Development of a maturity model to assess the FAIRness of architectural data in Switzerland

Valentina CARACUTA
valentina.caracuta@hesge.ch
https://orcid.org/0000-0002-2576-7844
Spécialiste Open Science, bibliothèque HEPIA, Genève

Charlotte SCHAER
c.schaer@mamco.ch
https://orcid.org/0009-0000-1594-5494
Conservatrice de la collection, MAMCO, Genève

Résumé

This research carries out an in-depth assessment of the application of the FAIR (Findable, Accessible, Interoperable and Reusable) principles by the Swiss scientific community specialized in architecture, and consequently its positioning in the context of open science. The FAIR maturity assessment of research data is based on the use of maturity models. They provide a structured framework for implementing and improving data management practices. Our methodology involved a careful comparison of six existing maturity models and their alignment with the FAIR principles. This ensured a relevant and appropriate selection of evaluation criteria for own model. Developing straightforward criteria that can be applied in real-world scenarios is a key aspect of our approach. Inspired by the FAIR principles, we formulated our matrix-based maturity model, the Architectural Maturity Model (AMM). The goal of the AMM is to improve the understanding of metrics using a question-answer approach. We then applied the AMM to evaluate selected datasets stored in the Zenodo and ETH Research Collection repositories to assess the FAIRness of architectural research data.

The results show that architectural data are findable and accessible, but that they not very interoperable and can be reused only with limitations. To improve the FAIRness of architectural research data we recommend data producers to prioritize licences without restriction (e.g. CC0) and open formats. We also encourage researchers to discuss with their data stewards how to use controlled vocabularies to improve the visibility of their data on digital platforms.

Mots-clés

open research data, FAIR principles; matrix base maturity model; dataset; repository; Switzerland; architecture

1. Introduction

The FAIR Principles (Findable, Accessible, Interoperable, Reusable), which comprise a set of best practices for managing data, offer broad applicability across domains (Wilkinson et al. 2016). To ensure that data within the architectural domain adheres to these principles, it is critical to assess current data management practices, identify potential gaps, and provide recommendations for improving these practices. These assessments facilitate the assignment of a FAIR maturity level to the data and allows to identify necessary improvements for each principle. The decision to use a matrix-based maturity model in our research allows for a cross-sectional analysis of multiple data repositories within the architecture domain, shedding light on current data management practices in this field. Recognition of the value that the scientific community places on datasets that support research outcomes underscores the need to measure the FAIRness of such data.

With a pressing need for transparent, accessible, and reusable research data, our study aims to develop a dedicated maturity model to assess the FAIRness of architectural research data in Switzerland. To achieve our goal, we carried out an in-depth analysis of six existing maturity models that focus on research datasets (Cox, Yu 2017; Bahim, Dekkers, Wyns 2019). We then created a user-friendly maturity model, the AMM-Architectural Maturity Model, using a question-based format. This model serves as a guide for data publishers and data stewards to align with FAIR expectations and thereby improves transparency and accessibility of their datasets. The goal is not to revolutionize the way FAIRness is assessed, but to simplify existing models and tailor them to our research needs.

To test our model, we performed a cross-analysis of the repositories recommended by the SNSF and the re3data repository using the “engineering science” tag. We identified 17 datasets on Zenodo from the EPFL community and 10 datasets from the ETH Research Collection.

The results of our study show that architectural data sets are excellent in terms of findability and accessibility. However, interoperability is lacking, and reusability is limited by restrictive licenses and closed formats.

To summarize, our approach has a two-fold effect of both contributing to the FAIRness of architectural research data and establishing a framework that may be generalized across research disciplines.

2. State of the art

2.1. Data FAIRness

The term FAIR was developed in 2014 by a working group of the Jointly Designing a Data Fairport workshop, which met at the Lorentz Center to rethink and improve the open science ecosystem (FORCE11 2021). The outcome of this workshop was a manuscript entitled “FAIR Guiding Principles for Scientific Data Management and Stewardship” and with this manuscript the FAIR Guiding Principles were formally published. These fifteen principles do not suggest a specific technology or even a standard, but have been designed to serve as a guide and best practice to be applied, enabling several implementation and integration possibilities for producers and publishers of digital data (Wilkinson et al. 2016).

To summarize, the FAIR foundational principles, Findability, Accessibility, Interoperability, and Reusability, are essential pillars that guide data producers and publishers to maximize the value and impact of scientific results published in digital form. The FAIR guiding principles, on the other hand, provide a comprehensive set of guidelines for data publishers to help them evaluate their choices and improve the findability, accessibility, interoperability, and reuse of their digital assets.

FOUNDATIONAL PRINCIPLE	FAIR GUIDING PRINCIPLE
Findable	F1. (meta)data are assigned a globally unique and persistent identifier
	F2. data are described with rich metadata (defined by R1 below)
	F3. metadata clearly and explicitly include the identifier of the data it describes
	F4. (meta)data are registered or indexed in a searchable resource
Accessible	A1. (meta)data are retrievable by their identifier using a standardized communications protocol
	A1.1 the protocol is open, free, and universally implementable
	A1.2 the protocol allows for an authentication and authorization procedure, where necessary
	A2. metadata are accessible, even when the data are no longer available
Interoperable	I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation
	I2. (meta)data use vocabularies that follow FAIR principles
	I3. (meta)data include qualified references to other (meta)data
Reusable	R1. meta(data) are richly described with a plurality of accurate and relevant attributes
	R1.1. (meta)data are released with a clear and accessible data usage license
	R1.2. (meta)data are associated with detailed provenance
	R1.3. (meta)data meet domain-relevant community standards

Table 1 : The 4 FAIR foundational principles and the 15 FAIR guiding principles

To meet the FAIR foundational principles, we need to be able to assess the FAIRness of the data using the FAIR guiding principles (Table 1). To do this, multiple metrics and indicators have been created by different groups over the last decade (Wilkinson et al. 2018. Bahim, Dekkers, Wyns 2019; Devaraju et al. 2020).

In 2018, the FAIRmetrics working group reflected on the qualities of the FAIR metrics. In their view, a good metric should be clear, realistic, discriminating, measurable and universal (Wilkinson et al. 2018). Indeed, these criteria define the essential characteristics that a FAIR metric must include to assess the FAIRness of data objectively. Although requirements in terms of FAIRness may vary from one scientific community to another, the main aim of this working group is to define at least one metric for each of the fifteen FAIR guiding principles. These metrics should be applicable to all types of digital resources and for all scientific fields combined (Wilkinson et al. 2018). The outcome of this work is shared on the Github platform (Github 2023). Subsequently, automated tests are carried out on digital resources. These evaluations provide the user precise advice for improvement (Wilkinson et al. 2019).

2.2. Maturity models

Data management encompasses all activities aimed at preserving and improving the discoverability, accessibility, and reusability of (meta)data (Mosley et al. 2010). The FAIR foundational principles represent a set of good data management practices that are general enough to be valid in all domains (Wilkinson et al. 2016). To meet these requirements and verify data compliance with FAIRness in the field of architecture, it is vital to assess the current

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state of research data management practices, identify any gaps and propose recommendations for improving data management in this specific domain.

In the context of our study, it is important to mention two distinct categories of models: models focused on data repositories (CoreTrustSeal 2022) and matrix-based maturity models that focus primarily on the assessment of digital objects hosted in repositories (Peng et al. 2015; Research Data Alliance 2020).

Models for ensuring the trustworthiness of data repositories (TDRs), are based on several evaluation criteria divided into three categories: the organization, the repository itself and the digital objects it contains (Research Libraries Group 2001). TDRs also play a crucial role in data preservation and sustainability. They ensure data accessibility and reusability, in line with the FAIR foundational principles (Lin et al. 2020).

In parallel, matrix-based maturity models (MMMs) focus primarily but not exclusively, on managing the metadata for individual digital objects and integrating it into the broader context of the repository. These types of matrices aim to improve the quality, visibility and interoperability of digital objects while simplifying their accessibility and reuse. MMMs have evolved significantly since they were first developed in 1973 (Nolan 1973). Milestones such as the Integration of the Software Engineering Institute's Capability Maturity Model Integration (CMMI) (Ahern, Clouse, Turner 2004) and the creation of ISO/IEC 15504, Information Technology - Process Assessment, in 2004 (International Organization for Standardization 2004), have played an important role in the development and refinement of the models, particularly for the IT domain.

Several MMMs have been developed to determine the degree of FAIR compliance of digital objects, and many of them use a rating system based on a scale of 1 to 5 (Cox, Yu 2017; Bahim, Dekkers, Wyns 2019). The application of these assessments thus makes it possible to assign a level of FAIRness to digital objects and to indicate the improvements needed in the processes linked to each criterion.

In line with our study's goal of developing a specialized maturity model for assessing the FAIRness of architectural data, we will examine six models specifically designed for research data. These models were inspired to different degrees by the FAIR foundational principles.

The Data Stewardship Maturity Matrix (DSMM) was developed by the joint efforts of the National Centers for Environmental Information (NCEI), the U.S. National Oceanic and Atmospheric Administration (NOAA), and the Cooperative Institute for Climate and Satellites-North Carolina (CICS-NC) as of 2015 (Peng et al. 2015). The Data Stewardship Maturity Matrix (DSMM) prioritizes the preservation of high-quality scientific climate datasets, with a keen focus on their alignment with the FAIR foundational principles.

The NCEI and the Data Stewardship Committee of Earth Science Information Partners (ESIP-DSC) collaboratively developed the NCEI/ESIP-DSC Maturity Matrix for Services (MM-Serv), to create a comprehensive tool for organizations active in environmental data and management (MM-Serv Working Group 2018). The NCEI/ESIP-DSC's MM-Serv offers an all-encompassing, multidimensional framework for evaluating the quality of climate data services, while ensuring their findability, accessibility and reusability.

In Australia, initiatives have been implemented by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to improve the discovery, access and reuse of research data, based on the FORCE 11 principles (CSIRO 2017). Specifically, the OzNome working group introduced the CSIRO 5-star Data Rating tool (Cox, Yu 2017), which provides a self-assessment tool developed in the form of questions that are inspired by, but do not strictly correspond to the FAIR foundational principles.

In 2019, the Netherlands' Data Archiving and Networked Services (DANS) developed the Self-Assessment Tool to Improve the FAIRness of Your Dataset (SATIFYD) maturity model. This matrix is inspired by the FAIR self-assessment tool of the Australian Research Data Commons (ARDC) (Fankhauser et al. 2019) and it places a strong emphasis on improving data discoverability, access, interoperability, and reusability in accordance with the FAIR foundational principles.

