

# Towards FAIR Research Data Management in Experimental Materials Science

## A Metadata Pipeline

Filippo Vasone

(Data Steward, University of Bologna)



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA



UNIVERSITÀ  
DI TORINO

Supervision: Dr. Michaela Kuepferling  
(INRiM); Prof. Luca Anselma (UniTo)



Paul Klee, *Hauptweg und Nebenwege*,  
Public domain, via Wikimedia Commons

# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Introduction

Among Open Science practices: research data management according to FAIR principles (Wilkinson et al., 2016).



# The Project



**Aim:** explore and implement a FAIRification process in one of the spintronics laboratories at INRiM (experimental materials science).

**Result:** metadata pipeline.

# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Background

There are several frameworks for FAIRification: general (e.g., Jacobsen et al., 2020; Welter et al., 2023) and specific (e.g., Sinaci et al., 2020)

Two important points (from Welter et al., 2023):

- Choose an **aspect** of the FAIR principles to be implemented - they are principles!
- **FAIR-by-design.**

# Background: The General Context

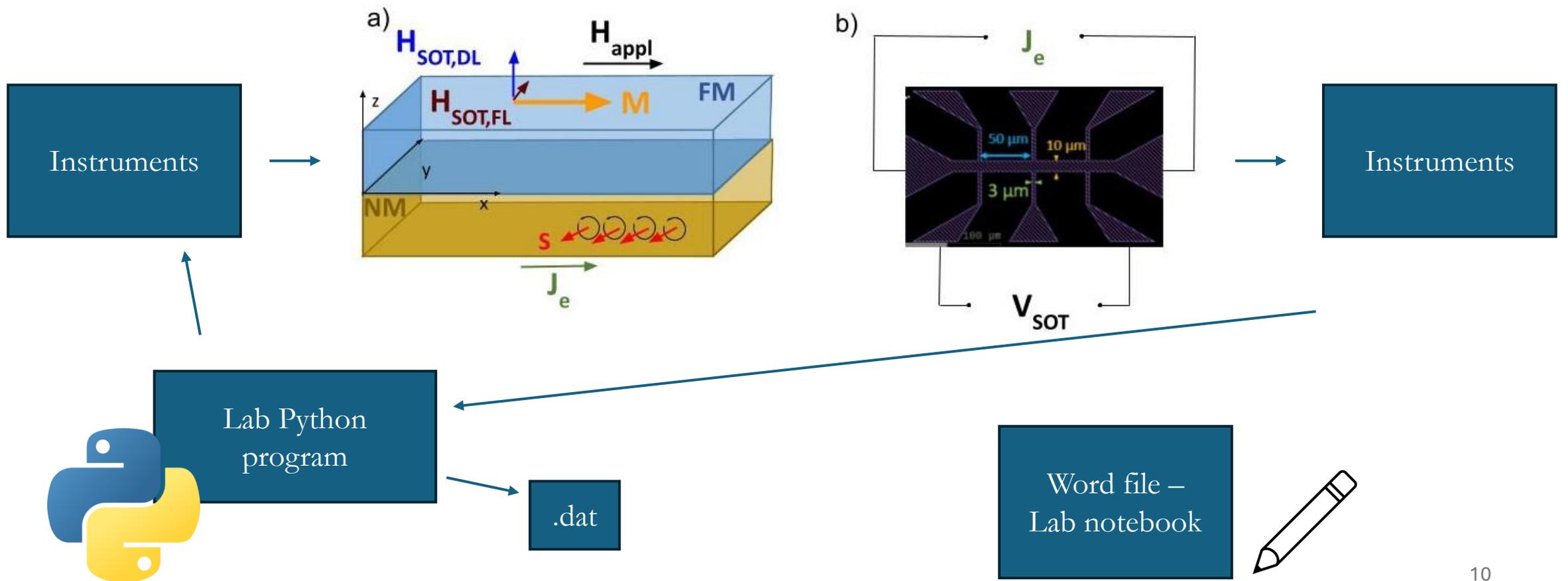
There are many FAIR tools for life sciences (Wilkinson et al., 2016).

Materials science has a lower level of digital maturity:

- There are several resources for computational materials science.
- Experimental materials science has fewer FAIR tools at its disposal (they are being built right now) (Ghiringhelli et al., 2023)

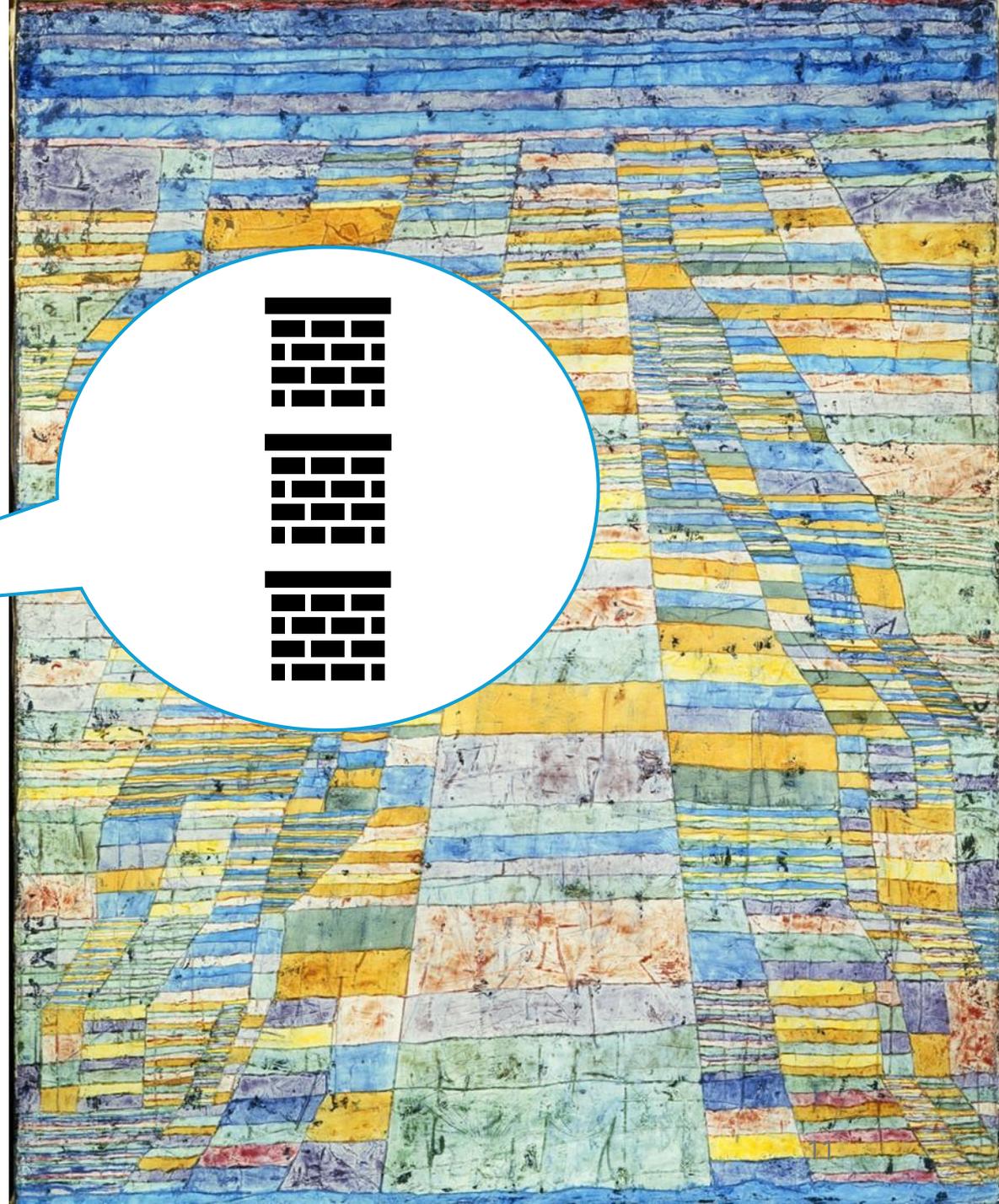
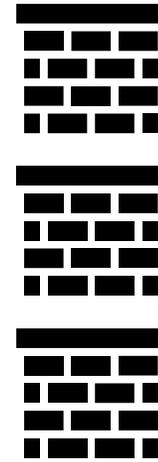
# Background: The Experimental Context

