leveraging the Amalgame tool for the alignment[2], and the ClioPatria[3] semantic server for the interactive conversion process. Sande *et al.* [15] proposed a lightweight semi-automatic learning loop based on string and lexical matching, exploiting an algorithm to find relations between columns by deriving information from lexicons and thesauri. The human-in-the-loop approach [16] was adopted in a methodology [17] based on a simple mapping language and RDB2RDF[4], envisioning an incremental development relying on community revision for data publication through a semantic wiki[5].

Another conversion pipeline was tested on the Norwegian Petroleum Directorate FactPages[6] through user-provided questions translated into SPARQL and SQL queries. The methodology aimed to define an OWL ontology[7] from a tabular dataset, passing through relational databases and RDF, by leveraging D2RQ[8] [9]. Readopting state-of-the-art approaches, CIDOC-CRM[9] and R2RML[10] were used in combination in a case study concerning Egyptian museums [18], while, the X3ML framework and its toolkit by FORTH-ICS introduced a declarative language for collaborative semantic mapping to CIDOC-CRM, dividing semantic formalisation activities, assigned to domain experts, from the technical aspects, such as URI transformation and generation [19]. When it comes to complex GLAM datasets, approaches supporting broader control are preferred to semi-automatic alternatives such as the Direct Mapping of Relational Data to RDF[11]. To guarantee more control over complex conversion procedures, solutions allowing for the incorporation of functions into mapping languages were proposed, such as FunUL [20] and the RDF Mapping Language (RML) [21]. Among the engines developed to implement RML-based conversions, the Python-based Morph-KGC [22] stands out for easy extensibility, a lively community, up-to-date maintenance, and support tools for YARRRML mapping rules definition [23], such as Matey[12]. These more human-readable approaches facilitate communication in multidisciplinary teams.

[2] https://github.com/jrvosse/amalgame
[3] https://cliopatria.swi-prolog.org/home
[4] https://www.w3.org/2001/sw/rdb2rdf/
[5] https://en.wikipedia.org/wiki/Semantic_wiki
[6] https://factpages.sodir.no/
[7] https://www.w3.org/TR/owl-features/
[8] http://d2rq.org/
[9] https://cidoc-crm.org
[10] https://www.w3.org/TR/r2rml/
[11] https://www.w3.org/TR/rdb-direct-mapping/
[12] https://rml.io/yarrrml/matey/

## 4. Methodology

The definition of the workflow started from a literature review and followed an iterative approach, allowing for refinement through its application in the case studies. RML was selected as the core technology, and Morph-KGC as the software engine to perform CSV to RDF conversions. From this central step, it was possible to laterally expand the workflow with preliminary and finalisation phases. The initial steps were dedicated to establishing good practices agreed upon among domain experts and digital humanists. Among the measures were included the adoption of good practices for separators selection in multi-value fields, consistent naming conventions, controlled vocabularies, and persistent identifiers (*e.g.*, VIAF, ORCID, Wikidata IDs). For data collection, real-time multi-user services providing functionalities for data entry guidance were adopted, such as Google Sheets[13]. Within the framework of the National Recovery and Resilience Plan Extended Partnership 5 (CHANGES), Spoke 4, Morph-KGC Python software was extended and published under the ISC license[14] as Morph-KGChad[15]: a ready-to-use tool for semi-automatic conversion of GLAM metadata collected using template spreadsheets [24]. The extension included mapping files, a launch script, and user-defined functions developed using RML-FNML [25]. The data model adopted for the RDF conversion was Chad-AP [26], an Application Profile based on CIDOC-CRM. The case studies allowed for the identification of gaps in the procedure and iterative refinement of the workflow through output data analysis and feedback from domain experts. To enhance RDF data reuse and exploitation by non-technical users, the Sampo [27] web framework of semantically interconnected platforms was identified as a suitable option for graph dissemination. To improve the workflow FAIRness, the Protocols[16] tool was chosen as it is free, provides a versioning system, and allows for the implementation of actionable steps to facilitate the reproduction of the pipeline. A supplementary phase of the methodology for the workflow development – currently ongoing – envisions the future developments implementation.

