D8.1: Use Case Definition and Digital Preservation Requirements

WP 8 – Industrial Project 2: Civil Engineering Infrastructure

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V2.1	16/08/2012	José Borbinha	Revised Second Version
V2.2	06/09/2012	Gonçalo Antunes	Minor Corrections

Disclaimer

Table of Contents

List of Figures

List of Tables

List of Acronyms

BP	Business Process
CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
CMS	Content Management System
DP	Digital Preservation
EC	European Commission
EDP	Energias de Portugal
GIS	Geographic Information System
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
IIS	Internet Information Services
INESC-ID	Instituto de Engenharia de Sistemas e Computadores Investigação e Desenvolvimento em Lisboa
IP	Intellectual Property
IT	Information Technology
LNEC	Laboratório Nacional de Engenharia Civil
MS	Microsoft®
PDT	Portable Data Terminal
PL/SQL	Procedural Language/Structured Query Language
RTD	Research & Technical Development
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
TCP/IP	Internet Protocol Suite
TIMBUS	Digital Preservation for Timeless Business Processes and Services
TOGAF	The Open Group Architecture Framework
UML	Unified Modelling Language
WP	Work Package

1 Executive Summary

The preservation of business processes that support the monitoring of civil engineering structures presents complex challenges. This deliverable describes these challenges along with the processes involved in the monitoring of large civil engineering structures, especially large dams. It also defines the digital preservation requirements and use cases for this specific scenario.

Dams are constructed to address several goals, serving primarily as a water barrier to retain water, which is then used for water distribution, but is also often used in conjunction with hydropower units to produce electricity.

This deliverable analyses the organisation envisaged by the scenario and its main internal and external stakeholders in order to set the business environment. It also details its business processes to ground the identification of the requirements and use cases, along with the principles that constrain the scenario along with the legal aspects related to the digital preservation of these processes.

The findings reported in this deliverable show how this business scenario benefits from digital preservation as it takes care of the critical processes information and legal obligations that are used to ensure the overall structural safety of concrete and masonry dams in particular and large civil engineering structures in general, As such the results reported here can impact the civil engineering community as it raises awareness to the importance of digital preservation in this particular area.

This version of this document is a revision of the initial version, where the main concerns addressed by the first review were addressed (details of what was improved can be checked in the Table 1).

2 Introduction

Large civil engineering structures, such as dams, are a critical infrastructure. Dams are important strategic resources used to control and manage extremely large volumes water and to produce energy. However, a structural failure would imply not only the loss of energy production but also the potential loss of life extensive property damage and environmental crisis due to massive flooding (Ullberg, 2001).

For these reasons, many countries, such as Portugal, enforce strict Dam Safety Legislation. In Portugal, the legislation regulates all Portuguese concrete and masonry dams where the height from the foundations is higher than 15 meters or that have a reservoir which can retain more than 100 000 m^3 of water. The legislation also states that the Laboratório Nacional de Engenharia Civil (LNEC) must monitor the structural safety of the regulated dams in the country.

The data required for analysing the behaviour of the dam and structural safety is acquired by a set of sensors placed along it. The data gathering process can be done manually or automatically. The raw data then follows a transformation process and is uploaded automatically or manually to LNEC for further analysis. One of the objectives of this deliverable is to identify the use cases and requirements of this specific scenario. To achieve the objective described above, the following approach has been taken:

- Description of the organisational scenario that will serve as background for the analysis resulting from this deliverable. This is done with the identification of the monitoring goals, activities and models used for monitoring the structural safety alongside with the legal issues involved. Additionally, this specific scenario is analysed by describing the host organisation (LNEC) and its business environment, followed by the architecture principles and polices.
- Identification of the processes which will be the target of preservation, based on the TIMBUS approach to digital preservation, and tracing of these processes to the identified policies.
- Gathering of the requirements for preserving the identified processes, where possible issues of preserving this information are also identified, along with the objectives and constraints.
- Finally, definition of the digital preservation use cases which are specific to this scenario.

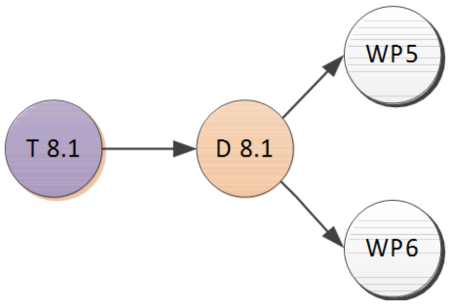


Figure 1: Integration with other work packages

The results of this deliverable will feed WP5, more precisely D5.1 (iERM architecture) and D5.2 (TIMBUS architecture) and the development will be carried out on WP6, as depicted in Figure 1.

2.1 Addressing of Reviewers Comments to Version 1

This version of this document is a revision of the initial version, where the main concerns addressed by the first review were addressed as described in the Table 1.

Table 1: Changes against the previous version

Recommendation 2	Changes
Provide a formal, detailed, clear specification of what needs to be done. Please provide more technical details that are relevant for the TIMBUS ICT solution, formalised requirements and a description of the data and processes that will be available for the use case scenarios.	Section 5, providing a high-level description of the LNEC context and general scenario, was revised in its details, but with no new relevant contents. Instead, a new Section 6 was added providing now a more detailed description of the operational scenarios, in order to better make the case for the business processes to be preserved. This is complemented with two detailed appendices: Appendix A with formal detailed models of the business processes; Appendix B with complementary information of the domain entities, to make it easier to understand the domain of the case.
Align the requirements with the objectives of the project. This includes among others the need for preserving business processes that span over the organization and legislative boundaries.	The requirements section (formally Section 6, now Section 7) was revised, better specializing now the specific description of the use case. Also, especially important, the contents was restructured and aligned with the best practices of requirements engineering, with the requirements described more formally and in more details, and traced to business goals.

2.2 Structure of the Deliverable

This deliverable is structured as follows. Section 3 describes the problem and analyses the structural safety topic, detailing the monitoring objectives and activities, which include the monitoring plan, data acquisition, validation and transformation, and safety assessment. Section 4 describes the general legal context of the scenario, by detailing the issues that can affect the preservation of the concerned information, comprising the processes involved in the monitoring data acquisition and the respective data. In Section 5, the Laboratório Nacional de Engenharia Civil (LNEC) is introduced and described from the technical aspects to the organizational aspects, including the description of the processes targeted for preservation. Section 5 describes concrete preservation scenarios involving different types of sensors. In Section 7, the main requirements for preserving civil engineering data and processes are identified. Finally, in Section 8 we summarise our results and provide an overview for future work.

3 Problem Description

The safety of large civil engineering structures like dams, bridges or nuclear facilities requires a comprehensive set of efforts. According to Wieland and Mueller (2009) we must consider: the structural safety; the structural monitoring; the operational safety and maintenance; and the emergency planning. According to the same authors, the consequences of failure of one of these structures may be catastrophic in many areas and include loss of life (reduction of loss of life is the top priority of emergency planning); environmental damage; property damage (e.g., dam flood plain); damage of other infrastructures; loss of power plant and electricity production; socio-economic impact; political impact, etc.

These risks can be reduced by a number of structural and non-structural preventive measures, essentially to try to detect in advance any signs of abnormal behaviour, allowing the execution of corrective actions in time. The structural measures are mainly related to the physical safety of the structures. The non-structural measures can comprise a broad set of concerns, such as safe operational guidelines under normal and abnormal operational conditions; implementation of emergency action plans; implementation of alarm systems; training of personnel; action plans in case of specific safety concerns; periodic safety checks; engineering back-up to cope effectively with abnormal and emergency situations; land use planning (political decision); insurance coverage, third party liability coverage (protection from economic losses), etc.

3.1 On the definitions of “process”

TIMBUS aim is to extend traditional digital preservation approaches by introducing the need to analyse and sustain accessibility to business processes and the supporting services. For that, in this document the term “business process” must be understood as by the OMG (Open Management Group)[1], namely:

“The usage in OMG’s Business Motivation Model (…) declares that “Business processes realize courses of action. Courses of action are undertaken to ensure that the enterprise makes progress towards one or more of its goals.” This encompasses not only the usual cyclic process (taking and filling an order, e.g.), but also a well-defined process that runs only once.”

In this context, a business process in an organization starts as being a concept represented by a designed artefact (documented rules or code implemented in software) that prescribes how, in a specific context, data must be processed. This means that an instance of a process can comprise one or more sets of data that during some period of time were processed by one or more tasks executed in a specific context.

Once designed, a process is instantiated each time it is executed[2]. In TIMBUS we expect to deal with scenarios where processes are designed at a relatively low detail and are expected to be instantiated many

[1] http://www.omg.org/oceb/defbusinessprocess.htm

[2] A business process can exist in an organisation always when there is a conscience of it, even if it was not designed. Rising “as is” business processes that were not previously designed is commonly related with “process mining”, which are scenarios that TIMBUS is not considering. TIMBUS only concerns with “designed processes”, for which there is an original explicit design.

times with little differences between instances, as in WP8, as also with scenarios where processes are designed at a relatively high level, and are expected to have to be detailed when instantiated, as in WP9.

This conceptual map raises the requirement for the description of instance of a process as a conceptual framework that in some sense has to take in consideration the pointed three major views of Context, Data and Task (as depicted in the Figure 2).

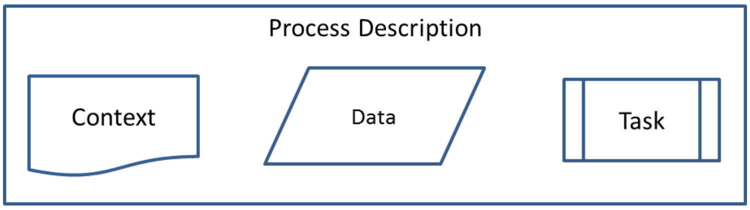


Figure 2: The fundamental views of a description of an instance of a process.

Finally, as in the scope of TIMBUS we are not dealing with the design of processes, but with the capture and preservation of instances of processes, for simplification in this document the terms “process” and “execution of a process” will be, from now used, to refer to instances of execution of processes.

3.2 Business processes at LNEC

Recently, a substantial technical and financial effort is being made in order to implement or improve the automatic data acquisition systems ability to perform real-time monitoring and trigger automatic alarms. This paradigm accomplishes a fully automated process that produces an imminent deluge of data captured by automatic monitoring systems (Hey and Trefethen, 2003). Along with the fact that these monitoring systems provide critical information to support decisions that can save lives and protect goods, they can also prevent costly repairs and help to save money in maintenance.

To understand the structural behaviour of civil engineering structures, systematic observation or monitoring is required. The interpretation of the correlation of several physical parameters measured in different physical locations of the structure can be used to validate the current state of the structure and predict the future behaviour under specific and controlled conditions (Wieland and Mueller, 2009). This in turn requires reliable data gathering and organisation mechanisms.

The behaviour of dams is continuously monitored by instruments, such as plumb lines[3] and piezometers[4] installed at strategic points of the dam (ASCE, 2000; ICOLD, 1999). Typically, a large concrete dam is monitored by hundreds to few thousands of sensors and instruments. Instrument readings are collected either manually by human operators using specific measuring instruments, or automatically by data acquisition units connected to a network of sensors. After the acquisition process, the raw data follows a specific process and is transformed into engineering quantities (e.g. relative displacements, seepage) by

[3]A common plumb line is a cord with a lead bob attached to the end, used to determine perpendicularity through horizontal displacements. In dams, the plumb line can also be inverted, where the cord is attached to the foundation and a buoy is responsible to maintain the cord tension.

[4]A piezometer is a device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point.

specific algorithms that use a set of calibration constants. In fact, the term `reading' does not correspond to raw data, since a reading is also a transformation from the raw data.

Figure 3 illustrates a typical transformation process for an electrical instrument such as a Carlson Extensometer[5]. Instruments (transducers[6]) convert a physical action (e.g., displacement) into an electrical signal (raw data produced as a voltage in mV), which is then converted by a gathering instrument or by a sensor into processed readings (e.g., resistance, relation of resistances). Finally, the readings are converted into engineering quantities (e.g., extension), which is the information used to assess the structural behaviour of the dam. The dam safety monitoring information includes, essentially, instrument properties, calibration constants, readings and engineering quantities to quantify the physical actions and the response of the dam, as well as all the processes required to execute the overall process.

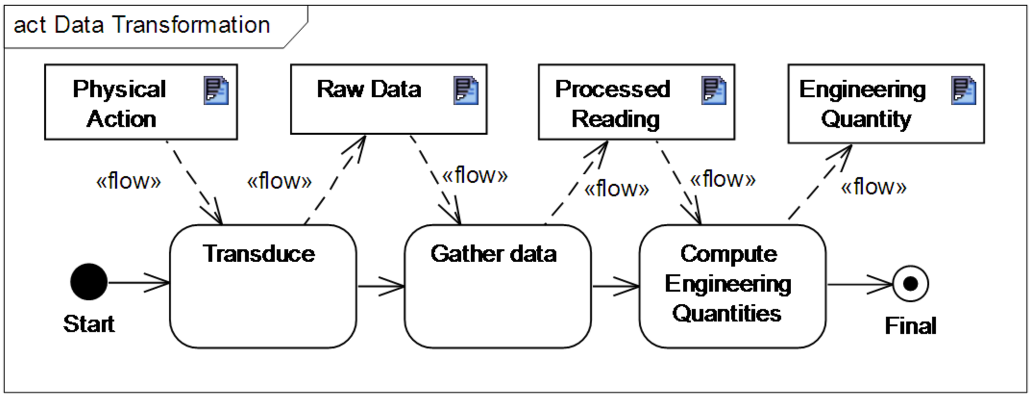


Figure 3: Data transformation process for an electrical instrument

Mathematical simulations are also crucial in dam safety control. Simulation uses a set of input files (e.g., geometry files, data files) and produces results such as tabular and graphical files in specific representations. These represent a theoretical model of the estimated behaviour of the dam. Additionally, physics tests are performed in scaled models to evaluate specific sets of actions. The results of physical tests and mathematical simulations, estimating the structural behaviour through specific and calibrated models, can then be compared with the real dam behaviour (interpreted from real observations). This comparison provides decision support criteria to assess the current structural behaviour, checking if it is expected or if an anomaly exists that justifies new studies. Note that physical models as well as mathematical simulations require data provided by the monitoring systems, and, as a consequence, depend on the business processes applied in the monitoring systems.

Determining the value of processes and data is a difficult and error-prone task. In the particular case of the monitoring of large civil engineering structures using sensor devices, it is almost impossible to consider that processes or data that cannot be used today will have no value in the future. New mathematical models along with powerful simulation technologies can use the data acquired in the past and produce relevant results which were not possible to achieve before. This may require a full re-execution of business processes, either to generate new or updated physical actions from raw data, or to ensure the authenticity

[5] A Carlson extensometer is an electrical device used to measure changes in the length of an object

[6] A transducer is a device that converts any type of energy into another.

of previous executions. Concluding, in this scenario, digital preservation can be critical to ensure the safety of large civil engineering structures, with the motivation being:

- **Compliance** with legal requirements in the case of dams, with contracts, with service level agreements established with the owners of the structures;
- **Replay a processes** using the same data and context. This requires (1) the redeployment and re-enactment of the original processes according to the original information generated during monitoring while ensuring the authenticity, correctness and validation of the execution;
- **Re-use of processes** (e.g. for new research), which can include the re-execution of the original process with modified data or context parameters, as well as the re-execution of a modified version of the preserved process using the original data (e.g. development of new calibration models that improve a specific step of the executed process);
- **Assessment** of the costs of retention of generated data against the costs of preserving the process that generates this data. For instance, in large scale mathematical simulations, we must consider the whether to preserve large datasets of generated data (e.g., by mathematical simulations) or to preserve the process that led to its generation.

Therefore, the preservation processes and data in the scope of civil engineering monitoring activities is a challenge that must be addressed. The research and engineering issues that need to be addressed to tackle this problem include:

- **heterogeneity of processes and the underlying data**;
- **heterogeneity of hardware and software technology**.
- **multiple components** involved in monitoring processes, ranging from sensors, applications, humans, etc.;
- **reliability** of the storage systems;
- **authenticity** of processes and data, which is connected with the accurate identification of its *provenance*;
- **integrity** of processes and data, ensuring that both the process behaviour and informational content were not modified without authorisation;
- **obsolescence** infrastructure components, applications and *data formats* specific to each process activity;
- **obsolescence of the storage** *media*;
- **obsolescence of the software** used;
- **scalability** in order to face both the evolution of the technology or the continuous execution of processes generating new data.

Provenance is especially relevant and complex to manage, due to all the computation taking place in the monitoring processes. Data transformations, analysis steps and the mechanisms used to carry them out are all part of the monitoring processes. This problem scales with the fact that each specific type of sensor or instrument has its own transformation processes and depends on a specific set of context information. All this forms part of the context of the process and adds meaning to the monitoring activities, without whom it might be impossible to interpret. Therefore, the preservation of the processes and the related informational object and context used during civil engineering monitoring activities is fundamental.

4 Legal Context

This section lists legal issues in the scenario of acquisition and preservation of sensor data. Besides these legal obligations, additional data protection and copyright issues concerning the software also apply.

4.1 Preservation of the acquired data

Construction and operation of large civil engineering constructions, like dams, bridges or nuclear facilities are connected with many risks. Structural failure may lead to serious consequences and damages. Therefore monitoring processes, the preservation of safety-sensor-data and the searching process to detect any signs of abnormal behaviour is in the interest of the population and of course in the interest of the operator of a large engineering structure, because he may be forced to proof that he fulfilled all security obligations to prevent a catastrophe. The commercial interests of operators to keep data private may create an area of conflict regarding the processing of captured sensor data.

4.2 Data Protection

The applicability of data protection law requires a specific level of data quality. Only if the acquired data contains information relating to an identified or identifiable natural person, the regulations of the data protection directive[7] (respectively their implementation in national law) have an impact on the possibilities of preserving the monitoring process and respective data. Therefore data privacy issues may not have a large impact on most of the automatically captured sensor data of civil engineering structures. In general, the sensors will capture only non-personal data, like temperature, movement, pressure, weight, electric tension. As it is not possible to directly or indirectly identify a person (*data subject*) by using or combining this sensor data, then data protection law has no impact on the data processing.

Within the process of monitoring thousands of sensors, some of these sensor data results are collected by human operators using special measuring instruments. Depending on the kind of data captured by these instruments, it may be possible for an employer to identify the characteristics, abilities, skills, motivation and performance of the employees. For example:

> The job of an employee of a dam operator company in Portugal is to collect different sensor data of sensors within the dam and around the reservoir. As an immediate assessment on each location is necessary, it is mandatory to manually collect the data. The special measuring instrument of the employee collects time, date, location (via GPS) and other specific information regarding the monitored dam/reservoir. By processing the captured data, it is possible to reconstruct the employees track and the time he needed to fulfil his duty. Therefore it is easily possible to evaluate the performance of the employee, even if the data is not collected for the purpose of performance check but the purpose of dam safety monitoring.

[7] Art. 2 Directive 95/46/EC

Depending on the law of a Member State, the consent of the employee and, sometimes, also the consent of the work council is mandatory. Therefore, if sensors and measuring instruments make it possible to use the captured data to directly or indirectly identify a data subject in any way, one should be aware of the possible impact of data protection law on the possibilities to process the captured data. Also one should think about possibilities and legal grounds to process personal data. In this case the capturing of data may be necessary for the compliance with a legal obligation[8], because according to the *Portuguese Dam Safety Legislation* (RSB, 2007) the data collector is responsible to keep an electronic archive of data concerning the safety of the dam and maintain an updated knowledge about the behaviour of the dam.

4.3 Preservation of the Analysis Software

Legal issues regarding the preservation of the analysis software mainly arise from the legal field of IP rights. If it is necessary to preserve software to ensure that the programmes and codes that process and analyse data are available in the medium / long term to validate conclusions drawn against them and to test analyses with new data, one has to be aware of possible copyright infringements. Preserving software means to copy the binary code of the software in preservation storage (e.g. server, hard disk, etc.). Every data transfer is a reproduction of the original source, even if the source data is deleted afterwards. The Art.4 Directive 2009/24/EC of the European Parliament and of the Council of 23 April 2009 on the legal protection of computer programs states that:

> "The permanent or temporary reproduction of a computer program by any means and in any form, in part or in whole; in so far as loading, displaying, running, transmission or storage of the computer program necessitate such reproduction is an exclusive right of the copyright holder."

Therefore the preservation of software is not a problem; if the preserver also is the right-holder (e.g. the preserver is also the author/ programmer of the program; cf. Art. 2 Directive 2009/24/EC). But if the preserving company uses third party software then it is necessary to be aware of the limitations of preservation (e.g. reproduction) limitations or the ending of license agreements. This issue can be even more aggravated if it is taken into account that software presumably runs in a specific version of a specific operating system, and the operating system will only run on current generation hardware. Thus the successful preservation of software has to deal with nested dependencies that can also suffer from limitations arising from license agreements.

4.4 Liability and Legal Obligation to Monitor

Operators of dams have the obligation to guarantee the safety of the surrounding area, environment, employees and neighbourhood. Owners are particularly obliged to avert the risks which arise from their facilities, e.g. bursting and overflow.

Legal rules for this duty are spread through all areas of law, e.g. environmental law, laws pertaining to water and waterways, pollution control law, law of torts, etc. Private environmental liability law might be applicable in particular. It is not a homogeneous field of law, but a term describing all kinds of liability for

[8] Art. 7 lit. c) of the Directive 95/46/EC

damages which are caused by the means of water, ground and clime. For example the operator of a facility under environmental law is generally liable for damages caused by the harmful environmental influence of the facility like death, bodily harm and property losses. The majority of such legal rules are however part of administrative law and their harmonisation in the European Union is merely as advanced as in the field of civil law. Therefore principles which are universally valid fail to be easily determined.

Each Member State has as well different statutory civil rules in regard to the liability of dam operators. An example of such a principle can be the strict liability in tort. This liability arises as a consequence from a legally permitted behaviour which generates dangers for the surrounding environment, e.g. driving, keeping of domestic animals or operating a facility, which might under circumstances represent a danger for the surroundings. Due to the fact that such behaviour is generally adequate, appropriate and useful, it is also legally permitted. Nevertheless the person who creates an abstract danger and benefits from the legal permission regarding this behaviour must as well be liable when damages actually occur. Therefore this kind of liability in tort is strict and does not depend on the personal fault or a specific violation of the tortfeasor. Having said this operating a dam can also appear abstractly dangerous for the surrounding area and population because of the eventuality of bursting and overflow. Therefore it must be analysed under national law if such strict liability in tort might be applicable.

Furthermore the dam operator can be liable for negligence if he violates the legal duty to maintain safety. This duty implicates the basic principle that everyone needs to undertake all considerable measures to secure their facilities and thus prevent the damages for the legally protected goods of others. The liability arises from the breach of the legal duty to maintain safety. The dam operator can be therefore liable if he fails for example to eliminate a shortcoming in the functioning of his facility and this leads to damages for the surrounding area.

A liability can arise as well from the property right of the dam owner. If a dangerous situation for the surroundings results from the facility, the state is ongoing and the dam owner is able to stop and eliminate the disturbance, he is also obliged to do so.

5 The LNEC Context and General Scenario

According to the Portuguese Dam Safety Legislation (RSB, 2007), LNEC is responsible to keep an updated electronic archive of information on dam safety and behaviour. This Legislation also defines the duties and responsibilities of the different parties involved on dam safety, namely the owners of a dam, the safety authority and the LNEC engineers. Since several different organizational entities need to share processes and data the preservation of processes and data is not an option but a legal obligation. On the other hand, business processes should also be preserved for future reuse and to improve the knowledge about the overall structural behaviour. Therefore, we can assume that the heterogeneity and interrelation of the safety processes and data of a dam composes a *data space* (Franklin, Havely, and Maier, 2005) that requires preservation and access facilities.

Currently, the dam safety monitoring processes are supported and maintained on by an information system named *GestBarragens* which will be one of the targets of preservation using the TIMBUS approach.