## Spin-Orbit Torque (SOT) Measurement



# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Method: Contextual FAIRification

- Fragmented context of FAIRification in experimental materials science
- Usually the ‘openness’ of Open Science values the pluralism of scientific disciplines (Leonelli, 2023)
- FAIR-by-design

⇒FAIRification starting from the context

The research and choice of tools was an important part of the project.  
(Usually, you would need the support of a data steward)

# Focus: Metadata and Interoperability

**Metadata:** set of key-value pairs that describe a potentially informative object (Pomerantz, 2015)

**Interoperability:** two or more information systems speak the same language (and refer to the same objects) (Guizzardi, 2020)

(e.g.: ‘Temperature’: of the environment? of the sample?)

| Interoperability (FAIR principles)  | 'Modest' interoperability |
|---|---------------------------|
| I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation | Clarity                   |
| I2. (meta)data use <b>vocabularies</b> that follow FAIR principles  | Unambiguity               |
| I3. (meta)data include qualified references to other (meta)data   | Qualified references      |

# Tool #1: CHADA

Conceptual metadata schema (PDF, non machine-actionable)

CHADA: 'Characterization Data' (CEN, 2021): CWA 17815:2021

- Controlled vocabulary for material characterization experiments and measurements
- Metadata schema divided into 4 sections
  - User case
  - Experiment
  - Raw data
  - Data processing

# Tool #2: eLabFTW

eLabFTW is an electronic laboratory notebook (CARPi et al., 2017).

=> machine-actionable (Higgins et al., 2022)

Two important features:

- 1) It allows you to record the metadata of an experiment in a custom way as JSON ('extra\_fields').
- 2) Templates for frequently done experiments.

## SOT\_FAIR\_def

 Team

 Category **PROPRIETÀ MAGNETICHE**

Status  NOT SET

This is the electronic laboratory notebook TEMPLATE for the spin-orbit torque (SOT) magnetoresistance measurement.

The vocabulary and the broad logical structure come from the [CEN CWA 17815](#), which established a documentation standard for material characterization data.

The standard, also known as CHADA, was adapted for the purpose of the present experiment.

▼ EXTRA FIELDS

▼ UNDEFINED GROUP

Experiment\_RunNumber

Number n specifying the number of times the code has been run

RawData\_Host\_Location

Location of the data file in the folder of the hosting computer

Experiment\_DateAndTime

The date and the time of the experiment

# Tool #3: NOMAD



= FAIR repository and archive for materials science (meta)data  
(Scheidegen et al., 2023)

The (meta)data are organized into 'sections', which can be default or defined by the user from the NOMAD Metainfo (schema language).

The screenshot displays the NOMAD web interface with three panels. The left panel shows the 'Entry' section, which is part of the 'EntryArchive'. It lists sub-sections: 'results', 'metadata', and 'data' (which is selected and highlighted in blue). Below this, it indicates 'REFERENCED BY' with a 'closed' button. The middle panel shows the 'SOTMeasurement' section, which is part of the 'SOTMeasurement' section and contains a sub-section 'data'. It lists quantities: 'short name' (SOT\_attempt\_API), 'composite system reference' (thin\_film.archive.json), 'UserCase Sample sample name' (09/D6), 'datetime' (28/02/2025 18:34), and 'Experiment RunNumber' (11). The right panel shows the 'Sample Structure' section, which is part of the 'SampleStructure' section. It lists quantities: 'name' (thin\_film), 'UserCase Sample device width' (100000 Å), 'UserCase Sample device length' (1.03·10<sup>+6</sup> Å), 'ID' (UserCase Sample device geometry = Hall bar), and 'description'. It also indicates 'REFERENCED BY' with a 'closed' button.