## 5. Case Studies

Within the CHANGES framework, the first case study concerned the metadata management of the digital twin of the temporary exhibition *The Other Renaissance – Ulisse Aldrovandi and the Wonders of the World* [28, 29, 30, 31]. In this context, general tabular templates for GLAM collections metadata and digitisation process paradata were defined[17]. Contextually, Morph-KGC codebase was extended, developing Morph-KGChad. The procedure was tested on real data, producing the graph Chad-KG [32, 26]. The refined pipeline was readopted on the digitisation of the Giovanni Cappellini Geological Museum's collections. Inconsistencies in the tabular templates were identified, and a polished second version of these was published. Additionally, the nature of the collections motivated the introduction of some new domain-specific metadata fields, as they were estimated to be general enough to be potentially relevant for describing other scientific GLAM collections.

The complete CHANGES Spoke 4 FAIR digitisation pipeline [30, 33] is depicted in Figure 1. Yellow steps concern metadata management, from data collection and analysis to publication, through simplification of value categories, negotiation of controlled sets of values, data cleaning and enrichment, CSV export, and RDF conversion. Once the graph is published and made available through a SPARQL endpoint, MELODY [34] is adopted for semi-automatic RDF data visualisation and storytelling, and HERITRACE [35] for tracking metadata provenance and changes.

The Digital Damaged Ceramics project [12] disseminates data about bombed ceramics collections. After defining data normalisation procedures, the restoration field-specific data were presented through web interactive data visualisations. As for the general GLAM metadata management, the CHANGES digitisation workflow was readopted.

[13] https://workspace.google.com/products/sheets/
[14] https://choosealicense.com/licenses/isc/
[15] https://github.com/dharc-org/morph-kgc-changes-metadata
[16] https://www.protocols.io/
[17] https://zenodo.org/records/14277220

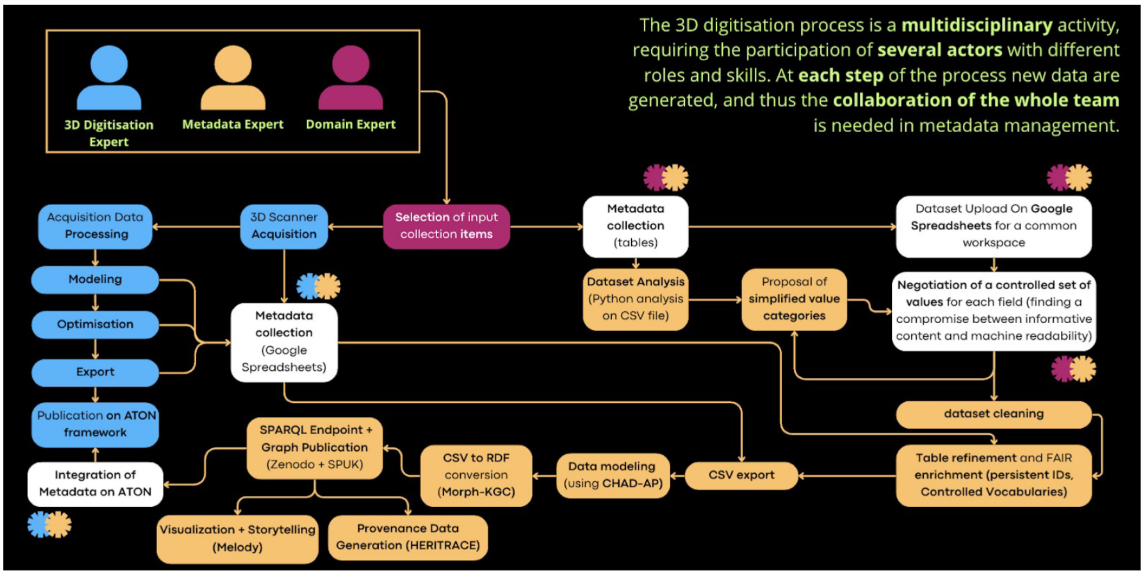


**Figure 1:** Interdisciplinary workflow for the metadata management of a digitised collection.

The project is available online on a dedicated platform including data visualisations, catalogues, tabular and RDF datasets[18], a SPARQL query interface, documentation, data collection templates, and 3D models[19]. The project brought up a gap in Chad-AP (version 2.0.4) and Morph-KGChad concerning the description of the artefacts' material, and allowed for iterative research refinement. Since modelling information about manufacturing materials was crucial in the analysis of damage, an operative extension of Morph-KGChad software made the RDF graph materialisation possible, using the CIDOC-CRM property "crm:P45_consists_of" to link objects, "lrmoo:F5_Item", to their materials, expressed as instances of "crm:E57_Material". Further, having been recognized as a sufficiently general descriptive necessity in the CH field, feedback was provided about the encountered gap, to suggest an official extension of the application profile, to make the CHANGES workflow more robust. In this case study, a hybrid methodology was tested (Figure 2), proving both the convenience of readopting CHANGES approach for general GLAM metadata management and the ease of integrating it with other tools to address the dissemination of domain-specific data.

