9. TECHNOLOGIES FOR RESEARCH DATA MANAGEMENT ACCORDING TO FAIR

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9.1 INTRODUCTION

Since science emerged as an activity separated from philosophy, it has evolved as the scientific community has been structuring, adapting and influencing technological change. In this matter, technology has always been present, being one of the results arising from science, mainly from rigid sciences, in partnership with engineering. However, it can be said that computer science and the Web, created in the middle of the 20th century, respectively, were landmarks that had a significant impact in the sciences, among other human activities. This is so clear that there are already studies on the so-called artificial science and virtual science, complementing the natural sciences, in which natural phenomena are simulated through computing, or virtual scenarios are created for research.

In scientific communication, the technology, mainly the web, also had such an impact on processes adopted by researchers that, for many thinkers, the Web has the same impact on sharing information as on the invention of Gutenberg's press. In this way of the Web, at the end of the 20th century, two initiatives arose and consolidated, being accepted in the worldwide scientific Community: Open Archives and Access, which are often confused for having the same acronym in English, but they have different aspects.

Open Archives have technological alignment, focused on interoperability, on the possibility of information exchange between computerized systems, initially oriented to digital libraries. This initiative was created by Convenção de Santa Fé (Santa Fé Convention), described by Van de Sompel and Langoze (2000) as oriented to the creation of informational infrastructure for interoperability, mainly for *preprints*. Soon after, it was used by Suleman and Fox (2001) for the creation of digital libraries of thesis and dissertations, for the creation of *Networked Digital Library of Theses and Dissertations* (NDLTD). In Brazil, Open Archives influenced the development of the Digital Library of Theses and Dissertations (DLTD).

Open Access, in its turn, has more philosophical aspects. Originated from the called journal crisis, it defends access with no restrictions to research results. For the implementation of this initiative, Harnad *et al.* (2004) suggested the use of open-access magazines (golden route) and the use of repositories (green route). In Brazil, initiatives such as Bioline *International*, 1993, and *Scientific Electronic Library Online* (SciELO), 1997, were pioneers in supporting the

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publication of sets of open-access magazines in electronic environments, representing the golden route. Later, several magazines started to offer free access, and universities created repositories for providing wide access and flow to their scientific production.

Even presenting distinct origins and settings, Open Archives and Open Access merged themselves, as some software sets for the creation of magazines and repositories blend some precepts from both initiatives. However, during some time, in Brazilian universities, libraries of thesis and dissertations and repositories coexisted, for they originated from different initiatives. Due to its conceptual aspects, Open Access comprises open archives in numerous instances.

In this path of opening up science activities, another initiative has been gaining force, the so-called Research Open Data, which acts on the dissemination of data collected or generated in the scope of scientific research. Data sharing through the Internet is not new, so Much that government data has been publicly available, as a way to provide more transparency to the public administration, according to the Access to Information Law (AIL) in Brazil. However, sensitive data resulting from research, still requires attention and discussions, in the same way that the act of sharing requires implementation of computerized platforms specific to the several types and formats of research data.

In this context, Open Data requires discussions for its implementation, even though it presents advantages to the research. One of the points is found in technologies available to be used for data deposit. Another point involves issues concerning protection, restriction, sensibility and many other issues in the scope of research data management, and that need more consensus so that technologies can reach levels of consensus, explicit, for instance, by initiatives as FAIR principles.

9.2 RESEARCH OPEN DATA

In the model of scientific communication proposed by Björk (2007), issues related to research data show up in the processes of research execution and communication of results. Regarding the research execution, the author reports that the research includes four global activities, one of which involves collecting existing data in repositories. That is, in addition to literature review, it is necessary to review existing data, relating them to the context of the research being executed. In the communication of results, in its turn, researchers must deposit their research data in repositories as a way to promote the reproducibility and the reuse in new studies.

This model is aligned to practices linked to open data, as it occurs in research processes and dissemination of data, in a cyclical process, in which existing data support the creation of new data. Murray-Rust (2008), discussing open data in science, emphasizes that they have data sharing for reuse as a principle, in a way to enable new perceptions, regrouping, additions, etc. Thus, the Open Data Initiative represents the removal of barriers when sharing research data, as in an Evolution of Open Access, which removed barriers for the access of articles resulting from research.

