Chapter 3
Quality and Interoperability:
The Quest for the Optimal Balance

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ABSTRACT

This chapter deals with the problem of defining and assessing the quality of a digital library. The chapter will provide a brief excursus on the evolution of digital libraries and their current complexity to make it clear that there is a strong need for systematic and exhaustive models which precisely define what digital libraries are and encompass a model for the quality of digital libraries. In this context, the authors will present an overview of the DELOS Reference Model for digital libraries and they will go into details about how quality has been modelled in it. The authors will also compare this model to another formal model for digital libraries, which is the Stream, Structures, Spaces, Scenarios, Societies (5S) model. The discussion addressed in the chapter will not be limited to quality issues but will show how quality impact on various dimensions of the digital library universe. In particular, they will discuss how quality relates to interoperability. To this end, they will describe the conceptual model for interoperability developed in support to the European Digital Library initiative and will highlight its relationships with the quality domain in the DELOS Reference Model. Finally, the authors will outlook some future directions that may be pursued to improve and automate the assessment and evaluation of quality in digital libraries.

1. INTRODUCTION

Since the field of digital libraries has come to light in the early nineties of the past century, a lot of improvements and a dramatic change in the viewpoint has happened. In the beginning, digital libraries were almost monolithic systems, each one built for a specific kind of information resources – e.g. text, images, or videos – and with very specialised functionalities developed ad-hoc for those contents. This approach caused a flourishing of systems where the very same functionalities, e.g. user management or repositories, were developed and re-developed from

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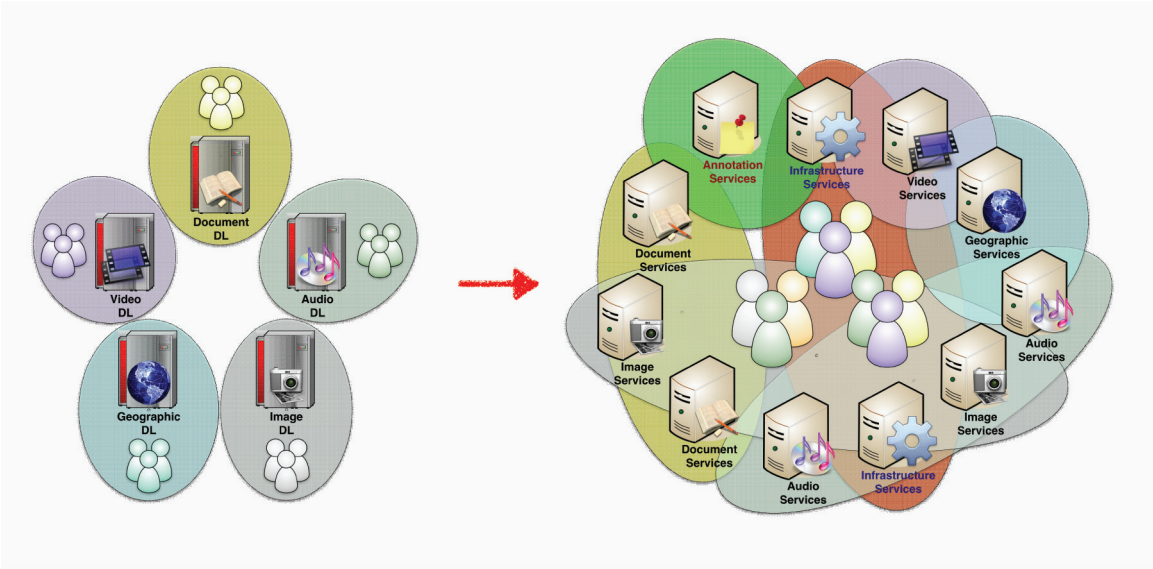
Figure 1. Evolution of the digital libraries from data-centric systems (shown on the left) towards user-centric systems (shown on the right)



scratch many times, causing them to be different and often incompatible one with the other. Moreover, these systems were confined to be applied to the realm of traditional libraries, being their digital counterpart, and they had a kind of "static" view of their role, since they were places where users can find and retrieve desired information resources with a data-centric vision rather than being systems where users can interact with and augment the managed information resources with a user-centric vision. The main motivation of this approach has been the high complexity of digital libraries which forced researchers and developers to specifically address each case in a kind of bottom-up approach which contributed to make the picture about digital libraries clearer and clearer.

With the passing of time and by exploiting the previous research results and achievements, a more mature way of facing the design and development of digital libraries has taken place. Digital libraries moved from being monolithic systems to being component and service-base systems, where easily configurable and deployable services can be plugged together and re-used in order to create a digital library. Moreover, digital libraries started to be seen as more and more user-centered systems, where the original content management task is partnered with new communication and cooperation tasks, so that digital libraries become "*a common vehicle by which everyone will access, discuss, evaluate, and enhance information of all forms*"(Ioannidis, Maier, Abiteboul, 2005). Finally, digital libraries are no more perceived as isolated systems but, on the contrary, as systems that need to cooperate together in order to improve the user experience in accessing information and to seamlessly integrate information resources of different domains.

In this evolving scenario, shown in Figure 1, the design and development of effective services which foster the cooperation among users and the integration of heterogeneous information resources become a key factor which needs to be pursued by researchers and developers. A relevant example of this kind of new services are annotations, i.e. providing users or groups of users with the possibility of adding personal annotations on the managed information resources, even crossing

the boundaries of the single digital library(Agosti & Ferro, 2008)(Ferro,2009).

The DELOS Network of Excellence on Digital Libraries[1] has been the main driver of this evolution of the field of digital libraries in Europe and has delineated and faced many of the issues discussed above. Two main contributions came out from DELOS with respect to this new vision of digital libraries and the interoperation among them: the DELOS Reference Model(Candela, Castelli, Ferro et al., 2007)[2] and the DelosDLMS(Agosti, Berretti, Brettlecker, 2007). The former lays the foundations of digital libraries and defines what are the constituent entities and stakeholders of the digital library universe as well as the relationships among them; in particular, the reference model provides a clear picture of what a digital library is and on what concepts and functionalities we can leverage in order to promote co-operation and interoperability. The latter is the prototype of the next generation digital library system, which embodies the vision discussed above, and provides an arena where experimenting new services and dealing with the cooperation among them. The seeds sow from DELOS are now carried on by DL.org[3], the European coordination action on digital library interoperability, best practices and modelling foundations.