The last case study focuses on the production of a polished dataset of Early Modern publications from the Bibliothèque Nationale de France (BnF) SPARQL endpoint[20]. Collected in tabular format, the data were manually and computationally analysed, and enriched with persistent identifiers, to implement a mapping with the English Short Title Catalogue[21], relying on date comparison and string matching. This project led to a deeper reflection upon data dissemination, highlighting the necessity to include in the workflow technologies allowing non-technical users to navigate Linked Data. The development of a SAMPO portal was planned, and it is ongoing at the time of writing.

## 6. Results

A workflow blueprint was developed to formalise semi-structured CH data from tabular format to RDF and enrich it using Semantic Web Technologies, with its technical core on the Morph-KGChad software extension.

The workflow was tested in several contexts. In the CHANGES framework, the case study about the Aldrovandi temporary exhibition allowed templates to be defined and the pipeline to be validated on

[18]https://zenodo.org/records/15854369
[19]https://bombedceramics.github.io/digital_damaged_ceramics
[20]https://data.bnf.fr/sparql/
[21]https://www.cerl.org/services/estc

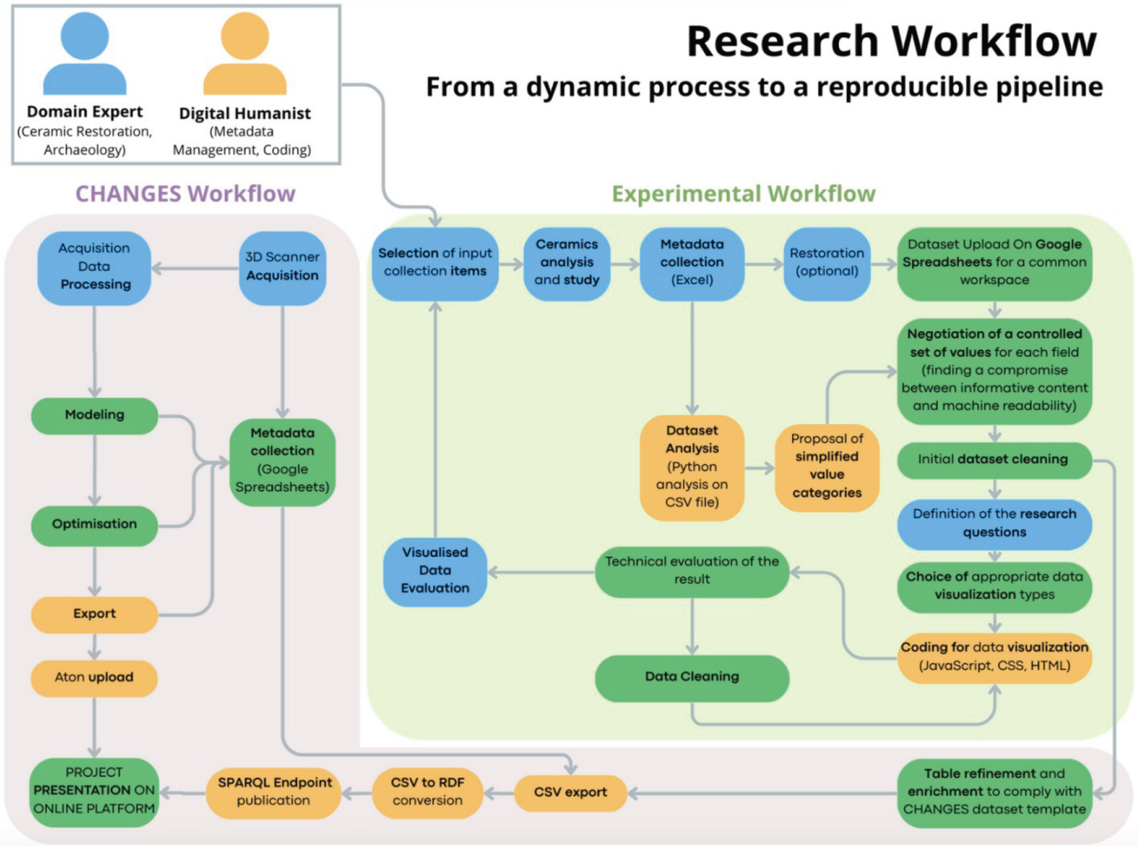


**Figure 2:** CHANGES workflow extended with an experimental component for the Digital Damaged Ceramics project. The original workflow provides reusable steps (data collection, general value normalization, CSV export, CSV-RDF conversion, publication via SPARQL endpoint), while the case study adds domain-specific activities (expert analysis, interdisciplinary value negotiation, and iterative dataset cleaning) without invasive changes to the core.