Pampel and Dallmeier-Tiessen (2014) advocate for what they call new science, made by sharing and reducing barriers, revealing the need to create strategies for promoting and opening data due to the increasing demand by the community for such practices. For the authors referred, one of the fundamental points for open data success is research data management through infrastructure based on robust policies that support cooperation among scholars, as far as changes in scientific practices only occur with the approval of the academic community.

Evidently, the challenges do not refer only to researchers' behavior. Borgerud and Borglunf (2020), for example, report that in Switzerland, even with federal regulations, opening research data is challenging and raises issues such as the preservation for long periods of time, in a Mertonian view of data archiving, based on accessibility, preservation, verification, and reusability principles. Despite being preliminary, this study reverberates what may countries face, reflecting that it is not enough for the community to accept a new practice, coupled with the government action in implementing laws and other support regulations; it is also necessary studies that support the creation of infrastructure that meets and supports these new practices.

Another point discussed in opening research data is quality. In this matter, Koltay (2020) discusses data reliability with several relations and criteria that help in its verification, such as originality, methods of collection and processing, authenticity, acceptability, applicability, among others. Likewise, the author points out concerns with technical quality in relation to databases shared, aiming at enabling the reuse of data in it. At this point, the author reaffirms the need of data curation to guarantee integrity and authenticity, with the aim of allowing researchers to access reliable and safe databases.

In this context, it is revealed that open data has complexities and challenges in its implementation, involving cultural, procedural, technological, legal issues, among others. Eliminating barriers for research data sharing requires studies in several fields, which must create an extensive conceptual basis that will guide the confrontation of several challenges. Thus, it must be ensured that the actions, methods, and Technologies seek to efficiently meet the purpose of reusing data.

9.3 RESEARCH DATA

The concept of research data, according to Costa (2017), may be affected or influenced by several categories that are assigned to data itself, thus causing the emergence of several definitions that reflect the typology of data, its forms of generation, collection or access, its purposes, research stages in which data is use or generated, etc.

In this matter, research data differs according to the subject, in most cases due to methods used, as rigid sciences generally have a preference for quantitative methods, while humanities, in its turn, prefer more qualitative methods. Thus, research data reflect methodological procedures, generating data more or less structured and composing databases with significant differences, which reflect the nature of the subject, creating different challenges.

Thus, the subjects must have different recommendations, depending on the type of database. Specifically in social sciences, Diaz (2019) recommends that data sharing requires concerns about the current regulations in the country, the code of ethics and laws that guide from data collection to data release, ensuring that data sharing, verification of risks, support from institution in the process are allowed by the researcher, and awareness about ethical responsibilities of the research and collected data.

In the same vein, Sayão and Sales (2016) observe that "the term 'research data' has a range of meanings that change according to specific scientific domains, research objects, methodologies of creation and collection of data and many Other variables".

One of the most recurrent definitions cited in literature is the one presented by the U.S. National Science Board (2011), according to which research data are factual records in the digital environment, generally accepted by the academic community with the purpose of validating research outcomes. Such definition may be understood as restrictive, once it excludes the possibility of data as physical objects and, in this case, including document objects, besides a different category of material records, not digital or computerized, which may be useful in the context of humanities, for instance. Nevertheless, the communication, in general, requires the transposition or different representations for other forms of record, with a heavier logical and conceptual upload. In this matter, the broader definition, presented by Sales and Sayão (2019), helps to accommodate possible variations of context. These authors define research data as "every and any type of record collected, observed or used by scientific research, treated and accepted as necessary for validating the research outcomes by the scientific community" (Sales; Sayão, 2019, p. 36).

The predilection for the digital nature of data is not new, and may refer to the concept of *datalogy*, originally presented by Peter Naur in 1966 to refer to the study and processing of data in already computerized environments (Naur, 2007; Zhu; Xiong, 2015). More recently, Zhu and Xiong (2015) also questioned an interesting distinction, to outline an object of study of data Science, based on the separation between natural phenomena (*real nature*), or observable through the natural or real world of digital phenomena, which other authors define as *data nature*.