The aim of this chapter is to discuss how the evolution in the field of digital libraries has shaped the notion of quality and how has put it in relation with other key problems in the field, such as interoperability. Indeed, even in the perspective of "monolithic and data-centric" digital libraries, defining and determining what quality means for a digital library is not trivial, since it requires, among others, to have a definition of what a digital library is, what its functionalities and the expected outcomes are, what the distinctive features of the data it is managing are and what requirements they have to meet. The problem becomes especially challenging when we come to the current "distributed and user-centric" approach, where quality in digital libraries has to take into account a completely new array of issues, which lay in the complex interactions among different entities.

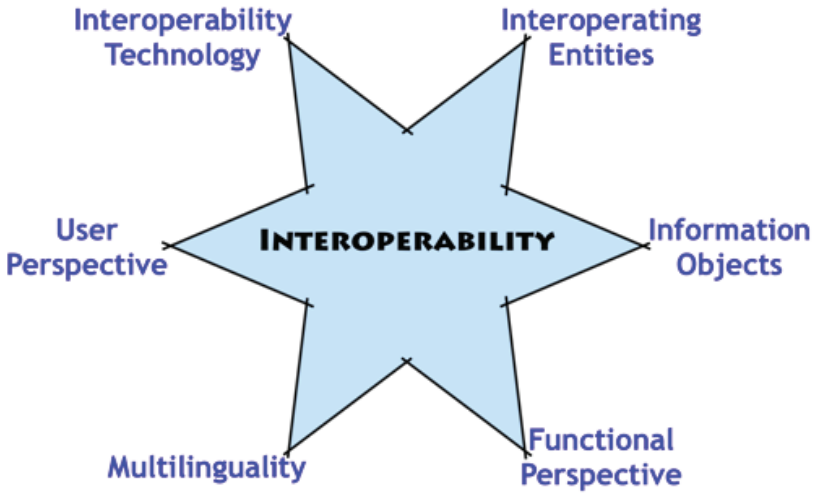
The chapter is organized as follows: Section 2 briefly discusses the problem of the interoperability in digital libraries and introduces and discusses a high level model for identifying its main factors; Section 3 proposes a comprehensive and exhaustive quality model for digital libraries, the one developed in the DELOS Reference Model, and compares it to alternative approaches that have been developed in the field so far; Section 4 examines the relationships among quality and interoperability in the light of the previous discussions; finally, Section 5 provides an outlook of possible future directions concerning the evaluation of quality in digital libraries.

2. INTEROPERABILITY

The evolution toward distributed and user-centric digital libraries has contributed to the vision that shapes the *European Digital Library* initiative, which will act as a common multilingual access point to Europe's distributed digital cultural heritage(European Commission. 2006) including all types of cultural heritage institutions. This ambitious goal is pursued by a constellation of projects around the "brand" Europeana[4], which deals with the information resources held by European libraries, museums, archives, and audio-visual archives. Europeana not only aims at aggregating and harvesting content from these institutions but also focuses on making these very different institutions cooperate and interoperate together as well as on defining an economic and governance model ensuring its success and sustainability(European Commission, 2008).

In order to support the work toward Europeana, the *European Commission Working Group on Digital Library Interoperability*(Gradmann, 2007), active from January to June 2007, has

Figure 2. Determining factors for the interoperability



provided recommendations for both a short term and a long term strategy towards interoperability.

The working group adopts the definition of interoperability proposed by the International Organization for Standardization (ISO) in the ISO/IEC 2382-1:1983[5] as *the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires minimal knowledge of the unique characteristics of those units* and identifies six determining factors of it, as shown in Figure 2:

- **Interoperating entities:** concerns the different entities which need to interoperate together and may have different objectives and backgrounds. Examples of these entities are: cultural heritage institutions – such as libraries, museums, and archives – digital libraries, institutional repositories, and so on.
- **Information Objects:** regard the different objects which need to interoperate and which call for different degrees of interoperability. For example, there could be interoperability at the level of actual digital objects and their content, or at the level of representations and surrogates of them, such as metadata, or event at level of the functionalities and services offered over them, which might be orchestrated together.
- **Functional perspective:** is about the way in which interoperation happens. For example, you might exchange or replicate digital object or their surrogates or you might interact with various digital libraries via unified interfaces, common protocols or even a shared service architecture;
- **Multilinguality:** deals both with the internationalization and localization of the user interfaces and with the problem of providing proper multilingual information access functionalities over the managed digital objects.
- **User perspective:** concerns the user needs of the different actors involved in digital libraries – such as content providers, end users, administrators, content aggregators and so on – and the way in which the interoperation over various digital libraries impacts their expectations;

- **Interoperability technology:** addresses and investigates the various technologies which can be used for enabling and improving interoperability, such as the Z39.50[6] protocol, the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH)[7], the Search/Retrieve via URL (SRU) specifications[8], Web Services[9], and so on.

The issue of interoperability in digital libraries is a very complex and challenging theme that needs to be carefully addressed and discussed. Nevertheless, this high level and conceptual vision of the interoperability will prove to be very useful in order to discuss its relationship with quality in digital libraries.

3. A QUALITY MODEL FOR DIGITAL LIBRARIES

In this section, we present and discuss the quality model that has been developed for the DELOS Reference Model[10] and that starts addressing the need for a systematic study and a complete modelling of what quality is in digital libraries (Agosti, Ferro, Fox, 2007). To this end, it relies on a comprehensive model for digital libraries, which provide them with the possibility of both defining quality in a consistent way across the different entities which comprise a digital library and modelling it at the proper level of abstraction in order to hide unnecessary details and to ensure the applicability to a wide array of concrete cases.

This quality model makes a step-forward with respect to previously existing evaluation schemes and models for digital libraries (Fuhr, Hansen, Micsik & Solyberg, 2001)(Fuhr, Tsakonas, et al, 2007)since it relies on an exhaustive model of what digital libraries are. Indeed, it is complementary to previously existing evaluation models for digital libraries, since a quality model not only deals with defining which parameters and indicators need to be examined to assess the quality of a digital library but also puts the notion of quality and its many facets in relationship with the other entities and concepts which constitute the digital library universe and determines how they affect each other.