5.1 Organisation Overview

The LNEC[9], established in November 1946, is a public Science and Technology institution, which is subject to Government supervision through the Ministry of Public Works, Transports and Communications. Its competences, as refers to the definition of strategic guidelines, are performed in articulation with the Ministry of Science, Technology and Higher Education. Its activity is developed in the various fields of civil engineering and its main assignments are the execution, supervision and promotion of scientific research and technological developments to achieve progress, innovation and good practices in civil engineering. The institution is also responsible for providing an unbiased and suitable scientific and technical support to the executive power, in its governing and regulatory activities. Presently, it has about 680 staff, of which approximately 42% have a University degree and about 22% are researchers holding a PhD or an equivalent degree (in 2006 Social Report). It also has about 80 scientific research fellows with a grant awarded by LNEC. From the annual LNEC budget, about 50% of LNEC's income results from the generation of private revenues, namely referring to the provision of science and technology services, the remaining 50% deriving from the National Budget and from other sources (in 2006 Activity Report).

5.2 Scenario Overview

The LNEC Departments for Concrete and Embankment are responsible for the development of studies in:

- The field of instrumentation;
- Observation and structural monitoring of concrete and masonry dams and their foundations, during the construction phase, first reservoir fill phase and operation phase, using experimental, analytical and numerical techniques;

[9] http://www.lnec.pt

- Management and maintenance of concrete and masonry dams.

Moreover, LNEC undertakes research in the following areas:

- Usage of monitoring technologies to gather observation data and automatic communication systems;
- Development of "smart systems" for just-in-time dam safety control;
- Risk analysis of dam construction and operation;
- Characterisation and modelling of future deterioration of dams and their foundations.

According to the Portuguese Dam Safety Legislation that regulates the dam safety control of big Portuguese dams (dams which maximum height from the foundation is more than 15 meters or with a reservoir with more than 100 000 m^3 of capacity), LNEC also has the responsibility to survey the behaviour and the structural safety of approximately 150 concrete and masonry dams. This comprises the elaboration of observation plans, the periodic inspection of the dam structure and potential anomalies, the generation of analysis and interpretation reports of the observed behaviour and also, the management and operation of an electronic archive of data concerning the dam safety.

5.3 The GestBarragens Information System for Concrete Dams

The *GestBarragens* system is the result of a close collaboration of three Portuguese institutions (LNEC, INESC-ID and EDP[10] and is currently deployed in the organisational context of LNEC and EDP. It is a modular information system providing components to manage dam observations, visual inspections, physical models and mathematical models. It supports the management of technical documents and provides a set of analysis tools such as tabular and chart reports and graphical visualisation of geo-referenced information (Silva, Galhardas, Barateiro, Matos, Gonçalves and Portela, 2006).

Figure 4 shows a simplified UML deployment model of the *GestBarragens* system, which also informas about the system's architecture. The system's client client is a web-based system developed on the top of the .NET 4.0 framework where the underlying data is stored and managed on an Oracle 10g database. Reports are designed and implemented using MS Reporting Services, and data is graphically and spatially visualised using the ESRI technology.

GestBarragens is designed as a Service Oriented Architecture (SOA), providing and exposing exploitation services as well as several ingesting services. For example, observation data can be automatically inserted by multiple sources such as automatic monitoring systems and portable data terminals. *GestBarragens* also provides several data export mechanisms, producing spreadsheets and generating large-period (e.g., 70 years) graphics in high-resolution CAD representations.

[10] EDP - Portuguese National Electricity Company (concrete dams' owner): http://www.edp.pt

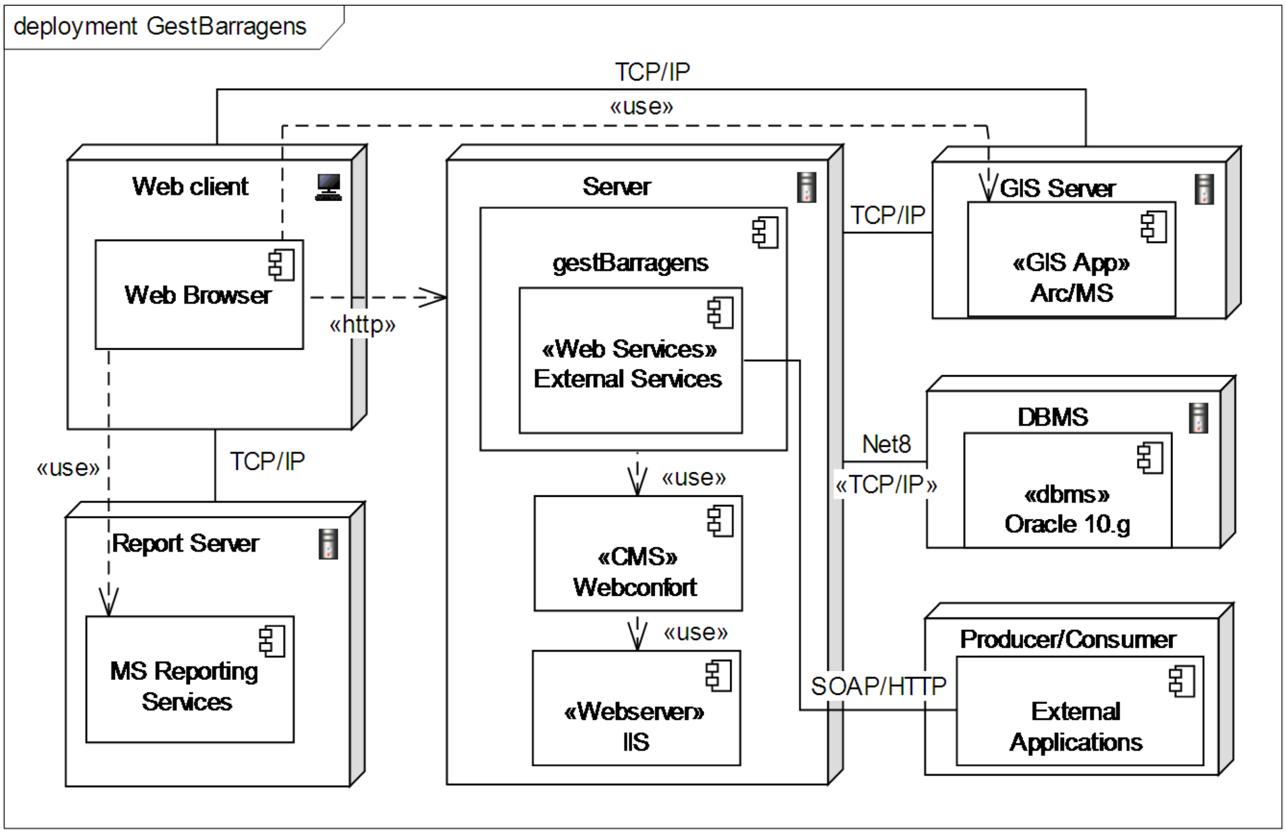


Figure 4: Deployment model of the GestBarragens system

GestBarragens provides a number of solutions that are critical in the field of civil engineering, with the following key aspects:

- **Instrumentation**: It integrates new observation instruments, supports the dynamic management of new types of instruments, and manages metadata about instruments.
- **Transformation process**: It manages the instrument specific algorithms to convert raw data into physical actions (results), using instrument metadata properties, such as calibration constants.
- **Management of types of observations**: It manages geodetic data information, information concerning visual inspections, and data provided by the automatic monitoring systems.
- **Data visualisation and exploitation**: It accesses data through a set of reports designed to support the required types of data analysis, and spatially depicts data using a set of graphics and diagrams.
- **Synchronisation**: It allows the deployment of the system in one or more locations (for example, LNEC and a dam owner) and the corresponding synchronisation of data.

Table 2 summarises an example of data generated by processes concerning the dam safety monitoring of a representative Portuguese concrete dam. Currently, LNEC supports 36 different types of instruments with manual data acquisition and 25 different types of automatic monitoring instruments implemented with sensors. Each of these 61 instrument types has its own characteristics, algorithms and calibrations constants and generates different types of processed readings and results, by specific algorithms. The current systems thus have to manage about 180 schema representations (61 to capture the sensor properties, 61 to represent the processed readings and 61 for the engineering quantities), and 61 distinct algorithms. Note that both the number and type of instruments installed in a specific structure depend on the stage of the structure's life and on hundreds or thousands of parameters that affect its behaviour.

Table 2: Typical data generated by processes for a representative concrete dam

Data Stage	Description	#per day	Representation	Notes
Raw	Depend on the instrument type (e.g. voltage)	Only captured in automatic moni-toring systems deployed by LNEC	Proprietary to the sensor	This information is not possible to register during manual acquisition. It is only captured in automatic monitoring systems controlled by the LNEC Scientific Information Centre.
Processed readings	Transformed from raw data	Aprox. 3300 rows	.xls, .mdb, PDT, ascii	Sensors register data in .xls or .mdb and in-voke a web service to send this information to LNEC. Manual acquisition is registered into a portable data terminal (PDT).
Engineering quantities	Calculated from readings	Aprox. 3250 rows	Oracle data-base	Algorithms to filter, clean and calculate engi-neering quantities are implemented as Ora-cle stored procedures (PL/SQL).
Analysed	Tables, graphics, GIS	Varies	.html, .xls,.pdf, .dxf (CAD), .xml	Uses several tools, including reporting tools and a geographic information system.

At this time, raw data is only stored in automatic monitoring systems deployed and controlled by LNEC. The raw data is internal to the sensors that include a transducer (the output is already a processed reading). In the case of manual data acquisition, raw data is converted by the measuring instrument making it impossible to be captured and preserved. Processed readings and engineering quantities are stored in a centralised Oracle database, while analysed data is generated, produced and managed by researchers, using their own programs.

Along with the need to manage a heterogeneous and large set of processes, including distinct transformation algorithms and dataset representations, the volume of data is growing rapidly. Figure 5 visualises the amount of sensor data per record that is acquired per year. In the 80s, several large dams were constructed, which caused the growth of the execution of process transformations, which is reflected on the amount of acquired data in that period and a subsequent stabilisation until 2005.

From 2005 until now, we see an imminent deluge with a linear growth estimation of 0.26x106 / Year. This is mainly caused by the deployment of the GestBarragens system, which supports a larger number of instrumentation types. The legacy systems implemented 23 types of manual data acquisition instruments, while GestBarragens currently supports 36 of these and 25 types of automatic monitoring instrumentation, as well as a larger number of dam types. A recent investment in automatic data acquisition additionally leads to a higher frequency of data acquisition

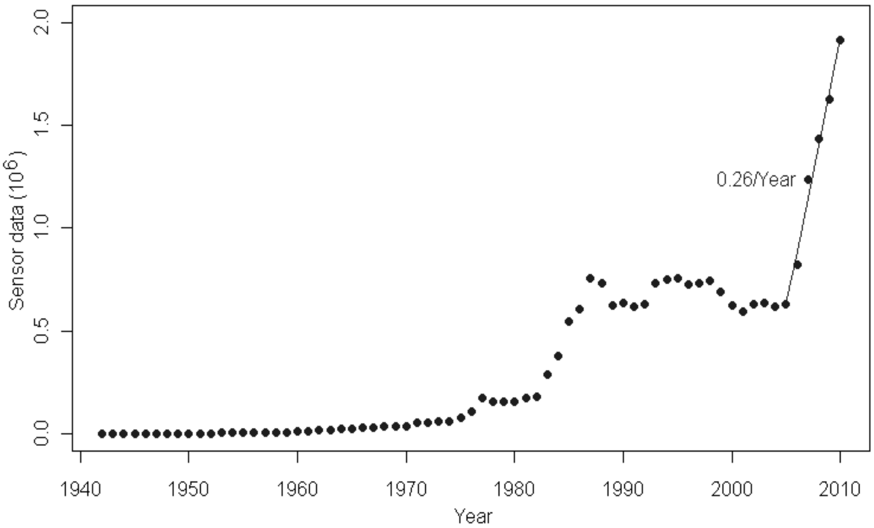


Figure 5: Sensor data acquisition per year

The current growth rate is expected to steady or increase in the next years, since new large dams are currently in construction and the major dam owners are investing in new automated monitoring systems to further increase the real-time monitoring of critical infrastructures.

Table 3 summarizes the number of executions of acquisition processes for large dams. Processes were executed approximately 1 million times according to sequence of actions where raw data was transformed into physical actions. These processes will continue to be executed in the future, at least during the life span of the structure.

Table 3: Number of process executions per dam

Dam	# of executions	First execution	# sensor types	# sensors	Automatic data gathering
Alto Rabagão	846832	06-06-1961	21	1583	Y
Alto Lindoso	832399	01-01-1987	20	1056	Y
Aguieira	774390	03-04-1979	13	1250	N
Vilarinho das Furnas	717676	01-01-1971	19	693	Y
Cabril	626851	13-11-1952	13	1082	N
Crestuma	619469	08-10-1980	22	1086	Y
Carrapatelo	563741	10-02-1967	12	878	N
Varosa	549650	17-01-1975	21	502	Y
Bouçã	516086	01-01-1959	22	597	Y
Valeira	512174	21-12-1972	9	673	N
Torrão	464050	01-03-1985	15	984	N
Venda Nova	412562	13-04-1951	20	648	Y
Miranda	394890	20-10-1960	14	732	N
Pocinho	394319	04-01-1982	9	572	N
Salamonde	381800	26-04-1953	18	335	Y
Fratel	376714	23-11-1973	18	377	Y
Pracana	371572	01-05-1951	14	674	N
Touvedo	360480	03-09-1990	19	298	Y
Régua	318108	03-01-1973	10	660	N
Caniçada	308808	01-10-1954	20	310	Y

5.4 Organisational Analysis

LNEC is headed by a Board of Directors that governs all other departments. The functional units belonging to the departments are the internal producers (e.g., FU Researcher, FU Technician) and consumers (FU Researcher) of information on the system. The IT Department manages (e.g., IT Manager) and maintains the GestBarragens system (e.g., IT Technician). Table 4 and Table 5 describe in more detail the roles of the internal and external stakeholders of LNEC which are more relevant for TIMBUS, within the Concrete and Embankment Department. Figure 6 provides a pictorial view, in the form of an UML domain model diagram, of the internal relationships between the organizational unities (departments) and these internal stockholders.

Table 4: Internal stakeholders

Stakeholder	Roles
Board of Directors	The Board of Directors is the final responsible for every activity performed by all departments of the organisation (including the Concrete Dam Department). Has a position of authority and decision making in the business. It is the ultimate responsible for the implementation of its decisions.
IT Manager	Manages the LNEC IT Centre and is responsible for the hardware, software and communications' infrastructure. Is also responsible for defining and maintaining the internal policies regarding that.
IT Technician	Operates the IT infrastructure supporting the services. Responsible for replacing damaged components, upgrade virus definitions, create new database users and set permissions, etc. Also, operates IT processes such as offline backups.
FU Researcher	Responsible for studies in the field of instrumentation, observation and structural monitoring of civil engineering structures, during the construction and operation phase, using experimental analytical and numerical techniques. Also, research is developed in the areas of monitoring technology for collecting observation data and automatic communication systems, development of smart-systems for structure safety control, risk structures' construction and operation, and characterisation and modelling of future deterioration of structures.
FU Technician	Responsible for the supervised upload of data into the system.

Table 5: External stakeholders

Stakeholder	Roles
Structure Owner	Is the entity responsible for the structure and its safety, having the responsibility to: implement the observation plan, by acquiring data in the established time frames; alert the authorities and civil protection in case of anomaly detection; update a digital archive; is responsible for the funding of all the safety activities, and for sending the observational data to LNEC, immediately after data gathering. The already referred Portuguese electrical company EDP is an example of a structure owner.
Authority	Has the responsibility to audit and promote the fulfilment of legal disposition concerning the safety of structures, as also to check/approve the observation and emergency plans in collaboration with LNEC.
Civil Protection	Establish the emergency plan (this has to be articulated with the observation plan) in accordance to the existing civil protection regulation.
Technology Provider	Provides the technological infrastructure (hardware and software) on request by the IT Chief..

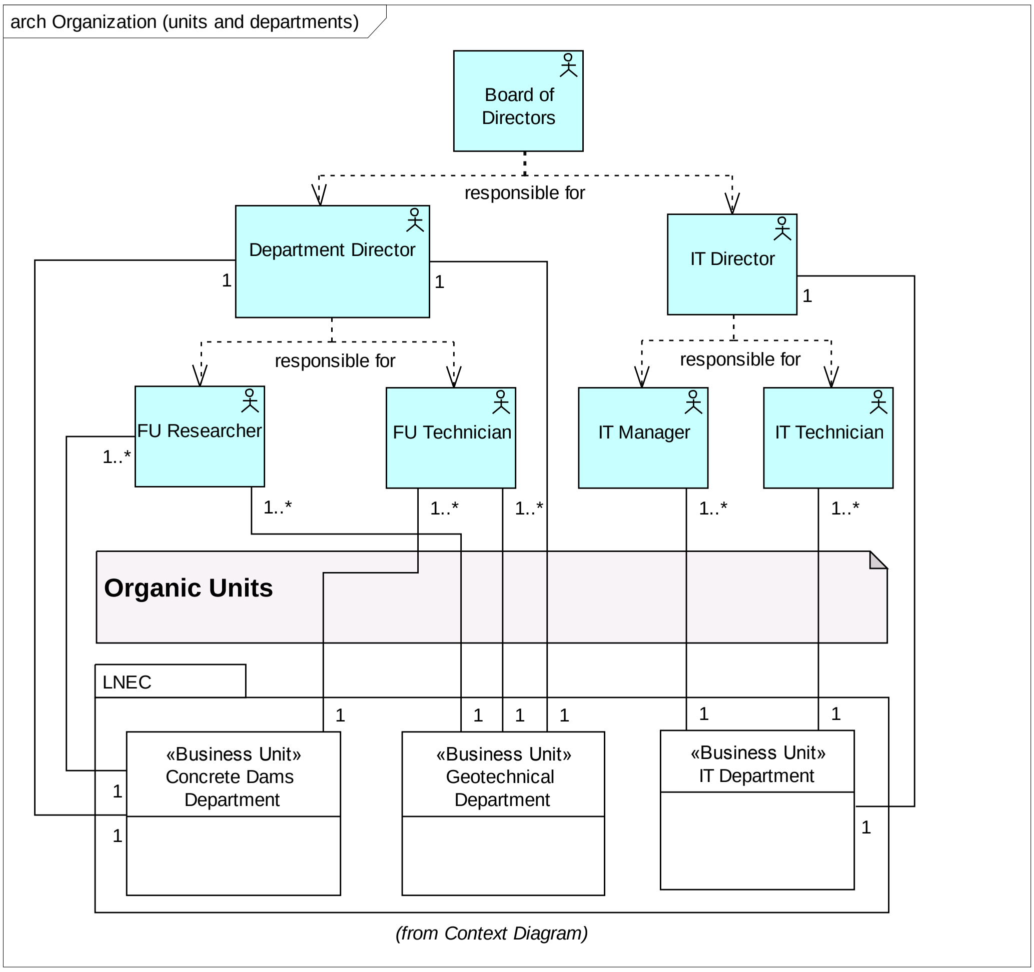


Figure 6: LNEC's organisational architecture

5.5 Business Environment

This section details the business environment related to structural monitoring, which is the main focus of TIMBUS. Figure 7 provides a generic business context diagram, the main relationships between LNEC and the external stakeholders described in Table 5, which is more detailed in Figure 8.

The safety control of structures is supported by monitoring hundreds of sensors installed on strategic points in a civil engineering structure. As depicted in Figure 8: Business Environment

, the sensor readings are collected and sent to LNEC by the Structure Owner (note that LNEC also does data acquisition, especially in the scope of inspections). Then, readings are processed (i.e., validated and transformed) by specific processes and stored in the GestBarragens information system.

The Authority is responsible to audit the execution of observation and emergency plans. Monitoring information can then be queried and used by authorised consumers, which are thus able to analyse the overall structural behaviour. Note that in TIMBUS this use case focus on sensor data and the underlying production process. Thus, the following sections detail the context of the data acquisition and processing, which is performed by structure owners and LNEC (Concrete Dams and Geotechnical departments). It does not detail the related processes; Section 5.8 and Annex A provide the more detailed information about the LNEC's related internal business processes and services.

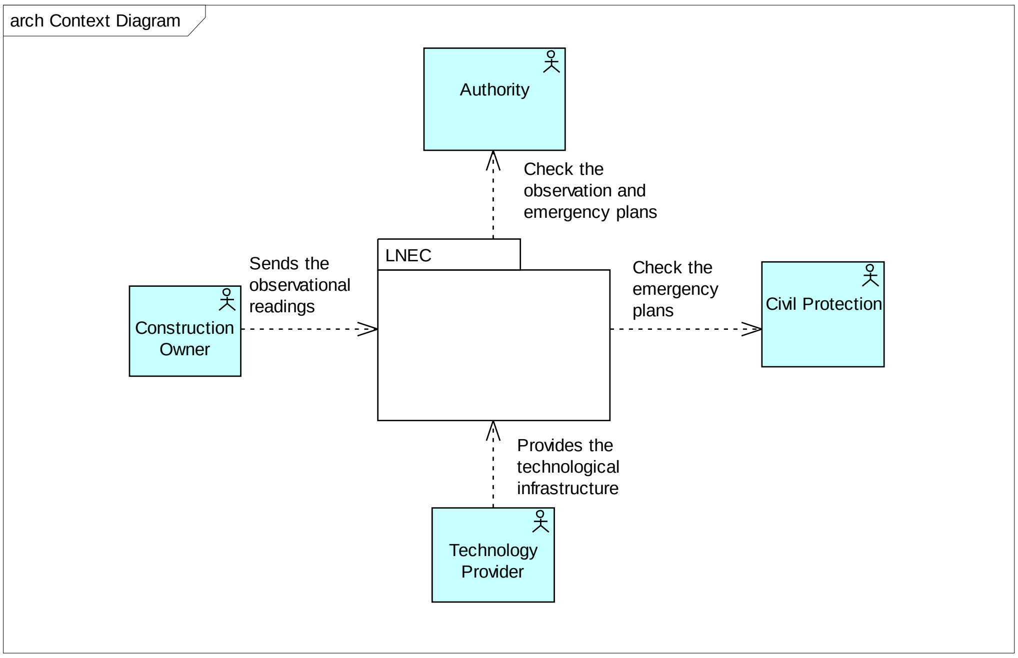


Figure 7: The global Business Context of LNEC

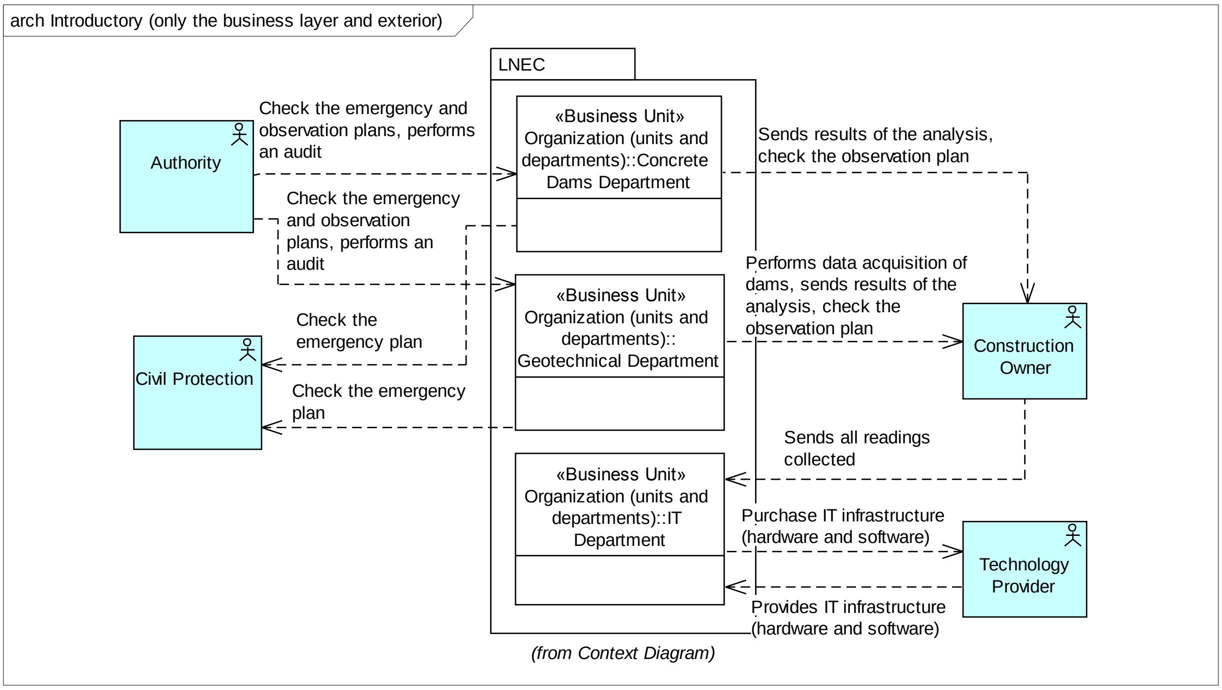


Figure 8: Business Environment

5.6 Architecture Principles

Architectural Principles are general rules and guidelines that should be followed in the organisation, that aim to inform and guide the fulfilment of its mission (The Open Group, 2011). In this section, we present the architectural principles that should be followed by LNEC systems and processes. These principles are not mandatory, and as such, exceptions can exist and be prompted by varied internal reasons that shall not be disclosed here. However any solution arising from the TIMBUS project shall take these principles into account. The principles are divided in business principles, data principles, application principles, and technology principles.