Still, in order to define and outline research data, Costa (2017) highlighted some important concepts and practices in this matter, among which the management and life cycle of research data. The author points out that management involves processes of planning, manipulation, storage, and preservation of research data, while Sayão and Sales (2016) discuss actions that collectively permeate the life cycle of research data, in addition to application of standards widely accepted by several academic or disciplinary instances. Sales, Costa and Shintaku (2020) present three potential contexts of research data management application, namely: the context of researchers themselves, the data supporting their research; the context of funding agencies focused on the impact and contribution of research, which is potentially measurable through data sharing; and the context of scientific editors, focused on the verification and reproducibility of research outcomes through data. Data life cycle, in its turn, may include several stages that vary according to the complexity of the cycle, which generally starts with the generation or collection stage, up to reuse or disposal stages, when it is applicable.

Considering the universe of technologies available in data context, it is important to consider different forms or media of data record for presenting a certain reality, such factors influence the capacity or conditions of accessing or using research data. Enabling data to transit among technologies, keeping its qualitative aspects and its reproducibility and preservation aspects, as well as data analysis and interpretation, requires an upload of what might be called data competence or a satisfactory level of so-called data literacy.

Baykoucheva (2015) presents this literacy as skills for data reading, interpretation and understanding, emphasizing the importance of incorporating programs aimed at literacy in data and information, with an index of content and specific competences. The author points out that many aspects that have already been researched with the aim of data literacy are close to or encompass statistical literacy, dealing with applying critical thinking to descriptive statistics. Calzada Prado and Marzal (2013), in turn, point out the emergency of training in competences beyond the statistical scope, encompassing competences for data acquisition, evaluation, treatment and processing, analysis and interpretation tasks. In this matter, it is essentially the understanding and domain of the technology universe that support such tasks.

9.4 TECHNOLOGIES AND THEIR FAIR CRITERIA

According to Björk's (2007) scientific communication model, research data can be sought and shared in repositories, depending on the type and moment in which the research is. Thus, repositories become the most appropriate information system to offer functionalities as database deposit and retrieval. Likewise, They can also offer functionalities for research databases management, involving other services.

However, repositories were originally considered Open Access as the Green Route (Harnad *et al.*, 2004), in which copies of articles published in magazines were freely available, so Weitzel (2006) considered repositories as a second source. With the possibility of managing research data, repositories have a different meaning, adding appropriate functionalities for this type of digital object.

Verification of software suitability for database management can be done in several ways, with several models of evaluation, depending on the purpose. In the study herein, compliance with FAIR principles, acronym for *findable, accessible, interoperable, reusable* is used. For that matter, it is considered:

a. **findable**: enables description by metadata and allows the use of persistent identifiers;

b. **accessible**: can be accessed by humans or machines, offer clear licenses and provide communication protocols;

c. **interoperable**: metadata standard can be understood by machines and functionalities for understanding databases;

d. **reusable**: database described to enable its rescue.

Evidently, FAIR basic criteria have developments, expanding their conceptual coverage. Likewise, data management based on these principles involve certain activities, as the data curation issue, which goes beyond purely tools themselves, involves activities, methods, and standards. Thus, repositories are instruments, as indicated in Bjork's (2007) scientific communication model, for depositing and retrieving databases, taking the form of sharing.

Thus, discussing Technologies under the aspects related to FAIR criteria, each criterium, including its refinements as presented by Henning *et al.* (2019), become requirements that software for repositories must meet. By these means, it is possible to discuss FAIR criteria under the observation of technology, in order to propose an understanding of the theme, for technology offers tools, while criteria represent a conceptual basis, which enables tools evaluation.

The Findable criterium initially treats databases and their metadata. Thus, in order to meet this criterium, repositories have to provide support for depositing databases, regardless of their format or type, and adopt metadata standards that can be accessed by people and machines. Most of the current technologies for building repositories generally meet this requirement, but some observations are required.