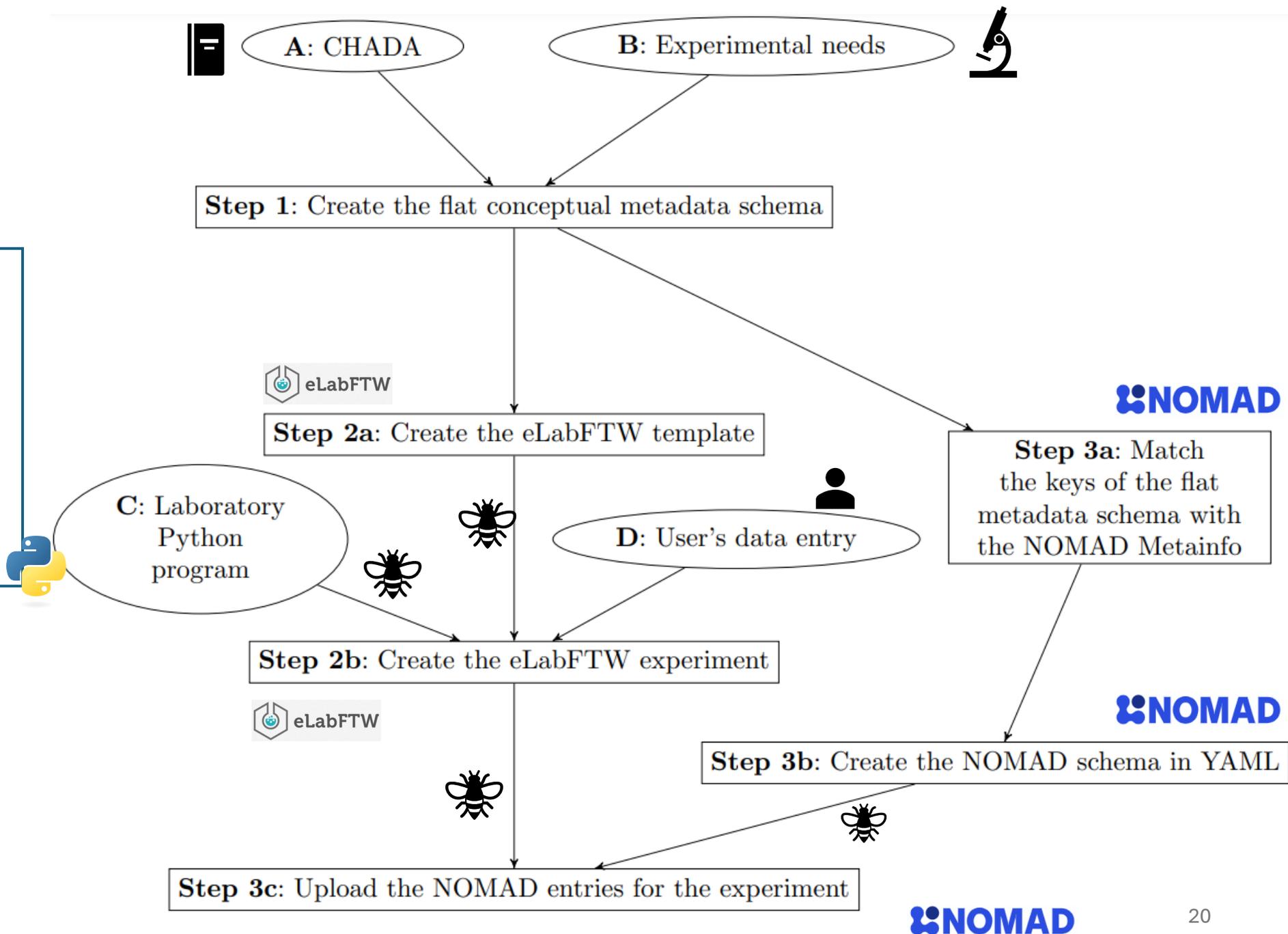
# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Result

Legend  
Ellipse: input  
Boxes: action/step  
Bee: API integration (Python)  
Step 1,2,3: temporal order



# Step 1: flat conceptual metadata schema

Adapt CHADA to the SOT measure (A)

+

Experimental needs (B)

|   |  |  |
|---|--|--|
| Experiment_RunNumber                          | Experiment_Detector_detector_1                 | DataProcessing_data_management                               |
| Experiment_DateAndTime                        | Experiment_Detector_detector_2                 | UserCase_Sample_device_geometry                              |
| UserCase_SamplePreparation                    | UserCase_Sample_sample_name                    | Experiment_MeasurementParameters_field_direction             |
| Experiment_InteractionVolume                  | UserCase_Sample_device_width                   | Experiment_Detector_detector_1_brand                         |
| Experiment_CalibrationProcess                 | RawData_Host_Location                          | Experiment_Detector_detector_2_brand                         |
| UserCase_CharacterisationEnvironment          | Experiment_MeasurementParameters_current_pulse | UserCase_SampleMaterialProperties_layer_1_material           |
| Experiment_Probe&PhysicsOfInteraction_probe_1 | UserCase_Sample_device_length                  | UserCase_SampleMaterialProperties_layer_2_material           |
| Experiment_Probe&PhysicsOfInteraction_probe_2 | UserCase_User_operator_name                    | UserCase_SampleMaterialProperties_layer_3_material           |
| UserCase_Sample_number_of_layers              | Experiment_Signal_signal_1_from_current        | UserCase_SampleMaterialProperties_layer_4_material           |
| UserCase_Sample_layer_1_thickness             | DataProcessing_data_normalisation              | UserCase_SampleMaterialProperties_layer_5_material           |
| UserCase_Sample_layer_2_thickness             | Experiment_Signal_signal_2_from_field          | DataProcessing_main_processed_signals                        |
| UserCase_Sample_layer_3_thickness             | UserCase_Batch_production_batch_name           | Experiment_Probe&PhysicsOfInteraction_physics_of_interaction |
| UserCase_Sample_layer_4_thickness             | DataProcessing_properties_elaborated_data      | DataProcessing_data_processing_level_of_expertise            |
| UserCase_Sample_layer_5_thickness             | UserCase_User_operator_level_of_expertise      | RawData_raw_data_file_column_headers_unit                    |
| DataProcessing_processing_reproducibility     | DataProcessing_data_analysis_procedure         | Experiment_MeasurementParameters_magnetic_field_sequence     |

# Step 2: eLabFTW

**Step 2a:** Create an experiment template on eLabFTW from the flat conceptual metadata schema (step 1).

```
object ▶ extra_fields ▶ UserCase_Sample_layer_1_thickness ▶ units ▶
├── object {1}
│   └── extra_fields {44}
│       ├── Experiment_RunNumber {5}
│       ├── RawData_Host_Location {3}
│       ├── Experiment_DateAndTime {3}
│       ├── UserCase_SamplePreparation {2}
│       ├── UserCase_Sample_sample_name {3}
│       ├── UserCase_User_operator_name {2}
│       ├── Experiment_InteractionVolume {3}
│       ├── UserCase_Sample_device_width {5}
│       ├── Experiment_CalibrationProcess {3}
│       ├── UserCase_Sample_device_length {5}
│       ├── DataProcessing_data_management {3}
│       ├── Experiment_Detector_detector_1 {3}
│       ├── Experiment_Detector_detector_2 {3}
│       ├── UserCase_Sample_device_geometry {3}
│       ├── DataProcessing_data_normalisation {3}
│       └── UserCase_Sample_layer_1_thickness {4}
│           ├── type : number
│           ├── unit : nm
│           └── units [1]
│               └── 0 : nm
│                   └── value : value
│                       ├── UserCase_Sample_layer_2_thickness {4}
│                       ├── UserCase_Sample_layer_3_thickness {4}
│                       ├── UserCase_Sample_layer_4_thickness {4}
│                       ├── UserCase_Sample_layer_5_thickness {4}
│                       ├── Experiment_Detector_detector_1_brand {3}
│                       └── Experiment_Detector_detector_2_brand {3}
```

Portion of the JSON metadata attached to the experiment template on eLabFTW.



