INTEGRATION OF DATA AND SERVICES FROM THE EARTHQUAKE ENGINEERING (SERIES) AND SEISMOLOGY (EPOS) FIELDS

A. Caverzan[(1)], A. Athanasopoulou[(2)], C. Sintoris[(3)], P. Pegon[(4)], S. Bousias[(5)], N. Avouris[(6)], K. Atakan[(7)], G. Tsionis[(8)]

[(1)] *Project Officer, European Commission, Joint Research Centre (JRC), Ispra, Italy, alessio.caverzan@ec.europa.eu*
[(2)] *Project Officer, European Commission, Joint Research Centre (JRC), Ispra, Italy, adamantia.athanasopoulou@ec.europa.eu*
[(3)] *Laboratory Teaching Associate, Department of Computer Engineering and Informatics, School of Engineering, University of Patras, Patras, Greece, sintoris@upatras.gr*
[(4)] *ELSA laboratory responsible, European Commission, Joint Research Centre (JRC), Ispra, Italy, pierre.pegon@ec.europa.eu*
[(5)] *Professor, Department of Civil Engineering, School of Engineering, University of Patras, Patras, Greece, sbousias@upatras.gr*
[(6)] *Professor, Department of Computer Engineering and Informatics, School of Engineering, University of Patras, Patras, Greece, avouris@upatras.gr*
[(7)] *Professor, Department of Earth Science, University of Bergen, Kuvvet.Atakan@uib.no*
[(8)] *Project Officer, European Commission, Joint Research Centre (JRC), Ispra, Italy, georgios.tsionis@ec.europa.eu*

Abstract

A number of European research projects in the fields of seismology and earthquake engineering have produced large amounts of data and related services with the scope of developing new approaches for seismic risk reduction (e.g., NERA - Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation, SERIES - Seismic Engineering Research Infrastructures for European Synergies, SHARE - Seismic Hazard Harmonization in Europe, SYNER-G - Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain) The SERIES project represents the most significant effort in Europe towards the interoperability of earthquake engineering experimental data, while two European organisations, namely ORFEUS (Observatories and Research Facilities for European Seismology) and EMSC (European Mediterranean Seismological Centre), have been collecting and sharing seismological data. In the field of solid Earth science, the ambition of EPOS (European Plate Observing System) is to set up a virtual environment, which federates the handling of research data and services by existing scientific data infrastructures and provides a one-stop-shop for seamless access to services supporting the research community along the data life cycle. This objective is in line with the European Open Science Cloud (EOSC) initiative, which reflects the willingness to "*embrace change, try new things and be willing to take risks to keep European research and innovation at the forefront of modernity and economic growth*". Nevertheless, the two adjacent scientific disciplines of earthquake engineering and seismology have not yet interfaced their data structures, lacking an interoperable data-sharing structure; this suggests that there is an urgent need for breaking the silos of these two disciplines. The SERA project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe) aims at creating a roadmap for integrating the most important databanks and related informatics services of the two research communities in Europe, i.e. SERIES and EPOS, so as to promote multi-disciplinary science, facilitate innovation and ultimately reduce the risk posed by natural and anthropogenic earthquakes. The paper presents a proposal for the integration of the platforms, or better, the SERIES database within the EPOS environment for improving access to data, services and research infrastructures in order to accelerate the cross-fertilization of the two disciplines.

Keywords: Data Banks; Data Products; Services; Earthquake Engineering; Seismology

1. Introduction

Over the years, a large amount of data has been produced by the earthquake engineering and seismology Research Infrastructures (RIs) in Europe, together with information technology tools for data sharing within each research community. Such web-based tools are an emerging trend to manage and share results with the scientific community, decision-makers and the general public. A number of European research projects in the fields of seismology and earthquake engineering have produced large amounts of data and related services with the scope of developing new approaches for seismic risk reduction (e.g. NERA - Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation, SERIES - Seismic Engineering Research Infrastructures for European Synergies, SHARE - Seismic Hazard Harmonization in Europe, SYNER-G - Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain etc.).

In a worldwide scale, collaborations in earthquake engineering lack a common interoperable framework, resulting in tedious and complex procedures to integrate data and results. Up to now, the SERIES project represents the most significant effort in Europe towards the interoperability of earthquake engineering experimental data in the period 2009 – 2013 [1]. In the field of seismology, global sharing of seismological data has been a long-lasting tradition tracing back to the beginning of the previous century. In Europe, this tradition emerged in the form of two European organizations, namely ORFEUS (Observatories and Research Facilities for European Seismology) for seismological waveform data and EMSC (European Mediterranean Seismological Centre), which both were sustained by the community for several decades. In addition to this, recently, the European Strategic Forum for Research Infrastructures (ESFRI) initiative and the European Plate Observing System (EPOS) project provided a larger framework for the integration of all solid Earth science data into a single pan-European e-infrastructure.