5.6.1 Business Principles

The business principles that should be followed by LNEC's systems and processes for the management and preservation of sensor data include: Compliance with the law (Table 6); harmonisation of Data Management Processes (Table 7); Maximise Benefit to the organisation (Table 8); Minimise Service Intrusion (Table 9); Service Orientation (Table 10); and Protection of Intellectual Property (Table 11).

Table 6: Compliance with the law

Name	BPR1. Compliance with law
Statement	Systems and supported processes should be able to comply with law and regulations.
Rationale	In this organisation, the preservation of some monitoring information is mandatory by law. Also, departments are subjected to internal regulation (also a law) which attributes responsibilities concerning preservation.
Implications	The organisation should be aware of the law and the responsibilities brought by it, since this principle has a big influence over the preservation drivers and objectives of the organisation.

Table 7: Harmonisation of Data Management Processes

Name	BPR2. harmonisation of Data Management Processes
Statement	Processes which manipulate data should be harmonised
Rationale	An organisation has different functional units that manipulate different data. By harmonising the processes, control over the processes is improved, and there is better opportunity for re-usage of technological components.
Implications	This has implication on the design of the system.

Table 8: Maximise Benefit to the organisation

Name	BPR3. Maximise Benefit to the organisation
Statement	Information management decisions should provide maximum benefit to the organisation
Rationale	All the decisions concerning the management of information should have the associated objective of providing benefit for the organisation. Some examples of benefits are improved service quality, better usage of the resources, minimise costs, etc.
Implications	This has implication in the process design decisions.

Table 9: Minimise service intrusion

Name	BPR5. Minimise service intrusion
Statement	Preservation services should not be intrusive, affecting the normal behaviour of operational services.
Rationale	Since digital preservation is not the main business of the organisation, preservation processes should be as less intrusive as possible.
Implications	This should have implication on the design of the system, through full automation of some preserva-tion processes.

Table 10: Service Orientation

Name	BPR6. Service Orientation
Statement	Preservation architecture should be designed "*-as-a-service", for modularity, scalability, heteroge-neity, interoperability reasons...
Rationale	Service orientation increases the agility of the preservation business.
Implications	This has implication in the choice of technology to be implemented

Table 11: Protection of Intellectual Property

Name	BPR7. Protection of Intellectual Property
Statement	The intellectual property of preserved contents must be protected. This protection must be reflected in the IT architecture, implementation, and governance processes.
Rationale	A major part of an enterprise's Intellectual Property is hosted in the IT domain.
Implications	Intellectual Property protection should be taken into consideration in the design and operation of the system and processes.

5.6.2 Data Principles

The data principles that should be followed by LNEC's systems and processes for the management and preservation of processes related to dam safety monitoring include: Accessibility of Information (Table 12); and Security of Information (Table 13).

Table 12: Accessibility of Information

Name	DPR1. Information is accessible
Statement	Information is accessible to stakeholders with adequate permissions.
Rationale	Information is only accessible to stakeholders with adequate access permissions.
Implications	This has implications on the design of the system, since an authentication mechanism should be present.

Table 13: Security of Information

Name	DPR2. Information Security
Statement	The integrity and authenticity of preserved contents is ensured at all times
Rationale	Information security mechanisms are essential to guarantee the trustworthiness of data.
Implications	This has implication on the design of preservation processes and on the introduction of security mechanisms

5.6.3 Application Principles

The application principles that should be followed by LNEC's systems and processes for the management and preservation of sensor data include: Ease-of-use (Table 14); and Application Independence (Table 15).

Table 14: Ease-of-use

Name	APR1. Ease-of-use
Statement	Applications are easy to use. The underlying technology is transparent to users, so they can concentrate on their specific tasks.
Rationale	The more a user has to understand the underlying technology, the less productive that user is. Ease-of-use is a positive incentive for use of applications. It encourages users to work within the integrated information environment instead of developing isolated systems to accomplish the task outside of the enterprise's integrated information environment. Most of the knowledge required to operate one system will be similar to others. Training is kept to a minimum, and the risk of using a system improperly is low.
Implications	Applications will be required to have a common "look-and-feel" and support ergonomic requirements. Hence, the common look-and-feel standard must be designed and usability test criteria must be developed. Guidelines for user interfaces should not be constrained by narrow assumptions about user location, language, systems training, or physical capability. Factors such as linguistics, customer physical infirmities (visual acuity, ability to use keyboard/mouse), and proficiency in the use of technology have broad ramifications in determining the ease-of-use of an application.

Table 15: Information representation Independence

Name	APR2. Information representation Independence
Statement	Data about processes should be independent of specific technology choices and therefore can be used on a variety of technology platforms.
Rationale	Independence of representations from the applications allows information about processes to be preserved and used in spite of software obsolescence. Software, which is subject to continual obsolescence and vendor dependence, becomes the driver rather than the user requirements themselves.
Implications	This might have implications on the format representations to describe the processes preserved by the developed systems.

5.6.4 Technology Principles

The application principles that should be followed by LNEC's systems and processes for the management and preservation of dam safety monitoring processes include: Requirements-based Change (Table 16); and Infrastructure Independence (Table 17).

Table 16: Requirements-based Change

Name	TPR1. Requirements-based Change
Statement	Only in response to preservation needs are changes to applications and technology made.
Rationale	This principle will foster an atmosphere where the information environment changes in response to the needs of the business, rather than having the business change in response to IT changes. This is to ensure that the purpose of the information support - the transaction of business - is the basis for any proposed change. Unintended effects on business due to IT changes will be minimised. A change in technology may provide an opportunity to improve the business process and, hence, change business needs.
Implications	Changes in implementation will follow full examination of the proposed changes

Table 17: Infrastructure Independence

Name	TPR2. Infrastructure Independence
Statement	Applications should be independent of specific technology choices and therefore can be used on a variety of technology platforms.
Rationale	Independence of applications from the technology allows data to be preserved and used in spite of technology obsolescence. Technology, which is subject to continual obsolescence and vendor dependence, becomes the driver rather than the user requirements themselves.
Implications	This might have implications on the technologies to be used on the system.

5.7 Data Management Policies

A policy can be understood as an agreement describing how something is to be achieved. Table 18 describes the policies currently followed on LNEC concerning the monitoring processes, divided in:

- Content Policy, which is related to the informational content of preserved objects;
- Metadata policy, which is related to any additional description accompanying monitoring information and that is important for its understanding;
- Submission policy, concerning processes to submit dam safety information to GestBarragens;
- Access and Reuse policy, which is related to the processes which allow access and re-usage of the stored monitoring information;
- Preservation policy, which concerns the preservation of monitoring information;
- Withdrawal of Information and Succession Plans policy, which is related to any plans to be followed if the GestBarragens system ceases its operations;
- IT Infrastructure policy, which concerns the IT infrastructure supporting the GestBarragens system.

Table 18: Policy Catalogue

Policy	Description
PP-SD-1. Content	1. The scope of the system is restricted to raw sensor data delivered by sensors installed in structures and data derived from transformations made of the sensor data into engineering quantities (in both cases, datasets). This data represents specific phenomena at a specific time and location, which is itself unrepeatable. Also processes to transform and validate information constitute content of this system. 2. The engineering quantities might be stored along with the raw data from which it was derived, or alone. In the first case, the relationship between data is maintained, as well as the mapping to the executed processed and required parameters.
PP-SD-2. Metadata	1. Access to metadata is restricted to people, internal or external to the organisation, which have authorised access in the system. 2. In case of need, structural metadata should be defined to maintain the relationships between different, related objects.
PP-SD-3. Submission	1. Submission is only permitted to authorised producers, such as structure owners, authorised technicians from the functional departments acting on behalf of the structure owners, project architects, contractors, or consultants. 2. All submissions should undergo validation processes in order to ensure its completeness and correctness. 3. All objects in the system must have a unique identifier. 4. LNEC rights over are determined by law and allow changes to information and process re-executions to the logical and physical supports as long as it is preserved, accessible, and trustable.
PP-SD-4 Access and Reuse	1. Access is restricted to people, internal or external to the organisation, which have authorisation, namely the internal (Researchers from the functional departments) and external (Structure Owners (e.g., EDP), Authority (e.g., Portuguese Water Institute)) stakeholders. 2. Only these actors are authorised to perform modifications and re-executions, in an ethical manner. 3. Copies can only be made for security or research reasons.
PP-SD-5. Preservation	1. Dam safety information must be retained indefinitely. 2. Backups are performed daily, incrementally, with full backups every month. Processes are validated through output analysis.
PP-SD-6. Withdrawal of Information and Succession Plans	No policy is currently being enforced for this aspect.
PP-SD-7. IT Infrastructure	1. The IT infrastructure should be fit for purpose. 2. Adequate storage capacity shall be available at all times. 3. Adequate connectivity to the system shall be ensured at all times.

5.8 Business Processes

In this section, the main processes related to the GestBarragens information system are described. Figure 9 depicts the main processes, grouped in "Upload Processes", "Access Processes" and "Other Processes", which are detailed in the following sections.

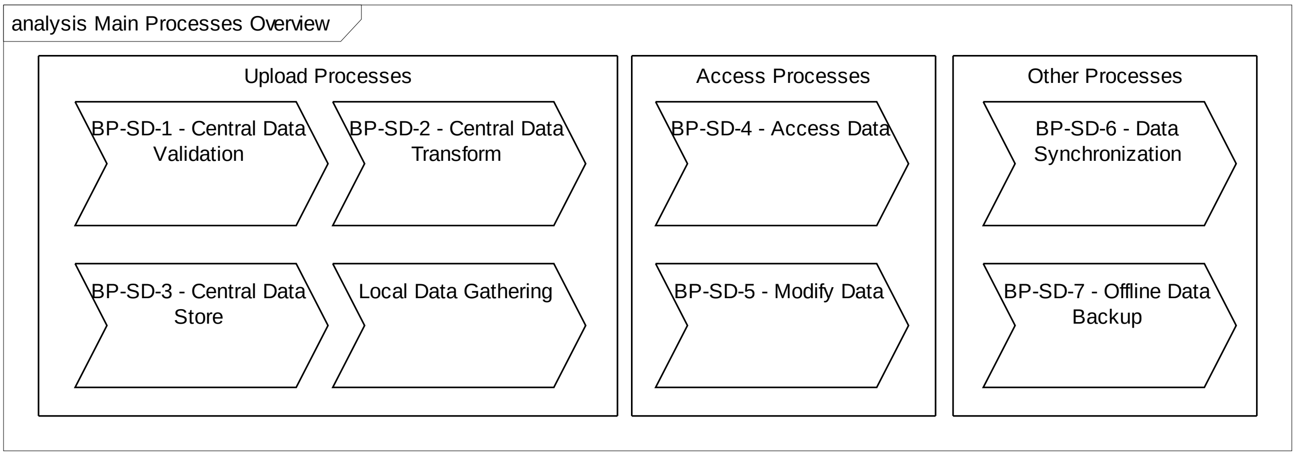


Figure 9: GestBarragens main processes overview

5.8.1 Upload Processes

The uploading of sensor data is performed trough four main processes (Figure 10):

1. Local data gathering: Acquires data from several sensors by automatic or manual means. This process can be executed by the Structure Owner or by LNEC (in the scope of periodic technical inspections, or automatic monitoring systems developed and maintained by LNEC). This process depends on the type of instrument (sensor) observed. An example for a specific instrument is detailed in Chapter 7, while Annex B provides details about the most common instrumentation used in large dams;

2. (BP-SD-1 - Central Data Validation: Validates the acquired data, so that no irregular data is ingested into the archive, annotating the submitted information with validation data;

3. BP-SD-2 - Central Data Transform: Depending on the type of sensor data, applies transformation algorithms to convert readings (sensor data) into engineering quantities;

4. BP-SD-3 - Central Data Store: Archives sensor data, engineering quantities (transformed data), and generated errors and warnings. The details of BP-SD-1 - Central Data Validation, BP-SD-2 - Central Data Transform and BP-SD-3 - Central Data Store processes are described below.

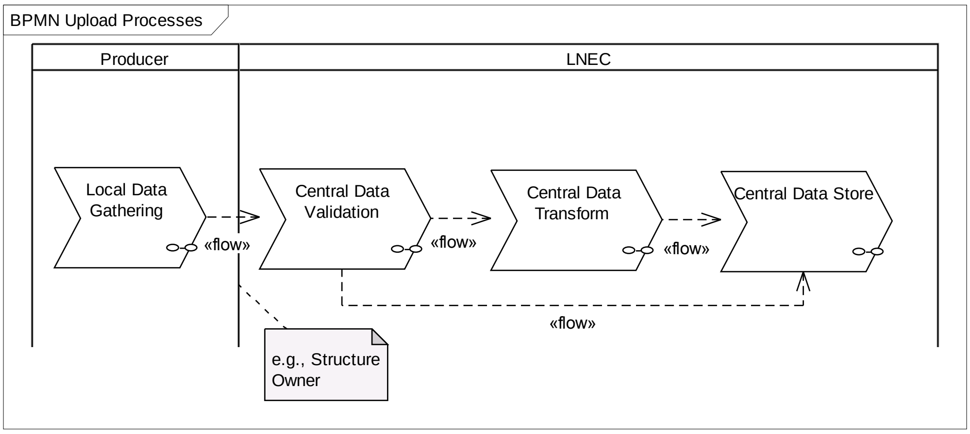


Figure 10: Data Submission Processes

5.8.1.1 BP-SD-1 - Central Data Validation

Periodically, data is sent from the data producer (e.g., Structure Owner) to the *GestBarragens* information system. Data can be submitted by automatic means, if mechanisms are present to make it possible, or manually, if the producer uses a portable terminal to read data directly from the sensors. In the former case, the sensors are connected to data gathering units which upload Raw Data automatically to the *GestBarragens* system. In the latter case, the producer applies a specific device into the sensors, and submits the gathered values into the *GestBarragens* system.

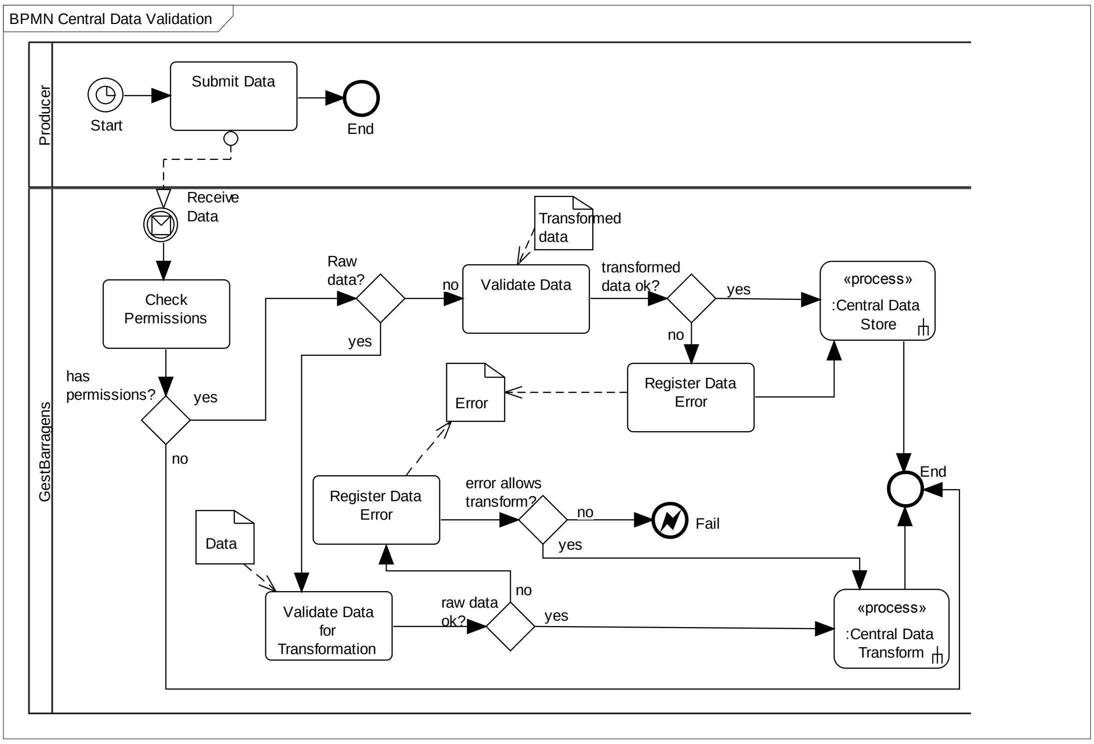


Figure 11: Central Data Validation

Both the raw data and the transformed data are validated. If the validation fails, validation errors are stored along with the erroneous data (the Error data object in the diagram). In the case of the Raw Data, depending on the type of error, the process stops or follows into the Data Transform process, where it will then undergo transformation into engineering quantities. In the case of the validation of Transformed Data, if data is valid it will then follow into the Data Store process. This process is depicted in Figure 11.

5.8.1.2 BP-SD-2 - Central Data Transform

In the transformation process, a transformation algorithm is selected from the algorithms catalogue depending on the type of readings. The selected algorithm consumes the submitted data, gathers required context information from the sensor definition, and applies the algorithm to generated the required physical actions (transformed data), which are stored in a central archive. Again, if the algorithm returns errors, these are registered, annotating the execution of this process (Figure 12).

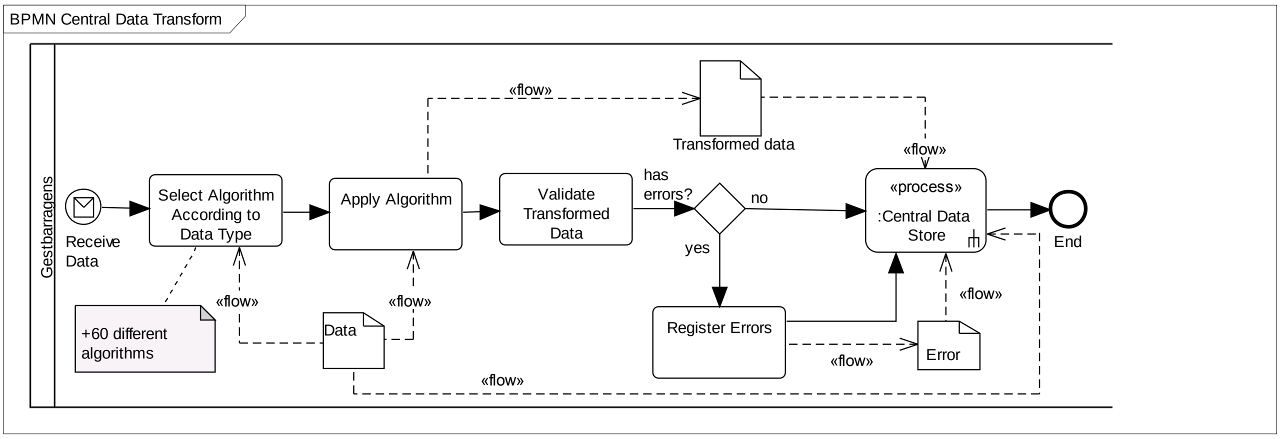


Figure 12: Central Data Transform

5.8.1.3 BP-SD-3 - Central Data Store

In this process, data integrity is validated and stored if valid. Otherwise, the requester is notified of any error (Figure 13). After being stored, data can be queried and reused. The archive suffers a daily incremental backup with a full backup every month. No additional preservation policies are employed.

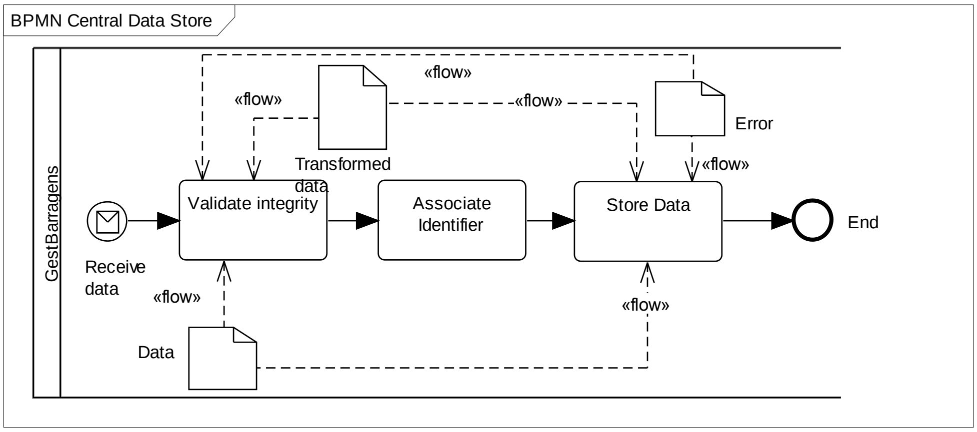


Figure 13: Central Data Store

5.8.2 Access Processes

This section is constituted by the Access Data and Modify Data processes.

5.8.2.1 BP-SD-4 - Access Data

The Access Data process comprises the verification of the permissions of the Consumer to access the requested data (Figure 14). This process is done to generate information required to analyze the structure behaviour. Based on that, a civil engineer can analyze and compare the physical quantities provided by the set of sensors, and apply statistical and mathematical models to check if the monitored behaviour is similar to the one expected by these models. After that, it is possible to report about the current and expected behaviour of a specific structure (note that complex statistical and mathematical analysis are not in the scope of work package 8 as they will be addressed in work package 9 of this deliverable).