The Research Data Alliance (RDA) maturity model is the result of collaboration between FAIR experts from different backgrounds (Europe, USA and Australia). Over 200 working group members have come together to create 41 criteria, known as Data Maturity Indicators (DMIs), which allow for a systematic assessment of the FAIRness of any given digital object (Bahim, Dekkers, Wyns 2019; Bahim et al. 2020).

Initiated in 2019, FAIRsFAIR plays a central role in promoting the openness of research data for the European Open Science Cloud (EOSC) (FAIRsFAIR 2019). The objective of this initiative is to evaluate digital objects, with a particular focus on research data hosted in reliable digital repositories. To achieve this goal, the project has developed a set of 17 metrics to measure the degree of FAIRness outputs of publicly financed research projects (Genova et al. 2021).

3. Materials and Methods

Our methodology includes a comprehensive review of six existing MMMs that focus on research data. To gain insights, we analyze their performance with respect to the fifteen FAIR guiding FAIR principles (Wilkinson et al. 2016). We then develop the AMM-Architecture Maturity Model, a user-friendly tool to help researchers evaluate their datasets prior to submission to a repository. We then conduct a search to identify repositories that host architectural research data relevant to our study. Finally, we use the AMM to evaluate the FAIRness of selected datasets using our model.

3.1. Analysis of the FAIRness of six maturity models

Six models were selected because they primarily assess the maturity of digital objects produced by researchers. In particular, the NCEI/CICS-NS and NCEI/ESIP DCS matrices were selected for their domain-specific FAIRness assessment of digital objects. Models such as CSIRO and SATIFYD were chosen because, although loosely inspired by FAIR, they use a simplified set of questions, which improves their usability. RDA and FAIRsFAIR were selected for their strict adherence to the four founding FAIR principles. Our evaluation involved assigning points to the matrix criteria using a scale of 0 for not related, 1 for weakly related, and 2 for strongly related to each of the fifteen FAIR guiding principles. This resulted in a cumulative score. The results illustrate the varying degrees of importance given to findability, accessibility, interoperability and reusability in each model.

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3.2. Design of a maturity model applicable to architecture research data

The AMM (Architecture Maturity Model) is implemented through a three-step process. First, we identify four axes related to the four foundational FAIR principles. Then, we formulate 12 criteria as simple questions, and finally, we establish a scale (1 to 3) for each criterion. This approach is based on an analysis of the fifteen FAIR guiding principles, a specific set of metrics, and an evaluation of the performance of existing maturity models within our research. The focus is on improving the FAIRness assessment rather than revolutionizing it. The goal is to simplify and tailor existing models to our research needs, rather than to revolutionize the way FAIRness is assessed.

3.3. Identification of repositories hosting architecture research data

In accordance with the Open Research Data (ORD) policy of the Swiss National Science Foundation (SNSF), grantees must deposit their research data in appropriate public repositories. The SNSF website lists 27 data repositories that comply with the ORD and the four foundational FAIR principles (Fonds national suisse 2023). In this study, we first browse re3data (re3data 2023) with the tag "Engineering Sciences" and isolate the repositories recommended by the SNSF. 9 repositories were identified by our research: Figshare, OLOS, OSF, Zenodo, Materials Cloud Archive, SWISSUbase, BORIS Portal, ETH Research Collection, and Yareta. In the selected repositories, we applied the search equation "Switzerland AND (Architecture OR Urban OR Construction OR Engineering)" to obtain results aligned with the focus of our study. We further refined our search by using institutional names and acronyms for Swiss architecture schools "ETH", "EPFL", "SUPSI" et "USI" and their specific departments, such as "D-ARCH", "D-BAUG", "ENAC", or "STI". As a result, we identified a total of 27 records, including datasets, articles, reports, and multimedia content, collectively referred to as digital objects. Seventeen of these are hosted on Zenodo and deposited by the EPFL community (Zenodo 2023), while ten are hosted on the ETH Research Collection and uploaded by ETH researchers (ETH Research Collection 2023).

3.4. Evaluation of the FAIRness of architecture research data records

The accessible population represents the 27 records that include different types of files (collectively referred to as digital objects) stored in the two repositories. Our sample therefore consists of the records collected and considered relevant for our study.

For a comprehensive comparative analysis, we evaluate the 27 records by collecting specific information regarding:

- DOI: a Digital Object Identifier (DOI) is associated with each digital object for identification and access purposes.
- Title: it provides an overview of what the digital object contains and helps contextualize it.
- Authorship: the names of the authors are listed to identify those responsible for creating the digital objects, and their affiliations include at least one Swiss institution.
- Date of publication: the information indicates when the digital object was deposited.
- License: reuse rights are clearly defined by the license under which the digital object was deposited.

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- Versioning: changes and updates are indicated by the digital object's version number.
- README: important information about the creation and interpretation of the single digital object or the entire record can be found in the accompanying README file.
- Number of digital objects: the total number of digital objects in each repository provides a measure of its size.
- Formats: the various file formats are listed to help understand the variety and nature of digital objects.

After selecting the variables, we analyzed 27 records to assess their completeness. We then used our Architecture Maturity Model (AMM) to evaluate each record, assigning scores from 1 to 3 for each of the 12 criteria within the model. These scores represent different levels of maturity for each criterion in the model.

4. Results

4.1. Analysis of the FAIRness of six maturity models

We systematically mapped and evaluated the performance of six maturity models with respect to the FAIR foundational principles, using the fifteen FAIR guiding principles as metrics. This comprehensive investigation provided insights into the structural aspects of each model and their correlation with the principles of findability, accessibility, interoperability and reusability.

4.1.1. Data Stewardship Maturity Matrix (DSMM NCEI/CICS-NC)

The Data Stewardship Maturity Matrix (DSMM) lists 25 criteria organized around the following 9 categories: Preservability, Accessibility, Usability, Production Sustainability, Data Quality (DQ) Assurance, DQ Control, DQ Assessement, Data Integrity and Transparency. The main objective of the DSMM is to ensure that the data produced are of certified scientific quality, adequately preserved and well documented, while remaining accessible, usable and up-to-date for potential users (Peng et al. 2019).

The DSMM NCEI/CICS-NC matrix strongly aligns with the FAIR foundational principles, enhancing findability with persistent identifiers and promoting reusability through rich metadata and community standards. However, its emphasis on accessibility and interoperability is comparatively less pronounced (Table 2).

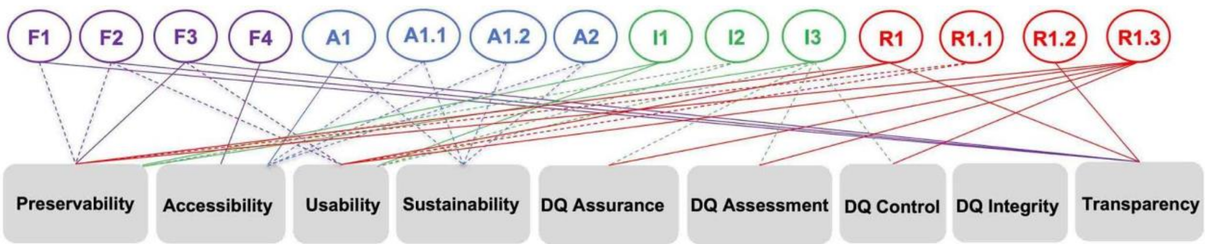

Figure 1 : Correlations between the FAIR guiding principles and the NCEI/CICS-NC matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	Identifiers	Criteria	Matrice DSMM NCEI/CICS-NC														
Preservability	NCEI/CICS-NC-1	Data storage, repository type, archiving metadata, archiving process monitoring&updating	1	1	2	-	-	-	-	-	2	1	2	2	1	-	2
Accessibility	NCEI/CICS-NC-2	Meta-data availability, data searchability and search metrics, data access service, dissemination report, future technology & standard planning	-	-	-	2	2	1	1	1	-	-	-	-	-	-	-
Usability	NCEI/CICS-NC-3	Knowledge required, documentation of production/origin of data, standard/community based (meta)data formats	-	1	2	-	-	-	-	-	2	1	1	2	1	-	2
Production sustanability	NCEI/CICS-NC-4	Institutional or National commitment, product update & improvement, fundings	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-
Data quality (DQ) Assurance	NCEI/CICS-NC-5	Defined procedure, standard or community-endorsed metadata	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
DQ Control	NCEI/CICS-NC-6	Spatial and temporal cross-validation, producers=>users feedbacks, quality control of metadata	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
DQ Assessment	NCEI/CICS-NC-7	Methods and products control, external ranking	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Transparency	NCEI/CICS-NC-8	Unique, persistent and resolvable object identifier, information abour provenance and availability of the product	2	2	2	-	-	-	-	-	-	-	-	2	-	2	-
Data integrity	NCEI/CICS-NC-9	Authenticity verification, accessibilty conform with community standards	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-

Table 2 : FAIR performance according to NCEI/CICS-NC matrix criteria.

The table illustrates the association between each criterion of the model and the FAIR principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

4.1.2. Maturity Matrix for Services (MM-Serv NCEI/ESIP-DSC)

The MM-Serv NCEI/ESIP-DSC consists of 9 criteria grouped into 9 distinct categories: Data Discoverability, Data Use, Data Service, Service Accessibility, Service Usability, Data Impact, Customer Service, and Customer Engagement. By focusing on the aspects of discoverability, accessibility and engagement with researchers, this model offers organizations an accurate representation of their level of readiness and the quality of their services (MM-Serv Working Group 2018).

The correlation between the components of the NCEI/ESIP-DSC matrix and the fifteen FAIR guiding principles reveals a complex dynamic. It closely ties to the findability principle, stressing rich metadata and effective indexing. Additionally, it aligns with the accessibility through standardized communication protocols. Most notably, the matrix strongly correlates with the reusability principle, emphasizing licenses and comprehensive metadata to enhance data usability (Table 3).