Nevertheless, up to now, the two adjacent scientific disciplines of earthquake engineering and seismology have not interfaced their data structures, lacking an interoperable data-sharing structure. Considering the large number of disciplines involved in data production and use (seismology, earthquake engineering, near-fault observation, geotechnical engineering, etc.), a large amount of heterogeneous data was produced in the past and is going to be produced for better understating the various phenomena. Different data management practices and access policies applied by the data providers, generate complex ecosystems of poorly interoperable data infrastructures. Resulting data silos slow down the circulation of knowledge and prevent cross-fertilisation of interdisciplinary research, which is essential for increasing the interaction within adjacent scientific disciplines.

This paper presents a roadmap towards the integration of data and services from the earthquake engineering and seismology fields focusing on the most important databanks and related informatics services in Europe, i.e. SERIES and EPOS (and in particular the EPOS community on seismology). The proposed integration of the SERIES database within the EPOS environment will facilitate access to data, services and research infrastructures within the two disciplines. The work discussed was performed in the framework of the Horizon 2020 project "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe – SERA" that promotes in the long-run multi-disciplinary science, facilitates innovation and ultimately aims to reduce the risk posed by natural and anthropogenic earthquakes [2].

2. The SERIES database and the EPOS platform

The SERIES project mission was to overcome the fragmentation that characterized the European earthquake engineering community by bringing together Europe's RIs in structural and geotechnical earthquake engineering into a coherent and sustainable platform of co-operation [1]. One of the activities within the project aimed at facilitating the exchange of data and data communication among research infrastructures in Europe providing both off-line access to data by means of a database and on-line access by means of telepresence implementation that allowed collaborative decision-making during experimental test campaigns.

The platform of co-operation between the RIs in SERIES comprised of: (i) a corporate web-portal (http://www.dap.series.upatras.gr/) as the central contact point for SERIES and the main reference point for RIs in earthquake engineering in Europe (Data Access Portal – DAP), and (ii) a distributed database of experimental information, where the data are saved at the individual facility and a communication protocol ensures their transfer to the end user in a common language and format [3, 4]. This virtual database was developed instead of a centralised repository in light of the differences in institutional practice within the SERIES consortium. Fig. 1 presents the global architecture scheme of SERIES [4].

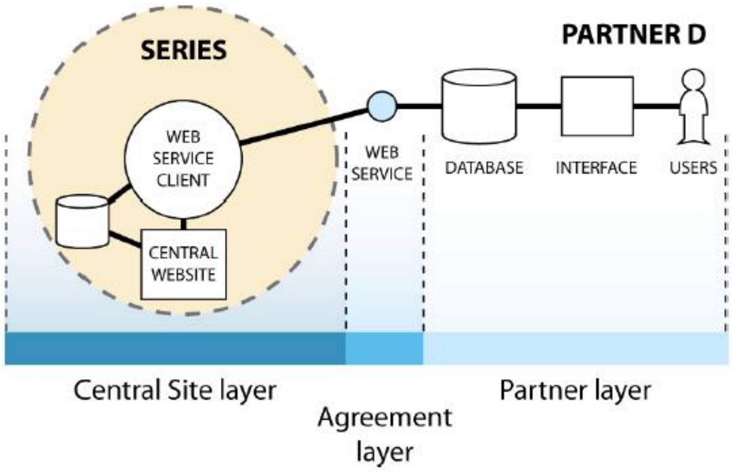

Fig. 1 – The SERIES architecture scheme

In the field of solid Earth science, the ambition of EPOS is to set up a virtual environment, which federates the handling of research data and services by existing scientific data infrastructures and provides a one-stop-shop for seamless access to services supporting the research community along the data life cycle. This objective is in line with the European Open Science Cloud (EOSC), which reflects the willingness to "*embrace change, try new things and be willing to take risks to keep European research and innovation at the forefront of modernity and economic growth*" [5].

EPOS provides for Thematic Core Services (TCS), which are responsible for integrating all data, metadata and services arriving from various national and international infrastructures. One of EPOS TCS is the Seismology that heavily depends on the community-driven European level institutions that are already established, namely ORFEUS and EMSC. It also provides Integrated Core Services (ICS), which offer a new interface for users by adopting data access policies aligned to open science principles. The ICS make data, services and products accessible to users in a useable form that allows innovative, disciplinary and cross-disciplinary research. The global architecture scheme of the EPOS platform is presented in Fig. 2 [6]

The EPOS and SERIES platforms have several similarities and some differences (for a detailed review, refer to [6]). The most important similarity is their principal mission, i.e. the development of interoperable data-sharing structures for the respective scientific communities and the provision of a single tool to make integrated use of data and data products provided by different European research infrastructures. However, the nature of the two projects is different. EPOS targets an integration of heterogeneous data coming from several communities in solid Earth science into a single and distributed infrastructure and facilitating access through a single online environment. On the contrary, SERIES is a domain-specific infrastructure (representing the earthquake engineering experimental research community) that stores data in independent, distributed sources and provides a single uniform user interface to access them. In both platforms' architecture, data are received from external data providers and/or centres. The external data centres share existing data with the corresponding central access point. In the case of EPOS, the external data centres are the national research infrastructures and data centres. In the SERIES platform, the data providers are the partner RIs, which send their data to update the SERIES central database.