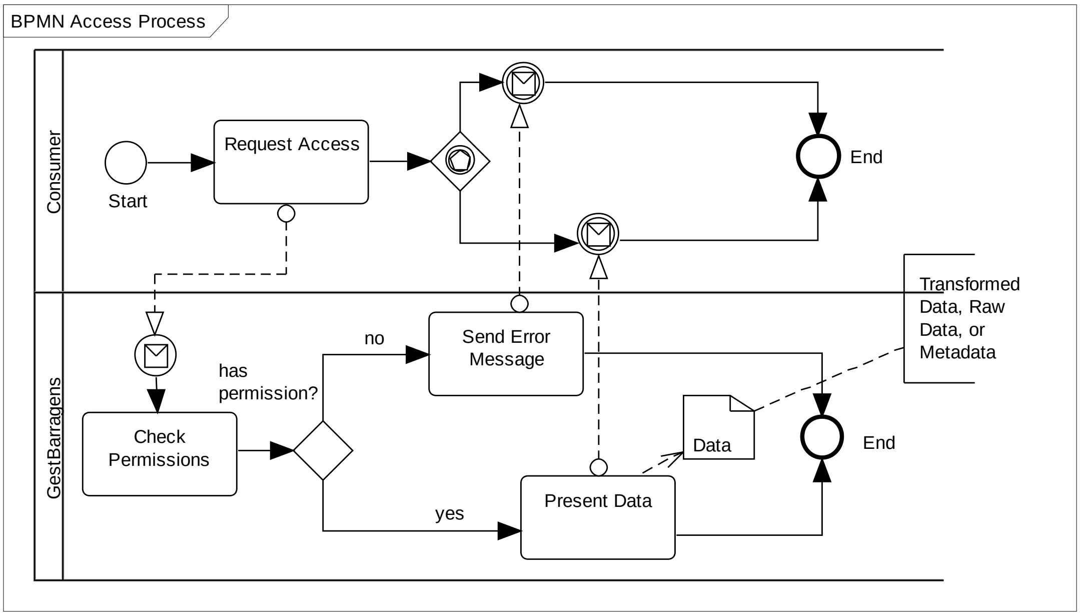


Figure 14: Access Data Process

5.8.2.2 BP-SD-4 - Modify Data

Again, the modification of data requires the validation of the permissions of the Producer. All modifications made to data are logged. Figure 15 depicts the data modification process. Notice that depending on the data that is being modified, a modification can require the re-execution of multiple data transformation processes

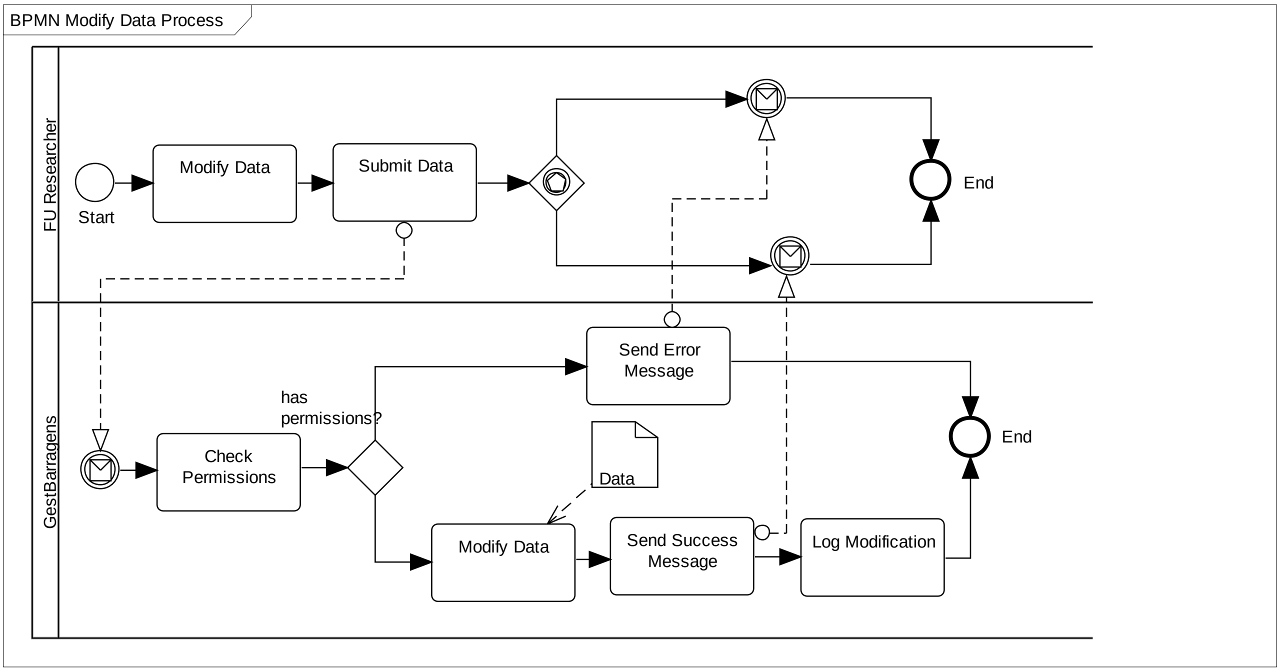


Figure 15: Modify Data Process

5.8.3 Other Processes

In this section, we describe other data management processes related to the *GestBarragens* system.

5.8.3.1 BP-SD-6 – Data Synchronisation

Since structure owners are entitled to possess local copies of observation data gathered from their structures, an instance of the *GestBarragens* information systems exists on the structure owner premises containing that data. That specific data is replicated on the central *GestBarragens* instance at LNEC. The processes depicted in this section were not designed for preservation purposes. As shown in Figure 16, synchronisation can either be Automatic or Manual. In case of the automatic synchronisation, its scheduling can be configured.

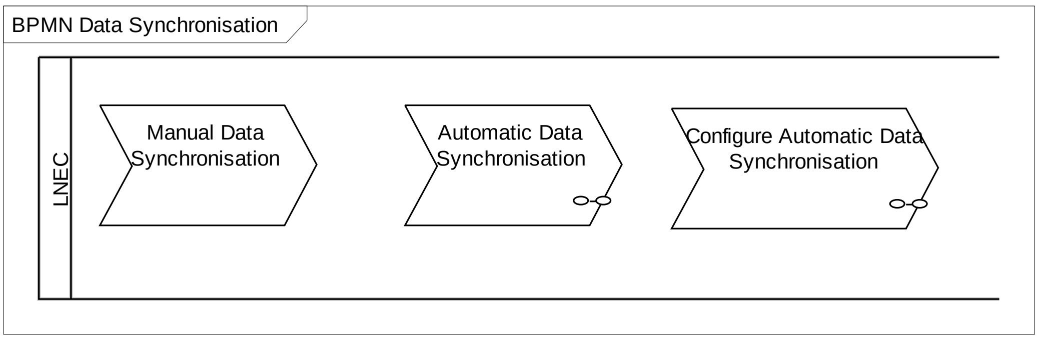


Figure 16: Data Synchronisation

The Manual Data Synchronisation process shown in Figure 17 gathers a list of files which are to be synchronised between different instances of the system. Not all of the data is replicated between the central instance and other external instances. Only data contained in the external instances is replicated on the central instance.

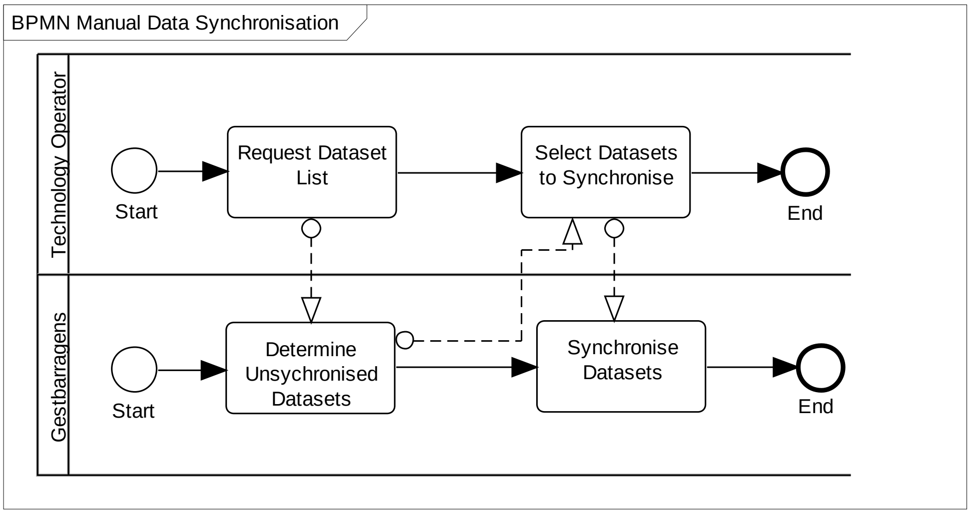


Figure 17: Manual Data Synchronisation

The Automatic Data Synchronisation process shown in Figure 18 is dependent on the Configure Automatic Data Synchronisation process, which configures the synchronisation settings, such as the datasets to be synchronised and the schedule of synchronisation. Again, only data contained in the external instances is replicated on the central instance.

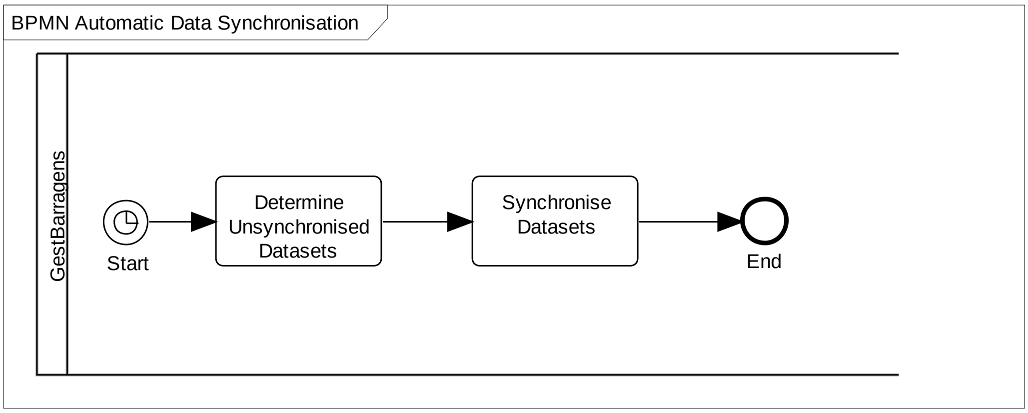


Figure 18: Automatic Data Synchronisation

The Configure Automatic Data Synchronisation process depicted in Figure 19 uses the information given by the Technology Operator such as the datasets to synchronise and the schedule of synchronisation. If the schedule is OK, the Automatic Data Synchronisation process will take place on the scheduled time.

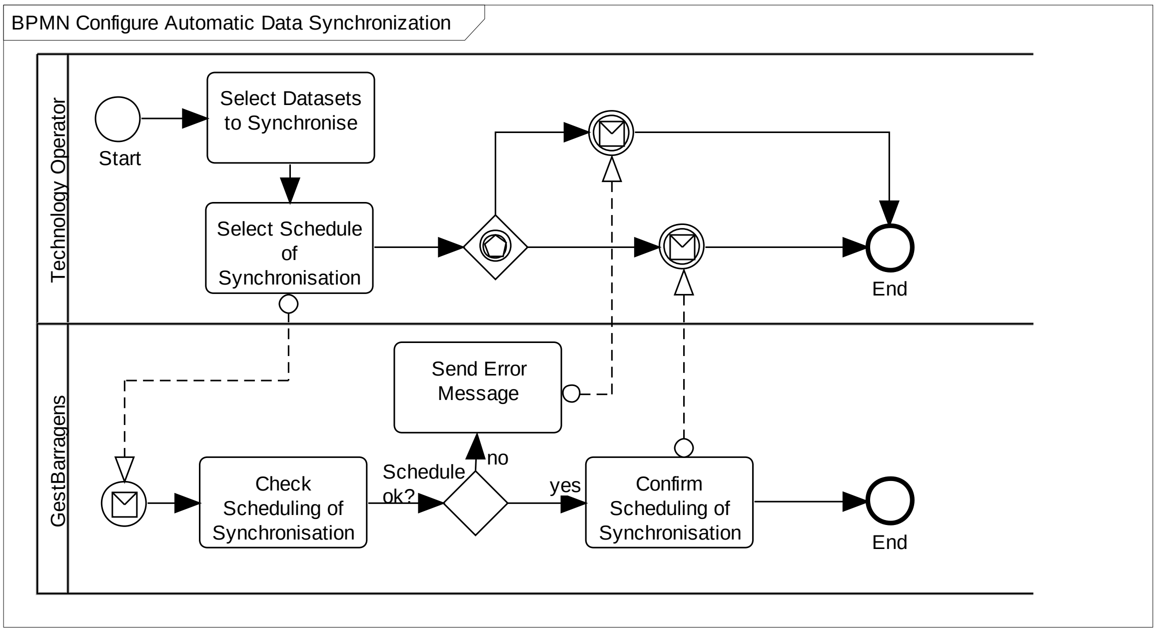


Figure 19: Configure Automatic Data Synchronisation

5.8.3.2 BP-SD-7 – Offline Data backup

The data stored in the GestBarragens system is also regularly backed-up, with a full backup happening each month and with incremental backups happening daily. Figure 20 depicts the process.

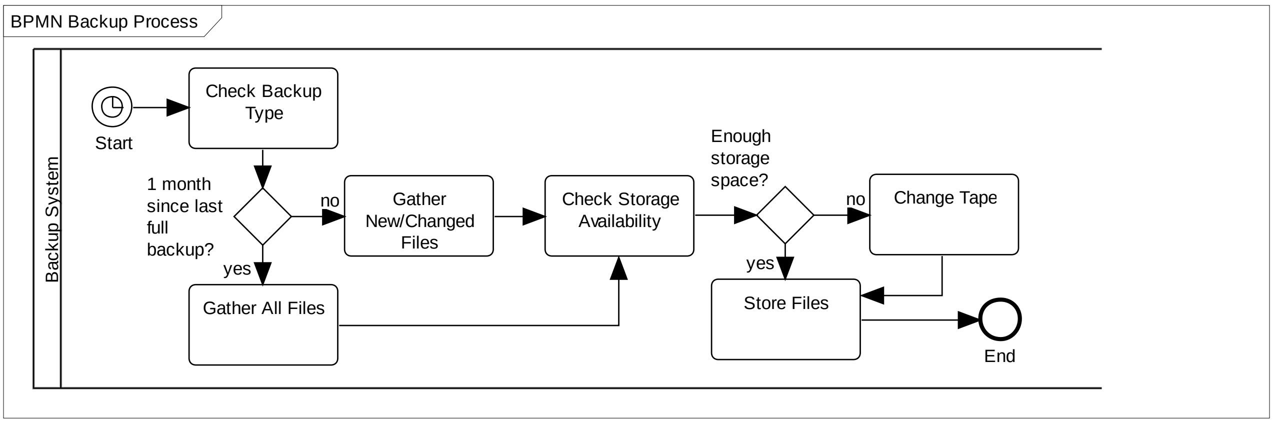


Figure 20: Offline Data Backup

5.8.4 Policies/Processes Mapping

Table 19: Policy/Preservation Process Catalogue traces the processes back to the policies. Some of the existing policies are not currently being enforced by existing processes (signalled with 'Not enforced'), while others are only partially enforced.

Table 19: Policy/Preservation Process Catalogue

Policy	Process	
PP-SD-1. Content	a	BP-SD-1, BP-SD-2, BP-SD-3
	b	BP-SD-1, BP-SD-2, BP-SD-3
PP-SD-2. Metadata	a	BP-SD-4 (partially enforced)
	b	BP-SD-1, BP-SD-2, BP-SD-3
PP-SD-3. Submission	a	BP-SD-1
	b	BP-SD-1
	c	BP-SD-3
	d	BP-SD-5
PP-SD-4. Access and Reuse	a	BP-SD-4
	b	Not demonstrable
	c	Not demonstrable
PP-SD-5. Preservation	a	All processes (partially enforced)
PP-SD-6. Withdrawal of Information and Succession Plans		
PP-SD-7. Adequacy	a	Not enforced
	b	Not enforced
	c	Not enforced

5.9 Domain Structure

Figure 21 details information which is characteristic of the various types of observations, i.e., information about campaigns, instruments, readings and results. The procedures involved in a geodesic observation campaign feature particularities in relation to the observation campaigns of the other instruments deployed in the structure. These particularities reflect in the information's organisation. In this way, the campaigns, measurements and results can be specialised in general observations or in geodesic observations. The relations between the concepts modelled in the domain diagram are:

- Each campaign has a set of readings from a certain instrument;
- Each measurement is associated with one or more events;
- One measurement can generate one result (there can be several scalar values associated with one measurement);
- Each result is associated with a reference campaign, and it is possible to determine in which campaign the result was generated, as well as, the reference campaign used to calculate it.

Note that in order to produce results, algorithms use information related to Measurements, as well as constants and parameters determined by instrument instance. Also note that the mapping between a measurement and a result is not always from one-to-one. Complex instrumentation required the concept of "Group of instruments", where transformations algorithms must take into account all the measurement gathered from instruments in their group (that is the case of instrumentation like plumb lines or inclinometers, where instrument results are an integration of multiple values).

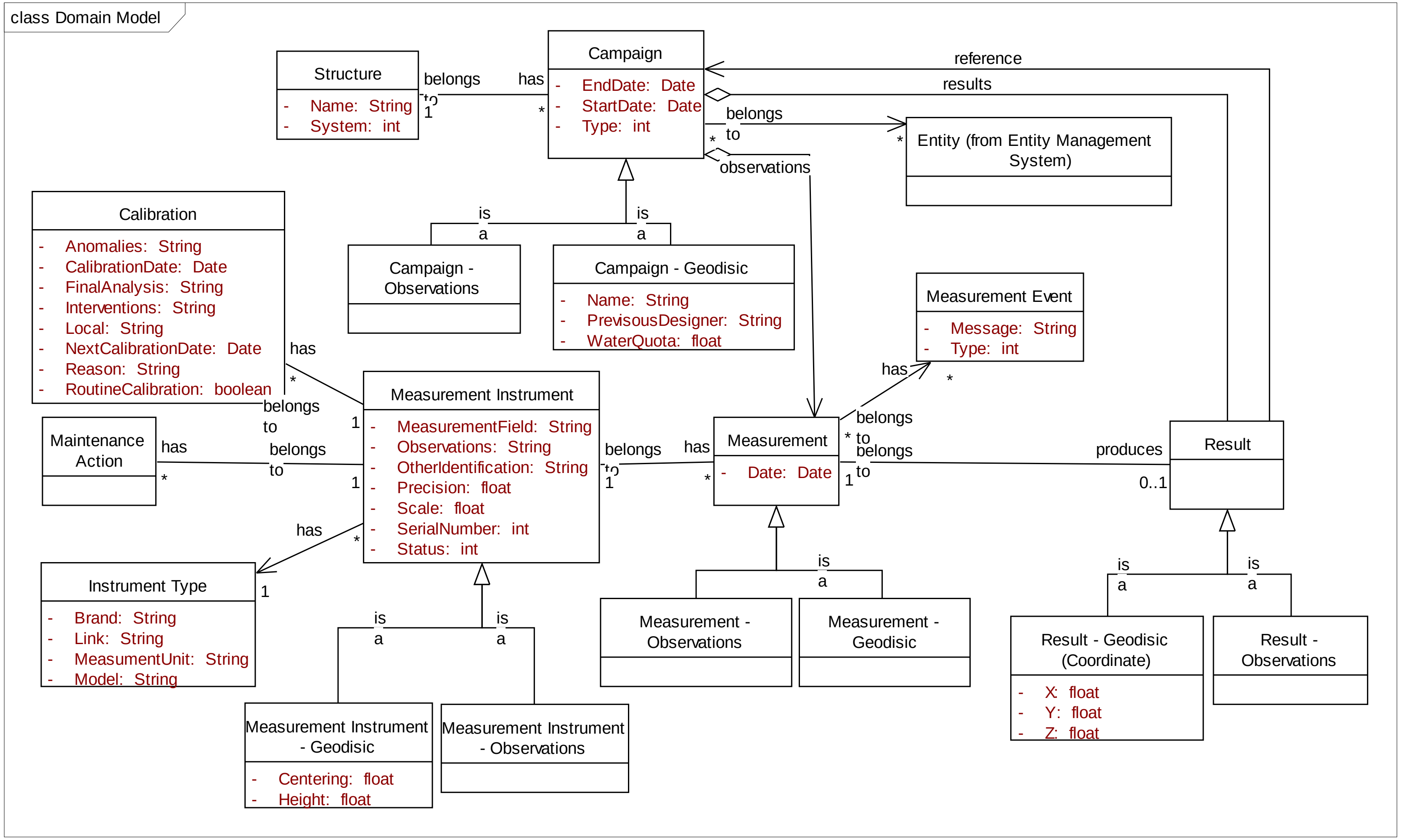


Figure 21: Domain Structure Diagram

6 Preservation Scenarios

The monitoring of large civil engineering structures involves several types of instrumentation. As shown in the previous chapter, LNEC is currently involved in processes of acquisition and transformation of 36 manual sensors and 25 automatic data gathering devices. It is the objective of the use case to preserve these processes. The data contained within them is not the only object of the preservation action, but also the context and the description of the tasks (workflows), according to the framework described in the Section 3.1.

The principles behind each specific acquisition process are the same, independently of the sensor type (each sensor type has its specific algorithms, validations and depend on distinct constants and calibration values). This chapter illustrates a real example of electrical resistance extensometers, detailing the algorithms it dependencies for both manual acquisition and automatic data gathering processes.

6.1 Electrical Resistance Extensometer (Strain Gage)

Distinct types of devices can be used to measure extensions (deformations[11]) in the concrete, ranging from mechanical, optical, electrical resistance, electrical inductance, electrical capacitance or piezoelectric principles. In dams, the main objective is to measure deformations inside the concrete, which is commonly measure by electrical resistance extensometers, Carlson type, as the example shown in Figure 22.

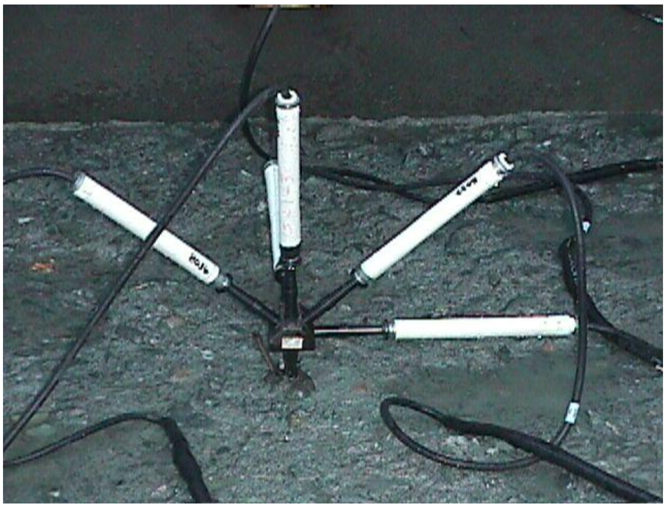


Figure 22: Group of electrical resistance extensometers

Resistance extensometers come in gage lengths from as little as a few thousandths of an inch to gages of several inches in length. Extremely short gage lengths are used for applications involving high strain gradients or where measurements are required in areas of small radius of curvature. At the other extreme, long special purpose gages are made to be embedded in non-homogeneous materials such as concrete where they automatically average the strain over a more representative sample of the material.

[11] Since gage lengths are always finite, the final measure is a deformation

Strain gages come in thousands of sizes, shapes, and configurations, varying on their range, accuracy and, as a consequence, each instance has its own properties and constants (although, the algorithm is the same for each instrument).

The extensometer principle of operation is based on the Lord Kelvin's theory that shows that the electrical resistance of a wire changes when the wire is deformed. Thus, the electrical resistance (*R*) of a wire of length (*L*) and a cross-sectional area (*A*) is given by the equation:

$$R = \frac{\rho L}{A}$$

In this equation, ρ is the electrical resistivity of the material. As a consequence, if the wire is stretched its length increases and the cross-sectional area decreases, resulting in an increase in the electrical resistance of the wire.

In this type of instrumentation, the resistance variation is very small, which makes it impossible to measure with conventional ohmmeters. To address small variations, the reading of extensometers is done by a Wheatstone bridge, followed by the measurement of the sum of the two resistance components, the total resistance (***R***) as shown in Figure 23, and the relationship of the resistances (***r***) as shown in Figure 24.