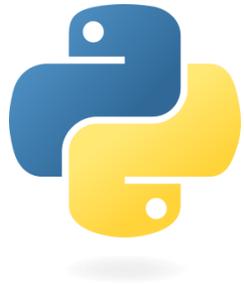
# Step 2: eLabFTW

## API Integration

Python library: <https://github.com/elabftw/elabapi-python>

- GET the experiment template
- POST the experiment
- Editing the metadata coming from the experiment with information from the lab Python program
  - Metadata quality considerations
- PATCH the experiment with the metadata coming from the lab Python program **(C)**

## Step 2: eLabFTW



Laboratory Python program

Upload\_metadata\_to\_eLabFTW  
\_with\_API.ipynb

(C)



**Step 2b: Create the  
eLabFTW experiment  
=> Locally FAIR**

User's data entry **(D)**



# Step 3: NOMAD

**Step 3a:** match the keys of our flat conceptual metadata schema (step 1) with the NOMAD metainfo.

In particular, we are able to model the structure of the sample (the thin film) with the NOMAD Metainfo.

**Step 3b:** create a NOMAD schema for the definition in YAML.

- ‘SOTMeasurement’ (experiment entry, in which most of the information converge).
- ‘SampleStructure’ (thin film).
- ‘Substance’ (the layers of the thin film).

```
definitions:
  name: SOT
  sections:
    SampleStructure:
      base_sections:
        - nomad.datamodel.metainfo.basesections.CompositeSystem
        - nomad.datamodel.data.EntryData
      quantities:
        UserCase_Sample_device_width:
          type: np.float64
          unit: mm
          m_annotations:
            eln:
              component: NumberEditQuantity
              display:
                unit: mm
      sub_sections:
        layers:
          section:
            quantities:
              layer:
                type: Substance
                m_annotations:
                  eln:
                    component: ReferenceEditQuantity
            repeats: true
    SOTMeasurement:
      base_sections:
        - nomad.datamodel.metainfo.eln.ElnBaseSection
        - nomad.datamodel.data.EntryData
        - nomad.datamodel.metainfo.basesections.CompositeSystemReference
      quantities:
        UserCase_Sample_sample_name:
          type: str
          m_annotations:
            eln:
              component: StringEditQuantity
        Experiment_RunNumber:
          type: int
          m_annotations:
            eln:
              component: NumberEditQuantity
    Substance:
      base_sections:
        - nomad.datamodel.metainfo.eln.Substance
        - nomad.datamodel.data.EntryData
      quantities:
        UserCase_Sample_layer_thickness:
          type: np.float64
          unit: nm
          m_annotations:
            eln:
              component: NumberEditQuantity
              display:
                unit: nm
```



# Step 3: NOMAD

**Step 3c:** the goal is the creation of NOMAD entries for the SOT measurement.

- GET the metadata from the eLabFTW experiment (elabapi-python).
- Creating Python dictionaries for each entry (experiment, thin film, layers of the thin film).
  - Part of the structure was hard-coded on the basis of the structure of NOMAD entries.
  - Dictionaries edited with the metadata coming from eLabFTW.
    - Metadata quality
      - Transforming strings containing numbers into integers and floats.
      - Date format: from Python datetime object into ISO 8601 format (accepted by NOMAD).
- The Python dictionaries are turned into JSON files and, together with the YAML schema, are uploaded onto NOMAD through API.

# Step 3: NOMAD

NOMAD parsers create structured and interoperable entries (partial interoperability, due to the (until now) ‘low’ population of NOMAD).

8 entries ☰

| <input type="checkbox"/> | Name            | Type            | Mainfile                     |   | Process status <span>↑</span> |   |
|--------------------------|-----------------|-----------------|------------------------------|---|-------------------------------|---|
| <input type="checkbox"/> | SOT             | Schema          | SOT.schema.archive.yaml      |    | SUCCESS                       | → |
| <input type="checkbox"/> | Tantalum        | Substance       | Tantalum.archive.json        |    | SUCCESS                       | → |
| <input type="checkbox"/> | CoFeB           | Substance       | CoFeB.archive.json           |    | SUCCESS                       | → |
| <input type="checkbox"/> | Platinum        | Substance       | Platinum.archive.json        |  | SUCCESS                       | → |
| <input type="checkbox"/> | SOT_attempt_API | SOTMeasurement  | SOT_attempt_API.archive.json |  | SUCCESS                       | → |
| <input type="checkbox"/> | Silicon dioxide | Substance       | Silicon dioxide.archive.json |  | SUCCESS                       | → |
| <input type="checkbox"/> | thin_film       | SampleStructure | thin_film.archive.json       |  | SUCCESS                       | → |
| <input type="checkbox"/> | Silicon         | Substance       | Silicon.archive.json         |  | SUCCESS                       | → |

# Step 3: NOMAD

Example of the 'data' section within the 'SOT\_attempt\_API' entry

The screenshot displays the NOMAD web interface. At the top, there is a navigation bar with a logo and menu items: PUBLISH, EXPLORE, ANALYZE, and ABOUT. Below this, the breadcrumb path reads: Your uploads / upload\_zip\_sot\_def / SOT\_attempt\_API / Data. The main content area is divided into three tabs: OVERVIEW, FILES, and DATA, with the DATA tab currently selected. A search bar is present at the top of the data view, containing the text 'quantity' and a placeholder 'Type your keyword here'. The left sidebar shows a tree view of the entry structure: Entry (section: EntryArchive), SUB SECTIONS (results, metadata, data), and REFERENCED BY (closed). The 'data' sub-section is highlighted in blue. The main panel displays the details for the 'SOTMeasurement' entry, specifically the 'data' sub-section. It lists several quantities with their values and edit options:

- short name: SOT\_attempt\_API
- composite system reference: thin\_film.archive.json (with edit icon)
- UserCase Sample sample name: 09/D6
- datetime: 28/02/2025 18:34 (with calendar icon)
- Experiment RunNumber: 11
- ID: (empty field)

# Step 3: NOMAD

Example of the 'results' section within the 'Platinum' entry

The screenshot displays the NOMAD web interface. At the top, there is a navigation bar with links for PUBLISH, EXPLORE, ANALYZE, and ABOUT. The user is logged in as Filippo Vasone, with options for LOGOUT and UNITS. The breadcrumb trail shows the path: Your uploads / upload\_zip\_sot\_def / Platinum / Data. The main interface is divided into four tabs: OVERVIEW, FILES, DATA (which is active), and LOGS. A search bar is present in the top left of the DATA tab. The central content area is split into four vertical panels, each representing a different section of the entry: Entry, Results, Material, and Elemental Composition. Each panel has a search bar and a list of sub-sections. The 'Results' panel is currently selected, showing sub-sections for 'material', 'properties', and 'eln'. The 'Material' panel shows various chemical formulae and quantities. The 'Elemental Composition' panel shows the element 'Pt' and its mass and atomic fractions. Each panel also includes a 'REFERENCED BY' section with a 'closed' button.

quantity  
Type your keyword here

code specific all defined technical view

Entry  
section EntryArchive

SUB SECTIONS

results  
metadata  
data

REFERENCED BY closed

Results  
section Results

sub section results

SUB SECTIONS

material  
properties  
eln

REFERENCED BY closed

Material  
section Material

sub section material

QUANTITIES

elements = 1 vector  
chemical formula descriptive = Pt  
chemical formula reduced = Pt  
chemical formula hill = Pt  
chemical formula iupac = Pt  
chemical formula anonymous = A

SUB SECTIONS

elemental composition

REFERENCED BY closed

Elemental Composition  
section ElementalComposition

sub section elemental\_composition

QUANTITIES

element = Pt  
mass =  $3.23944603 \cdot 10^{-25}$  kg  
atomic fraction = 1  
mass fraction = 1

REFERENCED BY closed

# Step 3: NOMAD

We have achieved partial interoperability.

- Description of the sample structure in an interoperable way.
- Adherence to the idea of modest interoperability (clarity, unambiguity, qualified references).

| Entry References                      |                |                              |   |                   |
|---------------------------------------|----------------|------------------------------|---|-------------------|
| Referencing the following entries ^   |                |                              |   |                   |
| Name                                  | Type           | Mainfile                     |   |                   |
| Silicon                               | Substance      | Silicon.archive.json         |    | <a href="#">→</a> |
| Silicon dioxide                       | Substance      | Silicon dioxide.archive.json |    | <a href="#">→</a> |
| Platinum                              | Substance      | Platinum.archive.json        |    | <a href="#">→</a> |
| CoFeB                                 | Substance      | CoFeB.archive.json           |    | <a href="#">→</a> |
| Tantalum                              | Substance      | Tantalum.archive.json        |    | <a href="#">→</a> |
| Referenced by the following entries ^ |                |                              |   |                   |
| Name                                  | Type           | Mainfile                     |   |                   |
| SOT_attempt_API                       | SOTMeasurement | SOT_attempt_API.archive.json |  | <a href="#">→</a> |

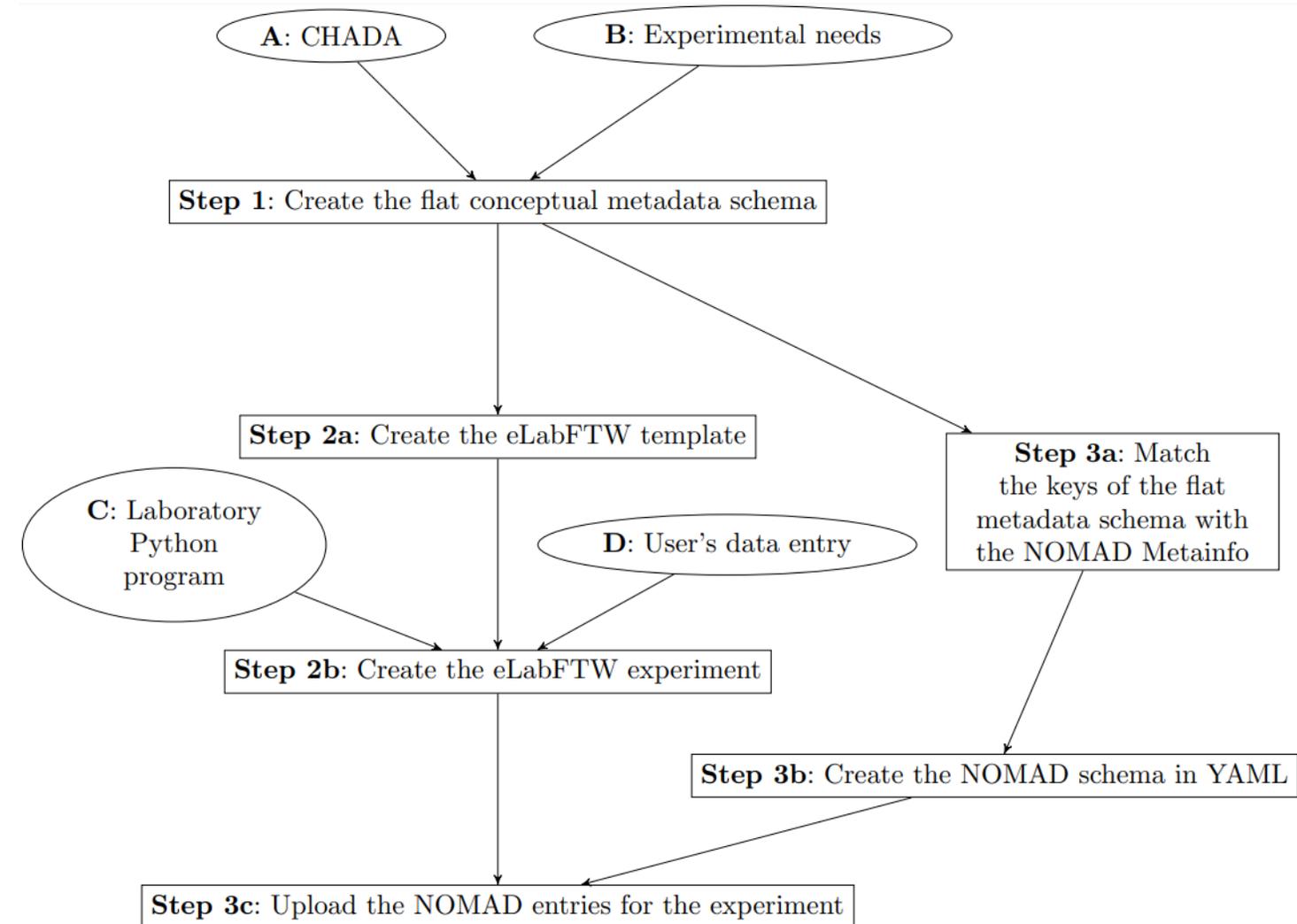
Esempio dei riferimenti nell'entry 'thin\_film'