Depositing databases requires some curation aspects, such as verifying if there is no virus, or even integrity mechanisms. However, in the findability recommendations, databases have lower emphasis in relation to metadata, mainly with the possibility of having this metadata indexed by search engines. For metadata, basic questions such as the use of persistent identifiers are mandatory. This point is relatively met by identifier systems such as *Handle* or *Digital Object Identifier* (DOI). However, Technologies must enable the application of enriched metadata devoted to some curation activities, which can present challenges for depositors, as Technologies are additional Fields to be implemented. Thus, it is noticed that the findable recommendation affects some points related to metadata quality, which goes beyond the tool.

This view, in which the location has aspects with a lower impact on technology, can be supported by Monteiro e Sant'Ana (2020) study, which presents technological solutions to meet FAIR criteria of accessibility. For the authors, FAIR principles were implemented in the infrastructure of CLARÍN research, including findable aspects through the use of standards currently implemented in several technologies for creation of repositories, such as the use of Dublin Core metadata standards, which have flexibility and minimum standards for interoperability, according to Open Archives Initiative – OAI.

In general, in order to meet the findable FAIR principle, technologies for repositories must allow the indexing through search engines, implement standards of flexible and interoperable metadata, which enable the use of persistent identifiers for databases, in order to the easily found. Thus, in case there are no reviews in these criteria, the majority of repository technologies meets them, to a higher or lower degree, as repositories, in their traditional function in scientific communication, have the function of making the access to their items easier.

For the accessible criteria, the technological aspects are greater, as they have relation to accessing databases through communication protocols or directly for their reusing. Databases deposited in repositories are in digital format depending on their type and, even if they can be considered raw data, they can present several formats. Thus, repositories can provide the files to be downloaded or streamed, depending on the permissions. In the streaming case, repositories need to offer optional functionalities in face of the various formats that research databases can take, such as tables, spreadsheets, audios, videos, texts, and others.

Access to resources occurs through the offer of access, enabling the interaction using communication protocols. These criteria are related to the infrastructure in which repositories will be hosted. This criterium is associated to the use of free tools for creating environments, such as the use of operational systems, application servers and free databases. It is not only using the free software for creating the repository, but having the whole environment built with free technologies.

The only point related to technology for creating repositories and the access criterium are related to metadata preservation, even that the database is not available anymore. This point must guide the removal of databases from repositories by any reason, requiring that metadata be maintained. Thus, it can have an impact on metadata, requiring the presence of field indicating the status of the database.

The criteria related to the interoperability are technological. Since the beginning of the open archive initiative, still at the end of the last century, many softwares have been implementing the *Open Archives Initiative* (OAI) protocol in its versions *Protocol Metadata Harvesting* (PMH) or *Object Reuse and Exchange* (ORE), based on *eXtensible Markup Language* (XML). However, with the technological Evolution, Other forms of notation can be used for the interoperability, such as *JavaScript Object Notation* (JSON) technology, or even with the use of *WebServices* services, with good results and more flexibility in collecting metadata.

In this matter, the idea of interoperability is bigger in FAIR criteria than in open archives, aimed at the possibility of metadata and digital objects exchange. Thus, technologies for implementing research data repository need to be adjusted to meet FAIR. Moreover, it requires developing supporting structures such as ontologies and thesaurus, standardizing content of metadata fields with controlled vocabularies. Likewise, it will require from data producers that They deposit data, data dictionary and, in the future, data narratives.

Even if the interoperability criteria have technological aspects, strong recommendations aimed at metadata are noted, such as in issues of relationship among databases. Thus, if a database is questioned, the original source can be cited indicating its provenance. Likewise, if a database is generated based on other databases, this must be indicated. All this information must be provided in metadata.

For databases to be reusable, complete descriptions are necessary, going beyond metadata. Therefore, FAIR criteria for reuse suggest developing narratives of data that comprise limitations, context, ways of collection, among others. The recommendations for reuse have procedural aspects, in which the information above-mentioned will allow their reuse.

It is worth noting that FAIR criteria guide data producers who desire to share and adopt open data and open science initiatives, researchers who promote transparency through research data dissemination. In that matter, FAIR criteria is presented as a basis for general orientation for all the initiatives that want to adopt data sharing as part of the research activities.