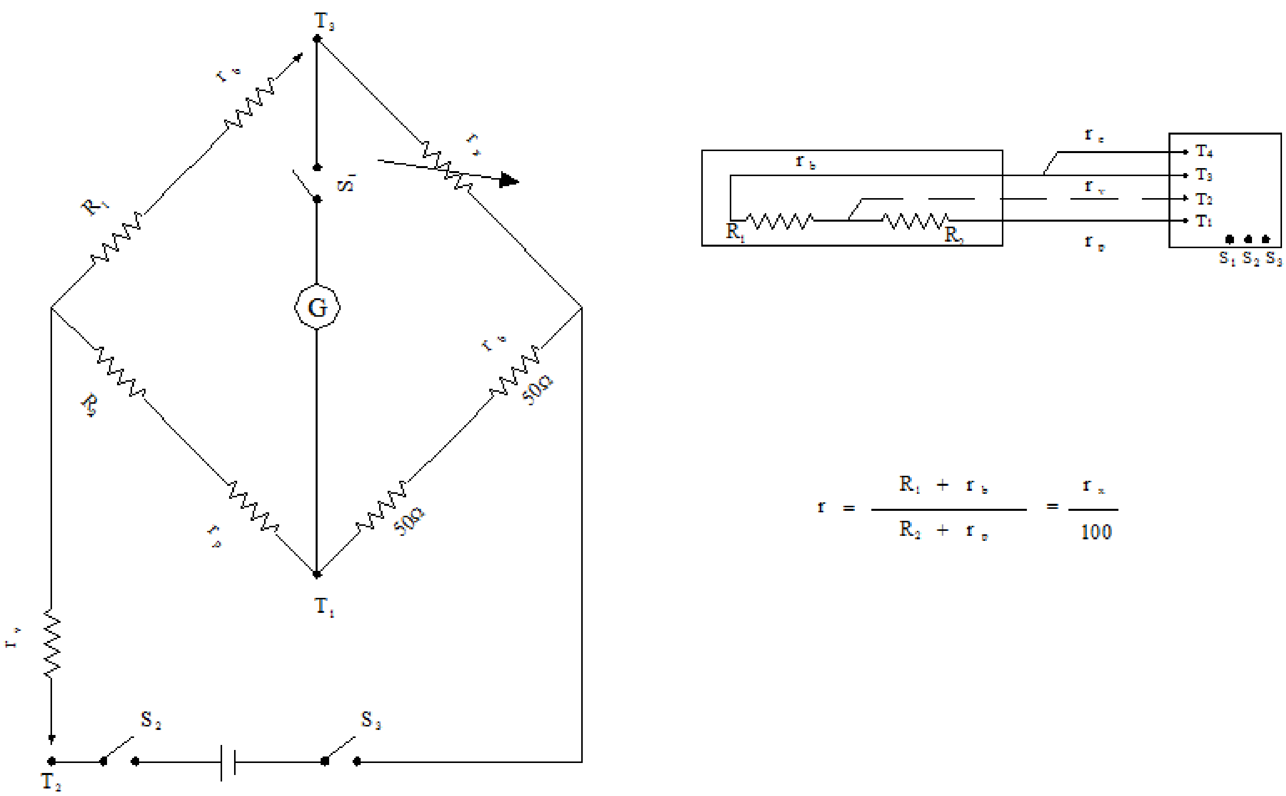


Figure 23: Total resistance

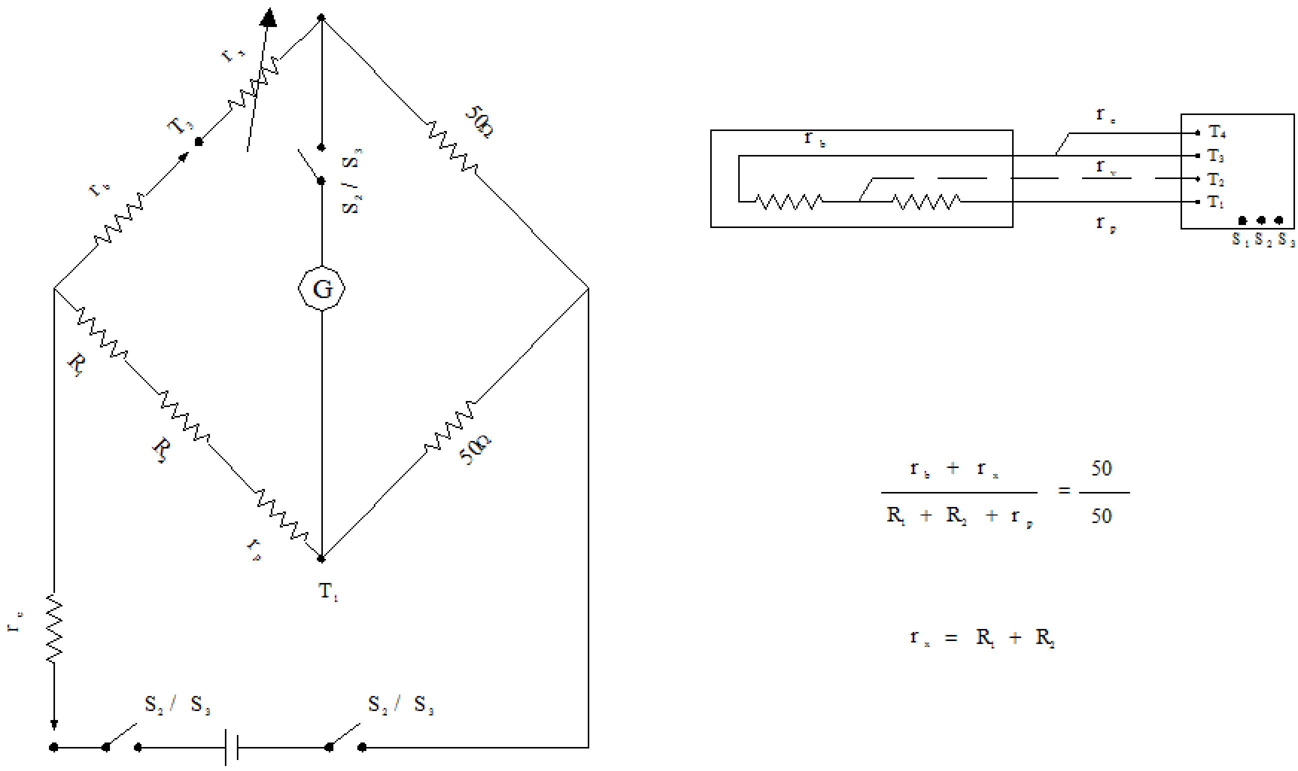


Figure 24: Resistance relation

6.2 Manual Acquisition

Manual data acquisition follows the data submission process described in Chapter 5, involving the following sub-processes:

- Local Data Gathering
- Central Data Validation
- Central Data Transform
- Central Data Store

Each specific instrument (sensor) has a set of properties, which are used to identify the sensor, to validate acquired data (during the local data gathering and the central data validation processes), and to be used during the transformation into physical quantities (central data transform process).

6.2.1 Sensor

In the case of electrical extensometers, the information is the following:

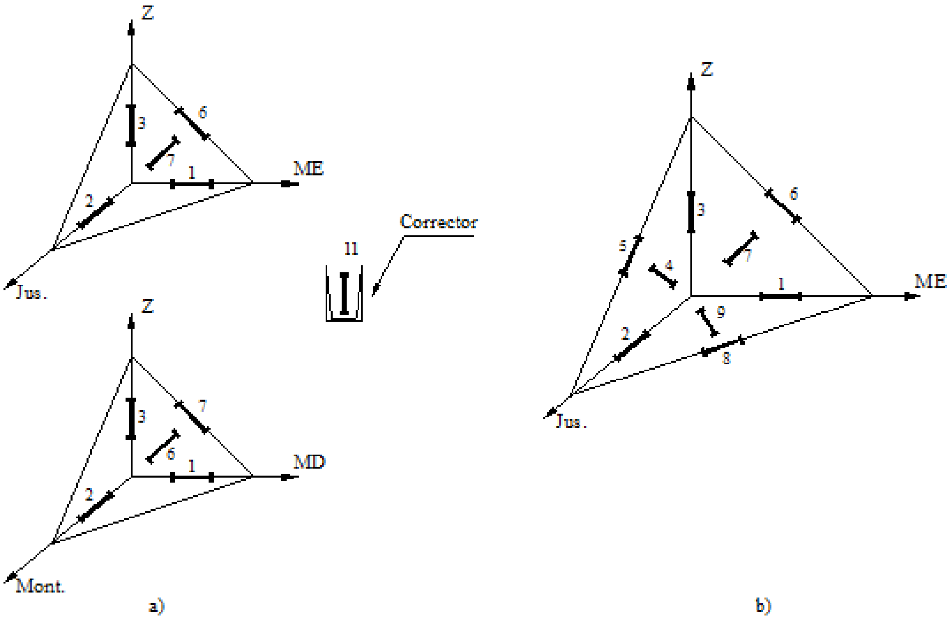


Figure 25: Arrangement code numbering and strain gauges installed close to the facings (a) or within a reservoir (b)

Group - Group of strain gauges (strain gauges can be arranged in groups to be able to compute tensions in several dimensions).
Position – Position of the gage in the group. In Figure 25 is depicted the usual arrangement of strain gauges installed near the vestments or inside the dam.
Code - Code for identification of the strain gage system (internal identification used by supporting systems).
Block - Block of the dam where the gage is located.
OE – Indicates whether this device code is part of the expedite observation (it affects the frequency of acquisition).
Quota – Quota location of the gage block.
R_0 – Total resistance at a temperature of ° C. Value provided by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Value provided by the manufacturer.
T_i – Initial temperature.
ε_2 – Correction of extension due to the variation of 1°C temperature. Value provided by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum limit for validation of the relationship of the resistances.
r_{Min} – Minimum limit to validate the reading of the ratio of resistors.
ε_1 – Change in length by ten thousandth of a variation in the resistance. Value provided by the manufacturer.
E – Modulus of elasticity of concrete per year, for transformation of the extension state into tensions.
Dg – Disposition of the group in the block. M - Upright; J - Downstream and & - ½ thick.

Validation limits can change over time due to the evolution of the dam's behaviour. On the other hand, constants (typically provided by the manufacturer) are also subject to variations in the scope of calibration activities. Finally, the extension is always relative to a specific instant in time. Thus, also initial value can change to better accommodate specific analysis that require the use of a distinct origin (represented by the initial values).

6.2.2 Data Readings

The readings provided by this type electrical extensometers in a given time n, are as follows:

Sid - identification of the strain gage

MD – identification of the measuring device used in the data gathering process (Kiowa reader)

Date – date and time of acquisition

Occurrence – Annotation of occurrences (temporarily defective instrument; defective instrument; no occurrences; reading does not stabilize; reading doubtful; reading repeated; lack of access; Lack of illumination; awash; works in progress; poor condition; leakage tubes in the zone of sealing; placed in second stage concrete; occurrence of flooding; abandoned; does not exist; sealed; obstructed; tube tilt does not allow the reading; defective measuring device; out of range of measurement device; others; anomaly in reading

Errors – Errors recorded during the acquisition process (annotated as out of range of the measuring device, or out of the validation limits)

Comments – Free text to add details about the data acquisition

R_n – Reading of the total resistance at the time *n*

r_n – Reading the ratio of the resistances at the time *n*

6.2.3 Algorithm

From the readings provided by the electrical extensometer, it is possible to calculate the temperature inside the concrete (absolute value), and the actual extension (relative value to a specific origin). The expressions for calculating the temperature (T) and the actual extension (εr) in each of the strain are as follows:

$$T = (R_n - R_0)\Delta_t \qquad (ºC)$$

$$\varepsilon r = (T - T_i)\varepsilon_2 + (r_n - r_i)\varepsilon_1 \qquad (x10^{-6})$$

Note that the algorithm to compute the temperature "just" depends on the reading of the total resistance and on two constants associated with each specific sensor, while the algorithm to compute the extension depends on both readings of the total resistance and the ratio of the resistances, on specific constants, but also on initial values (initial temperature and initial reading of the resistance relations), as it is a relative physical measure.

6.2.4 Process Flow

The manual data acquisition process is usually supported by a portable data terminal (PDT), which runs a specific application on top of the *Windows-CE* operating system. Figure 26 depicts such device. Using PDT devices, the operators select a specific electrical extensometer and register the reading of the total resistance, the reading ratio of the resistances and, if necessary, annotate the applicable occurrence and comments (both dates and errors are generated by the application running on the PDT device).

Figure 26: Portable Data Terminal (PDT)

After the acquiring sensor data, the operators connect the PDT to an internet connection, and upload the readings to the gestBarragens system (described in Section 5.3).

When the data acquisition is not supported with a PDT, the operators can upload the readings into the gestBarragens systems through the upload of data files (ASCII or spreadsheets), or manually registering the values in a web interface. Figure 27 depicts an example of the web interface that can be used to manage the readings of electrical extensometers.

At this level, the data is validated and, in case of anomalies, each reading is tagged with the detected anomaly. Note that some types of anomalies are considered warnings, meaning that the results can still be calculated, while other errors do not allow the computation of results.

After applying the algorithm, the previous example will produce a temperature of 17.745 ºC and an extension of -140.3863 x 10-6 mm for sensor 1 and a temperature of 16.762 ºC and an extension of -159.27988 x 10-6 mm for sensor 2. Figure 28 depicts such results. Also results are validated and finally, all the information (readings, computed results and annotations) is stored in a database.

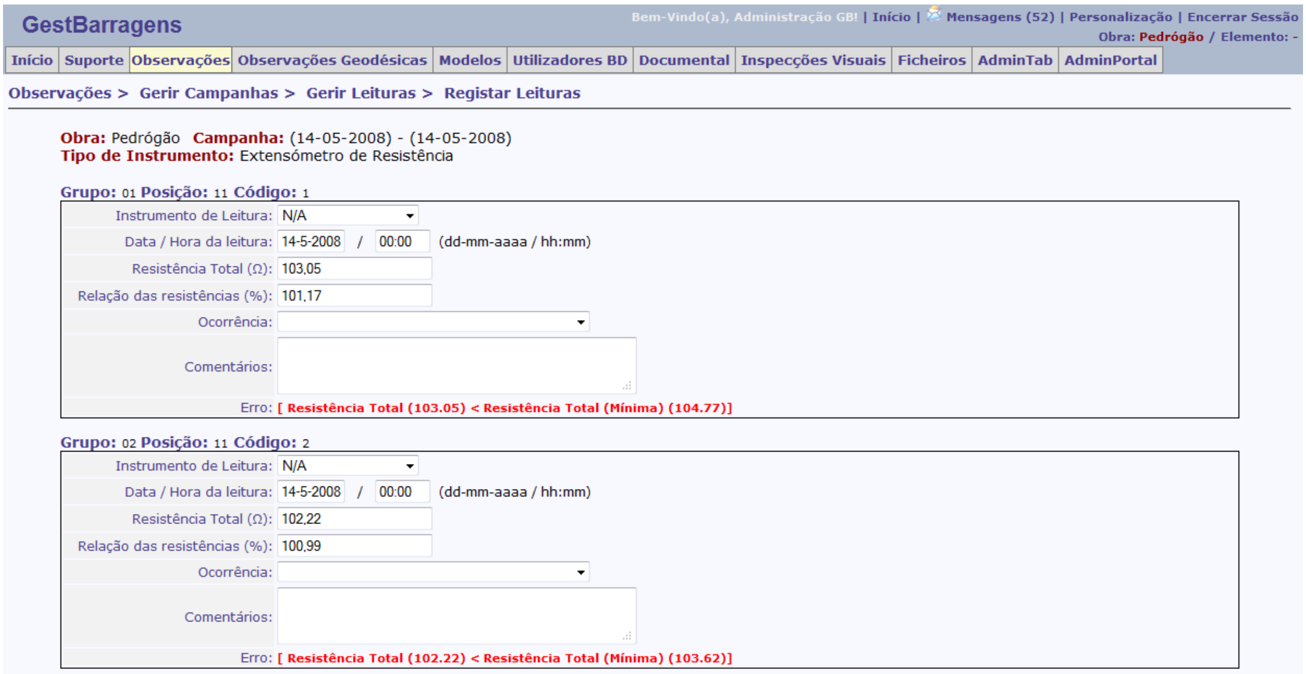


Figure 27: Managing readings (in Portuguese)

Figure 28: Electrical extensometer results

6.2.5 Process Instances

This section illustrates the execution of the transformation of electrical extensometers. For that purpose, we detail the definition of two sensors show a set of readings and the respective computed temperatures and relative extensions. Table 20 details the information that characterizes two manual electrical extensometers (sensor 1 and sensor 2), detailing the values for each of their properties (see section 6.2.1). Table 21 shows a set of illustrative readings (total resistance and relation of resistances) acquired for the sensors detailed in Table 20.

Table 20: Electrical extensometers

Parameter	Sensor 1	Sensor 2
Code	1	2
Block	4A-4B	4A-4B
OE	1	1
Quota	64.5	69
R_0	97.8	97.29
$R_{Máx}$	109.61	109.22
R_{Min}	104.77	103.62
Δ_t	3.38	3.4
T_i	26.85	25.16
ε_2	12.06	12.06
r_i	101.28	101.19
$r_{Máx}$	101.46	101.33
r_{Min}	101.05	100.7
ε_1	278	290
E	37.2	37.2
Dg	1m	1m

Table 21: Electrical extensometers (example readings)

Date	Sensor	R_n	r_n
14-05-2008 00:00	1	103,05	101,17
14-05-2008 00:00	2	102,22	100,99
30-04-2008 00:00	1	103,08	101,14
30-04-2008 00:00	2	102,19	101,06
15-04-2008 00:00	1	103,06	101,18
15-04-2008 00:00	2	102,32	100,98
19-03-2008 00:00	1	103,12	101,13
19-03-2008 00:00	2	102,39	100,86
07-02-2008 00:00	1	103,39	101,17
07-02-2008 00:00	2	102,65	101,03
09-01-2008 00:00	1	103,61	101,2
09-01-2008 00:00	2	102,88	101,04
26-12-2007 00:00	1	103,79	101,06
26-12-2007 00:00	2	103,07	100,99
13-12-2007 00:00	1	103,76	101,21
13-12-2007 00:00	2	103,13	101,01

Figure 29 graphically shows the evolution of the total resistance and the ratio of resistances for sensors 1 and 2. After applying the algorithm shown in section 6.2.3 to the readings illustrated in Table 21 for sensors detailed in Table 20, the produced results are listed in Table 22. Figure 30 illustrates the evolution of calculated temperatures and extensions for sensors 1 and 2.

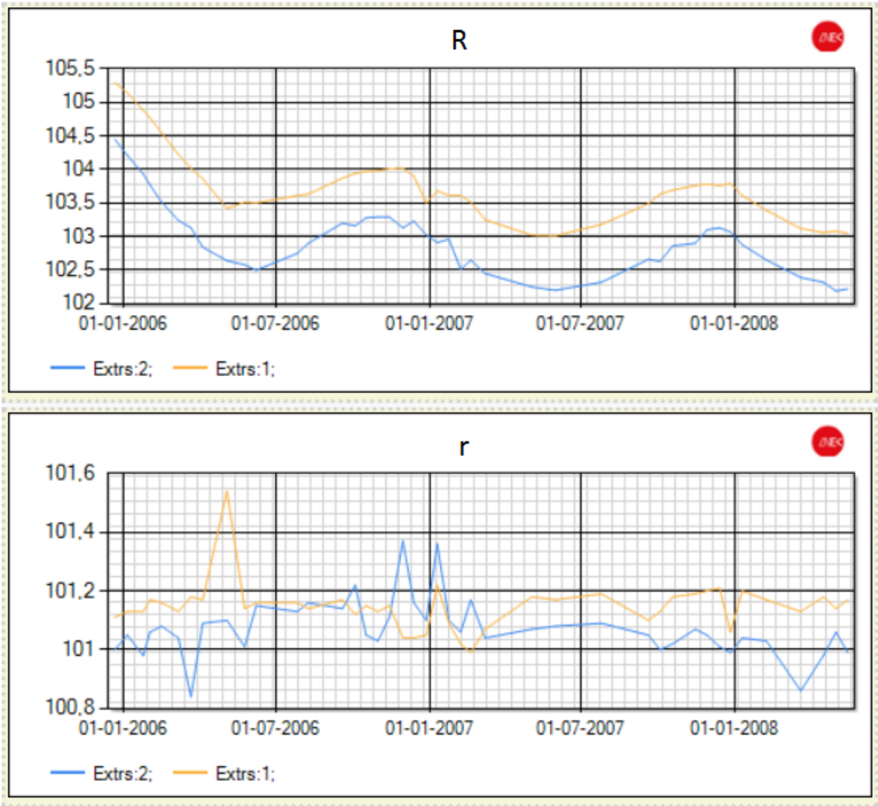


Figure 29: Variation of total resistance and resistance ratio for electrical extensometers 1 and 2

Table 22: Electrical extensometers (example results)

Date	Sensor	Temperature	Extension (x10-6)
14-05-2008 00:00	1	17,745	-140,3863
14-05-2008 00:00	2	16,762	-159,27988
30-04-2008 00:00	1	17,8464	-147,50341
30-04-2008 00:00	2	16,66	-140,21
15-04-2008 00:00	1	17,7788	-137,19867
15-04-2008 00:00	2	17,102	-158,07948
19-03-2008 00:00	1	17,9816	-148,6529
19-03-2008 00:00	2	17,34	-190,0092
07-02-2008 00:00	1	18,8942	-126,52694
07-02-2008 00:00	2	18,224	-130,04816
09-01-2008 00:00	1	19,6378	-109,21913
09-01-2008 00:00	2	19,006	-117,71724
26-12-2007 00:00	1	20,2462	-140,80182
26-12-2007 00:00	2	19,652	-124,42648
13-12-2007 00:00	1	20,1448	-100,32471
13-12-2007 00:00	2	19,856	-116,16624

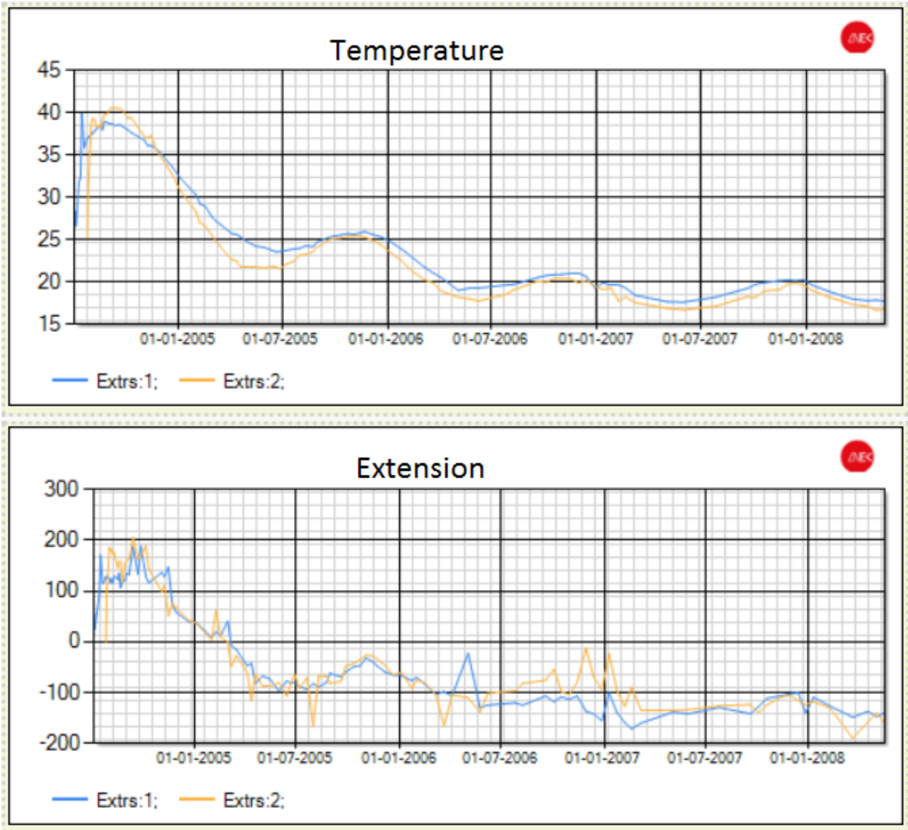


Figure 30: Calculated Temperature and Extension for sensors 1 and 2

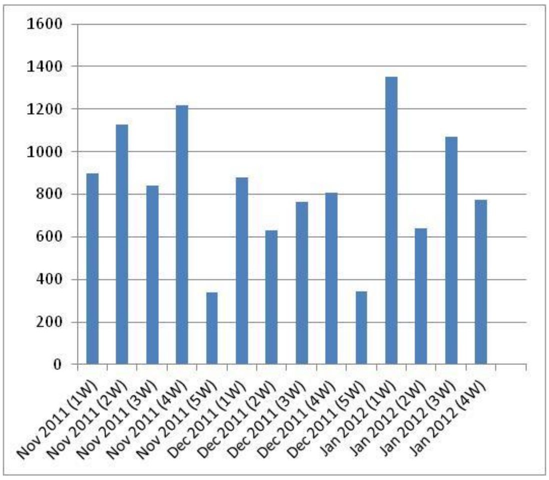


Figure 31: Process executions for electrical extensometers

6.2.6 Process Execution

Figure 31 illustrates the number of process executions per week for electrical extensometers. In fact, the data monitoring process is a continuous process that constantly requires the execution of both data gathering, data validation, data transform and data store sub-processes. That fact further escalates when considering the full set of instrumentation types.

6.3 Automated Data Gathering

The automatic data gathering process is similar to the manual data gathering process described in section 6.2. It also involves the sub-processes of:

- Local Data Gathering
- Central Data Validation
- Central Data Transform
- Central Data Store

The main difference between the manual data gathering process and the automatic data gathering process is related to the Local Data Gathering process, which is automated and involves different components, and the Central Data Transform, as it requires a parsing, pre-processing and adds another transformation step. Both the central data validation and central data store processes are similar to the manual data gathering, where the variations just depend on the sensor type. Figure 32 shows a typical installation of an automatic data gathering system.