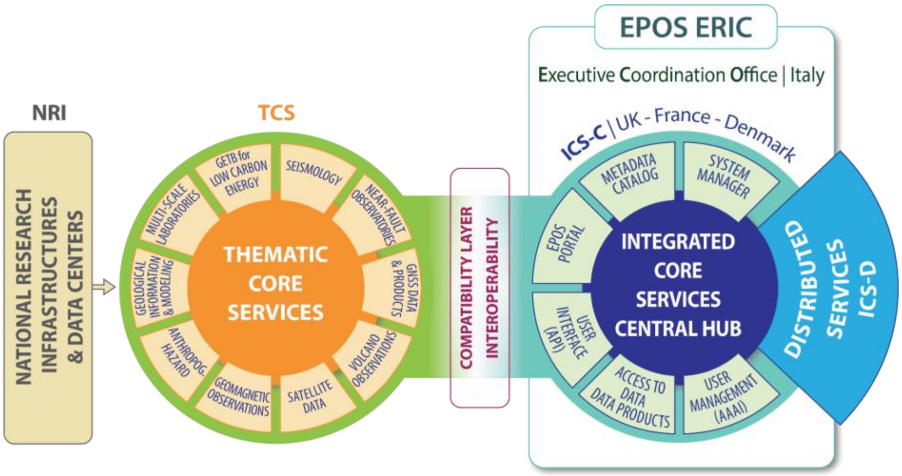

Fig. 2 – The EPOS platform global architecture scheme ([6])

A notable difference though, stemming from the wide range of scientific domains that relate to the EPOS project (e.g. seismology, multi-scale laboratories, near-fault observatories, etc.), is that an intermediate layer exists between the data providers and the central database, namely the TCS [7]. In this regard, SERIES being a thematic community service (i.e. the earthquake engineering community) can be compared to a TCS where the relevant data and products are already integrated and made available through a data gateway (the SERIES DAP). Similar TCS-level data gateways exist in EPOS, such as ORFEUS and EMSC in the TCS Seismology. Moreover, both systems are based on a Service-Oriented Architecture. While EPOS requires that data, data products, services and software (DDSS) provided by the national research infrastructures in each scientific community are exposed through a web service in the TCS layer, in SERIES each partner exposes their data through a web service towards the central site.

3. Integration of SERIES and EPOS data and services

There is no single roadmap to be proposed for the integration of databanks and access services from the EPOS and SERIES platforms, supporting data and service-sharing between the earthquake engineering and seismology research communities so as to facilitate the interoperation of the two communities. Nevertheless, at this stage, an approach is to consider the SERIES architecture from the point of view of the EPOS architecture, using the existing platforms for data sharing because the seismology community is already integrated in EPOS as a TCS. Thus, an immediate approach to effect the integration is to consider the SERIES database as the first service of a new Earthquake Engineering Thematic Core Service (E/ENG TCS) within the EPOS architecture.

By following this approach, SERIES may initially provide, through EPOS, integrated access to key data and experimental measures produced at some of the best facilities for earthquake engineering worldwide. Moreover, this approach would provide SERIES additional possibilities to interact with the other solid Earth science communities in EPOS and support data and services exchange with them. The SERIES DAP could serve as the domain-specific data gateway in the same way as most of EPOS TCS have (or are developing) domain-specific data portals. In its mature phase, the integration process will provide an advanced interoperability within the earthquake engineering community itself, with the sibling TCS seismology and other TCSs, and with international partners. This objective will be guaranteed by means of the implementation of new services and tools for improving user accessibility and experience.

The SERIES data model can be viewed as one of several domain-specific data models, concerning the scientific community of earthquake engineering. If one follows this line of thought, SERIES could provide metadata to EPOS by implementing a convertor from SERIES data model to the one used by EPOS at the level of the SERIES Central Site. No major redesign of the EPOS or SERIES architecture would be necessary to achieve this conversion, apart from consideration of semantic issues [6]. Naturally, development would be required in both sides: SERIES would need to create some web services in the central site to provide data and EPOS to create the components that will call the services and deliver data to the data consumers.

Other opportunities for data integration between the two communities already exist. For example, SERIES could use data services of EPOS as a client rather than as a server, while looking for direct interoperability opportunities with some of the relevant TCS (in particular TCS Seismology).

4. Requirements of earthquake engineering and seismology communities

In order to make the integration of the SERIES database within the EPOS environment as effective as possible, however, it was first necessary to identify the needs and priorities that the two scientific communities have. To this end, in the second semester of 2018, a questionnaire was given to users and stakeholders operating in the field of earthquake engineering and/or seismology (https://ec.europa.eu/eusurvey/runner/SERA_Survey_RUCs).

Fig. 3 – Geographical distribution of the responders to the questionnaire

The questionnaire aimed to collect information on requirements and use cases for earthquake engineering and seismological data that fed into the roadmap for integration of SERIES and EPOS databanks. It was composed of three parts. In the general part, after a brief introduction to the SERA, SERIES and EPOS projects and the scope of the survey, the users were asked to indicate their expertise and/or field of interest and provide some general information. In the quantitative part the users were asked to evaluate 13 different requirements for the databanks. The qualitative part was set in order to obtain, through open-ended questions, more extensive information regarding use cases, priorities, expectations and objectives to achieve through the database integration.