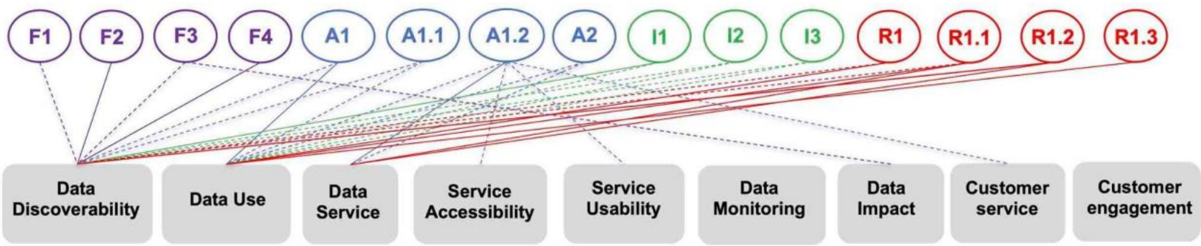

Figure 2 : Correlations between the FAIR guiding principles and the NCEI/ESIP-DSC matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	**Identifiers**	**Criteria**	**Matrice MM-Serv NCEI/ESIP-DSC**														
Data Discoverabilty	NCEI/ESIP-DSC-1	The state of dataset being easily found (product findable on catalogs; use of arborescence and machine redible metadata standards)	1	2	1	2	1	1	-	-	2	1	1	1	1	2	2
Data Use	NCEI/ESIP-DSC-2	The state of data product's use, usability and understandability (Institutional websites/repositoires offer interactive visualizations of relationships with other papers and researchers; standard metadata help users to understand/use the data)	-	-	-	-	2	1	1	1	1	1	1	2	2	-	2
Data Service	NCEI/ESIP-DSC-3	The state of data product being available and distributed (complete information about the service and data product)	-	-	-	-	-	-	2	1	-	-	-	-	2	2	-
Service Accessibility	NCEI/ESIP-DSC-4	The state of service being accessible (available 24*7, stable and secure with available status online)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Service Usability	NCEI/ESIP-DSC-5	The state of the service being easy to use (service provides self-help, easy navitation, and it is subjected to formal external evaluation)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Data Monitoring	NCEI/ESIP-DSC-6	The state of the data product being utilized for direct and indirect monitoring (domain-based metrics and reporting online in littérature)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Data Impact	NCEI/ESIP-DSC-7	The state of the data product impact assessment being publicly available (Identified users and use of data, users demonstrate an understanding of data)	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Customer service	NCEI/ESIP-DSC-8	The state of subject experts and customer service being available to users (support online 24*7; Help desk available on demand)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Customer engagement	NCEI/ESIP-DSC-9	The state of customer engagement for the dataset (data producers-users interactions)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 : FAIR performance according to NCEI/ESIP-DSC matrix criteria

The table illustrates the association between each criterion of the model and the FAIR principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

4.1.3. The Commonwealth Scientific and Industrial Research Organisation 5-star Data Rating Tool (CSIRO)

The CSIRO 5-star Data Rating tool offers a self-assessment system for datasets using 17 criteria divided into 4 categories: Publication and indexing, Linked and usable, Maintenance and provenance, Project, organizational and institutional. Users can assess the current state of their data for each criterion by assigning a score ranging from 1 to 5 (Yu 2017). This self-assessment also suggests ways for users to improve the production or collection of their data and its accessibility to other researchers (Cox, Yu 2017).

The CSIRO matrix prioritizes discoverability through persistent identifiers, while supporting data accessibility through standardized protocols. It also emphasizes reusability through structured metadata and open licenses and promotes interoperability by adopting open formats and community-endorsed metadata schemas (Table 4).

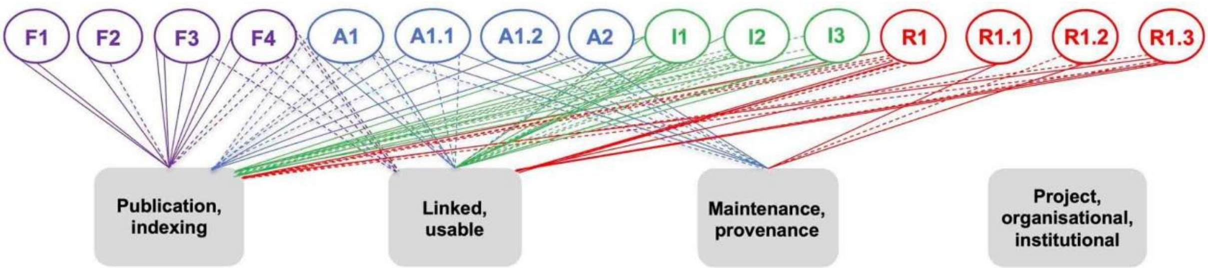

Figure 3 : Correlations between the FAIR guiding principles and the CSIRO matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	Identifiers	Criteria	Matrice CSIRO														
Publication and indexing	CSIRO-1	Dataset identity (name, url)	2	-	2	1	1	-	-	-	2	1	1	1	-	1	1
	CSIRO-2	Published - is the data accessible to users other than the creator or owner? (through person or institutional web site or formal repository or standard web service API)	-	-	-	2	1	2	2	2	-	1	-	-	-	1	-
	CSIRO-3	Citeable - denoted using a formal identifier (URL, URI)	2	-	2	1	1	-	-	-	2	1	2	1	-	-	1
	CSIRO-4	Described - tagged with standard and specialized metadata schemas using multiple standard RDF vocabularies	-	2	2	1	-	-	-	-	2	2	2	2	-	-	2
	CSIRO-5	Findable - indexed in a discovery system (internal; community wide and ranked in general purpose index (Google, Bing etc))	-	1	2	2	1	1	-	-	1	1	1	1	-	-	-
Linked and usable	CSIRO-6	Loadable - represented using a common or community-endorsed multiple standard formats	-	-	-	1	1	-	-	1	2	1	2	1	-	-	2
	CSIRO-7	Useable - structured using a discoverable, community-endorsed schema or data model (DDL, XSD, DDI, RDFS, JSON-Schema)	-	-	-	1	2	1	-	1	2	1	2	2	-	-	2
	CSIRO-8	Comprehensible - supported with unambiguous definitions for all internal elements (community standard labels, all fields linked to standard, externally managed definitions)	-	-	-	1	1	1	-	1	2	2	1	2	-	-	2
	CSIRO-9	Linked - to other data and definitions using public identifiers (out-bound links to related data and definitions using URI)	-	-	1	1	2	-	-	1	2	-	2	2	-	-	1
	CSIRO-10	Licensed - conditions for re-use are available and clearly expressed (link to a standard license (e.g. Creative Commons))	-	-	-	-	-	-	-	-	1	1	-	1	2	-	-
Maintenance and provenence	CSIRO-11	Curated - commitment to ensuring the data is available long term (institutional websites, certified repositories)	-	-	-	-	1	2	1	2	-	-	-	-	-	-	-
	CSIRO-12	Updated - part of a regular data collection program or series, with clear maintenance arrangements and update schedule (occasional to regular scheduled updates)	-	-	-	-	-	2	1	2	-	-	-	-	-	-	-
	CSIRO-13	Assessable - accompanied by, or linked to a data-quality assessment and description of the origin and workflow that produced the data	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
	CSIRO-14	Trusted - accompanied by, or linked to, information about how the data has been used, by whom, and how many times (statistics of impact)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Project Organisational Institutional	CSIRO-15	Complexity of the project (from low to high)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CSIRO-16	Interdisciplinary project? (1 to >5 disciplines)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CSIRO-17	Cross-organisational project? (1 to >5 organisations)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4 : FAIR performance according to CSIRO matrix criteria

The table illustrates the association between each criterion of the model and the FAIR principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

4.1.4. Self-Assessment Tool to Improve the FAIRness of Your Dataset (SATIFYD)

Structured around 12 questions, grouped in 4 categories reflecting each a FAIR principle, SATIFYD measures the findability, accessibility, interoperability and reusability of data on a scale of 1 to 5. This matrix aims to assess the overall maturity of a dataset by providing a FAIRness score, accompanied by advice on how to remedy the shortcomings identified during the analysis (Fankhauser et al. 2019).

The SATIFYD matrix closely adheres to FAIR guiding principles, emphasizing discoverability through unique identifiers, reusability through rich metadata and open licenses, and supporting interoperability through controlled vocabularies. Additionally, the matrix demonstrates a commitment to accessibility principles by requiring metadata access even when data is unavailable (Table 5).

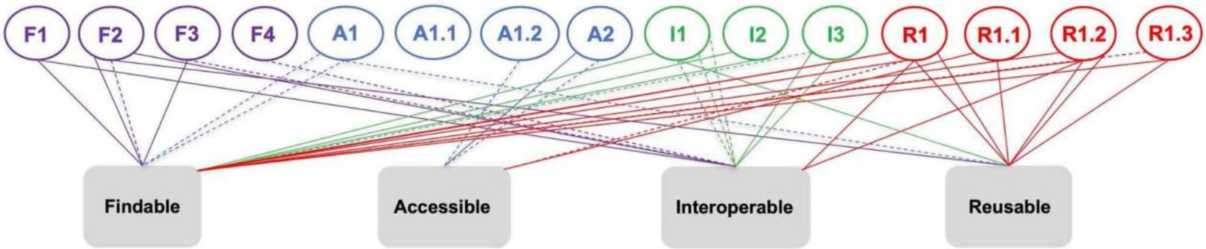

Figure 4 : Correlations between the FAIR guiding principles and the SATIFYD matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	**Identifiers**	**Criteria**	**Matrice SATIFYD**														
Findable	SATIFYD-1	Did you provide sufficient metadata (information) about your data for others to find, understand and reuse your data?	2	2	2	-	1	-	-	-	-	2	1	2	-	2	1
	SATIFYD-2	Did you use standards such as controlled vocabularies, taxonomies (thesauri) or ontologies to describe your dataset?	-	-	-	-	-	-	-	-	2	2	-	2	-	-	2
	SATIFYD-3	Did you provide rich and detailed additional documentation? (readme file, versioning, provenance)	-	1	-	-	1	-	-	-	-	-	-	2	-	2	-
Accessible	SATIFYD-4	Is the metadata publicly accessible even if the data is no longer available?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SATIFYD-5	Does your dataset contain personal data?	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
	SATIFYD-6	Which of the usage licenses provided did you choose in order to comply with the access rights attached ot the data?	-	-	-	-	-	-	1	1	-	-	-	1	2	-	-
Interoprable	SATIFYD-7	Are the data in your dataset stored in preferred formats?	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	SATIFYD-8	Do you link to other (meta)data and is this (meta)data online resolvable?	-	-	-	1	-	-	-	-	1	-	2	-	-	-	-
	SATIFYD-9	Did you provide contextual information about your dataset? (Persistent identifier, Reference to other datasets or publication, contextual information)	2	2	-	-	-	-	-	-	1	-	2	2	-	2	-
Reusable	SATIFYD-10	What kind of information did you provide about the provenance of your data? (Original vs reused, workflow, processing, verisoning)	-	2	-	-	-	-	-	-	-	-	-	2	-	2	-
	SATIFYD-11	Which usage license did choose for your dataset? (Open access (CC) restriced access, embargo)	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	SATIFYD-12	Does your (meta)data meet domain standards?	-	-	-	-	1	-	-	-	2	-	-	2	-	-	2

Table 5 : FAIR performance according to SATIFYD matrix criteria

The table illustrates the association between each criterion of the model and FAIR the principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

4.1.5. Research Data Alliance (RDA)

Published in open access in June 2020 (Research Data Alliance 2020), RDA encourages the widespread use of this model across different disciplines and fields of research. This matrix includes 4 axes and 41 criteria.