3.1. Overview of the DELOS Reference Model

The DELOS Reference Model approaches the problem of modelling the digital library universe by highlighting six domains or main concepts(Candela, Castelli, Ioannidis et al, 2006), as shown in Figure 3, which are at the core of what digital libraries are and what is their purpose:

- **Content:** the data and information that digital libraries handle and make available to their users;
- **User:** the actors (whether human or not) entitled to interact with digital libraries;
- **Functionality:** the services that digital libraries offer to their users;
- **Quality:** the parameters that can be used to characterize and evaluate the content and behaviour of digital libraries;
- **Policy:** a set of rules that govern the interaction between users and digital libraries;
- **Architecture:** a mapping of the functionality and content offered by a digital library onto hardware and software components.

These six domains represent the high level containers that help organize the DELOS Reference Model. For each of these concepts, the fundamental entities and their relationships are clearly defined and discussed. Note that these six domains are not separate, but, on the contrary, are strongly inter-related; the entities within a domain are often related to or influenced by the entities in other domains.

Moreover, the DELOS Reference Model distinguishes among three different "systems" which

Figure 3. The main domains of the digital library universe according to the DELOR Reference Model

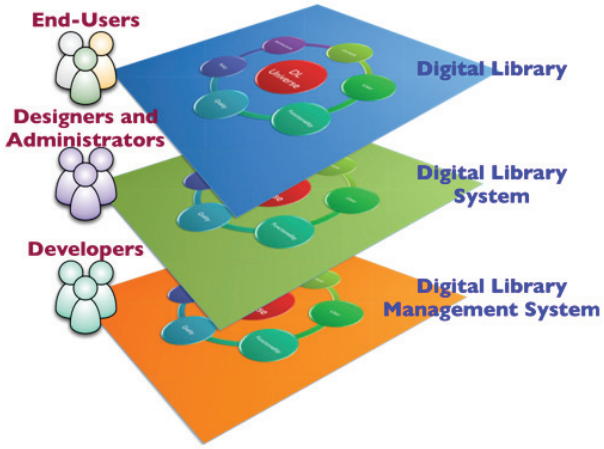
constitute the digital library universe, as shown in Figure 4, and rely on the six domains introduced above for their definition:

- **Digital Library (DL):** an organisation, which might be virtual, that comprehensively collects, manages and preserves for the long term rich *digital content*, and offers to its *user* communities specialised *functionality* on that content, of measurable *quality* and according to codified *policies*.
- **Digital Library System (DLS):** a software system that is based on a defined (possibly distributed) *architecture* and provides all functionality required by a particular Digital Library. Users interact with a Digital Library through the corresponding Digital Library System.
- **Digital Library Management System (DLMS):** a generic software system that provides the appropriate software infrastructure both (i) to produce and administer a Digital Library System incorporating the suite of functionality considered fundamental for Digital Libraries and (ii) to integrate additional software offering more refined, specialised or advanced functionality.

The three "systems" are at different levels of abstractions and constitute a kind of hierarchy: at the more general level there is the notion of DL, which is what is actually perceived by the end-users and what they interact with; in-between, there is the DLS, which mainly concerns system designers and administrators who have to instantiate and manage it; at the lower level, there is the DLMS, which typically interests system developers who implement the actual components that are used by the upper layers.

The hierarchy is also obvious because entities and definition introduced at a more general level are inherited by the levels underneath and can be

Figure 4. The DL, DLS, and DLMS "systems"



further specialised by them; in addition, a lower level can introduce new definitions and entities, that are specific only to that level. In this way, each one of the three "systems" contributes in an incremental way to the modelling of each one of the six domains introduced above.

3.2. The Quality Domain in the DELOS Reference Model

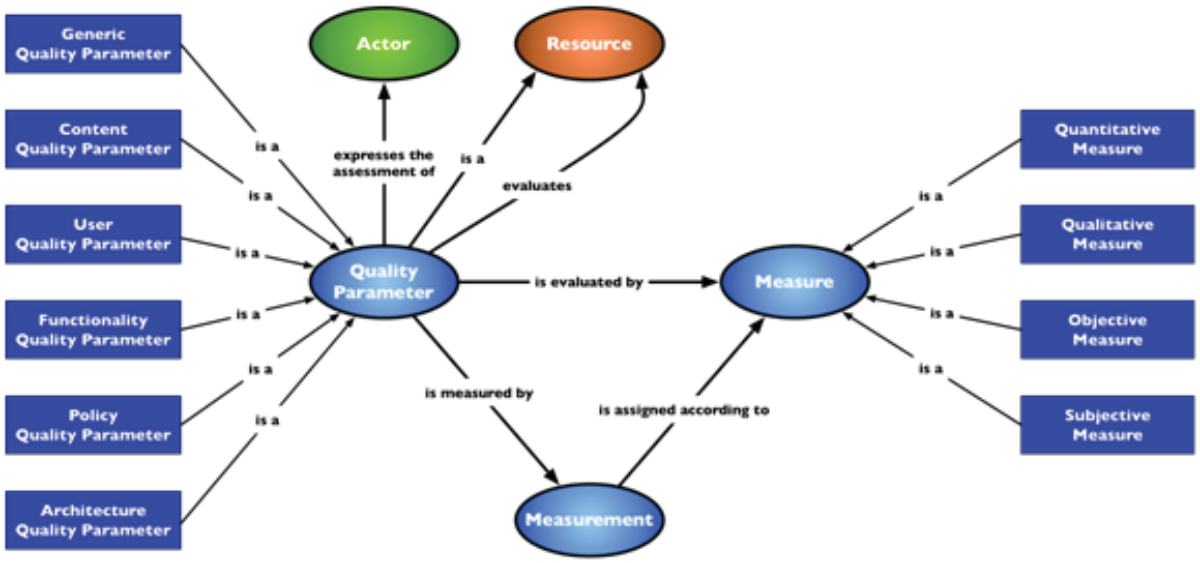
The quality domain takes into account the general definition of quality provided by the International Organization for Standardization (ISO) in the ISO 9000:2005[11] standard, which defines quality as "*the degree to which a set of inherent characteristics fulfils requirements*", where requirements are needs or expectations that are stated, generally implied or obligatory while characteristics are distinguishing features of a product, process, or system.

This general definition of quality provided by ISO needs to be contextualized to the case of digital libraries and has to be modified and enriched according to the entities that populate the six domains of the reference model and the three different "systems" introduced above.