The questionnaire was sent to a targeted audience of users operating in the field of earthquake engineering and seismology. The users have different profiles and roles like academic positions, researchers, laboratory managers and technical staff, practitioners, etc. Thirty-two users from sixteen countries (see Fig. 3) completed the questionnaire. The users' expertise and fields of interest covered a broad spectrum: most of the responders work in the experimental testing, numerical modelling and teaching fields.

In the quantitative part of the questionnaire, users evaluated different requirements for the data banks. Thirteen different requirements were indicated, namely: simple search, advanced search, access to search interface at local database, search for data in different formats, contact information at local database, contact information for individual project, data visualisation tools, tools to elaborate data, access to test reports and specific publications, description of the project, description of the specimen, description of the experimental setup, possibility to share own DDSS. Starting from the collected data it was possible to rank the requirements in order of importance attributed by the users. Each value associated to the requirements was computed considering a weighted average of the values expressed by the users. The three most important requirements for the users were: (i) access to test reports and publications, (ii) description of specimen and (iii) description of experimental setup. The users expressed a clear need for access to data that are essential for numerical simulations and reliability checks. Users suggested additional requirements, mainly summarized in: (i) the possibility to share information with other researchers and (ii) access to quality plans of experiments (including calibration procedures and check of data reliability).

The qualitative part of the questionnaire was designed with open-ended questions and more extensive information regarding use cases (simple, complex or advanced) were collected. A simple use case describes a basic and elementary functionality, i.e. search for data, simple visualisation and download. The simple use cases described by the users may be grouped in the three cases reported in Table 1. There are several data and data products already in the SERIES database that can be downloaded and visualised according to the three use cases. Examples of such data include the displacement, force and acceleration time-histories, photos and drawings of specimen and experimental setup, videos of experimental tests, description of equipment and instrumentation, calibration data, and acquisition configuration. Moreover, some services, like combined search criteria and search for structural response for a given earthquake, were already implemented in SERIES.

Table 1 – Simple use cases for earthquake engineering and seismological data

Step	Use case 1	Use case 2	Use case 3
1	Search	Search	Search for a project
2	Filter/sort	Select	Select a specimen
3	Select	Visualise data	Select an instrument
4	Download	Download accompanying documentation	Visualise data

A complex use case includes searching for and visualising datasets from various sources / local databases and possibly performing an analysis or processing. The complex use cases described by the users may be summarised in the three cases given in Table 2. These complex use cases require several interactions of the users with the web interface and a complex system workflow to process the query. Moreover, some particular data and features have not been implemented yet in the SERIES database (e.g. visualisation tools).

The questionnaire served to collect proposals on possible ways to better integrate data and services from the two adjacent scientific disciplines of earthquake engineering and seismology. The improved access to cross-discipline data, services and research infrastructures can help reduce the risk posed by natural and anthropogenic earthquakes, which is the main objective of the SERA project. A specific expectation is improving the regional loss assessment through integrating hazard and vulnerability assessment.

Different strategies can be followed to promote synergies between the earthquake engineering and seismology data providers and users. Considering the TCSs implemented in the EPOS platform, a simple way is to map data and establish a link when the same or related data exist in the SERIES database.

Table 2 – Complex use cases for earthquake engineering and seismological data

Step	**Use case 1**	**Use case 2**	**Use case 3**
1	Search for a structural typology (e.g. RC frame, steel frame, two storeys, etc.)	Search for a type of structural element (e.g. column, beam, joint, etc.)	Search for a specific input action
2	Select a point of a post-processed data series A (e.g. moment, shear, etc.)	Select two elements of this type (e.g. different geometry or material)	Filter to specific structural typology (e.g. RC frame, steel frame, two storeys, etc.)
3	Combine data series A with other post-processed data series (e.g. rotation, displacement, etc.)	Select two series of post-processed-data for each element (e.g. moment-rotation)	Select two specimens tested by means of different setup and/or methodology (e.g. pseudo-dynamic or shaking table tests)
4	Visualise data	Visualise comparison of selected post-processed data for selected elements	Visualise data and share with others
5	Download data	Download data	Download data

Examples of such data that are already available through the TCS Seismology and the SERIES database are given in Table 3. For example when a user is searching and selecting a well-defined input accelerogram in the proposed Earthquake Engineering TCS, a link to a service able to provide spectrum-compatible signals in the Seismology TCS could be highlighted. Alternatively, in the seismology TCS when a user is looking for a particular building typology in an exposure database, a link to the SERIES data related to tests performed on the same building typology could be highlighted.

Table 3 – Examples of links between data in the SERIES database and the EPOS TCS Seismology

SERIES database		**EPOS TCS Seismology**
Input accelerogram (Friuli, El Centro, etc.)	→	Seismological data related to the signal
Input accelerogram	→	Spectrum-compatible signals
All tests that used the accelerogram as input	←	Accelerogram (Friuli, El Centro, etc.)
All tests performed on the building typology	←	Building typology in a specific seismic region

5. Metadata formats and IT developments

In general, the SERIES and the EPOS metadata formats, when compared, reflect the differences of the scope and domain of the projects that produced them.