The RDA matrix emphasizes the use of persistent unique identifiers and rich metadata to improve discoverability. It advocates accessibility through standardized communication protocols and promotes interoperability through metadata schemas and formal description models. Additionally, it promotes data reuse through contextual information, licensing, and the adoption of community standards (Table 6).

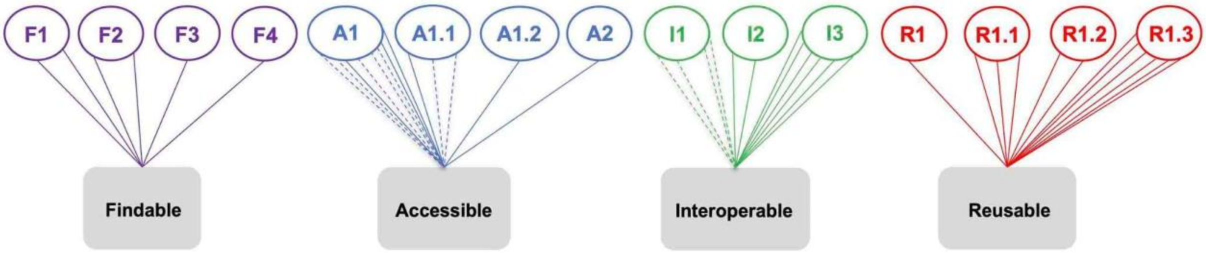

Figure 5 : Correlations between the FAIR guiding principles and the RDA matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	**Identifiers**	**Criteria**	**Matrice RDA**														
Findable	RDA-F1-01M	Metadata is identified by a persistent identifier	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RDA-F1-01D	Data is identified by a persistent identifier	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	RDA-F1-02M	Metadata is identified by a globally unique identifier	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RDA-F1-02D	Data is identified by a globally unique identifier	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	RDA-F2-01M	Rich metadata is provided to allow discovery	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
	RDA-F3-01M	Metadata includes the identifier for the data	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
	RDA-F4-01M	Metadata is offered in such a way that it can be harvested and indexed	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Accessible	RDA-A1-01M	Metadata contains information to enable the user to get access to the data	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	RDA-A1-02M	Metadata can be accessed manually (i.e. with human intervention)	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	RDA-A1-02D	Data can be accessed manually (i.e. with human intervention)	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	RDA-A1-03M	Metadata identifier resolves to a metadata record	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	RDA-A1-03D	Data identifier resolves to a digital object	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	RDA-A1-04M	Metadata is accessed through standardised protocol	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
	RDA-A1-04D	Data is accessible through standardised protocol	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
	RDA-A1-05D	Data can be accessed automatically (i.e. by a computer program)	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
	RDA-A1.1-01M	Metadata is accessible through a free access protocol	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
	RDA-A1.1-01D	Data is accessible through a free access protocol	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
	RDA-A1.2-01D	Data is accessible through an access protocol that supports authentication and authorisation	-	-	-	-	2	-	2		-	-	-	-	-	-	-
	RDA-A2-01M	Metadata is guaranteed to remain available after data is no longer available	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Interoperable	RDA-I1-01M	Metadata uses knowledge representation expressed in standardised format	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	RDA-I1-01D	Data uses knowledge representation expressed in standardised format	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	RDA-I1-02M	Metadata uses machine-understandable knowledge representation	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	RDA-I1-02D	Data uses machine-understandable knowledge representation	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	RDA-I2-01D	Data uses FAIR-compliant vocabularies	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	RDA-I3-01M	Metadata includes references to other metadata	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
	RDA-I3-01D	Data includes references to other data	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
	RDA-I3-02M	Metadata includes references to other data	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
	RDA-I3-02D	Data includes qualified references to other data	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
	RDA-I3-03M	Metadata includes qualified references to other metadata	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
	RDA-I3-04M	Metadata include qualified references to other data	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Reusable	RDA-R1-01M	Plurality of accurate and relevant attributes are provided to allow reuse	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
	RDA-R1.1-01M	Metadata includes information about the licence under which the data can be reused	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	RDA-R1.1-02M	Metadata refers to a standard reuse licence	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	RDA-R1.1-03M	Metadata refers to a machine-understandable reuse licence	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	RDA-R1.2-01M	Metadata includes provenance information according to community specific standards	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2
	RDA-R1.2-02M	Metadata includes provenance information according to a cross community language	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2
	RDA-R1.3-01M	Metadata complies with a community standard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	RDA-R1.3-01D	Data complies with a community standard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	RDA-R1.3-02M	Metadata is expressed in compliance with a machine-understandable community standard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	RDA-R1.3-02D	Data is expressed in compliance with a machine-understandable community standard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Table 6 : FAIR performance according to RDA matrix criteria

The table illustrates the association between each criterion of the model and the FAIR principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

4.1.6. Fostering Fair Data Practices in Europe (FAIRsFAIR)

The FAIRsFAIRs maturity model is organized around 4 categories that strictly abide to the FAIR foundational principles: Findable, Accessible, Interoperable and Reusable which include a total of 17 criteria that provide a structured approach for evaluating digital objects (Devaraju et al. 2020). These criteria are inspired by the criteria proposed by the RDA FAIR Data Maturity Model Working Group (David et al. 2020) and other previous initiatives such as FAIRdat, FAIREnough projects, and the WDS/RDA Assessment of Data Fitness for Use checklist (Diepenbroek et al. 2019). FAIRsFAIR applies these criteria through various means, including focus groups, internal reviews, user feedback, and the development of specialized tools such as F-UJI (Devaraju, Huber 2021) and FAIR-Aware (FAIR-Aware 2021).

The FAIRsFAIR matrix aligns strongly with both with the FAIR principles (both foundational and guiding), emphasizing the use of persistent identifiers and detailed metadata that can be retrieved automatically. It also underscores the need for standardized communication protocols to improve accessibility. Prioritizing standard knowledge representation languages and links between data enhances interoperability. Additionally, it highlights the importance of data provenance, licensing, and community standards to reinforce reusability (Table 7).

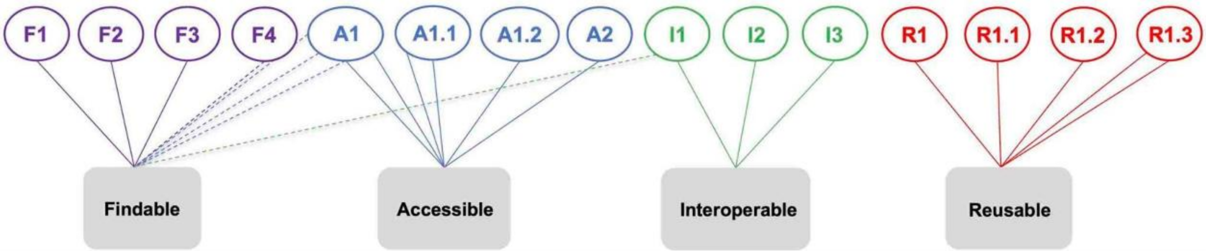

Figure 6 : Correlations between the FAIR guiding principles and the FAIRsFAIR matrix categories. Solid lines for high correlation, dashed lines for low correlation.

			Findable				Accessible				Interoperable			Reusable			
			F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
Categories	Identifiers	Criteria	Matrice FAIRsFAIR														
Findable	FsF-F1-01D	Data is assigned a globally unique identifier	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	FsF-F1-02D	Data is assigned a persistent identifier	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	FsF-F2-01M	Metadata includes descriptive core elements (creator, title, data ID, publisher, publication date, summary, keywords) to support data findability	-	2	-	-	-	-	-	-	-	-	-	2	-	-	-
	FsF-F3-01M	Metadata includes the identifier of the data it describes	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-
	FsF-F4-01M	Metadata is offered in such a way that can be retrived by machines	-	-	-	1	1	-	-	-	1	-	-	-	-	-	-
Accessible	FsF-A1-01M	Metadata contains access level and access conditions of the data	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	FsF-A1-02M	Metadata is accesible through a standardized communication protocol	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
	FsF-A2-03D	Data is accessible through a standardized communication protocol	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
	FsF-A2-01M	Metadata remains available, even if the data is no longer available	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Interoperable	FsF-I1-01M	Metadata is represented using a formal knowledge representation language	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	FsF-I1-02M	Metadata uses semantic resouces	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	FsF-I3-01M	Metadata includes links between the data and its related entities	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Reusable	FsF-R1-01MD	Metadata specifies the content of the data	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
	FsF-R1.1-01M	Metadata includes license information under which data can be reused	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
	FsF-R1.2-01M	Metadata includes provenance information about data creation or generation	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
	FsF-R1.3-01M	Metadata follows a standard recommended by the target research community of the data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	FsF-R1.3-02D	Data is available in a file format recommended by the target research community	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 7 : FAIR performance according to FAIRsFAIR matrix criteria

The table illustrates the association between each criterion of the model and the FAIR principles. The scores are indicated as follows: (-) for no correlation, (1) for low correlation, and (2) for correlation.

https://doi.org/10.55790/journals/ressi.2024.e1518

Our evaluation involved assigning points to the matrix criteria using a scale of 0 for not related, 1 for weakly related, and 2 for strongly related to each of the fifteen FAIR guiding principles. Our analysis aimed to evaluate the level of FAIRness of each maturity model. The cumulative scores in Figure 7 illustrate the various percentages of importance of each FAIR foundational principle in each model. The raw data from which the score was obtained are available at this address: https://zenodo.org/records/10471863

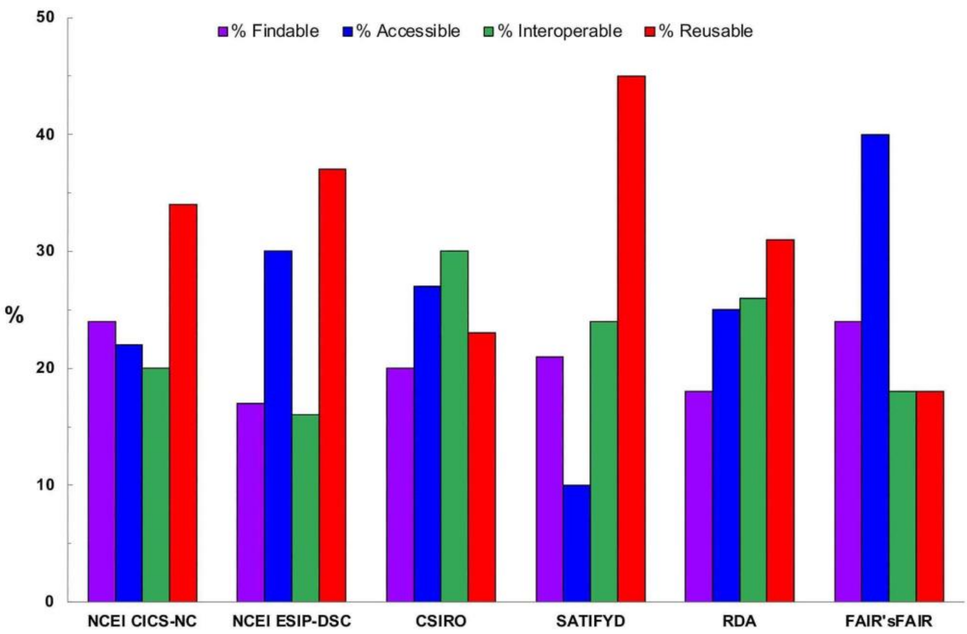

Figure 7 : Assessment of the importance of the FAIR principles across the six matrices.