According to the DELOS Reference Model, a Quality Parameter is a Resource that indicates, or is linked to, performance or fulfilment of requirements by another Resource. A Quality Parameter is evaluated by a Measure, is a Measurement, and expresses the assessment of an Actor. With respect to the definition provided by ISO, we can note that: the "set of inherent characteristics" corresponds to the pair (Resource, Quality Parameter); the "*degree of ... fulfilment*" fits in with the pair (Measure, Measurement); finally, the "*requirements*" are taken into consideration by the assessment expressed by an Actor.

In the following, we will discuss in detail each entity and its relationship with the other entities in the model. Figure 5 shows the main entities which constitute the quality domain and their relationships with entities belonging to the other domains. It makes use of the *concept maps*, which are graphical tools for organising and representing knowledge[12,13] in terms of concepts (entities) and relationships between concepts to form propositions. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement. In the graphical representation, concepts are inscribed in circles or boxes, while propositions are represented as directed lines connecting concepts, labelled with words describing the linking relationship.

Figure 5. Main entities and their relationships involved in the quality domain



Three main entities – Quality Parameter, Measure, and Measurement – belong to the quality domain, while two other entities – Actor and Resource – belong, respectively, to the user and content domains.

A Resource is any identifiable entity in the digital library universe and resembles the concept of resource used in the Web[14]. In addition to this general concept, the Resource in the DELOS Reference Model has some additional features: it can be arranged or set out according to a resource format which, for example, allows a Resource to be composed of or linked to other Resources; it can be characterised by various quality parameters, each capturing how the Resource performs with respect to some attribute; it is regulated by policies governing every aspect of its lifetime; it is expressed by an information object; and, it can be described by or commented on by an information object, especially by metadata and annotations.

An Actor is someone or something which interacts with the digital library universe, being it a human being or a computing device. An Actor is a Resource and inherits all its key characteristics, even if they are specialized to better fit to the notion of Actor. For example, the policies represent the functions that Actors can perform or the information objects they have access to.

Quality Parameters serve the purpose of expressing the different facets of the quality domain. In this model, each Quality Parameter is itself a Resource and inherits all its characteristics, as, for example, the property of having a unique identifier.

Quality Parameters provide information about how, and how well, a Resource performs with respect to some viewpoint[15]. They express the assessment of an Actor about the Resource under examination. They can be evaluated according to different Measures, which provide alternative procedures for assessing different aspects of a Quality Parameter and assigning it a value. Quality Parameters are actually measured by a Measurement, which represents the value assigned to a Quality Parameter with respect to a selected Measure.

Being a Resource, a Quality Parameter can be organised in arbitrarily complex and structured forms because of the composition and linking facilities, e.g. a Quality Parameter can be the compound of smaller Quality Parameters each

capturing a specific aspect of the whole or it can be itself characterised and affected by various Quality Parameters. For example, Availability[16] is affected by Robustness[17] and Fault Management[18]: in fact, when a function is both robust and able to recover from error conditions, it is probable that its availability is also increased.

A Quality Parameter can be regulated or affected by policies. For example, the Economic Convenience[19] of accessing a digital library may be affected by its charging policy, since the latter is responsible for the definition of the charging strategies adopted by the digital library.

Finally, a Quality Parameter can be enriched with metadata and annotations. In particular, the former can provide useful information about the provenance of a Quality Parameter, while the latter can offer the possibility to add comments about a Quality Parameter, interpreting the obtained values, and proposing actions to improve it.

In order to clarify the relationship between Quality Parameter, Measure and Measurement, we can take an example from the information retrieval field. One of the main Quality Parameters in relation to an information retrieval system is its effectiveness, meant as its capability to answer user information needs with relevant items. This Quality Parameter can be evaluated according to many different Measures, such as precision and recall[20]: precision evaluates effectiveness in the sense of the ability of the system to reject useless items, while recall evaluates effectiveness in the sense of the ability of the system to retrieve useful items. The actual values for precision and recall are Measurements and are usually computed using standard tools, such as trec_eval[21], which are Actors, but in this case not human.

Quality Parameters are specialized and grouped according to the Resource under examination as follows:

- Generic Quality Parameters when the assessed Resources are a Digital Library, or a Digital Library System, or a Digital Library Management System;
- Content Quality Parameters when the assessed Resources belong to the content domain;
- User Quality Parameters when the assessed Resources belong to the user domain;
- Functionality Quality Parameters when the assessed Resources belong to the functionality domain;
- Policy Quality Parameters when the assessed Resources belongs to the policy domain;
- Architecture Quality Parameters, when the assessed Resources belong to the architecture domain.

For each group a detailed list of Quality Parameters[22] is given in order to provide actual indicators that have to be taken into consideration when dealing with and evaluating the digital library universe.

It is important to note that the grouping described above is made from the perspective of the Resource under examination, i.e., the object under assessment. In any case, the Actor, meant as the active subject who expresses the assessment and knows the requirements a Resource is expected to fulfil, is always taken into consideration and explicitly modelled, since he is an integral part of the definition of Quality Parameter. For example, the User Satisfaction[23] parameter is put in the Functionality Quality Parameter group because it expresses how much an Actor (the subject who makes the assessment) is satisfied when he uses a given function (the object of the assessment). On the other hand, in the case of the User Behaviour parameter, the object of the assessment is an Actor together with his way of behaving with respect to some policy, while the subject who is making the assessment is another Actor, for example, an administrator; for this reason, this parameter is put in the User Quality Parameter group.

Measures are further categorized according to the following specializations:

- Objective Measures can be obtained by taking measurements and using an analytical method to estimate the quality achieved. They could also be based on processing and comparing measurements between a reference sample and the actual sample obtained by the system. Examples of objective factors related to the perception of audio recordings in a digital library are: noise, delay and jitter.
- Subjective Measures involve performing opinion tests, user surveys and user interviews which take into account the inherent subjectivity of the perceived quality and the variations between individuals. The perceived quality is usually rated by means of appropriate scales, where the assessment is often expressed in a qualitative way using terms such as bad, poor, fair, good, excellent to which numerical values can be associated to facilitate further analyses. Examples of factors related to the subjective perception of audio recordings in a digital library are: listening quality, loudness, listening effort.
- Quantitative Measures are based on a unit of measurement that is expressed via numerical values. They rely on collecting and interpreting numerical data, for example, by means of the wide range of statistical methods for analysing numerical data.
- Qualitative Measures are applied when the collected data are not numerical in nature. Although qualitative data can be encoded numerically and then studied by quantitative analysis methods, qualitative measures are exploratory while quantitative measures usually play a confirmatory role. Methods of Qualitative Measure that could be applied to a digital library are direct observation; participant observation; interviews; auditing; case study; collecting written feedback.