EPOS Integrated Core Services-Central (EPOS ICS-C) is the essential component of EPOS that provides end-users with a view of the data harvested from heterogeneous communities and being available in the central catalogue. In EPOS-ICS-C, metadata is represented in two levels, as follows. In the central catalogue, EPOS-ICS-C uses the CERIF (Common European Research Information Format) [8] to represent data. Metadata that are transferred from the EPOS scientific communities (i.e. TCSs) to the central catalogue are represented in the EPOS-DCAT-AP standard, an extension of the Data Catalogue Vocabulary Application Profile (DCAT-AP) standard [9]. Thus, the process of converting metadata, acquired from the EPOS TCSs, to CERIF is twofold. First, each TCS is required to map its domain-specific metadata into the EPOS-DCAT-AP baseline format. The mapping occurs between two metadata standards (from the source TCS format to the destination EPOS baseline format). The EPOS baseline, which serves as an abstraction layer, has been implemented by extending the DCAT-AP. Second, EPOS ICS is responsible for ingesting the EPOS baseline format (EPOS-DCAT-AP) into CERIF.

Current SERIES architecture is comprised of two conceptual parts, the central site and the remote nodes (see Fig. 1). The remote nodes act as distributed data storages and are controlled by SERIES partners. The central site provides data discovery and publication services. To achieve this, the central site harvests metadata from the remote nodes and allows end-users to search these metadata data and download data from the remote nodes via the central site interface. Currently, SERIES harvests and hosts the metadata from remote nodes (earthquake engineering community laboratories) while actual data are hosted by the nodes themselves. SERIES metadata format is the Exchange Data Format (EDF) and it is targeted at the specific needs of the earthquake engineering community, as they were seen in the past decade, when the metadata format was first designed and then used in the actual implementation of the SERIES DAP [10].The SERIES EDF has a hierarchical form that structures the metadata in a top-down approach, where laboratories are the top-level entities.

On the other hand, the EPOS metadata format, built upon the existing standard vocabularies (DCAT-AP), has been designed with the explicit aim of allowing different scientific domains that relate to the sciences of solid earth, to consolidate their data. These communities have varying needs and requirements to describe their data and EPOS metadata format has succeeded in integrating these communities as part of its Thematic Core Services. The similarities of the Earthquake Engineering community to those domains make some aspects of the EDF easy to map into EPOS-DCAT format. Entities such as Person, Organization, etc, can be mapped to corresponding the SERIES EDF entities with minor adjustments, such as adding global identifiers (i.e. OrcID, PIC, ISNI etc.) to such entities. The retrospective acquisition of such metadata for projects that have been concluded for many years may be problematic, but is not a major issue, given that the participating organizations are limited in number.

The mapping of the SERIES EDF hierarchical structure (see Fig. 4) into EPOS-DCAT-AP format is foreseen to be implemented with the Datasets entity [11], which, as specified in EPOS-DCAT-AP, can relate to other Datasets. Hierarchies of Datasets can be specified, reflecting the hierarchical relationship between the SERIES EDF Levels. The EPOS-DCAT-AP Dataset entity provides three properties that allow such an implementation, which a) denote that a Dataset is physically or logically included in another Dataset, b) relate the current Dataset to a Dataset that is part of the current one, and c) refer to a related Dataset from which the described Dataset is derived.

Fig. 5 depicts how the relationship between the TCS domain of E/ENG and the SERIES EDF metadata structure is will be established. All metadata that are shared via the SERIES Central Site, are exposed to a machine-readable format via a single web service. The web services exposes two operations, one for retrieving project metadata, and another for retrieving metadata for a specific specimen. SERIES metadata are exposed to EPOS through the TCS E/ENG metadata retrieval web service. The TCS metadata retrieval web service acts as the single point of access for automated metadata exchange of the underlying E/ENG data in the EPOS-DCAT-AP format, as described previously. The web services exposes project metadata and URLs that point to specific data, which are served directly by the SERIES remote nodes.