9.5 TECHNOLOGIES FOR FAIR REPOSITORIES

If FAIR criteria have guiding aspects, the *FAIR Data Point Specification (FDPS)* document presents the requirements for developing or evaluating technologies oriented to meet FAIR principles. Thus, according to specifications described in the document referred, a repository will be created to meet metadata and data that can be classified as FAIR. Likewise, the document can be used for evaluating existing software sets, mainly free and open-code softwares, whose purpose is modifications and adaptations.

The repository designed according to FDPS model is, in general, aimed at natural sciences, sometimes focused on biology, which presents certain restrictions. However, with adaptations, it can be used for other sciences bearing in mind the specificities of each field. The intention is to promote technologies that enable the creation of repositories that can interoperate metadata and databases in order to enable distributed research.

Thus, the repository designed by FDPD has two well-established sets of functionalities aimed at retrieval and deposit of databases. These points are in line with current repositories aimed at disseminating technical and scientific documentation. In this matter, conceptually, FDPD data repository presents aspects similar to digital repositories, only specialized in generating databases.

For database retrieval, there are simple processes such as find and access databases. The deposit in databases, in turn, can be manual or automatic. Regardless of processes, whether retrieval or deposit, it is required that the repository offers simple and standardized functionalities, so that users can use the platform for offering or using databases.

The initial requirements to meet FDPS start with the findability features of databases, that is, discovery features, which help users to find out where these databases are, involving issues related to indexing by search engines and others. Similarly, repositories must offer simple search tools, but with indexing made up of functionalities that support the datasets maintained by them.

Once the desired database is found, the access process begins. Thus, the licenses for accessing and using data must be presented, preferably those indicated by FAIR. Likewise, the repository must guide the standardization of format used for data, with strong indication for the use of free formats, so that standardized access is possible. Thus, users who which to aggregate databases from different repositories have their work facilitated, promoting the reuse.

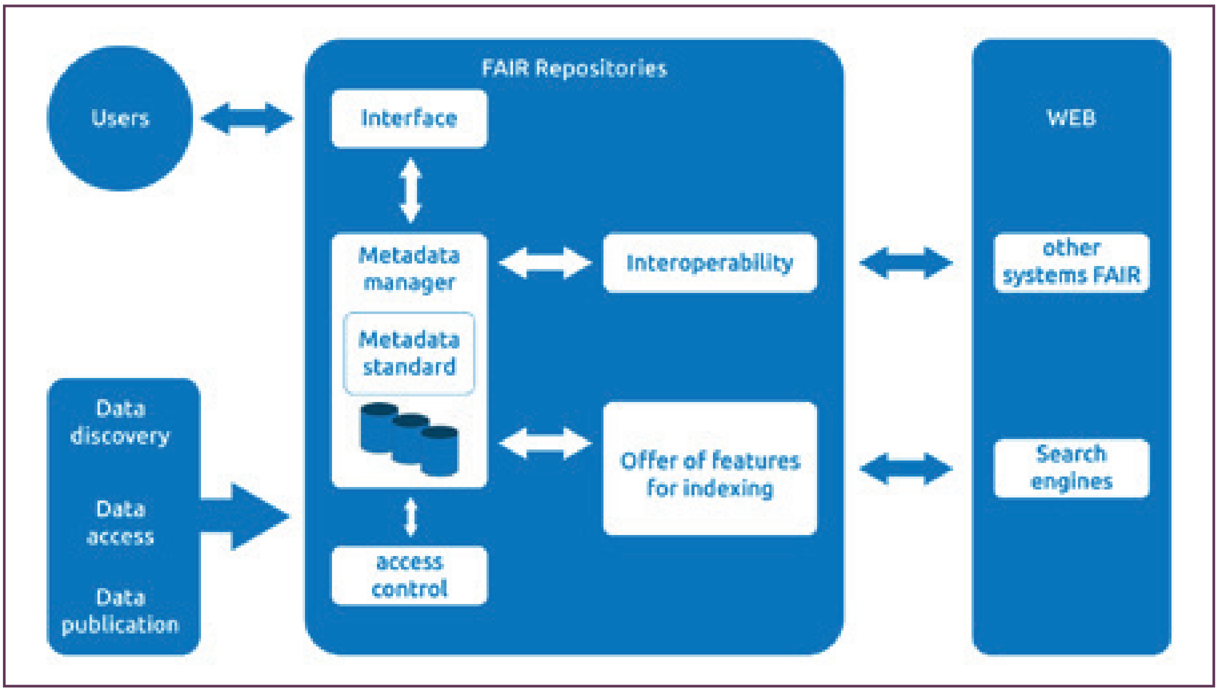
Data deposit, also called data release, consists of a set of functionalities that help authors to provide datasets through repositories, with a great variety of options to provide access, versioning, status, among others. So, it aims at meeting the specificities presented by the databases in relation to the restrictions of use, time of research and others, but allowing users to find those databases.