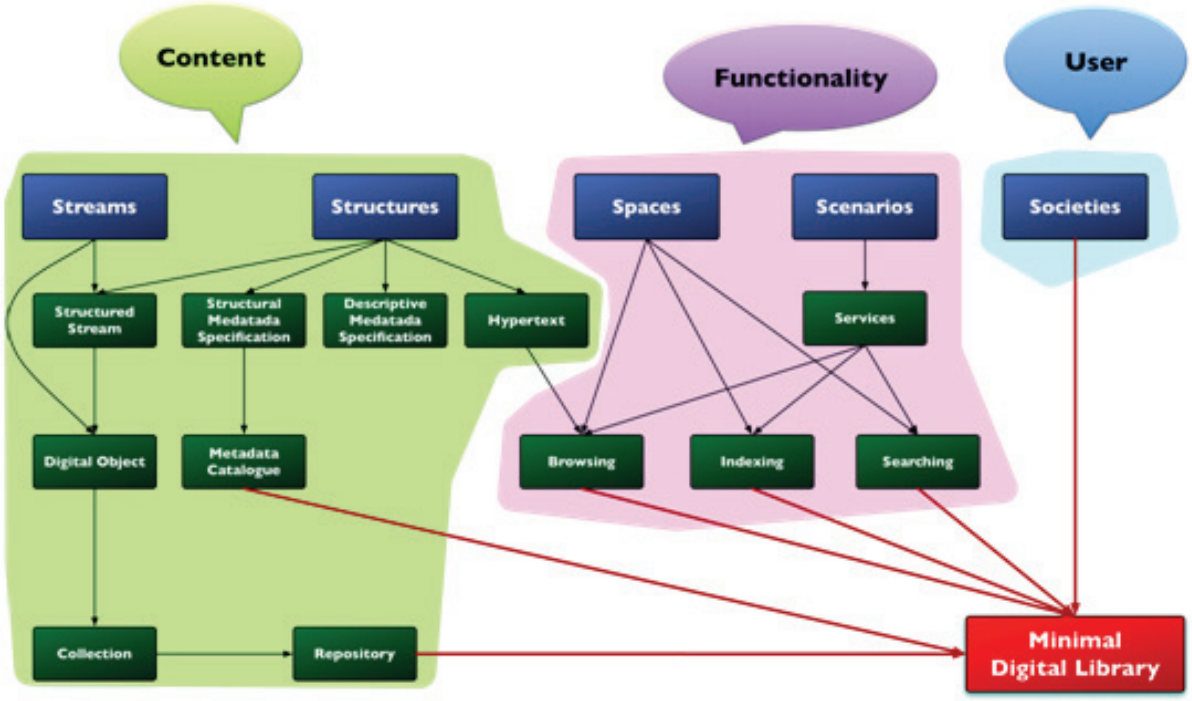
The quality domain is very broad and dynamic by nature. The representation provided by this model is therefore extensible with respect to the myriad of specific quality facets each institution would like to model. Quality Parameter is actually a class of various types of quality facets, e.g. those that currently represent common practice.

3.3. Comparison to the 5S Quality Model

The Streams, Structures, Spaces, Scenarios, Societies (5S)[24,25] is a formal model for digital libraries based on the following abstractions:

- **Streams** are sequences of elements of an arbitrary type (e.g. bits, characters, images) and thus they can model both static and dynamic content. Static streams correspond to information content represented as basic elements, e.g. a simple text is a sequence of characters, while a complex object like a book may be a stream of simple text and images. Dynamic streams are used to model any information flow and thus are important for representing any communication that takes place in the digital library. Finally, streams are typed and the type is used to define their semantics and application area.
- **Structures** are the way through which parts of a whole are organised. In particular, they can be used to represent hypertexts and structured information objects, taxonomies, system connections and user relationships.
- **Spaces** are sets of objects together with operations on those objects conforming to certain constraints. Document spaces are the key concepts in digital libraries. However, spaces are used in various con-

Figure 6. Main definitions of the 5S model and their relationships with the domains of the DELOS Reference Model



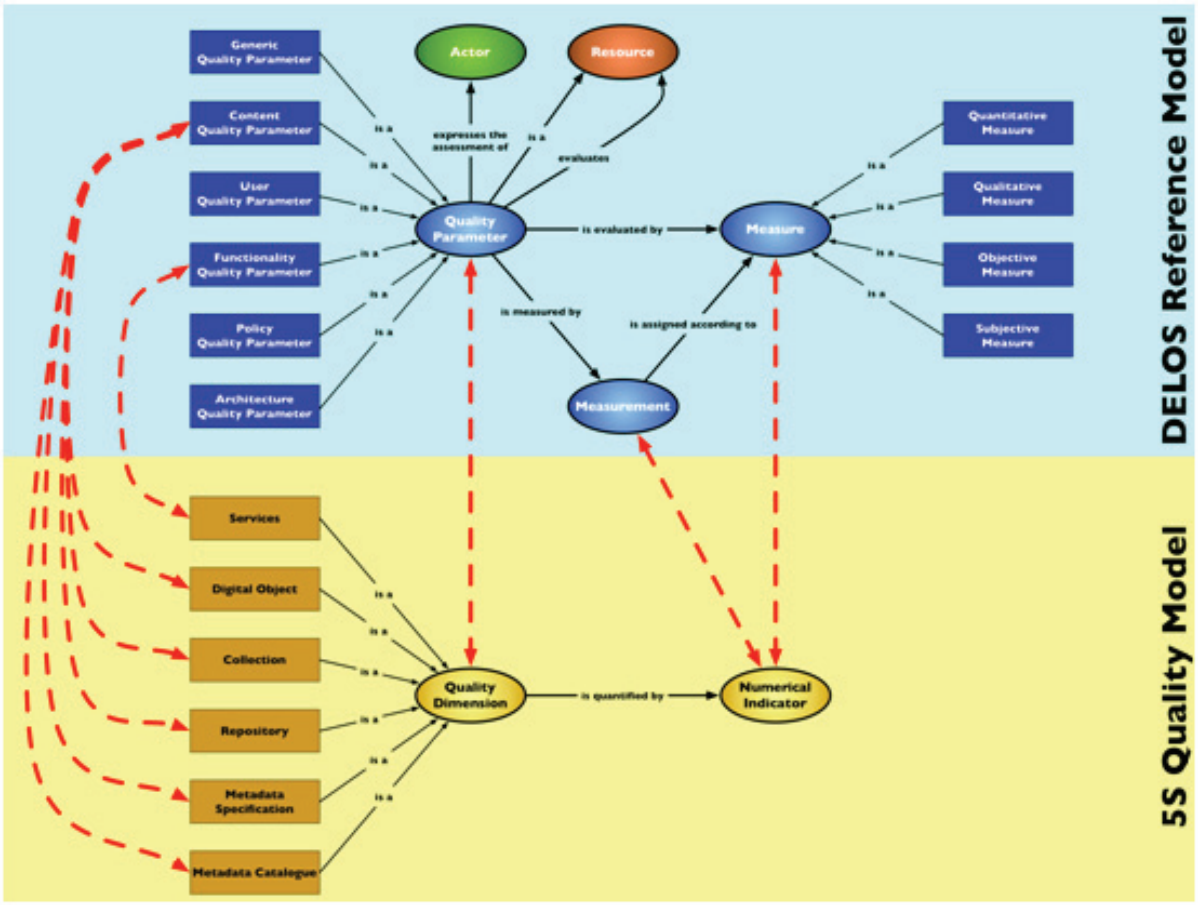
texts – e.g. indexing and visualising – and different types of spaces are proposed, e.g. measurable spaces, measure spaces, probability spaces, vector spaces and topological spaces.