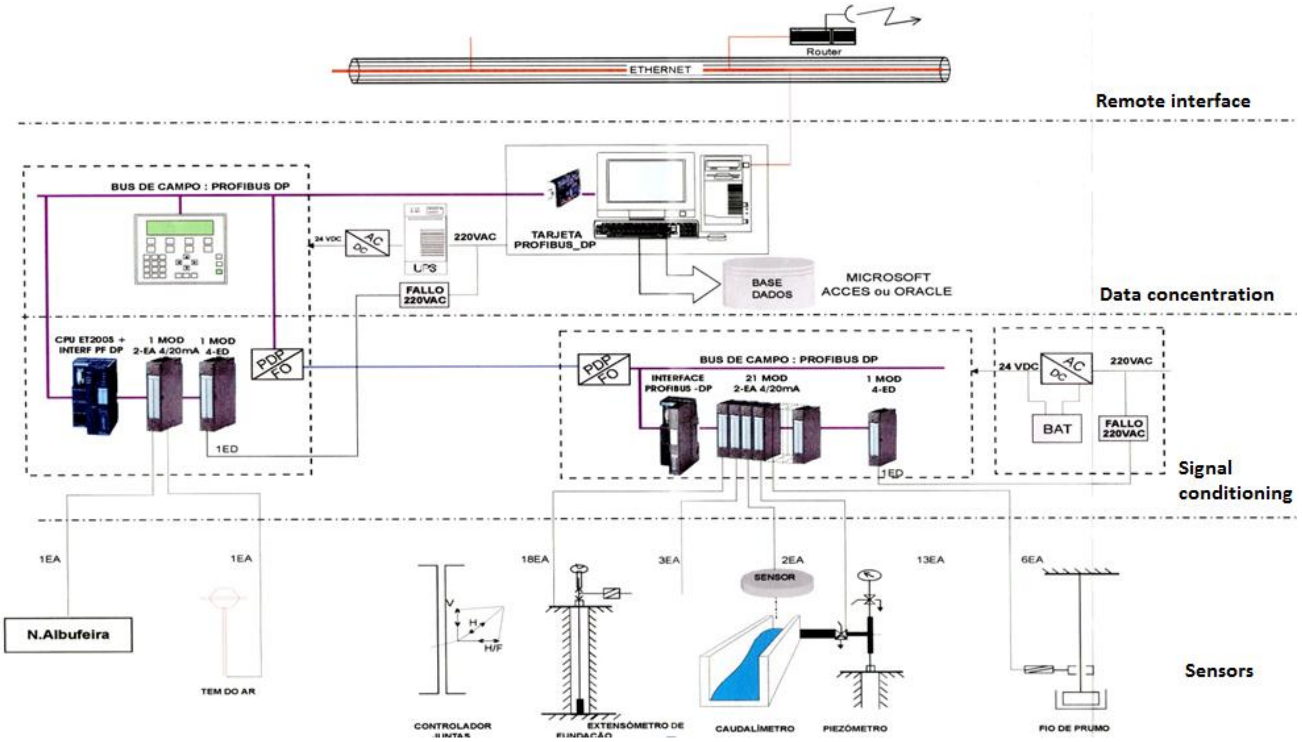


Figure 32: Automatic data gathering scheme

The automatic data gathering system is composed by four distinct layers:

- Sensors, usually known as the industrial layer, which is composed by a network of sensors installed in strategic points of the dam structure. The type and number of sensors depends on the structural properties of each specific dam;
- Signal conditioning, preparing the signal to the next stage for further processing, i.e., analog to digital conversion, amplification and clock synchronization;
- Data concentration, concentrating and recording data acquisitions. Depending on the number of sensors and acquisition frequency, this task is usually done by a set of data loggers, such as *dataTacker*[12] for static monitoring or Gantner *Instruments*[13] for dynamic data monitoring.
- Remote interface, to connect to central stations outside the boundaries of the dam structure. Usually, this is performed by an industrial computer, connected to the set of data loggers, and directly assessing servers at the dam owner or the LNEC.

As happens in the manual data gathering, each specific electrical extensometer sensor has a set of properties, which are used to identify the sensor, to validate acquired data (during the local data gathering and the central data validation processes), and to be used during the transformation into physical quantities (central data transform process). Each sensor is defined by the following properties:

Code - Code for identification of the strain gage.
Block - Block of the dam where the gage is located.
Quota – Quota location of the gage block.
AUnit – Acquisition unit connect to the strain gage.
Channel – Number of the channel in the acquisition unit
R_0 – Total resistance at a temperature of ° C. Value provided by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Value provided by the manufacturer.
T_i – Initial temperature.
ε_2 – Correction of extension due to the variation of 1°C temperature. Value provided by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum limit for validation of the relationship of the resistances.
r_{Min} – Minimum limit to validate the reading of the relationship of the resistances.
ε_1 – Change in length by ten thousandth of a variation in the resistance. Value provided by the manufacturer.
P – P constant in mV
Q – Q constant in mV
N – N constant in mV.W
D – *D* constant in mV

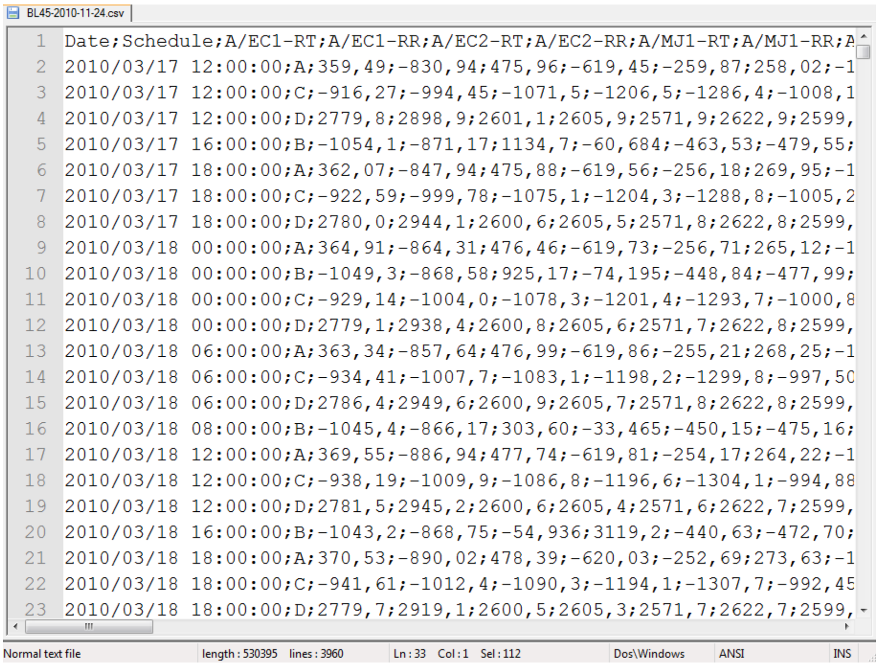
[12] http://www.datataker.com/

[13] http://www.gantner-instruments.com/distributed-systems/e-series

Table 23 details de information that characterizes two automatic electrical extensometers (sensor 3 and sensor 4), detailing the values for each of their properties. Data loggers are continuously storing sensor readings (in mV) in a specific ASCII format. Figure 33 shows an example of the representation of this information. Note that this is the artefact that is produced in the scope of the local data gathering sub-process, which will be submitted into the gestBarragens system.

Table 23: Automatic electrical extensometers

Parameter	Sensor 3	Sensor 4
Code	3	4
Block	7A-8	7A-8
Quota	64	69.3
R_0	97.19	97.47
$R_{Máx}$	110.27	109.69
R_{Min}	104.25	104.03
Δ_t	3.4	3.39
T_i	26.85	29.78
ε_2	12.06	12.06
r_i	101.5	101.12
$r_{Máx}$	102.03	101.22
r_{Min}	101.01	100.93
ε_1	284	281
P	-124583,6	-124450,3
Q	-124515,8	-124300,9
N	2651678	2646520
D	25365	25324


BL45-2010-11-24.csv

```
Date;Schedule;A/EC1-RT;A/EC1-RR;A/EC2-RT;A/EC2-RR;A/MJ1-RT;A/MJ1-RR;A
2010/03/17 12:00:00;A;359,49;-830,94;475,96;-619,45;-259,87;258,02;-1
2010/03/17 12:00:00;C;-916,27;-994,45;-1071,5;-1206,5;-1286,4;-1008,1
2010/03/17 12:00:00;D;2779,8;2898,9;2601,1;2605,9;2571,9;2622,9;2599,
2010/03/17 16:00:00;B;-1054,1;-871,17;1134,7;-60,684;-463,53;-479,55;
2010/03/17 18:00:00;A;362,07;-847,94;475,88;-619,56;-256,18;269,95;-1
2010/03/17 18:00:00;C;-922,59;-999,78;-1075,1;-1204,3;-1288,8;-1005,2
2010/03/17 18:00:00;D;2780,0;2944,1;2600,6;2605,5;2571,8;2622,8;2599,
2010/03/18 00:00:00;A;364,91;-864,31;476,46;-619,73;-256,71;265,12;-1
2010/03/18 00:00:00;B;-1049,3;-868,58;925,17;-74,195;-448,84;-477,99;
2010/03/18 00:00:00;C;-929,14;-1004,0;-1078,3;-1201,4;-1293,7;-1000,8
2010/03/18 00:00:00;D;2779,1;2938,4;2600,8;2605,6;2571,7;2622,8;2599,
2010/03/18 06:00:00;A;363,34;-857,64;476,99;-619,86;-255,21;268,25;-1
2010/03/18 06:00:00;C;-934,41;-1007,7;-1083,1;-1198,2;-1299,8;-997,50
2010/03/18 06:00:00;D;2786,4;2949,6;2600,9;2605,7;2571,8;2622,8;2599,
2010/03/18 08:00:00;B;-1045,4;-866,17;303,60;-33,465;-450,15;-475,16;
2010/03/18 12:00:00;A;369,55;-886,94;477,74;-619,81;-254,17;264,22;-1
2010/03/18 12:00:00;C;-938,19;-1009,9;-1086,8;-1196,6;-1304,1;-994,88
2010/03/18 12:00:00;D;2781,5;2945,2;2600,6;2605,4;2571,6;2622,7;2599,
2010/03/18 16:00:00;B;-1043,2;-868,75;-54,936;3119,2;-440,63;-472,70;
2010/03/18 18:00:00;A;370,53;-890,02;478,39;-620,03;-252,69;273,63;-1
2010/03/18 18:00:00;C;-941,61;-1012,4;-1090,3;-1194,1;-1307,7;-992,45
2010/03/18 18:00:00;D;2779,7;2919,1;2600,5;2605,3;2571,7;2622,7;2599,
```

Normal text file | length : 530395 lines : 3960 | Ln : 33 Col : 1 Sel : 112 | Dos\Windows | ANSI | INS

Figure 33: Example of automatic data gathering log

In the gestBarragens context, the information shown in Figure 33 is validated and pre-processed, in order to associate each voltage to the respective sensor. In fact, each electrical extensometer is monitored by two channels, providing voltage information for the total resistance (VRn) and for the relation of resistances (Vrn). These voltage values are then transformed into the physical values of total resistance (Rn) and relation of resistances (rn), using the following transformation algorithms:

$$R_n = \frac{N}{D + VR_n}$$

$$r_n = \frac{P + Vr_n}{Q + Vr_n}$$

After this pre-processing step, the calculation of the absolute temperature and the relative extension are computed using the same algorithm that is used for the manual instrument, as follows:

$$T = (R_n - R_0)\Delta_t \qquad \text{(ºC)}$$

$$\varepsilon_r = (T - T_i)\varepsilon_2 + (r_n - r_i)\varepsilon_1 \qquad (\mathrm{x}10^{-6})$$

Table 24 shows a set of readings acquired for the sensor 4 detailed in the previous table (values in voltage, before the initial transformation).

Table 24: Automatic electrical extensometer (voltage readings)

Date	Sensor	VR_n	Vr_n
26-06-2012 12:00	4	329,34	-703,72
26-06-2012 06:00	4	329,63	-703,72
26-06-2012 00:00	4	329,95	-703,72
25-06-2012 18:00	4	330,17	-703,72
25-06-2012 12:00	4	330,39	-703,75
25-06-2012 06:00	4	330,61	-703,92
25-06-2012 00:00	4	330,8	-703,75
24-06-2012 18:00	4	331,02	-703,84
24-06-2012 12:00	4	331,3	-703,84
24-06-2012 06:00	4	331,45	-703,88
24-06-2012 00:00	4	331,67	-703,72
23-06-2012 18:00	4	331,89	-703,75
23-06-2012 12:00	4	332,07	-703,8
23-06-2012 06:00	4	332,33	-703,97
23-06-2012 00:00	4	332,48	-703,97
22-06-2012 18:00	4	332,73	-703,88
22-06-2012 12:00	4	332,84	-703,88
22-06-2012 06:00	4	333,05	-703,92
22-06-2012 00:00	4	333,13	-703,84
21-06-2012 18:00	4	333,31	-703,84
21-06-2012 12:00	4	333,57	-703,84
21-06-2012 06:00	4	333,71	-703,88
21-06-2012 00:00	4	333,9	-703,88
20-06-2012 18:00	4	334,02	-703,86
20-06-2012 12:00	4	334,72	-703,69

After applying the first transformation, the total resistance and the relation of resistances are computed as processed readings. Table 25 shows the results of applying the process to the data shown in the previous table, using the specific constants of sensor 4.

Table 25: Automatic electrical extensometer (processed readings)

Date	Sensor	R_n	r_n
26-06-2012 12:00	4	103,16456	1,011762
26-06-2012 06:00	4	103,1634	1,011762
26-06-2012 00:00	4	103,16212	1,011762
25-06-2012 18:00	4	103,16124	1,011762
25-06-2012 12:00	4	103,16036	1,011762
25-06-2012 06:00	4	103,15948	1,011765
25-06-2012 00:00	4	103,15872	1,011762
24-06-2012 18:00	4	103,15784	1,011764
24-06-2012 12:00	4	103,15672	1,011764
24-06-2012 06:00	4	103,15612	1,011764
24-06-2012 00:00	4	103,15524	1,011762
23-06-2012 18:00	4	103,15436	1,011762
23-06-2012 12:00	4	103,15364	1,011763
23-06-2012 06:00	4	103,1526	1,011766
23-06-2012 00:00	4	103,152	1,011766
22-06-2012 18:00	4	103,151	1,011764
22-06-2012 12:00	4	103,15056	1,011764
22-06-2012 06:00	4	103,14972	1,011765
22-06-2012 00:00	4	103,1494	1,011764
21-06-2012 18:00	4	103,14868	1,011764
21-06-2012 12:00	4	103,14764	1,011764
21-06-2012 06:00	4	103,14708	1,011764
21-06-2012 00:00	4	103,14632	1,011764
20-06-2012 18:00	4	103,14585	1,011764
20-06-2012 12:00	4	103,14305	1,011761

Finally, the last step of this transformation process produces the temperature and extension for the above mentioned sensor, which are represented in Table 26.

Table 26: Automatic electrical extensometer (results)

Date	Sensor	Extension (x10-6)	Temperature
26-06-2012 12:00	4	-134,0005	18,1322
26-06-2012 06:00	4	-134,0478	18,12828
26-06-2012 00:00	4	-134,1	18,12396
25-06-2012 18:00	4	-134,1358	18,12099
25-06-2012 12:00	4	-134,1582	18,11801
25-06-2012 06:00	4	-134,1177	18,11504
25-06-2012 00:00	4	-134,225	18,11247
24-06-2012 18:00	4	-134,2205	18,1095
24-06-2012 12:00	4	-134,2661	18,10571
24-06-2012 06:00	4	-134,2726	18,10369
24-06-2012 00:00	4	-134,3803	18,10071
23-06-2012 18:00	4	-134,4027	18,09774
23-06-2012 12:00	4	-134,4096	18,09531
23-06-2012 06:00	4	-134,3755	18,09179
23-06-2012 00:00	4	-134,4	18,08977
22-06-2012 18:00	4	-134,4812	18,08639
22-06-2012 12:00	4	-134,4991	18,0849
22-06-2012 06:00	4	-134,5154	18,08206
22-06-2012 00:00	4	-134,5644	18,08098
21-06-2012 18:00	4	-134,5937	18,07855
21-06-2012 12:00	4	-134,6361	18,07504
21-06-2012 06:00	4	-134,6409	18,07314
21-06-2012 00:00	4	-134,6719	18,07058
20-06-2012 18:00	4	-134,7004	18,06895
20-06-2012 12:00	4	-134,8909	18,0595

6.4 Scenarios

In this scope, the concept of process consists of the execution, in a specific environment, of a set of actions. This means that a process can comprise data that in some moment in time was processed by a task executed in a specific context. This raises the requirement for a conceptual process description taking in consideration these three major views (Figure 2).

Thus, this implies that a coherent description of a process must be able to comprise sets of data that in some period in time were consumed or produced by sets of tasks coordinated or orchestrated by humans or automated processing services deployed in a concrete context.

Thus, this implies that a coherent description of a process must be able to comprise sets of data that in some period in time were consumed or produced by sets of tasks coordinated or orchestrated by humans or automated processing services deployed in a concrete context. Taking this into account, the scenario of the processes for the monitoring of civil engineering structures, the digital preservation processes is motivated by four distinct scenarios:

- Trust – re-execute the process with same data and parameters to ensure that the process produces the expected results. This scenario requires the redeployment and re-execution of the process with all its original entities.
- Correction – re-execute the process with the same data, but with changed parameters to correct any anomaly (exchange of channels in distinct sensors). The redeployment and re-execution of the process with its original entities, where data and/or context is partially modified.
- Reanalysis – re-execute the process with new or updated information (data or parameters). This is the case of relative physical measures (e.g., displacement or extension), where the references must be changed for a specific study or analysis. Technically, this scenario is similar to the correction scenario, requiring the redeployment and re-execution of the process with its original entities by with data and/or context partially modified.
- Continuity – civil engineering structures like dams are expected to operate during a long-time (several decades). The acquisition and transformation processes must be preserved and secured in the future, ensuring that monitoring processes are continuously executed. Requires the re-execution of the process with new data.

As a consequence, in order to preserve a process as a coherent self-contained information object we must preserve not only the description of all the tasks and the way they were coordinated and orchestrated, but it may also require a set of relevant data (the data it consumed and the data it produced), and the articulation/interfaces between the behavioural part of the business process (tasks and their coordination) and the structural part (data, representation, dependencies). The following subsections provide examples of each of the above mentioned preservation scenarios, using the case described in section 6.2.

6.4.1 Trust

Trust is already a common requirement for digital preservation of static objects. For business processes, it is even more relevant as one need to assure that all steps of the process have been execute as expected. On the other hand, the process flow escalates in the sense that an error or anomaly of one process will produce wrong outputs that will be the input for the next process.

In the case of the monitoring of civil engineering structures, it is critical to trust both on the execution of monitoring processes and on the respective produced results (note that the monitoring activities are the basis for several analyzes that are required to ensure the structural safety of large structures and, as a consequence, avoid or reduce the risk of catastrophic failures).

The trust requirement mainly influences the need for provenance, authenticity assurance and integrity; so that the final user can trust that the process was executed as expected without being compromised.

Technically, this requires the process execution using the same tasks, data and context, being able to assess if the same process produces the same results.

6.4.2 Correction

The correction scenario is common when an anomaly is detected (e.g., to channels changed), or modifications in calibration constants. To illustrate this case, this section demonstrates the re-execution of the process described in section 6.2, where the channels for sensor 1 and sensor 2 change. This scenario means that the readings used for sensor 1 must swap with the readings for sensor 2 (using the values described in Table 27). As can be seen, since in this scenario the process is re-executed with a new set of data, both the produced values for temperature and extension have changed from the original execution.

Table 27: Correction scenario

Date	Sensor	Temperature	Extension	N-Temperature	N-Extension
14-05-2008	1	17,745	-140,3863	14,9396	-224,2594
14-05-2008	2	16,762	-159,27988	19,584	-73,04656
30-04-2008	1	17,8464	-147,50341	14,8382	-206,0223
30-04-2008	2	16,66	-140,21	19,686	-80,51644
15-04-2008	1	17,7788	-137,19867	15,2776	-222,9631
15-04-2008	2	17,102	-158,07948	19,618	-69,73652
19-03-2008	1	17,9816	-148,6529	15,5142	-253,4697
19-03-2008	2	17,34	-190,0092	19,822	-81,77628
07-02-2008	1	18,8942	-126,52694	16,393	-195,6114
07-02-2008	2	18,224	-130,04816	20,74	-59,1052
09-01-2008	1	19,6378	-109,21913	17,1704	-183,456
09-01-2008	2	19,006	-117,71724	21,488	-41,38432
26-12-2007	1	20,2462	-140,80182	17,8126	-189,611
26-12-2007	2	19,652	-124,42648	22,1	-74,6036
13-12-2007	1	20,1448	-100,32471	18,0154	-181,6053
13-12-2007	2	19,856	-116,16624	21,998	-32,33372

Note that in this type of scenario, the preservation of business process also requires to maintain, identify and describe the interfaces between data and processes. In fact, to be able to correct a parameter in the business process execution, one needs to be able to change this specific parameter (using the execution formats or the ones used for preservation), and rerun the process.

6.4.3 Reanalysis

To illustrate a reanalysis scenario, this subsection illustrates the case where the reference is changed. Let us consider the date 21st of December 2005 as the new reference. In order to do the reanalysis using this reference, the values for r_i for each sensor must be updated, thus, for sensor 1, we have r_i 101.28 -> 101.11 and for sensor 2, we have: r_i 101.19 -> 101

Table 28 illustrates the difference between the results produced by the original process and the one with a distinct origin (using the same properties as defined in

Table 20 and the same sensor readings as defined in Table 21). As can be seen, since the temperature is an absolute physical quantity, its value does not change (that fact also demonstrates the correctness and trust on the original process execution). The new value for the extension is different, using the same process behaviour but with a different parameter.

Table 28: Process reanalysis

Date	Sensor	Temperature	Extension	N-Temperature	N-Extension
14-05-2008	1	17,745	-140,3863	17,745	-93,1263
14-05-2008	2	16,762	-159,27988	16,762	-104,17988
30-04-2008	1	17,8464	-147,50341	17,8464	-100,243416
30-04-2008	2	16,66	-140,21	16,66	-85,11
15-04-2008	1	17,7788	-137,19867	17,7788	-89,938672
15-04-2008	2	17,102	-158,07948	17,102	-102,97948
19-03-2008	1	17,9816	-148,6529	17,9816	-101,392904
19-03-2008	2	17,34	-190,0092	17,34	-134,9092
07-02-2008	1	18,8942	-126,52694	18,8942	-79,266948
07-02-2008	2	18,224	-130,04816	18,224	-74,94816
09-01-2008	1	19,6378	-109,21913	19,6378	-61,959132
09-01-2008	2	19,006	-117,71724	19,006	-62,61724
26-12-2007	1	20,2462	-140,80182	20,2462	-93,541828
26-12-2007	2	19,652	-124,42648	19,652	-69,32648
13-12-2007	1	20,1448	-100,32471	20,1448	-53,064712
13-12-2007	2	19,856	-116,16624	19,856	-61,06624

Similarly to the correction scenario, the reanalysis scenario requires that the preserved business is able to run with a distinct set of data that must use the formats expected by the behavioural components of the business process.

6.4.4 Continuity

The common use of digital preservation define that its main goal is "…to ensure continued access to digital materials...it refers to all of the actions required to maintain access to digital materials beyond the limits of media failure or technological change". Thus, to provide the future use of information, digital preservation solutions must assure the access from multiple and heterogeneous systems, while ensuring their understandability, integrity and authenticity.

In that sense, this scenario also requires the "continued access" to the business processes, since sensors are already installed, and both acquisition and processing processes must be executed in the long time span. In this case, the objective is to ensure that the business processes will be executed in the future, using new information captured from the sensor networks. This is seen as the continuity scenario, which continuously requires the deployment and execution of business processes, maintaining their behaviour, as they are operating in today's systems and environment.

7 Requirements for preserving civil engineering processes

Digital preservation is a core issue in cultural heritage scenarios such as libraries, archives and museums. There, the content to be preserved is often composed of separate semantic units of information that, while related, can be understood in isolation, a typical example is scanned books.

In scenarios like the monitoring of civil engineering structures, however, the concept of an isolated digital object makes little or no sense. In fact, for dam safety purposes, the minimum granularity level that can be accepted is on the level of the dam unit, i.e. a digital object containing the complete set of sensor data, processes and generated results for a specific dam. It is admissible to partition these objects in the time dimension, but it does not make sense to have objects with a subset of the sensors: Their information alone is not valuable to control structural safety, as this activity requires a full understanding of multiple physical actions and how their correlations can affect the overall structural behaviour.