Finally, FDPS data repositories must enable the Generation of use statistics. Indicators must be offered as strategic information for decision-making related to infrastructure management, for instance. Likewise, it is possible to know the relevance of databases, generating information for the authors about their data reuse. Thus, statistics are useful even to justify the repositories and their investments.

On the other hand, as all repositories, the systems in line with FDP must have an architecture that makes it possible to manage items composed of databases and their metadata, which can be manipulated by both humans and machines. Thus, it must have a Web interface in which users can Search, deposit and retrieve databases through the databases' metadata. Likewise, it must provide access so that machines can retrieve information. The access must be controlled by permissions in order to protect sensitive data. Metadata must follow FAIR standards, offering information on five levels: about the repository itself; about the brochure (database sets that make up the collection); about the database; about distribution; and about data records.

Simply put, the architecture of a repository that meets FAIR principles (Figure 1) helps human users through a Web interface, offering interoperability for Other systems and allowing search engines to index their metadata. The access to metadata and databases must be controlled in order to enable staggered dissemination due to different levels of data sensibility. Metadata follows standards that facilitate the integration, finding, and description of databases. In short, FDPS repository makes data finding, access and deposit easier.

Figure 1 – Architecture of a repository that meets FAIR principles



Source: Elaborated by authors based on *FAIR Data Point Specification* (FDPS).

The specifications for FDPS repositories do not differ Much from the Technologies used for the creation of academic repositories, such as computerized systems. However, databases have specificities that require different treatments. As a result, the differences between databases and academic publications will distinguish from the systems, as well as the types of functionalities proposed.

9.6 FINAL CONSIDERATIONS

FAIR guidelines have features that change the way of analyzing science practices, as they change the focus of research outcomes, represented by articles, books, annals and others, to research data with the aim to store them to be shared. They change, in a certain way, the perspective of research data, as a social asset that must be shared as a way to contribute with other scientists.

For that matter, it requires informational infrastructure, made up of computerized systems, currently helped by research data repositories. Thus, in order to implement these systems, free and proprietary technologies are offered, meeting part of the criteria. However, the task of implementing FAIR principles in research data dissemination is, at a certain point, up to the managers and researchers, as the technologies aimed at the creation of academic repositories meet great part of the demand.

In this matter, it is emphasized that the change for using FAIR principles is behavioral, on the one hand, as it depends on researchers to deposit data from their studies in data repositories with open licenses, with well-described metadata and using free formats. Likewise, it depends on well-structured data repositories that implement FAIR principles, offered by institutions recognized in the academic world, ensuring the necessary curation.

For authors that adopt FAIR principles, the link for data in repositories can be inserted in the methodology section of the article, for example. Another valid option is the adoption of a metadata field in the magazine for inserting the link in the submission process, as many magazines have already done. Regarding the technology, softwares for creating data repositories, magazines, or even formats for article formatting meet the principles.

It may be that in the future not all FAIR principles will be met because the repositories still do not meet all the developments of the principles. Most repositories are based on the sharing process and not on curating their collection. Therefore, the challenges in relation to technological infrastructure still require studies

Possibly, the greatest challenge of research data management in regard to technologies is related to the ones that meet the needs of curation, since the dissemination is only the final part of the process, in which FAIR is contextualized. It is possible that FAIR, in the near future, adapts to the new demands when adopting criteria met by technologies.

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