# Outline

1. Introduction
2. Background
3. Method and Tools
4. Result: Metadata Pipeline
5. Conclusion and Discussion



# Conclusion and discussion

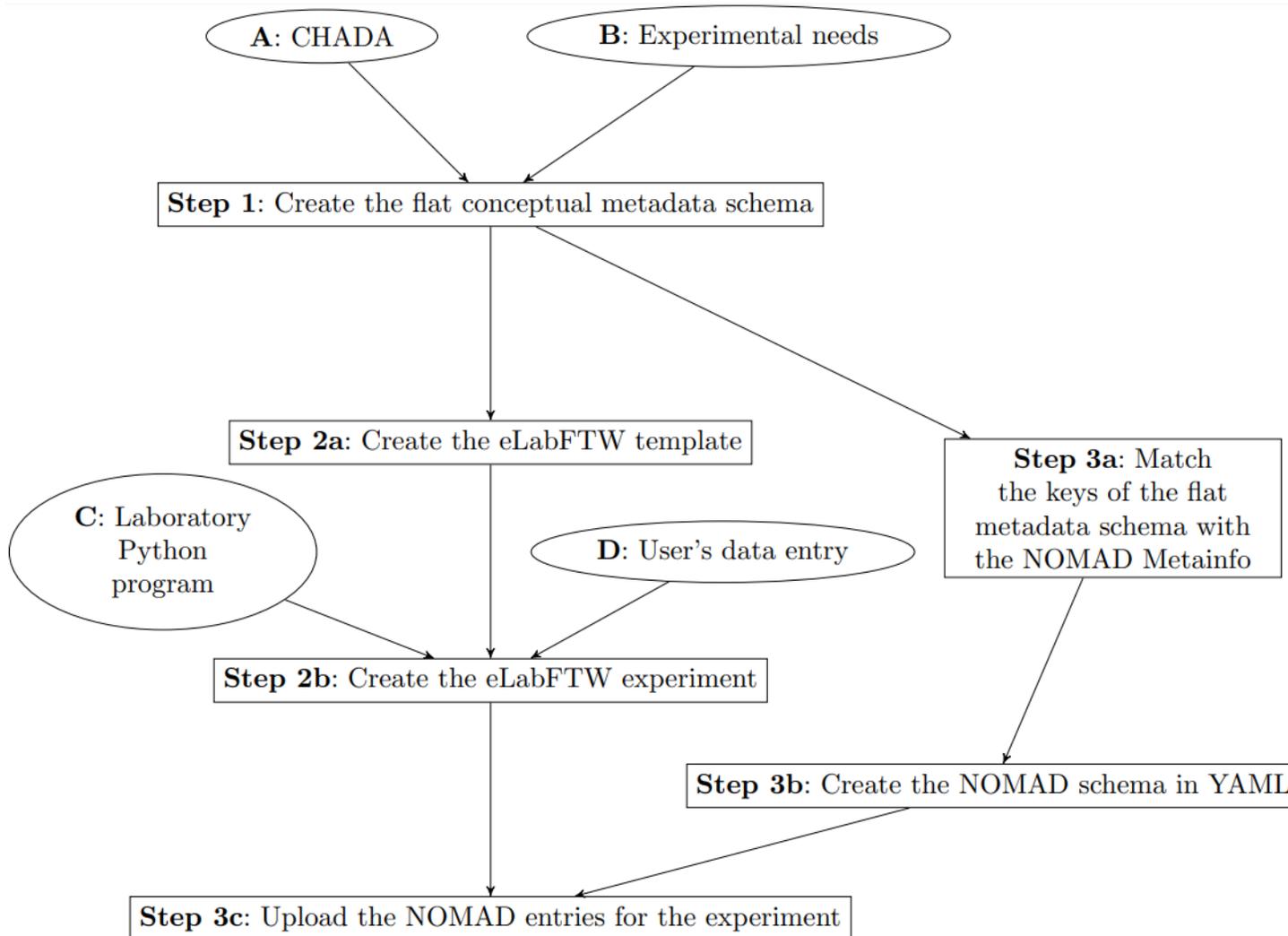


- The project achieved a semi-automation and FAIRification of an initially manual and non machine-actionable process.
- This technological infrastructure allows possible future data analysis, even with ML tools.
- Electronic laboratory notebooks have great potential for carrying out FAIRification projects.