- **Scenarios** are sequences of events that may have parameters, and events represent state transitions. Thus a scenario tells what happens to the streams in spaces and through the structures. When considered together, the scenarios describe the services, the activities and the tasks representing digital library functions. Workflows and dataflows are examples of scenarios.
- **Societies** are sets of entities and relationships. The entities may be humans or software and hardware components, which either use or support digital library services. Thus, society represents the highest-level concept of a digital library, which exists to serve the information needs of its societies and to describe the context of its use.

We can relate the 5S to some of the aims of a digital library: societies define how a digital library helps in satisfying the information needs of its users; scenarios provide support for the definition and design of different kinds of services; structures support the organisation of the information in usable and meaningful ways; spaces deal with the presentation and access to information in usable and effective ways; and, streams concern the communication and consumption of information by users.

As shown in Figure 6, from the five abstractions of streams, structures, spaces, scenarios, and societies, a series of concepts are derived, which are then used to define what a digital library is. Indeed, in accordance with this framework, a minimal digital library is defined a constituted

Figure 7. Main concepts in the 5S quality model and their relationship with the DELOS Reference Model



by: a *repository*, that is a service encapsulating a family of collections and specific services to manipulate the collections; a set of *metadata catalogues* for all the collections in the repository; a set of *services* containing, at least, services for indexing, searching and browsing; and, a society whose information needs have to be satisfied.

As you can note from Figure 6, only three out of the six domains of the DELOS Reference Model are taken into consideration in the 5S model, namely the Content, Functionality, and User domains; the other three – Quality, Policy, and Architecture – are not dealt with but are left to additional models that can be built starting from the 5S model.

Indeed, as far as quality is concerned, a separate quality model[26] has been developed. As shown in Figure 7, for each major digital library concept in the 5S framework, a number of Quality Dimensions are formally defined and a set of Numerical Indicators for those quality dimensions are proposed. In particular, they consider key concepts of a minimal digital library: Digital Object, Metadata Specification, Collection, Metadata Catalogue, Repository, and Services. For some key concepts, pairs of form (quality dimension, numerical indicator) are illustrated through their application to a number of "real-world" digital libraries. To help operationalize this approach, a digital library quality assessment toolkit has been developed and deployed[27]. It can be used by digital library man-

agers to assess the quality of their digital library, based on the toolkit's processing of system logs and its access to digital library content.

Figure 7 shows a comparison between the quality domain in the DELOS Reference Model and the 5S quality model. The concept maps of both models are shown and the dotted thick lines show the correspondences between the concepts in the two models.

From a broad modelling point of view, the notion of Quality Parameter in the DELOS Reference Model corresponds to the Quality Dimension in the 5S quality model and both models further specialize these notions according to relevant digital library facets: the six domains in the former case and the major digital library concepts in the latter case. As it is shown in Figure 7, many of the major digital library concepts of the 5S quality model refer to what is called Content Quality Parameter in the DELOS Reference Model, while the Services major digital library concept corresponds to the Functionality Quality Parameter.

The notion of Numerical Indicator in the 5S quality model corresponds to the (Measure, Measurement) pair in the DELOS Reference Model, which in addition gives us finer control in modelling the distinction between the process adopted for measuring a quality parameter and the actual value assigned to a given measurement. Furthermore, the DELOS Reference Model explicitly takes into account both the Resource under assessment and the Actor who is carrying out the assessment, aspects which are not dealt with in the 5S model.

Therefore, as discussed above, the wider breadth and the more systematic modelling of the DELOS Reference Model with respect to the 5S quality model impact different areas of the quality realm. On the other hand, the 5S quality model gains much more depth in certain areas where the DELOS reference model only provides support for further investigation and extension.