real data. The subsequent digitisation of the Cappellini Geological Museum led to the identification of inconsistencies, and thus to the refinement of data collection templates and conversion software. Furthermore, the Digital Damaged Ceramics project motivated a pipeline extension to meet domain-specific requirements, such as the semantic representation of the objects' materiality, use of specific controlled vocabularies, and templates' structural adaptations.

In terms of output and performance, testing the process on the Aldrovandi dataset, consisting of two tables (267 and 270 rows), the conversion generated 18,800 IRIs, with an overall materialisation time of 19.70 s per 1,000 rows and a memory usage peak of 297.03 MB. To support dissemination and trustworthiness, the resulting RDF graph was published as a dataset[22] and made available to be queried via a SPARQL endpoint[23]. The same approach was re-adopted to generate the graph for the Digital Damaged Ceramics collection. In this latter case, to facilitate data dissemination to non-technical users, a minimum set of pre-compiled SPARQL queries was provided on the website platform, enabling exploration and analysis without requiring semantic web skills.

## 7. Limitations and Future Works

At the time of writing, the Protocols workflow is not publicly available, causing limitations in reproducibility and trustworthiness. In the workflow execution, complexities emerged in domain-specific knowledge formalisation among domain experts and digital humanists. Thus, the Chad-Ask tool is

[22] https://zenodo.org/records/18190607
[23] https://chad-kg.duckdns.org/chadkg/sparql

being finalised to exploit structured output files of LimeSurvey questionnaires to derive mapping rules and semi-automatically extend the Morph-KGChad codebase. In conclusion, an orchestrating tool will be integrated to manage connections between technical components of the pipeline by controlling the flux of inputs and outputs. MITAO [36, 37], originally developed for Topic Modelling tasks, allows for the definition of visual workflows embedding automatic operations. The software will be extended to broaden its scope and reapply it to the workflow discussed in this paper. Further work will also include FAIR-oriented experimentation on metadata embedding for digitised 3D objects, following state-of-the-art virtuous practices [1, 38, 39] to finalise the Digital Damaged Ceramics digitisation and the ongoing development of a digital exhibition.

## 8. Conclusions

This paper presented a workflow for semantically formalising and disseminating GLAM data, with the aim of providing a reusable tool for multidisciplinary research teams involved in CH digitisation. Regarding RQ1, the main obstacles for non-technical users in semantic conversion pipelines concern the need for at least basic skills in semantic technologies due to the tools' configuration complexity. Even when adopting more human-readable mapping languages, precise technical decisions and syntactic checks are still required. In this sense, the case studies highlighted the usefulness of intervening upstream, at the layer of normalisation and guided formalisation of data, with tools such as Chad-Ask, so as to achieve the input format for pre-configured semi-automatic tools. In relation to RQ2, the workflow was articulated into core steps (data collection and tabular normalisation, definition of mapping rules for CSV to RDF conversion, publication and data dissemination) and Protocols was identified as a highly effective option for facilitating reproducibility, promoting FAIRness compliance, and offering a wide range of built-in graphic elements that enhance user understanding. Thanks to the case studies, pitfalls were identified and the workflow was readjusted to better respond to real FAIR formalisation use cases, with growing interest in experimenting in compatible areas, including the management of scholarly bibliographic and citation data [40]. With regard to RQ3, the pilot studies revealed that the workflow is reusable in projects that differ in scale, domain and objectives. The human-in-the-loop approach provides major pipeline control and adds value in terms of data quality, thus it should not be replaced by fully automated processes, as it remains crucial for keeping the workflow updated through iterative refinement.

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## Declaration on Generative AI

According to the GenAI Usage Taxonomy, AI was ethically adopted to support Text Translation (DeepL) and Paraphrase and reword (ChatGPT – GPT-5, Grammarly).

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