Preserving monitoring information thus raises several challenges. First, the sensor data cannot be understood if it is not related to contextual information that provides additional semantics. For instance, in order to maintain the value of a temperature that is captured by a specific sensor; one needs the properties of the sensor, its location, and so on. On the other hand, multiple processes are involved in the same dam unit, which can required human intervention or be fully automated. This fact is also reflected on the use of multiple and heterogeneous technologies to support distinct parts of the process, raising several challenges to be able to preserve processes, either to ensure the authenticity of produced results, to re-execute processes with new or updated information, or even to ensure the business continuity dimension where multiple processes must be continuously executed.

In the particular scenario of civil engineering, the analysis of isolated monitoring information is insufficient to infer/predict the behaviour of the structures. Indeed, it requires a comprehensive set of data (from multiple types of sensors and multiple locations, which depends on multiple processes), as well as the historical values. On the other hand, monitoring activities are not static, since each sensor is continuously acquiring new data (at a predefined frequency). Furthermore, new sensors (with different characteristics, results and algorithms) have to be accommodated in the future, requiring the management of new representations. Finally, the way that monitoring information is represented can evolve in the future (new devices can use different representations to store the same data, or use new or improved algorithms), limiting the ability to understand the same type of data, or execute the same algorithm, as well as relating the same type of digital objects when they were captured by devices using different data representations, or calculated by distinct algorithms.

Corresponding to the above mentioned requirements, the concept of a digital object in this context must include the sensor data, the sensor properties, information about the representation of the sensor data and sensor properties, and information about the workflow of transformation used to generate the information in this digital object. As in common digital preservation scenarios, it is required that future consumers can trust that they are able to obtain the preserved information as its creators intended, dealing with obsolescence threats. This requirement encloses several challenges, where provenance information and the migration to new or updated representations, are crucial techniques to avoid obsolescence threats and ensure trust. However, migrating the representations of datasets and algorithms (both to support internal migration strategies or migration on access) require an accurate description of the representation used in the information packages, as well as the transformation rules to produce the new representation. We thus consider the main challenges to preserve this civil engineering data and processes as:

- The nature of complex interlinked objects composed by data sets, algorithms and their representation information (both are meaningless without context)
- The dynamic nature of sensor data (continuously growing in the time dimension), requiring the continuous execution of transformation processes
- The heterogeneous representations of sensor data, the respective algorithms and the related context information that are continuously changing or increasing
- Migration support for a heterogeneous set of schema representations and processes to deal with migration/mapping techniques for complex objects (e.g., sensor data represented in datasets, algorithms defined in a specific language).

7.1 Issues

The first challenge in preserving the LNEC processes is dealing with the high volume of sensor data, which is difficult to manage and brings storage scalability issues. Normally, this raises technological issues. The solution for this first challenge can be addressed, in part, by designing a scalable system.

Another challenge is the heterogeneity of the data at semantic and syntactic level, which is stored in different formats (usually depending of the type or version of sensor). This is mainly a technological issue but it can also be considered an organisational issue, since the involved organisations should harmonise data formats at semantic or syntactic levels.

The existence of multiple and different data delivery processes from structure owners to the GestBarragens instance at LNEC raises data control and management issues. These should be normalised at the organisational level. From data gathering to data storage, data is transformed by several business processes, e.g., analogue-digital conversion, digital data format normalization, etc. These transformations must be properly annotated in order to ensure the authenticity and trustworthiness of data.

7.2 Constraints

The constraints that should be taken into account in creating a solution for this business scenario are the following:

- The operation of the observation data Information System should not be disrupted due to the high importance of monitoring;
- The solution should be developed as an external system/module that can fulfil all the requirements.

7.3 Goals

In order to proper identify requirements we used a goal/scenario approach (for more on the subject of goal-oriented requirements engineering, please refer to (Pohl, 2010)). The use of goals and scenarios to identify requirements allows the stakeholders to better understand the requirements since those are traceable to the objectives and to concrete system interactions – the scenarios. The artefacts below (goals, scenarios and requirements) were elicited mainly through interviews, observation, workshops and perspective-based reading. The main goal identified is:

- G: Preserve the dam monitoring information

The goal G is refined in to the following three sub-goals (AND-decomposition)

- G1: Preserve the dam monitoring process
- G2: Redeploy the dam monitoring process
- G3: Improve the dam monitoring process

Note that G2 can only be satisfied by satisfying G1. The goal G1 is refined in the following three sub-goals (AND-decomposition):

- G1.1: Preserve the dam monitoring context
- G1.2: Preserve the dam monitoring data
- G1.3: Preserve the dam monitoring task

The goal G2 is refined in the following four sub-goals (OR-decomposition):

- G2.1: Perform a trust analysis
- G2.2: Perform a correction analysis
- G2.3: Perform a reanalysis
- G2.4: Perform a continuity analysis

The goal G3 is refined in the following two sub-goals (AND-decomposition):

- G3.1: Reduce the number of formats used
- G3.2: Reduce the number of data delivery processes

Figure 34 models all the goals identified and the relations between them. Table 30 to Table 34 further document the identified goals using the template described in Table 29.

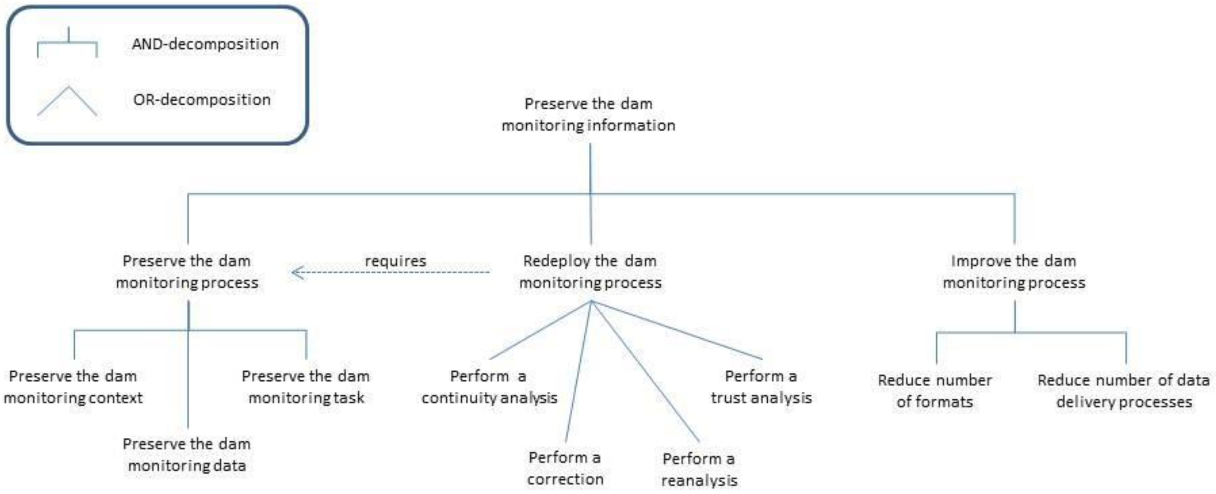


Figure 34: Goals identified for preserving the dam monitoring information modelled with extended AND/OR graphs

Table 29: Template for documenting goals

Attribute	Description
ID	Unique identifier of the goal
Name	Unique name for the goal
Super-goal	Reference to the super-goal
Sub-goals	Reference to the sub-goals including the type of decomposition (AND, OR or AND/OR)
Goal Description	Description of the goal
Supplementary Information	Additional information about the goal
Responsible stakeholder(s)	Stakeholder(s) who is(are) responsible for the goal
Using stakeholder(s)	Stakeholder(s) who benefit from the satisfaction of the goal
Other goal dependencies	Further dependencies with other goals such as “requires”, “support”, “obstruc-tion”, “conflict” and “equivalence”
Associated scenarios	References to scenarios that describe the satisfaction of the goal or a failure to satisfy the goal

Table 30: Main goal (G): Preserve the dam monitoring information

ID: G	**Name**: Preserve the dam monitoring information	**Super-goal**: NA	**Sub-goals**: G1, G2, G3 (AND)
Goal Description: LNEC must be able to preserve the dam monitoring information			
Supplementary Information: none			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher, Administrator	
Other goal dependencies: none	**Associated scenarios**: UC-DP-1 – Plan Preservation of Dam Monitoring Information		

Table 31: Main goal "G: Preserve the dam monitoring information" sub-goals (G1, G2 and G3)

ID: G1	**Name**: Preserve the dam monitoring process	**Super-goal**: G	**Sub-goals**: G1.1, G1.2, G1.3 (AND)
Goal Description: There must be a system capable of preserving the dam monitoring process			
Supplementary Information: In the scope of TIMBUS, an abstract process consists of the execution, in a specific environment, of a set of actions. This means that a process can comprise data that in some in time was processed by a task executed in a specific context.			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher, Administrator	
Other goal dependencies: none	**Associated scenarios**: UC-DP-2 – Preserve Dam Monitoring Process		
ID: G2	**Name** Redeploy the dam monitoring process	**Super-goal**: G	**Sub-goals**: G2.1, G2.2, G2.3, G2.4 (OR)
Goal Description: There must be a system able to redeploy the dam monitoring process			
Supplementary Information: none			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher	
Other goal dependencies: This goal can only be satisfied by satisfying "G1: Preserve the dam monitoring process"		**Associated scenarios**: UC-DP-3 – Redeploy Dam Monitoring Process	
ID: G3	**Name**: Improve the dam monitoring process	**Super-goal**: G	**Sub-goals**: G3.1, G3.2 (AND)
Goal Description: There must be a system that motivates the improvement of the dam monitoring process			
Supplementary Information: For issues present in the dam monitoring process please refer to chapter "7.1. Issues"			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Administrator	
Other goal dependencies: none	**Associated scenarios**: UC-DP-4 – Improve the dam monitoring process		

Table 32: Goal "G1: Preserve the dam monitoring process" sub-goals (G1.1, G1.2 and G1.3)

ID: G1.1	**Name**: Preserve the dam monitoring context	**Super-goal**: G 1	**Sub-goals**: none
Goal Description: The system must be able to preserve the context of the dam monitoring process			
Supplementary Information: In TIMBUS, context is defined as "the immediate environment in which a function (or set of functions in a diagram) operates". It is also assumed that the concept of context can comprise multiple relevant views, not only the supporting technological infrastructure but, eventually also others involving organizational, business, legal or social attributes			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher	
Other goal dependencies: none	**Associated scenarios**: UC-DP-2 – Preserve Dam Monitoring Process		
ID: G1.2	**Name** Preserve the dam monitoring data	**Super-goal**: G1	**Sub-goals**: none
Goal Description: The system must be able to preserve the data of the dam monitoring process			
Supplementary Information: In TIMBUS, data is defined as "a reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing"			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher	
Other goal dependencies: This goal can only be satisfied by satisfying "G1: Preserve the dam monitoring process"		**Associated scenarios**: UC-DP-2 – Preserve Dam Monitoring Process	
ID: G1.3	**Name**: Preserve the dam monitoring task	**Super-goal**: G1	**Sub-goals**: none
Goal Description: The system must be able to preserve the tasks of the dam monitoring process			
Supplementary Information: In TIMBUS, task is defined as "required, recommended, or permissible action, intended to contribute to the achievement of one or more outcomes of a process"			
Responsible stakeholder: Preservation Operator		**Using stakeholders:** Researcher	
Other goal dependencies: none	**Associated scenarios**: UC-DP-2 – Preserve Dam Monitoring Process		

Table 33: Goal "G2: Redeploy the dam monitoring process" sub-goals (G2.1, G2.2, G2.3 and G2.4)

ID: G2.1	**Name**: Perform a trust analysis	**Super-goal**: G 2	**Sub-goals**: none
Goal Description: LNEC shall be able to perform a trust analysis			
Supplementary Information: A trust analysis consists on re-executing the process with the same context, data and tasks as originally preserved to assess if the same process produces the same results. For more information about a trust analysis please refer to chapter "6.4.1 Trust"			
Responsible stakeholder: Researcher		**Using stakeholders:** Researcher	
Other goal dependencies: none	**Associated scenarios**: UC-DP-3.1 – Perform a Trust Analysis		
ID: G2.2	**Name** Perform a correction	**Super-goal**: G2	**Sub-goals**: none
Goal Description: LNEC shall be able to perform a correction			
Supplementary Information: A correction consists on re-executing the process with its original entities, where data and/or context are partially modified. For more information about a correction please refer to chapter "6.4.2 Correction"			
Responsible stakeholder: Researcher		**Using stakeholders:** Researcher	
Other goal dependencies: none		**Associated scenarios**: UC-DP-3.2 – Perform a Correction	
ID: G2.3	**Name**: Perform a reanalysis	**Super-goal**: G2	**Sub-goals**: none
Goal Description: LNEC shall be able to perform a reanalysis			
Supplementary Information: Technically a reanalysis is similar to a correction consisting on re-executing the process with its original entities, where data and/or context are partially modified. However the motivation behind a reanalysis (update data and context) is different from a correction (correct data and context). For more information about a reanalysis please refer to chapter "6.4.3 Reanalysis"			
Responsible stakeholder: Researcher		**Using stakeholders:** Researcher	
Other goal dependencies: none	**Associated scenarios**: UC-DP-3.3 – Perform a Reanalysis		
ID: G2.4	**Name**: Perform a continuity analysis	**Super-goal**: G2	**Sub-goals**: none
Goal Description: LNEC shall be able to perform a continuity analysis			
Supplementary Information: A continuity analysis consists on re-executing the process with new data through time. For more information about a continuity analysis please refer to chapter "6.4.4 Continuity"			
Responsible stakeholder: Researcher		**Using stakeholders:** Researcher	
Other goal dependencies: none	**Associated scenarios**: UC-DP-3.4 – Perform a Continuity Analysis		

Table 34: Goal "G3: Improve the dam monitoring process" sub-goals (G3.1 and G3.2)

ID: G3.1	**Name**: Reduce number of formats		**Super-goal**: G3	**Sub-goals**: none
Goal Description: There must be a system that motivates the use of a reduced set of formats				
Supplementary Information: none				
Responsible stakeholder: Preservation Operator			**Using stakeholders:** Preservation Operator, Administrator	
Other goal dependencies: none		**Associated scenarios**: UC-DP-4 – Improve the dam monitoring process		
ID: G3.2	**Name**: Reduce number of data delivery processes		**Super-goal**: G3	**Sub-goals**: none
Goal Description: There must be a system that motivates the harmonization of data delivery processes				
Supplementary Information: There should be only two delivery methods, either automatic or manual. Also, there should be only one entry point for each delivery method				
Responsible stakeholder: Preservation Operator			**Using stakeholders:** Preservation Operator, Administrator	
Other goal dependencies: none		**Associated scenarios**: UC-DP-4 – Improve the dam monitoring process		

Table 35 provides a breakdown of preservation drivers, goals and policies existing within the organisation. Current policies already cover some of the objectives, however a large portion of the goals are still lacking policy support.

Table 35: Driver/Policy/Goals Catalogue

Driver	**Goals**		**Policy**
Legal obligation of retaining observation data for ensuring structural safety	G1. Preserve the dam monitoring process	G1.1	PP-SD-1, PP-SD5
		G1.2	PP-SD-1, PP-SD5
		G1.3	PP-SD-1, PP-SD5
	G2. Redeploy the dam monitoring process	G2.1	N/A
		G2.2	N/A
		G2.3	N/A
		G2.4	N/A
	G3. Improve the dam monitoring process	G3.1	N/A
		G.32	N/A

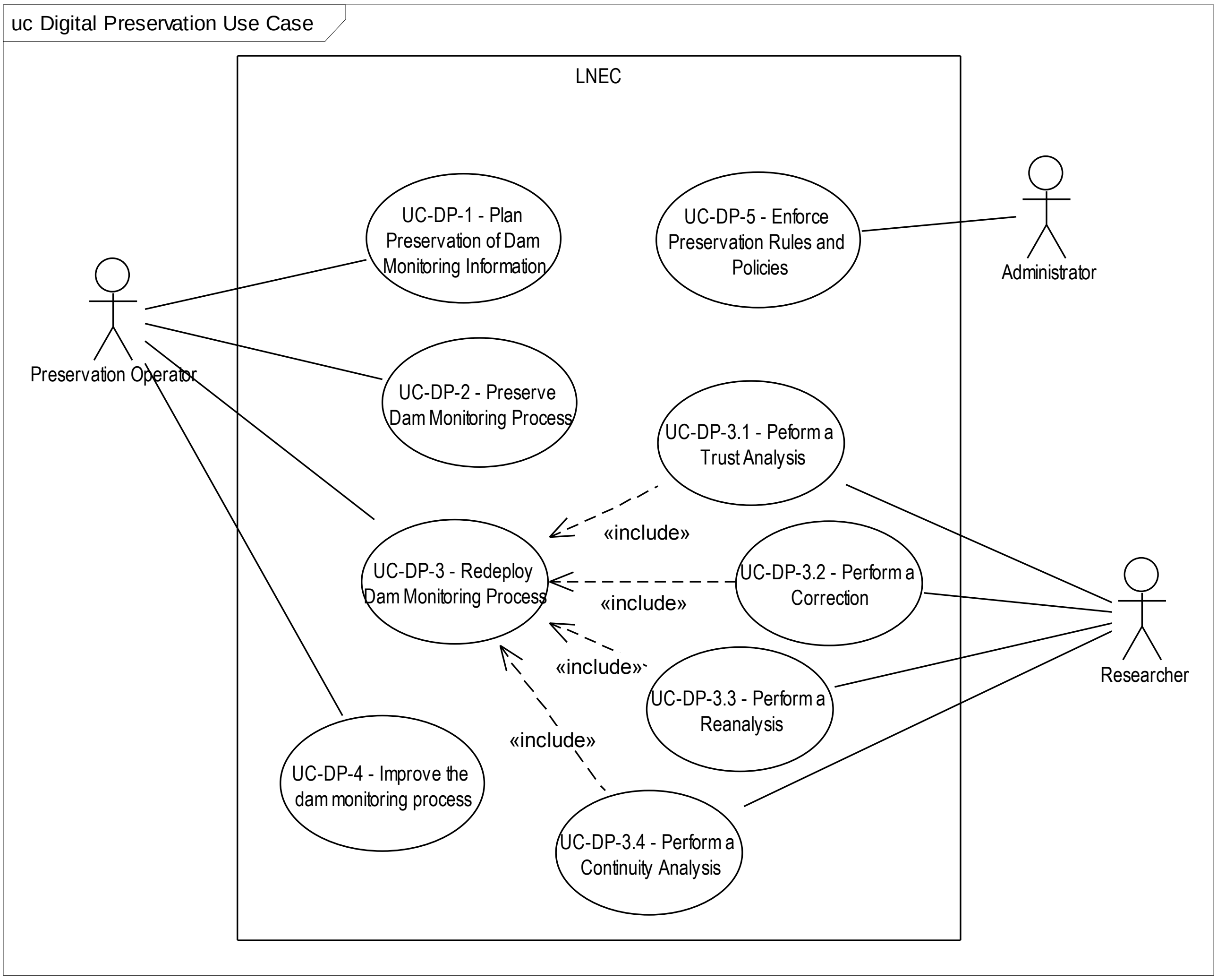


Figure 35: Digital Preservation Use Cases

7.4 Digital Preservation Use Cases

We can determine that the fundamental things that should be preserved can be shown in the digital preservation use cases depicted in Figure 35. In these use cases LNEC is responsible for inputting data into the system, this is, use the system and guarantee that it is working in the desired way. Also is responsible for assuring that the preserved information has not lost any context or coherence. As for the TIMBUS consortium is responsible for designing the system according to LNEC specification and guarantee that the system is working in the way it was intended to. In the scope of TIMBUS we must determine what should be preserved by analysing the risk experienced by the organisation.

At a more abstract level, digital preservation of software services and supporting technology landscape can be viewed as a dependency graph. So, there should be tools or processes which also help to determine dependencies between objects. We should also guarantee that all the relevant information executed or stored is preserved for future reference. This includes the management of legal aspects of information and virtualisation of business processes. Finally, we should ensure the exhumation of the previously preserved information in a way that it doesn't lose any context or coherence, so that it can be used in future research work or be analysed. In case the information preserved is a complete system, it should provide a working version of the system.

7.4.1 Actors

In this scenario the actors depicted in Table 36 were considered.

Table 36: Digital Preservation Actors

Actor	Description
Preservation Operator	The Preservation operator is responsible for the safe and secure handling of sensitive client digital assets. The operator will work with data from a variety of sources and is charged with migrating, archiving, verifying and preserving these assets. In the future this role can be play by a smart tool for preservation instead of a preservation operator.
Researcher	The Researcher is responsible for studies in the field of instrumentation, observation and structural monitoring of dams. Therefore we will be responsible for running different kind of analysis to assure the effectiveness of the dam monitoring process.
Administrator	The Administrator is responsible for defining and managing standard preservation rules, policies and strategies for the organisation.

7.4.2 Use Cases

In the LNEC scenario the use cases specified in Table 37 were identified, these are specific to digital preservation.

Table 37: Digital Preservation Use Cases

Use Case	Description
UC-DP-1 – Plan Preservation of Dam Monitoring Information	In this use case we determine what should be preserved by analysing the risk it poses to LNEC. This is achieved by analysing the service dependencies in a specific business process. A service should be preserved only if there is some assurance that its complete dependency graph can be correctly reconstructed at any lifetime, between the time of preservation and the preservation guarantee provided.

Use Case	Description
UC-DP-2 - Preserve Dam Monitoring Process	In this use case we preserve the dam monitoring process which can include, for instance, metadata about objects, metadata about file formats and associated tools, metadata about events and agents involved in the events, metadata about versions of objects, metadata about simulation, executed commands, applications snapshots. It also includes, for instance, the preservation of the operating system environment details, including the type, version, architecture. This includes libraries used for transforming and managing data, and if those libraries are compiled within the organisation, the compiler version and environment should also be preserved. Also the context, in which the data was gathered, should be preserved, so that it can be understood in the future during exhumation. This should include, why the data was gathered, if it is a legal obligation, to what law it obliges, when was gathered, who gathered it and other parameters such as weather conditions and so on. Finally, the entire information workflow should be preserved, from ingestion to the end of the information life cycle. This includes data transformations, user access, updates, and transfer; in conclusion, all operations the information was submitted to.
UC-DP-3 - Redeploy Dam Monitoring Process	In this use case we gather all data linked to the preserved process and retrieve it to the user which requested it in a meaningful way, ensuring that it doesn't lose any context or coherence. This implies analysing the current environment and check if all the conditions necessary for redeploying the process are met (i.e., verify who has the authority to rerun the business process, locate or generate the data (original data and/or new instances of data), verify if external services are still available, and so on).
UC-DP-3.1 – Perform a Trust Analysis	This use case includes UC-DP-3, which is executed previously. A trust analysis consists of the redeployment and re-execution of the process with same data and parameters to ensure that the process produces the expected results.
UC-DP-3.2 – Perform a Correction	This use case includes UC-DP-3, which is executed previously. A correction consists of the redeployment and re-execution of the process with the same data, but with changed parameters to correct any anomaly (exchange of channels in distinct sensors).
UC-DP-3.3 – Perform a Reanalysis	This use case includes UC-DP-3, which is executed previously. A reanalysis consists of the redeployment and re-execution of the process with new or updated information (data or parameters). This is the case of relative physical measures (e.g., displacement or extension), where the references must be changed for a specific study or analysis.
UC-DP-3.4 – Perform a Continuity Analysis	This use case includes UC-DP-3, which is executed previously. A continuity analysis consists of the redeployment and re-execution of the process with new data. This is the case whenever a new acquisition process starts. The new process need then to be preserved and secured (see UC-DP-3.1) to ensure that monitoring processes are continuously executed.

Use Case	Description
UC-DP-4 – Improve the dam monitoring process	In this use case we improve the dam monitoring process by reducing the number of formats used in the process and by harmonizing the data delivery process. Regarding the formats LNEC should use a reduced set of formats and maintain a list of the formats being used, version of format in use and possible conversions methods from other formats. To harmonize data delivery LNEC must motivate only two types of data delivery (automatic or manual) with only one entry point for each delivery method. This assures that the ingestion of data is centralised and managed from a single point consequently reducing data management and control issues.
UC-DP-5 - Introduce and Enforce Preservation Rules and Policies	This is the process of introducing standard preservation rules for preserving and maintaining digital materials and ensuring their availability for current and future use. The primary aims of a policy are to provide guidance and authorisation on the preservation of digital materials and to ensure the authenticity, reliability and long-term accessibility.

7.5 Requirements

The requirements identified in this business scenario will be feed into Work Package 5, more specifically to Tasks 5.1 and 5.2, with the purpose of driving the architecture development. They also must feed into Work Packages 4 and 6.