The analysis of the different maturity models shows that each of them assigns a different level of priority to the FAIR foundational principles. The NCEI CICS-NC model places a strong emphasis on reusability (34%), while NCEI ESIP-DSC equally prioritizes reusability (37%) and accessibility (30%). Compared to other models, CSIRO has a strong focus on interoperability (30%), while SATIFYD strongly promotes reusability (45%). RDA emerges as the most balanced of all models, being strong on reusability while equally promoting accessibility, interoperability, and findability. FAIRsFAIR stands out for its significant emphasis on accessibility (40%). These differences highlight the different priorities of each model in promoting FAIRness in data management practices. Assessing the importance given by each model to each of the FAIR foundational principles was an essential step in ensuring that our model was as balanced as possible.

4.2. Design of a matrix-based maturity model applicable to architecture research data

The definition of the Architecture Maturity Model (AMM) axes aligns with the four FAIR foundational principles: Findable, Accessible, Interoperable, and Reusable. Drawing inspiration from the RDA, FAIRsFAIR, and SATIFYD maturity models, we have personalized our axes with descriptors such as Object Findability, Service Accessibility which is strongly influenced by the type of repository, Machine Interoperability, and Protocol of reusability. This choice ensures the clarity and simplicity of the axes of our model.

Presenting criteria in a question-based format, similar to the CSIRO and SATIFYD models, enhances engagement with data producers. Each axis consists of three criteria for a total of 12 questions. The selection of a limited number of criteria, expressed in simple language and using recurring vocabulary, ensures that the Architecture Maturity Model is consistent, familiar and accessible. Criteria identifiers follow the format AMM-criterion number, where AMM is the acronym for our model.

The model includes a detailed section on levels. Each level serves as a measure of the quality of a criterion and a prerequisite for assessing the FAIRness of the record. It outlines the FAIR expectations and emphasizes the additional steps required for higher levels. The scale, ranging from 1 to 3, allows for nuanced responses to the matrix questions, moving away from a binary (yes/no) assessment of the data. Level 1 signals non-compliance with Open Science criteria, while level 2, which demonstrates sensitivity to FAIR practices, may be considered acceptable. Level 3 conforms to the FAIR foundational principles. By identifying gaps and providing practical examples for improvement, this section serves as an important resource.

AXIS	CRITERIA	LEVEL
Object findability	AAM-01 Do you provide sufficient information to identify and find your object?	Level 1: No identifier Level 2: Unique identifier (e.g. Uniform Resource Identifier - URI) Level 3: Persistant and unique identifier (e.g. Digital Object Identifier - DOI)
	AMM-02 Do you provide detailed contextual information about your object?	Level 1: Minimum 10 (e.g. title, author, publisher, publication date, object identification) Level 2: Between 10 and 20 Level 3: More than 20 (e.g. file format and size, summary, keywords, licenses, language, localization, backers)
	AMM-03 Is the object findable by users other than the creator?	Level 1: Not indexed Level 2: Indexed in the repository Level 3: Indexed in databases searching engines
Service accessibility	AMM-04 Is your object easy to access?	Level 1: Accessible only by the creator Level 2: Accessible to the reference community Level 3: Accessible to all users
	AMM-05 Does the repository provide a free protocol for accessing the object?	Level 1: No protocol Level 2: Community-endorsed protocol Level 3: Open protocol (e.g. OAI-PMH - Open Archives Initiative Protocol for Metadata Harvesting)
	AMM-06 Does the service ensure metadata is accessible long term even if the data is no longer available?	Level 1: No conservation Level 2: As long as the repository exists Level 3: Throught migration to a perennial archive
Machine interoperability	AMM-07 Is your object described using community-endorsed metadata schema?	Level 1: Basic schema Level 2: Specialized schema (e.g. ethz) Level 3: Community-endorsed schema (e.g. XML schema, JSON schema)
	AMM-08 Is your object tagged with unambiguous definitions from controlled vocabularies?	Level 1: No vocabulary Level 2: Basic vocabulary (e.g. Wikidata) Level 3: Community-endorsed vocabulary (e.g. Getty Vocabularies, LCSH - Library of Congress Subject Headings, TGN - Thesaurus of Geographic Names, NASA Thesauri)
	AMM-09 Do you link your object to other objects using public identifiers?	Level 1: No link Level 2: Linked to an object of the same creator Level 3: Linked to an object of a different creator
Protocol of reusability	AMM-10 Is your object described so that it can be trusted for reuse?	Level 1: Basic informations (e.g. title, author, date) Level 2: Contextual informations (e.g. where, how and by whom the data were collected) Level 3: Contextual informations and README file
	AMM-11 Is your object reusable under an open licence?	Level 1: Proprietary license Level 2: License under conditions (e.g. CC BY-NC, CC BY) Level 3: Open License (e.g. CC0)
	AMM-12 Do you use open format to enable reusability?	Level 1: Proprietary file format (e.g. xls, doc, ppt) Level 2: Community-endorsed proprietary file format (e.g. format from 3D modelling, technical drawing or geospatial software) Level 3: Open file format

Table 8 : The matrix of the Architecture Maturity Model (AMM) including 4 axes, 12 criteria and 3 levels for evaluation.

4.3. Identification of repositories hosting architecture research data records

Once we identified the repositories recommended by the SNSF that hosted architectural research data, we proceeded with an in-depth search through the records stored at the ETH Research Collection and on Zenodo. We started with the ETH repository, using the equation “Switzerland AND (Architecture OR Urban OR Construction OR Engineering)” to search for relevant records. To refine our search, we also used equations that included ETH's D-BAUG (Department of Civil, Environmental and Geomatic Engineering) and D-ARCH (Department of Architecture). Overlapping results were observed and the 10 records that appeared in all searches were retained1. A preliminary analysis

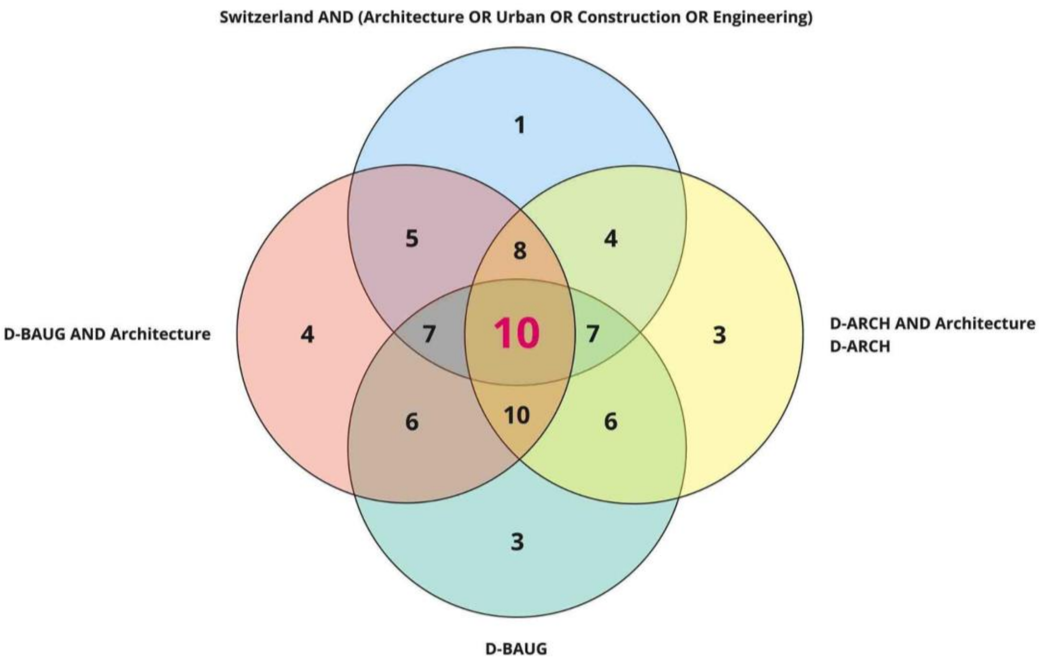

Figure 8 : Graph showing the results of our queries in ETH Research Collection

We continued our search in Zenodo, which is the recommended repository for the EPFL researchers. We began with the equation “Switzerland AND (Architecture OR Urban OR Construction OR Engineering)”, which didn’t give any results, and then added the tags EPFL and ENAC (School of Architecture, Civil and Environmental Engineering of the EPFL). By crossing the results of the different queries, we identified 17 records2. The initial analysis ensured that these records were in line with our research criteria.

https://doi.org/10.55790/journals/ressi.2024.e1518

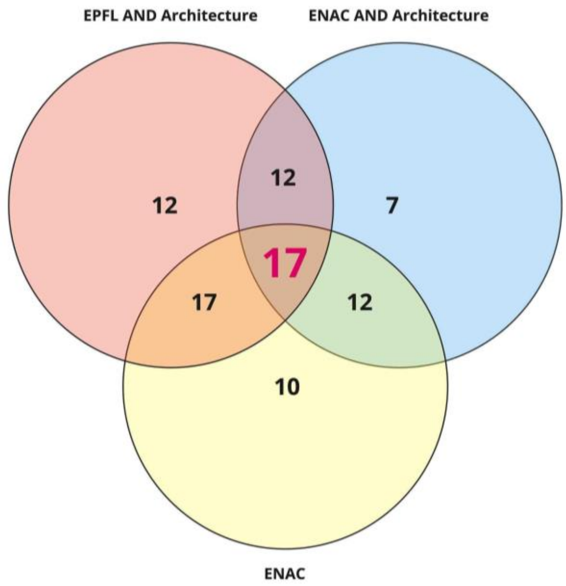

Figure 9 : Graph showing the results of our queries in Zenodo

4.4. Evaluation of the FAIRness of architecture research records

4.4.1. Preliminary evaluation

The 27 records found in the Zenodo and the ETH Research Collection repositories were evaluated. A checklist was created based on the defined parameters. The main findings are summarized below:

- DOI: all records contained a DOI, a feature systematically provided by Zenodo and by the ETH Research Collection.