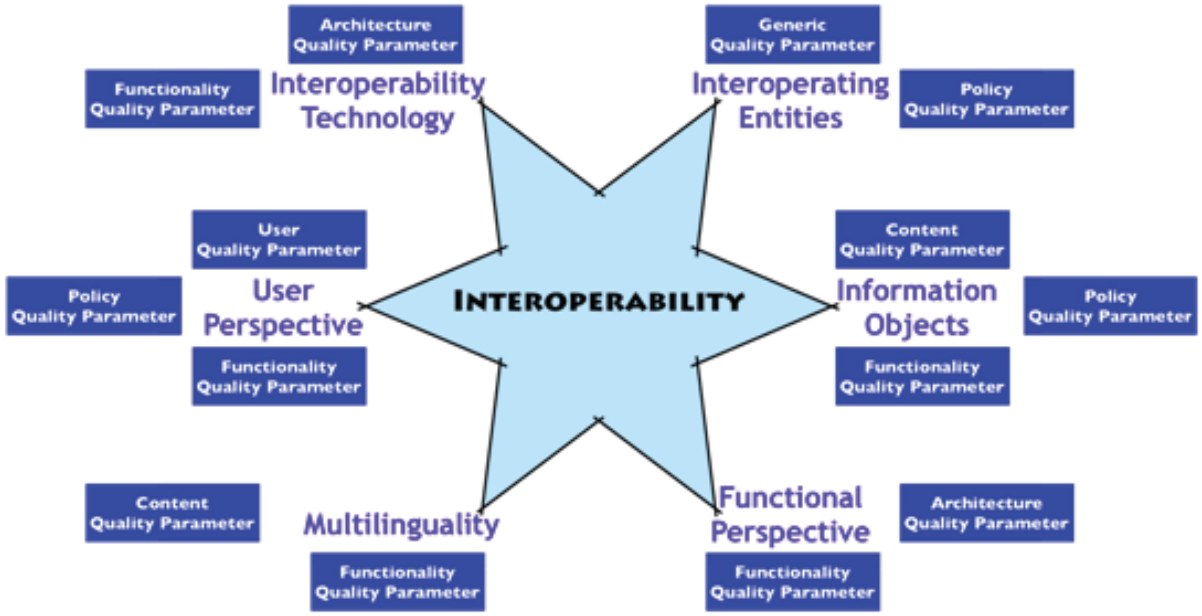
4. QUALITY AND INTEROPERABILITY

As discussed in Section 1, the relationships and the interdependencies among quality and interoperability can be extremely complex and we start discussing them by means of a concrete example.

Consider the case of digital annotations which aim at allowing users to augment the resources managed by a digital library with personal comments, tags, discussions and to link resources that belong to different digital libraries or the Web[28,29]. Making this scenario concrete requires to address several issues related to the interoperability among an annotation service and different digital libraries. The overall perceived quality of the service depends on the ability of effectively and flexibly composing components and functionalities coming from different systems, that is, it depends on the degree of interoperability among the different components that need to interact. On the other hand, an annotation service may also give the possibility of making different digital libraries interoperate together, even if they were not designed with this objective in mind[30]. Indeed, the annotation service can offer access, by navigating the annotations, to resources managed by different digital libraries that otherwise would have not been directly accessible from one to another. The effect is to increase the perceived quality of different digital libraries, which would not interoperate otherwise, by means of the added-value services offered over them.

This brief example should give the reader an idea about how quality and interoperability can affect each other and how much they can be interrelated: offering high quality services can require a high degree of interoperability among the different components of a system; similarly, poorly designed or low quality services can affect the degree of interoperability among different components that can be achieved, thus preventing the successful cooperation among different systems.

Figure 8. Determining factors of interoperability and the quality domain in the DELOS Reference Model



The above considerations mainly concern a functional perspective. Nevertheless, the distributed nature and the composition of different services in a user-centered perspective impacts also different dimensions of the quality of a digital library. Consider, again, the case of annotations: they basically break the traditional curatorial and selection process that, for example, distinguishes digital libraries from the Web, ensures the quality and reliability of the managed information resources, and keeps a digital library updated and fitting to the needs of one or more user communities. Indeed, the quality of the content added by users via annotations may be varying and it may not match the level and the requirements adopted when selecting the information resources to be managed by the digital library. This impacts not only the overall perceived quality of the digital library but also the policies adopted and enforced by the digital library: for example, a moderation step could be envisioned to review user's annotations before accepting and publishing them in a digital library, but this requires to have specific policies concerning the staff responsible for moderating annotations, the rules of which define when an annotation can be accepted or not, the procedures and functionalities for the ingestion of new content and so on. As a consequence, the quality of the policies themselves adopted by the digital library is concerned in this scenario, since they need to prove to be exhaustive, flexible, and powerful enough to be able to deal with the creation and the addition of new content by users.

This discussion shows how the complex interactions between different entities – e.g. users, information resources, added-value services, policies, and so on – which are a distinctive feature of next generation digital libraries, are closely related to the quality of a digital library, how they affect each other, and how the need to be faced with comprehensive quality models which go well beyond the problem of rating some feature of a digital library according to some scale.

In this context, the progressive development of models for defining the different facets of digital libraries and for investigating the various factors which affect interoperability represents a key step to be able to deal with these issues in a systematic

and exhaustive way. Consider, for example, the possibility of relating the quality domain of the DELOS Reference Model with the conceptual model of interoperability proposed by the European Commission Working Group on Digital Library Interoperability, as shown in Figure 8.

- **Interoperating entities:** both Generic Quality Parameters, such as Reputation[31] or Economic Convenience[32], and Policy Quality Parameters, such as Policy Precision[33], may affect this dimension of interoperability, since they influence the motivations for different institutions to get in touch and the rules according to which these institutions can cooperate.
- **Information Objects:** the Content, Functionality, and Policy Quality Parameters play an important role in assessing the interoperability among different information resources, as it clearly emerges from the previous examples about annotations.
- **Functional perspective:** the Functionality and Architecture Quality Parameters are directly related to the evaluation of how different components can interact and be integrated together.
- **Multilinguality:** the Content and Functionality Quality Parameters provide us, for example, with the means for assessing the quality of metadata describing the language of an information resource or the effectiveness of a multilingual information access service in a digital library.
- **User perspective:** User, Functionality, and Policy Quality Parameters allow us to understand what users expects by the functionalities of different digital libraries, how they behave and exploit the interaction with various content and services, as well as how the rules enforced by different digital libraries support their daily activities.
- **Interoperability technology:** Functionality and Architecture Quality Parameters can serve the purpose of judging how effectively and to what extent the different technologies that enable interoperability have been successfully exploited and deployed.

Finally, the DELOS Reference Model cater to the need for a complete model of the relationships among quality and interoperability by providing a Generic Quality Parameter, called Interoperability Support[34], which reflects the capability of a digital library to inter-operate with other digital libraries and represents the extension point for developing, in the future, a whole hierarchy of Quality Parameters which appraise the interoperability.

5. FUTURE PERSPECTIVES FOR QUALITY AND INTEROPERABILITY

As it emerges from the previous discussions, digital libraries are becoming increasingly complex and they need to satisfy user needs and carry out tasks that are getting more and more complicated. The amount of information managed by such systems, its heterogeneity and variety, and the demand for an insightful access to it are key challenges in the present research agenda.