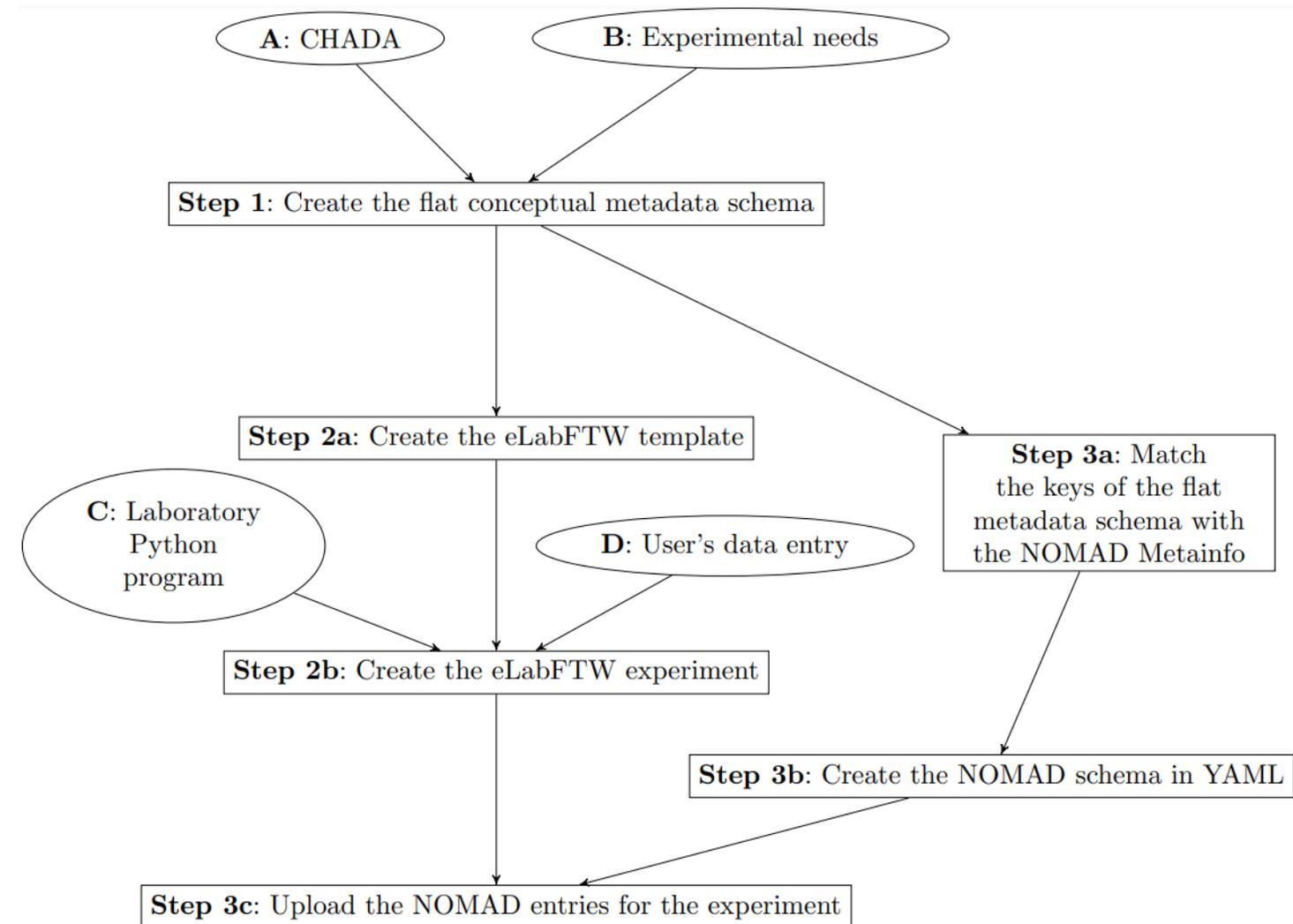
# Conclusion and discussion

## Limitations

- This pipeline has two ‘bosses’: CHADA and NOMAD.
- eLabFTW has limited interoperability.
- Interoperability is partial due to the ‘low’ population of the NOMAD Metainfo.



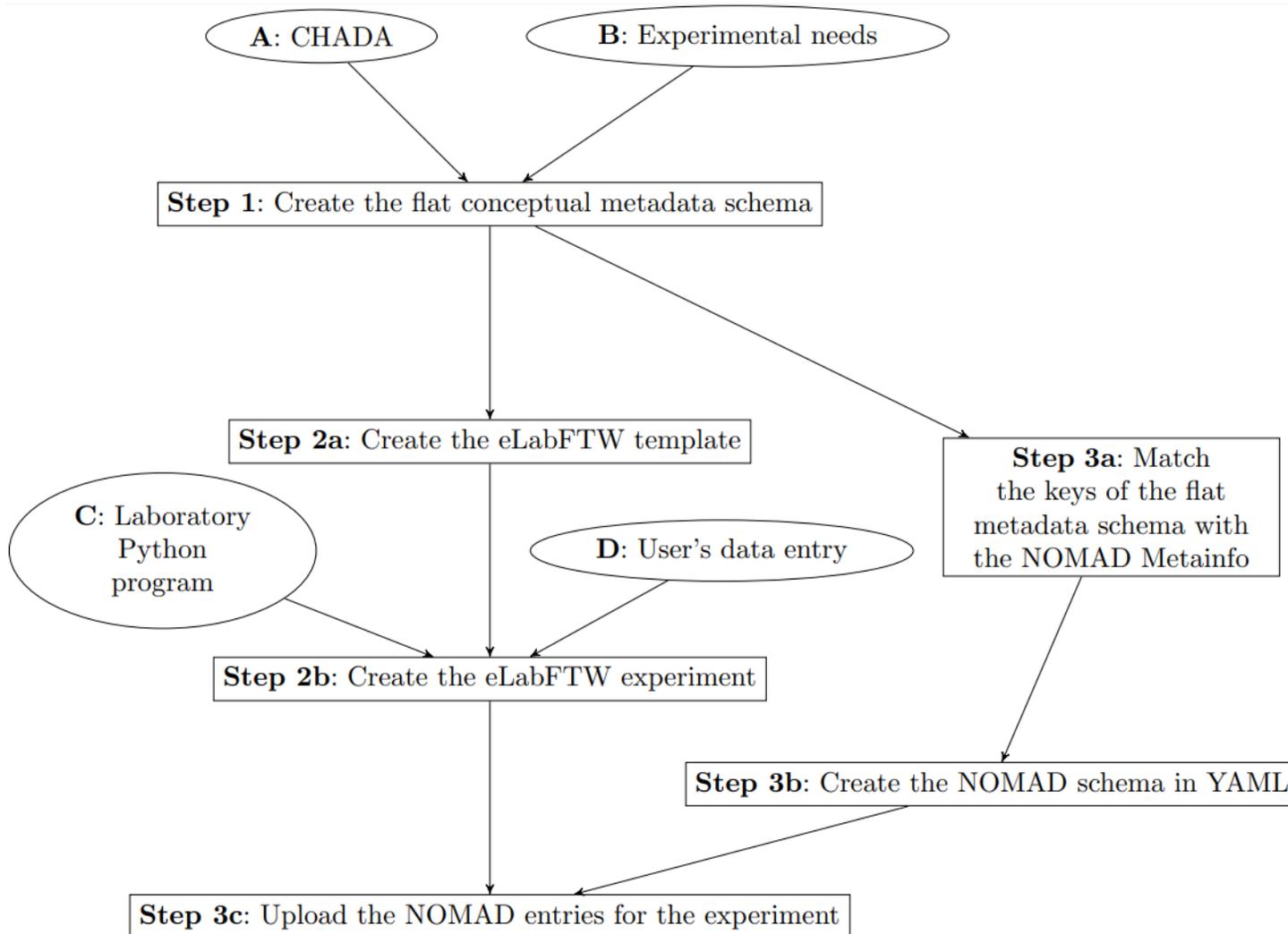
# Conclusion and discussion



## Future developments

- NOMAD plugin for CHADA.
- Thin film modeling in the NOMAD Metainfo.
- UI for the pipeline.
- Integration of the Metainfo NOMAD with materials science ontologies or foundational ontologies.