- Title: all titles were in line with the field of architecture.

- Authorship: at least one of the authors was affiliated with a Swiss institution.

- Publication date: the records had been deposited since September 2014 until March 2023. This timeframe reflects an important development phase for Open Science practices, with the SNSF introducing its ORD policy in 2017.

- License: sixteen records were published under a CC BY 4.0 license, with a further four opting for CC BY-SA 4.0 and two for CC BY-NC 4.0. These licenses allow unrestricted sharing while requiring proper attribution to the authors. CC BY-SA 4.0 adds the “share under the same conditions” clause, while CC BY-NC 4.0 requires sharing for “non-commercial purposes only”. Only one record has chosen CC0, an option that completely removes copyright (Creative Commons 2023). One record used the Academic Free License v3.0 (AFL-3.0), designed specifically for open-source software (Academic Free License 2023). Four records used the Copyright - Non-Commercial Use Permitted statement, which is intended to provide a standardized statement of rights for cultural heritage materials available online. This statement is equivalent to the CC-BY-NC 4.0 license (Rights Statements 2023).

- Versioning: fifteen out of 27 records did not have a version number.

- README: twelve records were accompanied by README files; except for two README files in PDF format, the rest were in the TXT.

- Number of digital objects: the majority of the records included between 1 and 23 digital objects; there was only one record that had more than 290 digital objects in a ZIP file.

- Formats: twenty-eight file formats were identified, of which 17 were open and non-proprietary formats (DoRANum 2023; CECO 2023; UNIGE 2017). TXT (open) is the most common, followed by XLSX (closed), CSV (open), and PDF (open). Seven proprietary formats specific to architecture were identified, see details in Figure 10.

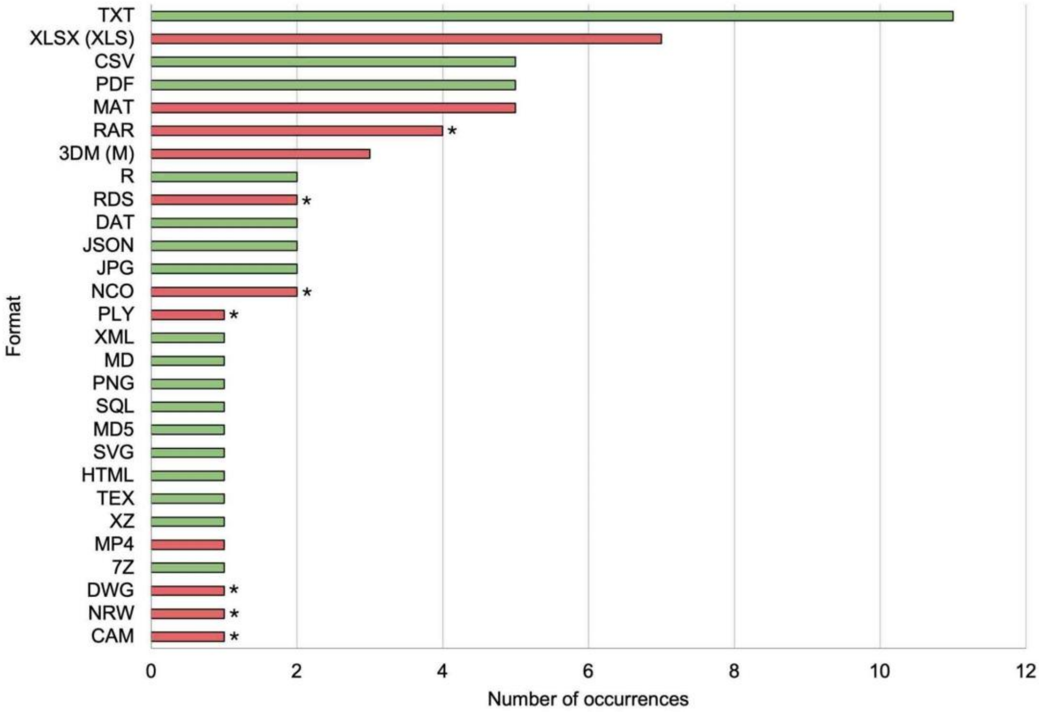

Figure 10 : Type of formats used in the architecture research records. Open formats are in green and proprietary formats are in red. Asterix indicates community-endorsed formats.

4.4.2. Evaluation of the FAIRness using the AMM

A comprehensive evaluation of the 27 datasets was undertaken, with each dataset carefully evaluated and each question systematically addressed. Since some of the questions were interrelated, they were evaluated at the same time. For example, criteria such as AMM-02, AMM-07, and AMM-08 were assessed together because they all address different facets of metadata associated with digital objects: confirming the presence of contextual information in the metadata (AMM-02), ensuring the use of a metadata schema to describe the object (AMM-07), and verifying the inclusion of controlled vocabulary in the metadata (AMM-08). Likewise, criteria AMM-10, AMM-11, and AMM-12 were considered simultaneously, taking into account aspects such as the presence of a README file (AMM-10), the type of licensing (AMM-11), and the adoption of open file formats (AMM-12). For criterion AMM-12, since it is common for a record to include digital objects in different formats, we calculated an average score. A low score was assigned if the formats were proprietary (level 1) or community-endorsed (level 2). To achieve level 3, all formats had to be open and non-proprietary. Most researchers in the architectural community typically use proprietary software, so it is not surprising that many records scored very low for criterion AMM-12 (Figure 10).

REPOSITORY	SOURCE	EVALUATION											
		Object findability			Service accessibility			Machine interoperability			Protocol of reusability		
		AMM-01	AMM-02	AMM-03	AMM-04	AMM-05	AMM-06	AMM-07	AMM-08	AMM-09	AMM-10	AMM-11	AMM-12
Zenodo	Ceperley et al. 2018	3	2	3	3	3	2	3	1	2	1	2	1
	Tondelli et al. 2014	3	2	3	3	3	2	3	1	1	3	2	1
	Tarquini, Almeida, Beyer 2018	3	2	3	3	3	2	3	1	1	3	2	2
	Petry, Beyer 2014a	3	2	3	3	3	2	3	1	2	1	2	1
	Tarquini, Almeida, Beyer 2015	3	2	3	3	3	2	3	1	1	1	2	2
	Paparo, Beyer 2015	3	2	3	3	3	2	3	1	2	1	3	2
	Petry, Beyer 2014b	3	2	3	3	3	2	3	1	2	1	2	1
	Terzis, Lyesse 2018	3	2	3	3	3	2	3	1	1	1	2	1
	Eskandari, Weinand 2023a	3	2	3	3	3	2	3	1	1	1	2	2
	Eskandari, Weinand 2023b	3	2	3	3	3	2	3	1	1	1	2	2
	Godio, Beyer 2018a	3	2	3	3	3	2	3	1	1	3	2	2
	Koseki 2020	3	2	3	3	3	2	3	1	1	1	2	3
	Godio, Beyer 2018b	3	2	3	3	3	2	3	1	2	3	2	3
	Asadollahi et al. 2019	3	2	3	3	3	2	3	1	1	1	2	3
	Yazandi et al. 2021	3	2	3	3	3	2	3	1	2	3	2	3
	Liu, Lecampion 2021	3	2	3	3	3	2	3	1	1	1	2	3
	Yazandi et al. 2022	3	2	3	3	3	2	3	1	2	3	2	2
ETH Research Collection	Chirkin 2018	3	3	2	3	3	3	2	1	2	3	2	3
	Schützeichel, Hänsli 2022	3	3	2	3	3	3	2	1	1	2	2	3
	Wicki et al. 2021	3	3	2	3	3	3	2	1	2	2	2	2
	Genser et al. 2022	3	2	3	3	3	3	2	1	2	1	2	3
	Lee, Mata Falcón, Kaufmann 2022b	3	2	2	3	3	3	2	1	2	3	2	1
	Lee, Mata Falcón, Kaufmann 2022c	3	2	2	3	3	3	2	1	2	3	2	1
	Lee, Mata Falcón, Kaufmann 2022a	3	2	2	3	3	3	2	1	2	3	2	1
	Lee, Mata Falcón, Kaufmann 2020	3	2	2	3	3	3	2	1	2	3	2	1
	Reuer et al. 2022	3	3	2	3	3	3	2	1	2	3	2	3
	Zimmerli, Abdala, Müller 2022	3	3	3	3	3	3	2	1	1	2	2	3
	AVERAGE SCORE	**3**	**2,3**	**2,6**	**3**	**3**	**2,5**	**2,5**	**1**	**1,6**	**2,1**	**2**	**2,1**

Table 9 : Results of the evaluation of the selected records using the AMM matrix.

While the primary focus of the Architecture Maturity Model (AMM) is to assess the FAIRness of records hosted in repositories, understanding the structural aspect of the repository becomes essential to provide a comprehensive assessment of this evaluation. In recognition of this fact, specific criteria, namely AMM-04, AMM-05, and AMM-06, have been incorporated into the model to address repository-specific attributes. These criteria play a critical role in evaluating aspects such as the ease of access to digital objects (AMM-04), the provision of a free protocol for accessing these objects (AMM-05), and the repository's commitment to ensuring the long-term accessibility of metadata (AMM-06). The average score for criterion AMM-06 is 2.5. This reflects the fact that services like Zenodo, unlike the ETH Research Collection, do not guarantee the long-term persistence of the records stored in them.

Through the inclusion of these criteria, the AMM aims to measure essential dimensions of FAIRness that go beyond the level of the record and to provide a comprehensive assessment that encompasses both the quality of the records and the supporting structures provided by the hosting repositories.

5. Discussion

This study aims to assess the FAIRness of architectural research data to highlight the limitations of current practices and to propose new ways to improve the accessibility, transparency, and reusability of this type of records. To achieve this, we propose the AMM, a user-friendly maturity model based on a matrix. This model provides data producers with a tool to evaluate the FAIRness of their data before submission to a repository.

Our approach includes an analysis of six existing models to identify criteria applicable to our domain, as there was no specific maturity model for architectural data prior to this study. We started analyzing these models to identify criteria relevant to our field. The results indicate that most matrices prioritize one FAIR principle over others: The NCEI/CICS-NS, NCEI/ESIP-DCS, and SATIFYD models place significant emphasis on reusability, while the FAIRsFAIR matrix assigns the greatest importance to accessibility. The RDA and CSIRO matrices give relatively equal weight to each principle. Overall, the principle of reusability is consistently strong across all matrices, indicating a comprehensive interest in making data as open and reusable as possible. In contrast, the percentage of criteria associated with findability and interoperability remains relatively low. Finally, the principle of accessibility varies across different matrices. The SATIFYD matrix places the least emphasis on accessibility, while the FAIRsFAIR matrix gives it the most importance.