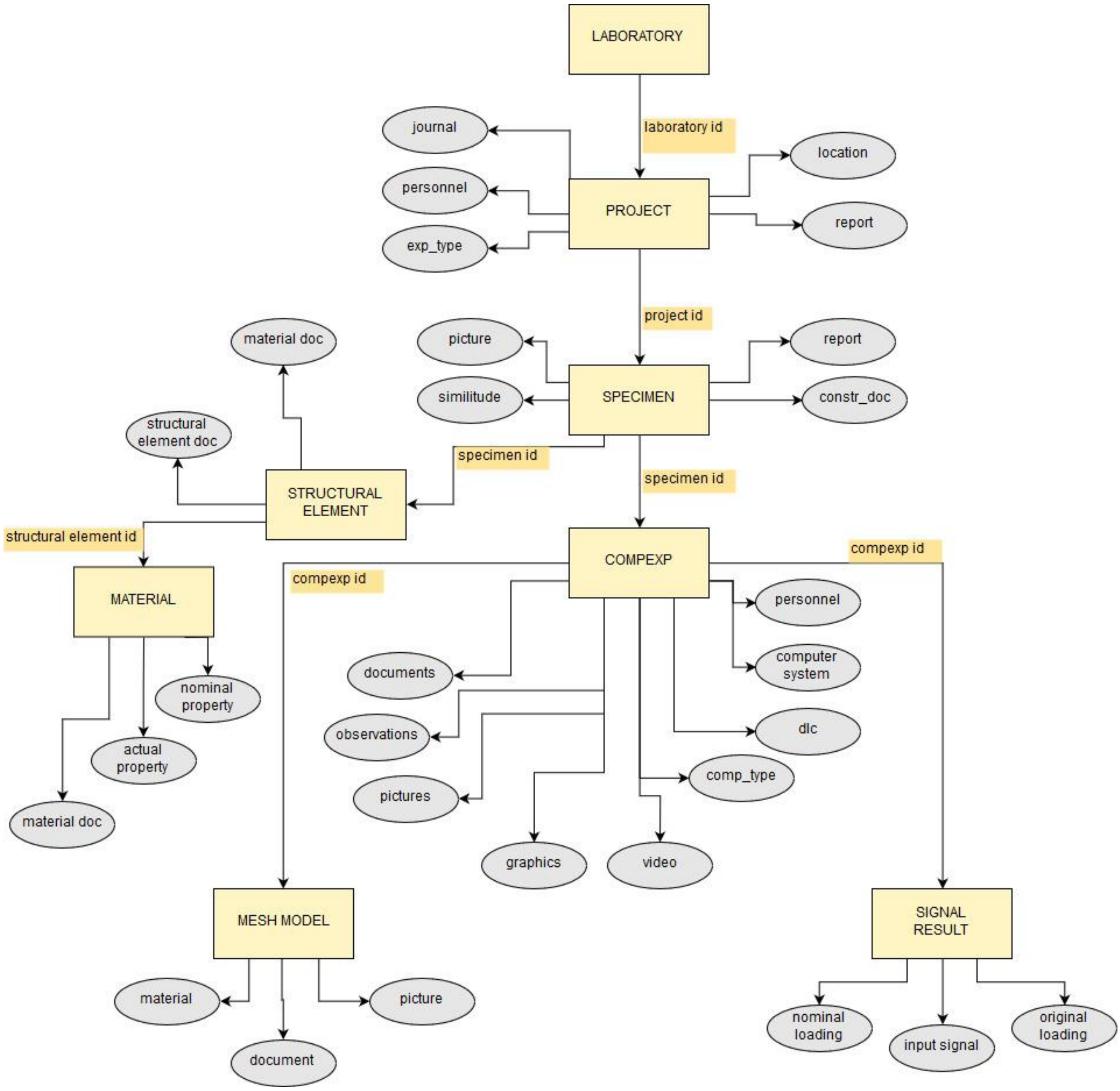

Fig. 4 – The entities of the SERIES Exchange Data Format hierarchy and their main properties. Arrows denote a hierarchical relationship.