The design and development of such complex information systems calls for proper evaluation methodologies, benchmarks, testing and validation techniques in order to ensure that they meet the expected user requirements, provide the desired effectiveness and efficiency, guarantee the required robustness and reliability, and operate with the necessary scalability; in one word, they need proper methodologies for assessing their quality.

Large-scale evaluation campaigns at international level have proved to give a fundamental contribution to advancement of state-of-the-art techniques and development of innovative information systems through common evaluation

procedures, regular and systematic evaluation cycles, comparison and benchmarking of the adopted approaches and solutions, spreading and exchange of knowledge and know-how. Examples of such initiatives in the information retrieval field, are: the Text Retrieval Conference[35] (TREC) events organized by the US National Institute of Standards and Technology (NIST); the NTCIR Evaluation of Information Access Technologies[36] organized by the National Institute of Informatics, Japan; the Cross Language Evaluation Forum[37] (CLEF). These major initiatives covered a wide array of different media types and tasks and produced, over the years, a huge amount of scientific data deriving from their experimental activities.

All these initiatives follow a similar evaluation paradigm[38] and face many common issues when it comes to the creation, management, analysis, mining, enrichment, archiving, curation, re-use, dissemination of the experimental data, performance metrics and figures, and statistical analyses. Nevertheless, the existence of so many initiatives has led to a fragmentary picture where the development and implementation of (partial) solutions and systems to address the above mentioned issues are often replicated and tackled in ad-hoc or proprietary ways. Moreover, running these initiatives, conducting the experiments, gathering the data, and performing the necessary analyses often requires a great deal of human labour which could be greatly lowered by developing appropriate systems and automated evaluation procedures, thus saving time to be dedicated to further research and development.

Finally, the growing interest in the proper management of experimental and scientific data has been brought to general attention by different world organizations, among them the European Commission, the US National Scientific Board, and the Australian Working Group on Data for Science. The European Commission in the i2010 Digital Library Initiative clearly states that "digital repositories of scientific information are essential elements to build European eInfrastructure for knowledge sharing and transfer, feeding the cycles of scientific research and innovation uptake"[39]. The US National Scientific Board points out that "organizations make choices on behalf of the current and future user community on issues such as collection access; collection structure; technical standards and processes for data curation; ontology development; annotation; and peer review". And, those organizations "are uniquely positioned to take leadership roles in developing a comprehensive strategy for long-lived digital data collections"[40]. The Australian Working Group on Data for Science suggests to "establish a nationally supported long-term strategic framework for scientific data management, including guiding principles, policies, best practices and infrastructure", that "standards and standards-based technologies be adopted and that their use be widely promoted to ensure interoperability between data, metadata, and data management systems", and that "the principle of open equitable access to publicly-funded scientific data be adopted wherever possible [...] As part of this strategy, and to enable current and future data and information resources to be shared, mechanisms to enable the discovery of, and access to, data and information resources must be encouraged"[41].

Therefore, there is a strong need to affect the current fragmented situation by advancing and automating the evaluation, testing, and benchmarking of complex multimedia, multimodal, and multilingual digital libraries and develop an information management and access infrastructure which supports and operates the evaluation of such complex systems as well as the organization and running of evaluation initiatives. Some key areas that need to impacted to improve the assessment of quality in digital libraries are:

- design and development of an infrastructure that allows for the experimental evaluation of digital libraries managing a variety of media (text, images, audio, video, user generated content,...) and with respect to

different tasks and needs (medical domain, intellectual property domain, cultural heritage domain,...);
- support of different experimental methodologies (batch experimentation, log mining, recording and reusing interaction data,...) as well as different analyses and comparisons (metrics, statistics,...), including benchmarking of system components;
- proper and coherent management of the scientific data produced during the experiments; promotion of scientific data reuse and facilitation of the comparison of new systems with respect to the existing knowledge-base;
- support for the interaction, manipulation, enrichment, exploitation of the scientific data and their analyses by researchers, industries, students,... so that a community can work and interact with the data held by the infrastructure, add their own analyses and interpretations, facilitate collaboration over those data;
- provision of a set of standard interfaces and modular components so that the infrastructure can be shared and extended with personalized components and can be used for remote, distributed, and automated evaluation as well as for instantiating ad-hoc evaluation systems for specific needs.

These fairly ambitious objectives aim at making the suggested infrastructure suitable for the evaluation of the quality of a variety of information access systems, including search engines, digital libraries, enterprise portals, and so on. Moreover, being modular and standardized, the infrastructure would allow for its customization and adaptation to specific communities, e.g. legal, music, medical, and so on. Finally, this kind of infrastructure would support innovative evaluation modalities. Indeed, today, the evaluation is mainly unidirectional and very rigid: system owners have to download experimental collections, upload their results, and wait for the performance measurements by the organization. On the contrary, the proposed infrastructure would also allow for two additional scenarios: (1) it could be remotely accessible: a system owner would be able to operate the infrastructure through standard interfaces, run a test, obtain the performance indicators, and compare with the existing knowledge base and state-of-the-art, managed by the infrastructure; (2) in the case of a system implementing a set of standard interfaces, the infrastructure would be able to directly operate the system and run a set of test to assess its performances, speeding up the adoption of standard benchmarking practices.

Note that the suggested quality evaluation infrastructure is something different from, for example, the tool developed for operationalizing the 5S quality model[42]. Indeed, the former is a system external to any specific digital library with the aim of both managing the whole process of quality evaluation and acting as a shareable knowledge base to compare with; the latter is more similar to a kind of plug-in or service that a digital library administrator can use to gauge some quality indicators about his own digital library.

This need for improving and automating the evaluation of quality in digital libraries relates with interoperability too but from a perspective different from the one discussed so far. Indeed, this vision needs a high degree interoperability between a digital library and the infrastructure used to evaluate it. Therefore, quality and interoperability are related not only because they can reinforce (weaken) each other but also because interoperability is indispensable to move a step forward and automate the evaluation of quality in digital libraries[43].

Some initial steps in this direction have been started with the experience gathered in designing and developing the Distributed Information Retrieval Evaluation Campaign Tool[44] (DIRECT) digital library system, which has been successfully adopted in CLEF for some years[45,46]. DIRECT not only manages the different types of information

resources employed in a large-scale evaluation campaign and supports the different stages of the campaign, but also facilitates the sharing and dissemination of the results. DIRECT is proving an important instrument to improve cooperation among researchers and to facilitate the transfer of scientific and innovative results and can act as a starting point to embody the vision described above.

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ENDNOTES

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