Inspired by the RDA model, we chose to balance the weight of the FAIR foundational principles in the design of our model. For clarity, we labeled our axes as Object Findability, Service Accessibility, Machine Interoperability, and Protocol of Reusability. In keeping with our commitment to a comprehensive approach to FAIRness, each axe includes three criteria that are aligned with the FAIR foundational principles proposed by Wilkinson (Wilkinson et al. 2016). To engage data providers, we have chosen to develop our model in a format similar to that used by CSIRO and SATIFYD, as the questions will be easy for non-specialists to understand. In summary, to simplify the process, our Architecture Maturity Model (AMM) consists of 12 criteria, in the form of questions, divided into four axes, each rated on a scale of 1 to 3.

Before submitting the selected records for evaluation using our AMM model, we performed a preliminary analysis. This first rough evaluation applied to 27 architecture-related records from Zenodo and the ETH Research Collection enabled us to observe the following: Each record had a DOI from one of the two repositories. The licenses were varied, with most of them using Creative Commons licenses. Fifteen records had no versioning and twelve contained README files. The file formats identified were for the most open formats. However, a significant number of proprietary architecture-specific formats were also used. Overall, these findings highlight the diverse characteristics of architectural research records regarding DOI, licensing, versioning, and format.

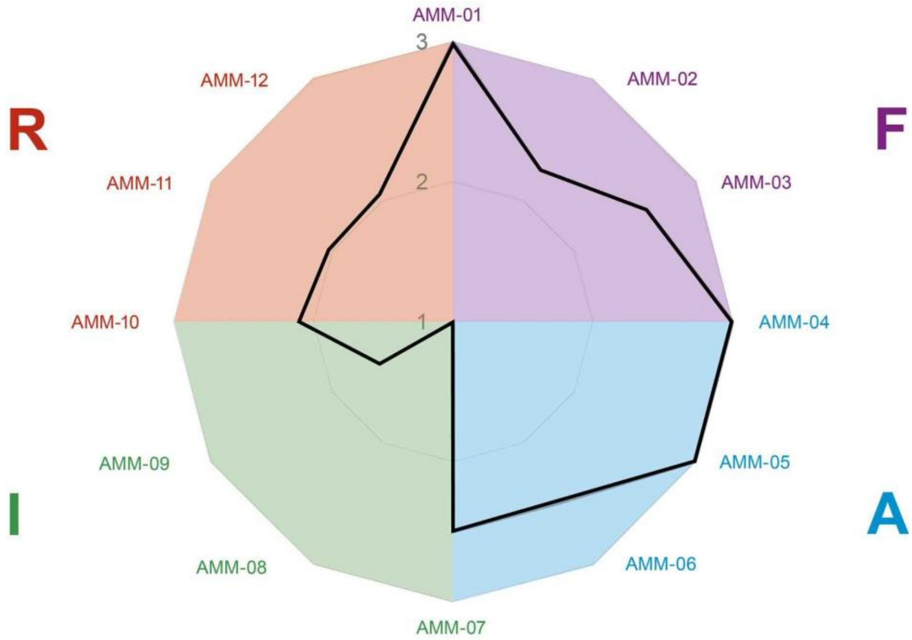

Figure 11 : Average scores for each criterion across the 27 records analyzed: the radar chart provides a visual representation of our evaluation by presenting the scores on a scale of values (1 to 3).

To evaluate the FAIRness of the 27 datasets based on the scores for each criterion used by the AMM model, we look at the assigned scores for Object Discoverability, Service Accessibility, Machine Interoperability, and Protocol of Reusability. The scores for each criterion (AMM-01 through AMM-12) indicate the degree to which the FAIR foundational principles are met, with 3 being the highest and 1 being the lowest.

All records achieve the maximum score for AMM-01 because they all have a DOI, but not all records are described by detailed metadata and therefore score lower for AMM-02. In addition, records in the ETH repository score low at AMM-03, due to their lack of external indexing, which affects their overall findability.

The service structure has a significant impact on the accessibility of the data. Since both repositories provide an open protocol to ensure easy access, all records achieve the highest accessibility scores for AMM-04. Because the repositories ensure long-term access to the metadata, the records also have a high score for AMM-05. Only the datasets stored in the ETH Research Collection, which guarantee long-term accessibility of the data, achieve a high score for AMM-06.

In terms of interoperability, most datasets excel at describing digital objects using metadata standards, as reflected by their high scores in AMM-07. However, their performance drops significantly in AMM-08, where the lack of controlled vocabularies in the metadata results in the lowest possible score of 1. Finally, most records receive low scores in AMM-09 because few digital objects are described using public identifiers in the metadata.

The need for improvement around reusability is evident, as the lack of thorough descriptions in most digital objects is a contributing factor to low AMM-10 scores. In addition, the prevalence of licenses with restrictions contributes to low scores in AMM-11. Finally, choosing proprietary over open formats affects AMM-12. Overall, none of the repositories achieve a maximum score.

6. Conclusion

This study uses a self-developed maturity model to assess the FAIRness of architectural research data in Switzerland. The maturity model is derived from the evaluation of six existing MMMs against the fifteen FAIR guiding principles. Our maturity model, the AMM, prioritizes object findability, service accessibility, machine interoperability, and protocol of reusability, and encourages detailed scoring on a scale of 1 to 3.

The decision to use a question-based framework was driven by the belief that this format is not only accessible, but also creates a direct connection with those producing the data, thus encouraging better engagement. Consistent with our commitment to a single, familiar, accessible maturity model, we chose to use a limited number of criteria. These criteria are articulated using simplified language and recurring vocabulary.

In our study, we identified 27 relevant datasets. We performed a comprehensive evaluation and applied the AMM to determine their level of FAIRness. The evaluation of the architectural research records based on our AMM model reveals varying degrees of adherence to the FAIR foundational principles. While all records achieve high score for findability due to the presence of DOIs, challenges arise in the areas of detailed metadata and external indexing, affecting overall findability. Accessibility also scores highly, thanks to open protocols and long-term metadata access. Interoperability performs poorly, especially when it comes to controlled vocabularies and linked identifiers. Reusability is hampered by detailed descriptions, licensing restrictions and proprietary formats.

In conclusion, our analysis shows that architectural research records are remarkably discoverable and accessible, but that challenges remain in achieving interoperability. Despite these challenges, our findings suggest that promoting reusability in Swiss architectural research is achievable by adopting open formats and licenses. Finally, our research underscores the critical importance of adopting the AMM. This model can be used to assess the FAIR maturity of data across disciplines because it relies on metrics that are easily understood, transparent, and unambiguous.

Bibliography

AHERN, Dennis, CLOUSE, Aaron et TURNER, Richard, 2004. CMMI distilled: a practical introduction to integrated process improvement. Addison-Wesley [en ligne]. Disponible à l'adresse : https://www.researchgate.net/publication/234831325_CmmiR_distilled_a_practical_introduction_to_integrated_process_improvement_third_edition [consulté le 5 novembre 2023].

BAHIM, Christophe et al., 2020. The FAIR Data Maturity Model: An Approach to Harmonise FAIR Assessments. Data Science Journal. No 19, pp. 1 7. DOI 10.5334/dsj-2020-041. Accepted: 2021-04-06T19:47:01Z

BAHIM, Christophe, DEKKERS, Makx et WYNS, Brecht, 2019. Results of an Analysis of Existing FAIR Assessment Tools [en ligne]. Disponible à l'adresse : https://zenodo.org/records/3629618 [consulté le 5 novembre 2023]. DOI 10.15497/rda00035

CORETRUSTSEAL, 2022. CoreTrustSeal Requirements 2023-2025. DOI 10.5281/zenodo.7051012.

COX, Simon et YU, Jonathan, 2017. OzNome 5-star Tool: A Rating System for making data FAIR and Trustable. In : 11th eResearch Australasia Conference. eResearch Australasia. 2017. DOI http://hdl.handle.net/102.100.100/87792?index=1.

CSIRO, 2017. 5-star Data Rating Tool. csiro-enviro-informatics.github.io [en ligne]. 2017. Disponible à l'adresse : https://csiro-enviro-informatics.github.io/5stardata/ [consulté le 10 novembre 2023].

DAVID, Romain et al., 2020. Templates for FAIRness evaluation criteria - RDA-SHARC ig. Zenodo. DOI 10.5281/zenodo.3922069.

DEVARAJU, Anusuriya et al., 2020. FAIRsFAIR Data Object Assessment Metrics. Fostering FAIR Data Practices in Europe. DOI 10.5281/zenodo.4081213.

DEVARAJU, Anusuriya et HUBER, Robert, 2021. An automated solution for measuring the progress toward FAIR research data. Patterns. Vol. 2, no 11. DOI 10.1016/j.patter.2021.100370.

DIEPENBROEK, Michael et al., 2019. WDS/RDA Assessment of Data Fitness for Use WG Outputs and Recommendations [en ligne]. Disponible à l'adresse : https://www.rd-alliance.org/group/wdsrda-assessment-data-fitness-use-wg/outcomes/wdsrda-assessment-data-fitness-use-wg-outputs [consulté le 10 novembre 2023]. DOI 10.15497/rda00034

ETH RESEARCH COLLECTION, 2023. Repository for Publications and Research Data. research-collection.ethz.ch [en ligne]. 2023. Disponible à l'adresse : https://www.research-collection.ethz.ch/?locale-attribute=en&locale-attribute=de [consulté le 2 août 2023].

FAIR-AWARE, 2021. Online assessment tool. fairaware.dans.knaw.nl [en ligne]. 2021. Disponible à l'adresse : https://fairaware.dans.knaw.nl [consulté le 10 novembre 2023].

FAIRSFAIR, 2019. FAIRsFAIR in EOSC. fairsfair.eu [en ligne]. 2019. Disponible à l'adresse : https://www.fairsfair.eu/fairsfair-eosc [consulté le 10 novembre 2023].

FANKHAUSER, Eliane et al., 2019. SATIFYD : Self-Assessment Tool to Improve the FAIRness of Your Dataset [en ligne]. Data Archiving and Networked Services. Disponible à l'adresse : https://satifyd.dans.knaw.nl/#fhelp [consulté le 13 novembre 2023].

FONDS NATIONAL SUISSE, 2023. Quels dépôts de données peuvent être utilisés ? snf.ch [en ligne]. 2023. Disponible à l'adresse : https://www.snf.ch/fr/WtezJ6qxuTRnSYgF/dossier/undefined/fr/WtezJ6qxuTRnSYgF/dossier/ [consulté le 22 mars 2023].