# Conclusion and discussion



The code is available on GitHub:  
<https://github.com/filippo-vasone/FAIR-metadata-pipeline-for-experimental-matsci>

The thesis is available on Zenodo:  
<https://zenodo.org/records/15226191>

# Take-home message #1

FAIRification is not a yes/no matter but it is a **gradual process** of concretization of the FAIR principles to your case.

# Take-home message #2: The advantages of ELN

- An ELN facilitates **collaboration within the laboratory** – even with **staff turnover**.
- An ELN promotes **collaboration between laboratories**: standardization **fosters interoperability** in the collection and production of data and metadata.
- An ELN improves **data integrity**: it prevents data loss and enables **version control** and **time-stamping**.
- An ELN promotes the **findability and accessibility** of data, metadata, and protocols. For example, it allows you to reconstruct laboratory activities in the **past**.

# Take-home message #3:

## Consideration for implementation

- Consider the **goal** (and therefore the desiderata and constraints) with which the ELN is adopted.
- Some ELNs need to be installed on a **local server**, others rely on the **cloud**: evaluate the best option.
- Try the **demos**, if available.
- Consider **backup and data security** measures.
- If you are adopting an **open source ELN**, rely on software that has been backed by a strong community of developers for a long time.
- The ELN should allow the export of (meta)data in **interoperable formats** (e.g., JSON, CSV, ELN).

# References

- CARPi, N., Minges, A., & Piel, M. (2017). eLabFTW: An open source laboratory notebook for research labs. *The Journal of Open Source Software*, 2(12), 146. <https://doi.org/10.21105/joss.00146>
- Comité Européen de Normalisation. (2021). *CEN Workshop Agreement 17815: 2021*. Retrieved on 27/02/2025 from <https://www.cenelec.eu/media/CEN-CENELEC/CWAs/ICT/cwa17815.pdf>.
- Ghiringhelli, L. M., Baldauf, C., Bereau, T., Brockhauser, S., Carbogno, C., Chamanara, J., Cozzini, S., Curtarolo, S., Draxl, C., Dwaraknath, S., Fekete, Á., Kermode, J., Koch, C. T., Kühbach, M., Ladines, A. N., Lambrix, P., Himmer, M.-O., Levchenko, S. V., Oliveira, M., ... Scheffler, M. (2023). Shared metadata for data-centric materials science. *Scientific Data*, 10(1), 626. <https://doi.org/10.1038/s41597-023-02501-8>
- Guizzardi, G. (2020). Ontology, Ontologies and the “I” of FAIR. *Data Intelligence*, 2(1–2), 181–191. [https://doi.org/10.1162/dint\\_a\\_00040](https://doi.org/10.1162/dint_a_00040)
- Higgins, S. G., Nogiwa-Valdez, A. A., & Stevens, M. M. (2022). Considerations for implementing electronic laboratory notebooks in an academic research environment. *Nature Protocols*, 17(2), 179–189. <https://doi.org/10.1038/s41596-021-00645-8>
- Jacobsen, A., Kaliyaperumal, R., Da Silva Santos, L. O. B., Mons, B., Schultes, E., Roos, M., & Thompson, M. (2020). A Generic Workflow for the Data FAIRification Process. *Data Intelligence*, 2(1–2), 56–65. [https://doi.org/10.1162/dint\\_a\\_00028](https://doi.org/10.1162/dint_a_00028)
- Leonelli, S. (2023). *Philosophy of open science*. Cambridge University Press. <https://doi.org/10.1017/9781009416368>

# References

Pomerantz, J. (2015). *Metadata*. The MIT Press.

Scheidgen, M., Himanen, L., Ladines, A. N., Sikter, D., Nakhaee, M., Fekete, Á., Chang, T., Golparvar, A., Márquez, J. A., Brockhauser, S., Brückner, S., Ghiringhelli, L. M., Dietrich, F., Lehmborg, D., Denell, T., Albino, A., Näsström, H., Shabih, S., Dobener, F., ... Draxl, C. (2023). NOMAD: A distributed web-based platform for managing materials science research data. *Journal of Open Source Software*, 8(90), 5388. <https://doi.org/10.21105/joss.05388>

Sinaci, A. A., Núñez-Benjumea, F. J., Gencturk, M., Jauer, M.-L., Deserno, T., Chronaki, C., Cangoli, G., Cavero-Barca, C., Rodríguez-Pérez, J. M., Pérez-Pérez, M. M., Laleci Erturkmen, G. B., Hernández-Pérez, T., Méndez-Rodríguez, E., & Parra-Calderón, C. L. (2020). From Raw Data to FAIR Data: The FAIRification Workflow for Health Research. *Methods of Information in Medicine*, 59(S 01), e21–e32. <https://doi.org/10.1055/s-0040-1713684>

Welter, D., Juty, N., Rocca-Serra, P., Xu, F., Henderson, D., Gu, W., Strubel, J., Giessmann, R. T., Emam, I., Gadiya, Y., Abbassi-Daloi, T., Alharbi, E., Gray, A. J. G., Courtot, M., Gribbon, P., Ioannidis, V., Reilly, D. S., Lynch, N., Boiten, J.-W., ... Burdett, T. (2023). FAIR in action—A flexible framework to guide FAIRification. *Scientific Data*, 10(1), 291. <https://doi.org/10.1038/s41597-023-02167-2>.

Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., Da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., ... Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, 3(1), 160018. <https://doi.org/10.1038/sdata.2016.18>

# Further Reading on ELNs

<https://www.kuleuven.be/rdm/en/tools/elc>;

<https://book.the-turing-way.org/reproducible-research/rdm/rdm-elns>;

**Thank you for your  
attention!**

Contacts:  
[filippo.vasone@unibo.it](mailto:filippo.vasone@unibo.it)