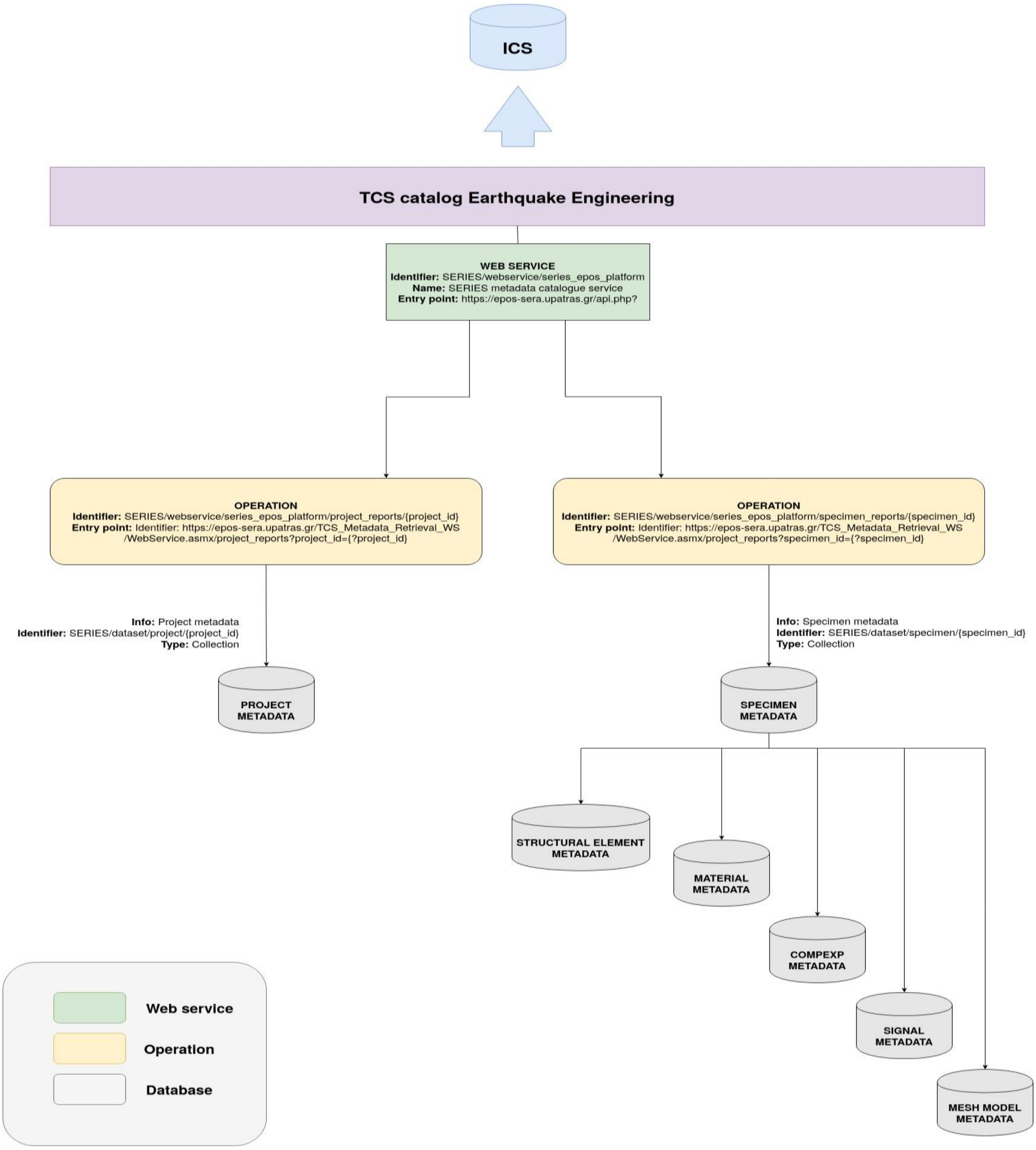

Fig. 5 – Structure of the metadata retrieval web service of the TCS Earthquake Engineering. A single webservice provides retrieval operations for DDSSs that follow the SERIES metadata structure.

6. The way ahead

The work conducted in SERIES enabled the automated integration of experimental results within a number of European laboratories and brought a source for experimental data so that the earthquake engineering community can access data from any SERIES partner by using a single, unified web interface. On the other hand, EPOS integrates the key research infrastructures in seismology, volcanology, geodesy, geology, geomagnetism, anthropogenic hazards and geoenergy applications. Each thematic community develops specific services that are validated and introduced in EPOS for sustainable operation.

The main objectives of the integration of databanks and services from SERIES and EPOS is to improve access to earthquake engineering and seismology data and services and facilitate cross-discipline collaboration. This integration will strengthen the advanced community of earthquake engineering and seismology developed within the SERA project and more in general the community of earthquake hazard and risk mitigation. This effort will serve the needs of the individual communities and, more important, improve the interoperability of the data exchange services aiming at smarter access, integrated data and knowledge that is needed to develop innovative technologies for the reduction of the vulnerability of the built environment to earthquakes and the mitigation of seismic risk.

It is proposed that the most immediate approach to realize the integration is to consider the SERIES database as the first service of a new Earthquake Engineering Thematic Core Service within the EPOS architecture (Fig. 6). Such an approach promotes an efficient use of resources and know-how sharing along with the added value of bringing together the data sources and data exchange services of the two communities. It will serve as a step forward in the provision of tools and knowledge for the benefit of a wide range of users.

The strategy for integrating the databanks and services of SERIES in the EPOS framework has been organized in three different steps (short-, mid- and long-term) as illustrated in Fig. 6. In the short-term a pre-operational access service is envisaged to be provided to selected SERIES datasets in order to allow validation of identified access technologies and involvement of the user community, for further implementation in EPOS.