FORCE11, 2021. The FAIR Data Principles. force11.org [en ligne]. 2021. Disponible à l'adresse : https://force11.org/info/the-fair-data-principles/ [consulté le 27 mars 2023].

GENOVA, Françoise et al., 2021. Recommendations on certifying services required to enable FAIR within EOSC [en ligne]. Luxembourg : Publications Office of the European Union. ISBN 978-92-76-28112-2. Disponible à l'adresse : https://data.europa.eu/doi/10.2777/127253 [consulté le 7 janvier 2024].

GITHUB, 2023. FAIR Maturity Indicators and Tools [logiciel] [en ligne]. 16 août 2023. FAIR Maturity Testing and Evaluation. [consulté le 22 septembre 2023]. Disponible à l'adresse : https://github.com/FAIRMetrics/Metrics [consulté le 22 septembre 2023].

LIN, Dawei et al., 2020. The TRUST Principles for digital repositories. Scientific Data. Vol. 7, no 1, p. 144. DOI 10.1038/s41597-020-0486-7.

MM-SERV WORKING GROUP, 2018. NCEI/ESIP-DSC Data Use and Services Maturity Matrix (MM-Serv) [en ligne]. ESIP. Disponible à l'adresse : https://esip.figshare.com/articles/poster/MM-Serv_ESIP_2018sum_v2r1_20180709_pdf/6855020/1 [consulté le 8 novembre 2023]. DOI 10.6084/m9.figshare.6855020.v1

MOSLEY, M. et al., 2010. DAMA guide to the data management body of knowledge [en ligne]. Technics Publications. Disponible à l'adresse : https://www.dataversity.net/what-is-the-data-management-body-of-knowledge-dmbok/ [consulté le 10 novembre 2023].

NOLAN, Richard L., 1973. Managing the computer resource: a stage hypothesis. Communications of the ACM. Vol. 16, no 7, pp. 399 405. DOI 10.1145/362280.362284.

ORGANISATION INTERNATIONALE DE NORMALISATION, 2004. Information technology — Process assessment [en ligne]. Genève : International Organization for Standardization. ISO/IEC 15504-3:2004. Disponible à l'adresse : https://connect.snv.ch/en/iso-iec-15504-3-2004 [consulté le 8 novembre 2023].

PENG, Ge et al., 2015. A Unified Framework for Measuring Stewardship Practices Applied to Digital Environmental Datasets. Data Science Journal. Vol. 13. DOI 10.2481/dsj.14-049.

RE3DATA, 2023. Browse by subject. re3data.org [en ligne]. 2023. Disponible à l'adresse : https://www.re3data.org/browse/by-subject/ [consulté le 27 mars 2023].

RESEARCH DATA ALLIANCE, 2020. FAIR Data Maturity Model: specification and guidelines [en ligne]. Disponible à l'adresse : https://www.rd-alliance.org/group/fair-data-maturity-model-wg/outcomes/fair-data-maturity-model-specification-and-guidelines [consulté le 26 mars 2023]. DOI 10.5334/dsj-2021-004

RESEARCH LIBRARIES GROUP, 2001. Attributes of a Trusted Digital Repository: Meeting the Needs of Research Resources [en ligne]. Mountain View CA. Disponible à l'adresse : https://www.oclc.org/content/dam/research/activities/trustedrep/attributes01.pdf [consulté le 5 novembre 2023].

WILKINSON, Mark et al., 2016. The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data. Vol. 3, no 1. DOI 10.1038/sdata.2016.18.

WILKINSON, Mark D. et al., 2018. A design framework and exemplar metrics for FAIRness. Scientific Data. Vol. 5, no 1. DOI 10.1038/sdata.2018.118.

WILKINSON, Mark D. et al., 2019. Evaluating FAIR maturity through a scalable, automated, community-governed framework. Scientific Data. Vol. 6, no 1. DOI 10.1038/s41597-019-0184-5.

YU, Jonathan, 2017. 5 Star Data Rating Tool. data.csiro.au [en ligne]. 2017. Disponible à l'adresse : https://data.csiro.au/collection/csiro:33417 [consulté le 10 novembre 2023].

ZENODO, 2023. Zenodo - Research. Shared. zenodo.org [en ligne]. 2023. Disponible à l'adresse : https://zenodo.org/ [consulté le 2 août 2023].

Sources of evaluated datasets

ASADOLLAHI, Mitra et al., 2019. Dataset from: Transport and water age dynamics in soils: a comparative study of spatially-integrated and spatially-explicit models. Zenodo. DOI 10.5281/zenodo.3457960.

CEPERLEY, Natalie et al., 2018. Salt gauging and stage-discharge curve, Avançon de Nant, outlet Vallon de Nant catchment. Zenodo. DOI 10.5281/zenodo.1154798.

CHIRKIN, Artem, 2018. Qua-kit data: Urban Design Submissions: Urban Design submissions produced by students of the Future Cities course series at edX and analysis materials. ETH Research Collection. DOI 10.3929/ethz-b-000310053.

ESKANDARI, Farzaneh et WEINAND, Yves, 2023a. Three dimensional reconstruction of an existing age-old wooden shingle roof. Zenodo. DOI 10.5281/zenodo.7752044.

ESKANDARI, Farzaneh et WEINAND, Yves, 2023b. Digital twin of wooden shingle envelopes. Zenodo. DOI 10.5281/zenodo.7748986.

GENSER, Alexander et al., 2022. A traffic signal and loop detector dataset of an urban intersection regulated by a fully actuated signal control system. ETH Research Collection. DOI 10.3929/ethz-b-000556642.

GODIO, Michele et BEYER, Katrin, 2018a. Supplemental material to « Tri-linear model for the out-of-plane seismic assessment of vertically-spanning unreinforced masonry walls ». Zenodo. DOI 10.5281/zenodo.3257530.

GODIO, Michele et BEYER, Katrin, 2018b. Supplemental material to « Evaluation of force-based and displacement-based out-of-plane seismic assessment methods for unreinforced masonry walls through refined model simulations ». Zenodo. DOI 10.5281/zenodo.3258143.

KOSEKI, 2020. Communs paysagers de la Ville-territoire: Design, démocratie et outils numériques. Zenodo. DOI 10.5281/zenodo.3938438.

LEE, Minu, MATA FALCÓN, Jaime et KAUFMANN, Walter, 2020. Uniaxial tension tests on concrete elements with weft-knitted textile reinforcement (KnitCrete). ETH Research Collection. DOI 10.3929/ethz-b-000443651.

LEE, Minu, MATA FALCÓN, Jaime et KAUFMANN, Walter, 2022a. Four-point bending tests on concrete elements with weft-knitted textile reinforcement, short integral glass fibres and spatial features (KnitCrete). ETH Research Collection. DOI 10.3929/ethz-b-000535030.

LEE, Minu, MATA FALCÓN, Jaime et KAUFMANN, Walter, 2022b. Three-point bending tests on concrete beams with thin-walled I-profile cross-sections using stay-in-place flexible formworks with integrated transverse textile reinforcement (KnitCrete). ETH Research Collection. DOI 10.3929/ethz-b-000555795.

LEE, Minu, MATA FALCÓN, Jaime et KAUFMANN, Walter, 2022c. Three-point bending tests on concrete beams with rectangular cross-sections using stay-in-place flexible formworks with integrated transverse textile reinforcement (KnitCrete). ETH Research Collection. DOI 10.3929/ethz-b-000546394.

LIU, Dong et LECAMPION, Brice, 2021. Hydraulic fracturing block test experiments in Gabbro & Marble - experiments # GABB-002 & MARB-007 [en ligne]. Zenodo. Disponible à l'adresse : https://zenodo.org/records/5525773 [consulté le 10 novembre 2023].

PAPARO, Alessandro et BEYER, Katrin, 2015. Quasi-static cyclic tests on 2 systems with one RC and one URM wall each [en ligne]. Zenodo. Disponible à l'adresse : https://zenodo.org/records/13824 [consulté le 10 novembre 2023].

PETRY, Sarah et BEYER, Katrin, 2014a. Cyclic test data of five URM walls at half-scale. Zenodo. DOI 10.5281/zenodo.12873.

PETRY, Sarah et BEYER, Katrin, 2014b. Cyclic test data of six unreinforced masonry walls with different boundary conditions. Zenodo. DOI 10.5281/zenodo.8443.

REUER, Kevin et al., 2022. Realization of a Universal Quantum Gate Set for Itinerant Microwave Photons. ETH Research Collection. DOI 10.3929/ethz-b-000555800.

SCHÜTZEICHEL, Rainer et HÄNSLI, Thomas Daniel, 2022. Experimental Design in the Post-War Period (Research Data): Heinz Isler's (1926-2009) Contribution in the Perspective of the History of Engineering and Culture. ETH Research Collection. DOI 10.3929/ethz-b-000570137.

TARQUINI, Danilo, ALMEIDA, João Pacheco et BEYER, Katrin, 2015. Database on 16 reinforced concrete walls with lap splices and 8 reference units with continuous reinforcement (V2 models included). Zenodo. DOI 10.5281/zenodo.2653488.

TARQUINI, Danilo, ALMEIDA, João Pacheco et BEYER, Katrin, 2018. Uniaxial Cyclic Tests on Reinforced Concrete Members with Lap Splices [en ligne]. Zenodo. Disponible à l'adresse : https://zenodo.org/records/1205887 [consulté le 10 novembre 2023].

TERZIS, Dimitrios et LYESSE, Laloui, 2018. 3-D micro-architecture and mechanical response of soil cemented via microbial-induced calcite precipitation. Zenodo. DOI 10.1038/s41598-018-19895-w.

TONDELLI, Marco et al., 2014. Dynamic testing of a four-storey building with reinforced concrete and unreinforced masonry wall: Data set. Zenodo. DOI 10.5281/zenodo.11578.

WICKI, Michael et al., 2021. Dataset: Housing Situation and Acceptance of Densification in Global Metropolises. ETH Research Collection. DOI 10.3929/ethz-b-000513683.

YAZANDI, Amir et al., 2021. AMS and FTIR spectra of primary and aged fine PM from wood burning and coal combustion. Zenodo. DOI 10.5281/zenodo.4882967.

YAZANDI, Amir et al., 2022. AMS and FTIR measurements and the corresponding codes for their statistical combination. Zenodo. DOI 10.5281/zenodo.5872710.

ZIMMERLI, Nora, ABDALA, Paula Macarena et MÜLLER, Christoph R., 2022. Probing the Electronic, Atomic and Nanoscale Structure of Ni-Ga/SiO2 Catalysts for CO2 Hydrogenation to Methanol Via Operando X-Ray Absorption Spectroscopy and X-Ray Total Scattering. ETH Research Collection. DOI 10.3929/ethz-b-000555801.