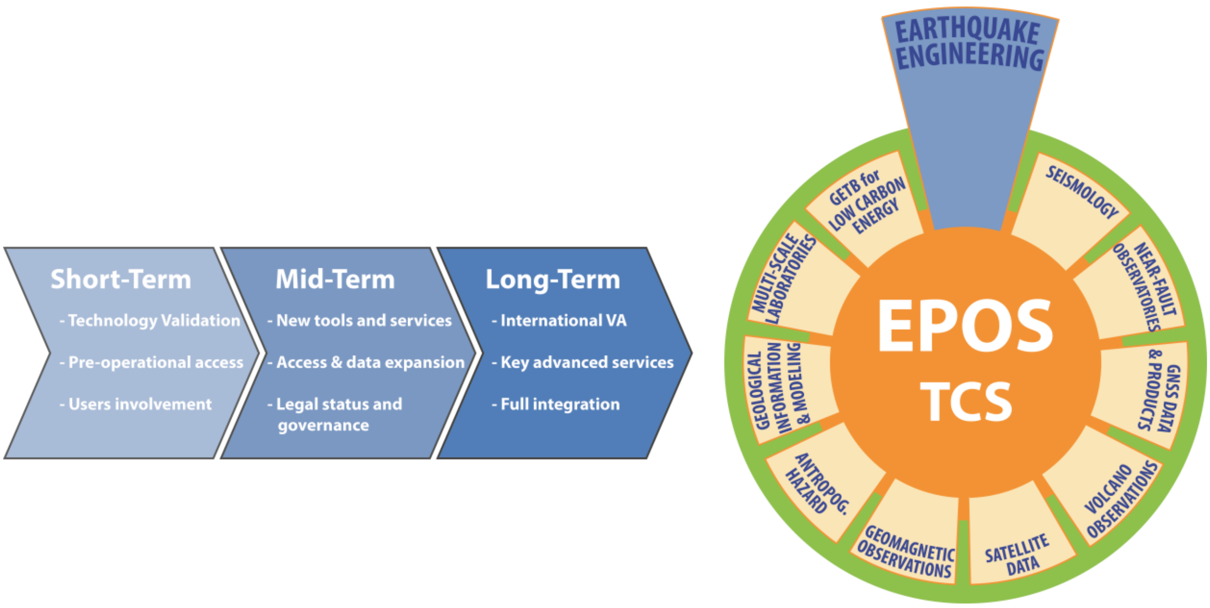

Fig. 6 – Timeline for integration of databanks and services from SERIES and EPOS research infrastructures

The activities to be performed in the mid-term includes a review of how the newly developed services and products will be fully compatible with the requirements of EPOS, at the technical, legal, governance and financial levels. The mid-term activities will also aim at expanding the access to and collection of data and at performing an in-depth study of the full range of data to characterise the level of maturity of the DDSS elements and prepare for moving to the next stage, i.e. full data integration.

In the long-term perspective, it is foreseen to provide a critical contribution to the successful construction and validation of EPOS, by developing major building blocks for the provision of key advanced services in earthquake engineering and seismology. At the end of the long-term period, the services developed by the earthquake engineering community will be mature to constitute a fully-integrated Thematic Core Service in EPOS. This new TCS will be a new important pillar of EPOS that will provide access to data, services and infrastructures that are important for other TCSs and the society at large.

7. Acknowledgements

The work presented in this paper is part of the SERA project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

8. References

[1] Fardis M. (2012): Seismic Engineering Research Infrastructures for European Synergies (SERIES), *14th World Conference on Earthquake Engineering*, Lisbon, Portugal

[2] Freda, C., Cocco, M., Saleh, K., & Giardini, D. (2018): Strategic interaction of SERA activities with EPOS-IP, *SERA Deliverable 1.3*.

[3] Lamata Martinez, I., Ioannidis, I., Pegon, P., Williams, M. S., & Blakeborough, A. (2014): Process and Future of Data Integration within the European Earthquake Engineering Laboratories. *ASCE Journal of Computing in Civil Engineering,* Volume 28, Issue 3 DOI 10.1061/(ASCE)CP.1943-5487.0000308.

[4] Lamata Martinez I., Ioannidis I., Fidas C., Williams M. S., Pegon P. (2015): The SERIES Virtual Database: Architecture and Implementation. Experimental Research in Earthquake Engineering. Chapter 3 of Experimental Research in Earthquake Engineering EU-SERIES Concluding Workshop, Eds. F. Taucer, R. Apostolska, Geotechnical, Geological and Earthquake Engineering, Vol. 35, *Springer International* DOI 10.1007/978-3-319-10136-1_3

[5] Schouppe, M., & Burgelman, J.-C. (2018): Relevance of the EOSC initiative and FAIR principles in the realm of Open Science and implementation phases of the EOSC. *Proceedings of the XX International Conference "Data Analytics and Management in Data Intensive Domains*" (DAMDID/RCDL'2018), Moscow.

[6] Athanasopoulou, A., Sintoris, C., Atakan, K., Lamata Martinez, I., Pegon, P., Bousias, S., Tsionis, G., Molina, J.F., Avouris, N. (2018): Deliverable 6.4: Review of current SERIES and EPOS databases, *SERA Deliverable 6.4*.

[7] Atakan, K., Michalek, J., Tellefsen, K., & WP 6 & 7 Team. (2017): Deliverable D6.1 – Description of TCS Requirements and Use cases.

[8] Jörg, B., Jeffery, K., van Grootel, G., Asserson, A., Dvorak, J., & Rasmussen, H. (2008): CERIF 2008-1.2 Full Data Model (FDM) Introduction and Specification.

[9] Bailo, D., & Jeffery, K. G. (2014):. EPOS: A novel use of CERIF for data intensive science. https://doi.org/10/ggkd57

[10] Bosi, A., Kotinas, I., Lamata Martínez, I., Bousias, S., Chazelas, J. L., Dietz, M., Hasan, R., Madabhushi, G. S. B., Prota, A., Blakeborough, A., & Pegon, P. (2015): The SERIES Virtual Database: Exchange Data Format and Local/Central Databases. In F. Taucer & R. Apostolska (Eds.), Experimental Research in Earthquake Engineering: EU-SERIES Concluding Workshop (pp. 31–48). *Springer International Publishing*. https://doi.org/10.1007/978-3-319-10136-1_4.

[11] Paciello, R., Trani, L., Bailo, D., & Vinciarelli, V. (2019): EPOS-DCAT-AP: An extension of the DCAT Application Profile for Research Infrastructures in the solid-Earth domain. *EPOS*. https://github.com/epos-eu/E1POS-DCAT-AP/blob/EPOS-DCAT-AP-shapes/docs/EPOS-DCAT-AP_extension_v0.1%20-%20209.07.10.pdf