The requirements are described using the template in Table 38. They are categorized into functional (section 7.5.1) and non-functional (section 7.5.2) requirements. The level of description is provided for the sake of analysis at this moment of the solutions to be provided by TIMBUS. One must be aware that for the further tasks of design and implementation of those solutions some of these requirements also might have to be analysed again, according to the specific needs of these implementations. For that purpose, the descriptions detailed in Annex 9 and Annex 10 might be especially relevant.

Table 38: Template for Documenting Requirements.

Attribute	Description
ID	Unique identifier of the requirement
Name	Unique name for the requirement
Goal	Goal(s) related to the requirement
Short description	Briefly summaries the content of the requirement
Additional information	Contains additional information provided by the creator
Cross references	Describes the relationships to other development artefacts (use cases, scenar-ios, goals and requirements)

7.5.1 Functional Requirements

This section describes the functional requirements for this use case scenario. In the descriptions the term "system" is used to refer to the solution to be provided by TIMBUS to this case. Table 39 lists the requirements.

Table 39: Functional requirements of the use case.

ID: FR1	**Name**: Monitor context	**Goal**: G1.1
Short description: The system must be able to monitor and assess the environment of the dam monitoring process		
Additional information: The environment of a system includes developmental, technological, business, operational, organizational, political, economic, legal, regulatory, ecological and social influences. The context information must include the sensor data, the sensor properties, information about the representation of the sensor data and sensor properties, and information about the workflow of transformation used to generate the information in this digital object		
Cross references:		
ID: FR2	**Name**: Monitor data	**Goal**: G1.2
Short description: The system must be able to capture the data of the dam monitoring process		
Additional information: In the case of data transformations, the system must capture data before transformation, after transformation, and steps required transforming data.		
Cross references:		
ID: FR3	**Name**: Monitor tasks	**Goal**: G1.3
Short description: The system must be able to monitor and keep track of the sequence of tasks followed in the dam monitoring process		
Additional information: For each process the system must record, for example, any upload, access, modify or validation task		
Cross references:		
ID: FR4	**Name**: Relevant information	**Goal**: G1
Short description: The system must be able to determine from all the information captured in FR1, FR2 e FR3 which is relevant to preserve the local analysis process		
Additional information: The set of relevant information is the minimum information necessary to preserve the local analysis process		
Cross references: • Requires compliance with FR1, FR2 and FR3 in order to be fulfilled		
ID: FR5	**Name**: Preservation-worthy information	**Goal**: G1

Short description: The system must be able to determine from all the information captured in FR1, FR2 e FR3 which is preservation-worthy		
Additional information: The decision of determining if information is preservation-worthy can, for example, be made through its value of risk loss. In case of data transformations that can be a huge overhead on the system, there should be risk analysis made a priori to validate if saving all this data is critical or not. If possible, when we only can save data after transformation, we should make use of reversible transformations. In this way, in the future we could derive the initial values from the transformed values.		
Cross references: • Requires compliance with FR1, FR2 and FR3 in order to be fulfilled		
ID: FR6	**Name**: Capture semantic relationships	**Goal**: G1
Short description: The system must be able to store the relevant information, determined in FR4, in a way where the semantic relationships between that information are maintained		
Additional information: The system must be able to store relations between context, tasks and data. The set of information stored along with the relations define the process to be preserved		
Cross references: • Requires compliance with FR1, FR2 and FR3 in order to be fulfilled • Requires compliance with FR4 and FR5 in order to be fulfilled		
ID: FR7	**Name**: Redeploy Local Analysis	**Goal**: G2
Short description: The system must be able to redeploy the relevant information, determined in FR4, in a way where it is assured that the local analysis process can be rerun		
Additional information: The system must be able to redeploy not only the context, tasks and data but also the relations between those entities		
Cross references: • Requires compliance with FR1 to FR6 in order to be fulfilled		
ID: FR8	**Name**: Select Redeploy Information	**Goal**: G2.1, G2.2, G2.3, G2.4
Short description: The system must allow the researcher to select which preservation information he wants to redeploy		
Additional information: The Researcher may want to redeploy only the context, tasks or data or a combination of them.		
Cross references: • Requires compliance with FR1 to FR6 in order to be fulfilled • Requires compliance with FR7 in order to be fulfilled		
ID: FR9	**Name**: Detect context gaps	**Goal**: G2

<table>
<tr><td colspan="3">Short description: When redeploying (see FR7), the system must be able to detect gaps between the original environment of the process and the redeployment environment</td></tr>
<tr><td colspan="3">Additional information: This requirement is important to decide which information is going to be redeploying when rerunning the local analysis process.</td></tr>
<tr><td colspan="3">Cross references:
• Requires compliance with FR1 to FR6 in order to be fulfilled
• Requires compliance with FR7 in order to be fulfilled</td></tr>
<tr><td>ID: FR10</td><td>Name: Export Preserved Process</td><td>Goal: G2</td></tr>
<tr><td colspan="3">Short description: The system must be able to export the preserved process</td></tr>
<tr><td colspan="3">Additional information: The export must not lose any content or context in case a transfer to another system is needed (i.e., in case the organization or the project ceases)</td></tr>
<tr><td colspan="3">Cross references:
• Requires compliance with FR1 to FR6 in order to be fulfilled</td></tr>
<tr><td>ID: FR11</td><td>Name: Detect information redundancy</td><td>Goal: G1</td></tr>
<tr><td colspan="3">Short description: The system must be able to detect when information is already captured and preserved</td></tr>
<tr><td colspan="3">Additional information: none</td></tr>
<tr><td colspan="3">Cross references:
• Requires compliance with FR1 to FR6 in order to be fulfilled</td></tr>
<tr><td>ID: FR12</td><td>Name: Redeploy Access Control</td><td>Goal: G2</td></tr>
<tr><td colspan="3">Short description: The system must restrict the redeployment and re-execution of the dam monitoring process to authorized users</td></tr>
<tr><td colspan="3">Additional information: The system must allow specific restrictions. This means that a user can, for example, be authorized to perform a trust analysis but unauthorized to perform a correction analysis</td></tr>
<tr><td colspan="3">Cross references:
• Requires compliance with FR1 to FR8 in order to be fulfilled</td></tr>
<tr><td>ID: FR13</td><td>Name: Format Database</td><td>Goal: G3.1</td></tr>
<tr><td colspan="3">Short description: The system must have a data format database to keep record of all formats being used at the moment</td></tr>
<tr><td colspan="3">Additional information: For each format the database must have at least a format description with the format version being used.</td></tr>
<tr><td colspan="3">Cross references:</td></tr>
<tr><td>ID: FR14</td><td>Name: Preservation Formats</td><td>Goal: G3.1</td></tr>
</table>

Short description: When using a format (see FR13), the system must be able to inform if the format is suitable for preservation		
Additional information: none		
Cross references: • Requires compliance with FR13 in order to be fulfilled		
ID: FR15	**Name**: Recommend Preservation Formats	**Goal**: G3.1
Short description: If a format is not suitable for preservation (see FR14), the system must be able to recommend a format more suitable		
Additional information: Whenever possible the system must also present conversion instructions from the used format to the recommended		
Cross references: • Requires compliance with FR13 and FR14 in order to be fulfilled		
ID: FR16	**Name**: Data Delivery Types	**Goal**: G3.2
Short description: The system must only allow two delivery methods, either automatic or manual		
Additional information: none		
Cross references:		
ID: FR17	**Name**: Data Delivery Entry	**Goal**: G3.2
Short description: The system must only allow one entry point for each delivery method (see FR16)		
Additional information: In this way all data ingest would be centralised and managed from one point. This would reduce the data management and control issues		
Cross references:		

7.5.2 Non-Functional Requirements

This section describes the non-functional requirements for this use case scenario. Table 40 lists the requirements.

Table 40: Non-functional requirements of the use case.

ID: NF1	**Name**: Non-intrusive and transparent capture	**Goal**: G1
Short description: The system must be able to capture the dam monitoring process in a non-intrusive and transparent way		
Additional information: The system must not change the dam monitoring process		
Cross references:		

ID: NF2	**Name**: Information Integrity	**Goal**: G1
Short description: The system must guarantee the integrity of the preserved information		
Additional information: The system must ensure that information is not altered or destroyed in an unauthorized manner.		
Cross references:		
ID: NF3	**Name**: Information provenance and authenticity	**Goal**: G1
Short description: The system must guarantee the provenance and authenticity of the preserved information		
Additional information: The system must be able to confirm the identities of the requesters and providers of the information.		
Cross references:		
ID: NF4	**Name**: Information backup	**Goal**: G1
Short description: The system must guarantee the information preserved is never lost		
Additional information: This can be made using data redundancy and synchronisation. This is of most importance since this data cannot be collected again		
Cross references:		
ID: NF5	**Name**: Scalability of the storage system	**Goal**: G1
Short description: The system must guarantee the scalability of the storage system		
Additional information: This can be achieved by designing a modular system which can be improved by adding more nodes to the system when sensor data volume increases in the future which is, in fact, a distributed system		
Cross references:		
ID: NF6	**Name**: Scalability of the network	**Goal**: G
Short description: The system must guarantee the scalability of the network		
Additional information: The system must support the imminent and continuous data deluge		
Cross references:		
ID: NF7	**Name**: Adequate information representation	**Goal**: G1
Short description: The system must use adequate representation information so that the user can understand and use it properly		
Additional information: none		
Cross references:		
ID: NF8	**Name**: Ease of use	**Goal**: G

Short description: The system must guarantee that is easy to use and interact with
Additional information: none
Cross references:

7.6 Summary

In this section, we presented the digital preservation requirements of the business scenario being analysed in this deliverable. The goals, requirements and use cases should drive the engineering of the digital preservation processes (Task 4.5). The processes resulting from that task should work as an additional level of detail of the use cases presented in this section.

The requirements will also drive the work on the architecture that is being carried out in WP5, which should also be supporting the processes in Task 4.5. Following a waterfall approach to systems development, the next logical step would be the design of the architecture and its components (Tasks 5.1 and 5.2), with the allocation of the requirements to the components of the architecture, which also include user interfaces that are in line with the use cases here demonstrated. Table 41 provides a breakdown of goals, scenarios and requirements existing within this chapter.

Table 41: Goals/Scenarios/Requirements breakdown.

Goals		Scenarios	Requirements
G1. Preserve the dam monitoring process	G1.1	UC-DP-2	FR1, FR4-6, FR11 and NFR1-8
	G1.2	UC-DP-2	FR2, FR4-6, FR11 and NFR1-8
	G1.3	UC-DP-2	FR3, FR4-6, FR11 and NFR1-8
G2. Redeploy the dam monitoring process	G2.1	UC-DP-3.1	FR7-10, FR12, NF6 and NF8
	G2.2	UC-DP-3.2	FR7-10, FR12, NF6 and NF8
	G2.3	UC-DP-3.3	FR7-10, FR12, NF6 and NF8
	G2.4	UC-DP-3.4	FR7-10, FR12, NF6 and NF8
G3. Improve the dam monitoring process	G3.1	UC-DP-4	FR13-15, NF6 and NF8
	G3.2	UC-DP-4	FR16-17, NF6 and NF8

8 Conclusions and Outlook

This deliverable described the Civil Engineering Infrastructure scenario, where the preservation needs concerning observational data are described and analysed. The main conclusion is that this specific business scenario will take benefit of preservation as it takes care of critical information which is tied to legal obligations and monitoring of critical civil engineering structures, specifically concrete and masonry dams.

This deliverable defines the use cases and digital preservation requirements for the civil engineering infrastructures. The main task of WP8 is to find a comprehensive definition and requirements specification for a large-scale, long-term civil engineering scenario involving sensors/devices and CAD/CAM services in order to produce an effective pilot study and appropriate test beds. In this sense, this deliverable provides use cases which will guide RTD work in other work packages and also be used to drive the design and execution of the test beds and pilots. The expectation behind this deliverable is that it might have a strong impact the civil engineering community, raising awareness for the problems of digital preservation and provide new practices and techniques for achieving preservation.

Next steps in Work Package 8 will focus on understanding the risks, costs and economic potential of digital preservation in this scenario, of which this deliverable will be a valuable input. That analysis should be fed into the Intelligent Enterprise Risk Management Tasks (T4.1, T5.1, and T6.1). That result along with the current deliverable should provide a complete characterisation of this Industrial Scenario, from a digital preservation point of view, that will surely be relevant for the civil engineering community.

Other steps in the same work package will involve the deepening of the application of digital preservation solutions to this scenario. Task 8.4 will focus on the emulation of sensor networks so that digitally preserved data acquisition processes can be exhumed and re-executed in conditions that are similar to those where the process used to run in the past. Additionally, Task 8.5 will look into the preservation of CAD/CAM business processes used in the creation of Observation Plans for civil engineering structures. The current deliverable is also an important piece of work for informing the analysis that will be undertaken in both tasks: Task 8.4 is an important step towards the fulfilment of the requirements and Task 8.5 should function as a complement of the requirements stated in the current document.

In terms of dissemination activities, our understanding is that the analysis undertaken in the current deliverable is potentially publishable in conferences both in the digital preservation community and in the civil engineering community. As such, a set of publications should be submitted in the following of this work.

9 Appendix - Architecture

9.1 Internal and External Services

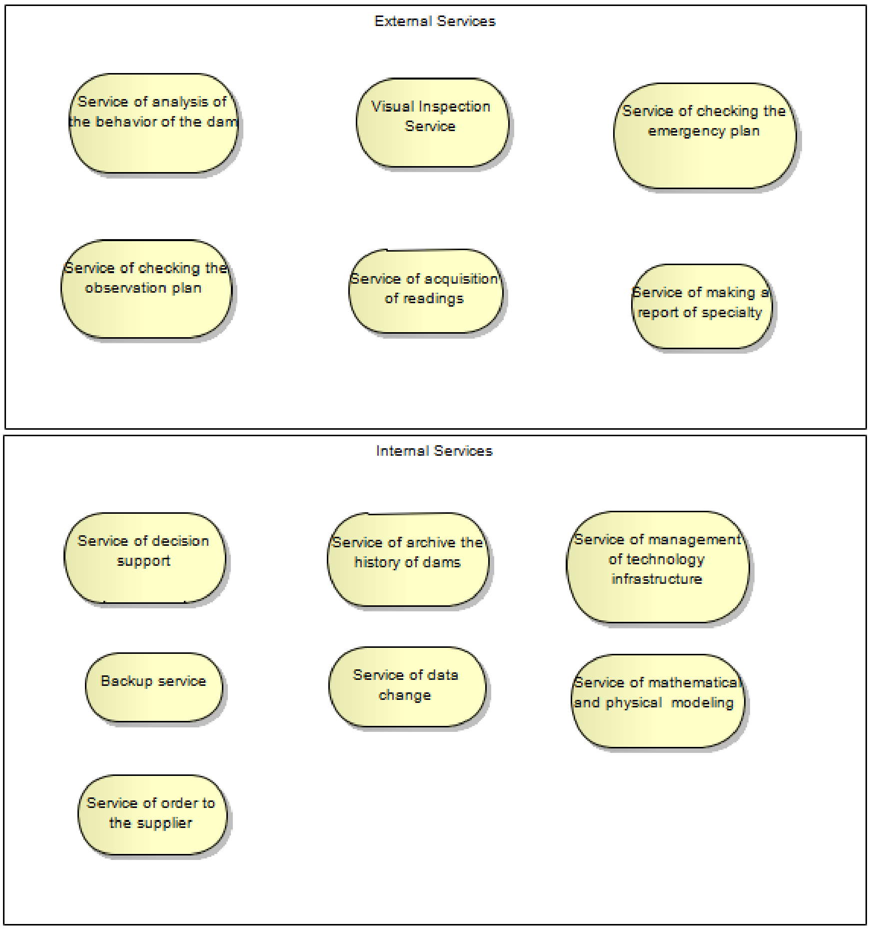


Figure 36: Internal and external services

9.2 Business processes

9.2.1 Level 1 Description

This section identifies the engineering processes that are related to external services. LNEC delivers services to:

- the Structure Owner, which are:
  - Acquisition of readings service;
  - Analysis of the behavior of the dam service;
  - Visual Inspection Service
  - Service to make a report of specialty;

    - Verification / approval of the observation plan service.
- National Authority for the Dam Safety, which are:
    - Verification / approval of the plan of emergency service;
    - Verification / approval of the observation plan service.
- National Authority for Civil Protection (ANPC), which is:
    - Verification / approval of the plan of emergency service.
- Supplier of Technology, which is:
    - Service of order to the supplier.

9.2.2 Level 2 Description

Acquisition of readings: this process begins after the structure owner makes the acquisition of readings or in the case of the Geotechnical Department after they have made the acquisition of the readings of the dam. When these readings are received by LNEC (GestBarragens system) are stored first, then validated, then converted to physical quantities, are once again checked and, finally, back to be stored;

Analysis of the behaviour of the dam: this process starts after the data have been processed by LNEC. The engineer access to data in physical, then analyzes (choosing the best methods to analyze the data) and, finally, prepare a summary analysis of the behaviour of the dam with the results;

Making a report of specialty: this process begins when it is necessary to fulfil a contract or by agreement of both parties (between the LNEC and the structure owner).

Visual inspections: this process begins when LNEC engineers go to a dam to perform a specialist visit. The civil engineer performs before going to the dam, an analysis of the data previously received from the dam, then holds its visual analysis of the dam and, finally, produces a summary with the conclusions of the local analysis;

Checking the emergency plan: this process begins when an emergency plan is drawn up by the National Authority for Civil Protection (ANPC). This study analyzes the plan and, finally, a report;

Checking the observation plan: this process begins when a plan of observation (by the National Dam Safety Authority). This study analyzes the plan and, finally, produces a report with the conducted analysis and conclusions;

Order to the supplier: this process begins when it is necessary to update or repair a software or hardware component. It is necessary to order, then receiving and verifying the order, and finally installing the software or hardware component.

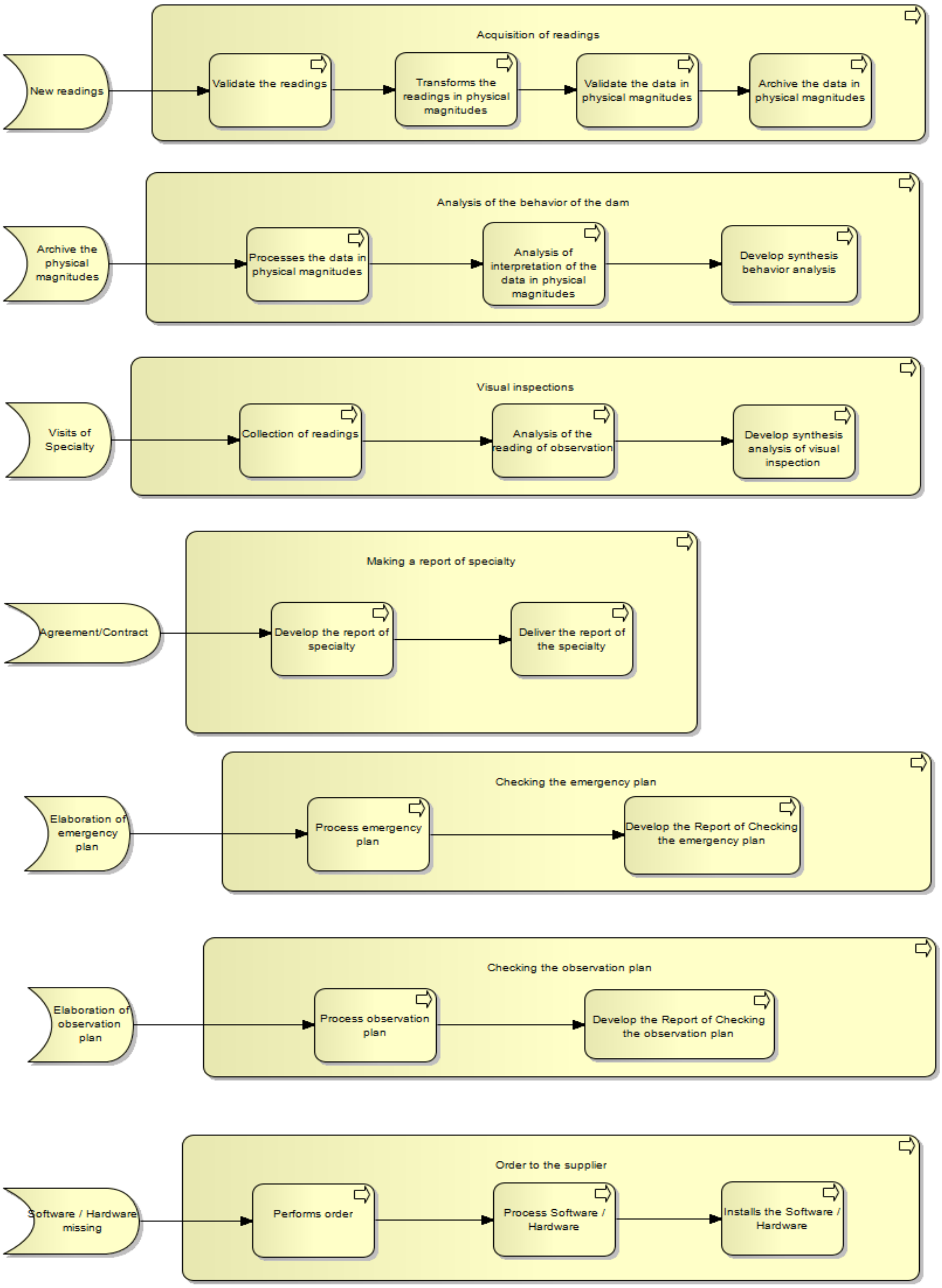


Figure 37: Business processes level 2

9.2.3 Level 3 Description

9.2.3.1 Acquisition of readings

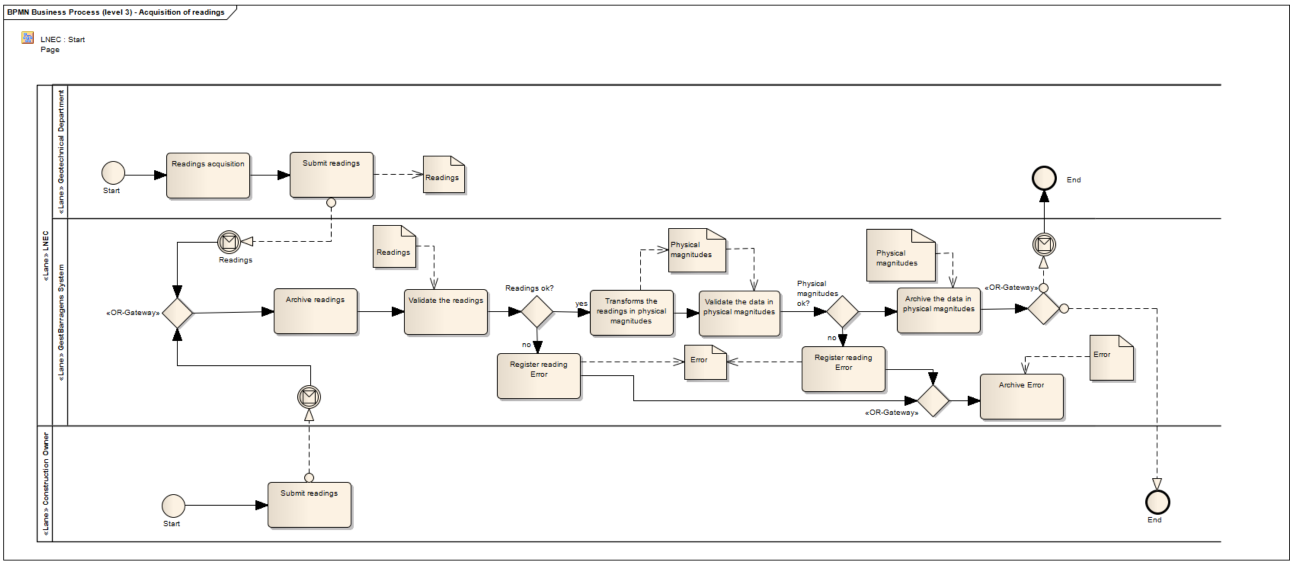


Figure 38: Acquisition of readings

9.2.3.2 Analysis of the behaviour of the dam

A civil engineer performs an analysis of the readings converted into physical quantities by means of statistical / trend data / physical models / mathematical models and, finally, prepares a summary of the behavior of the dam with the results and conclusions.

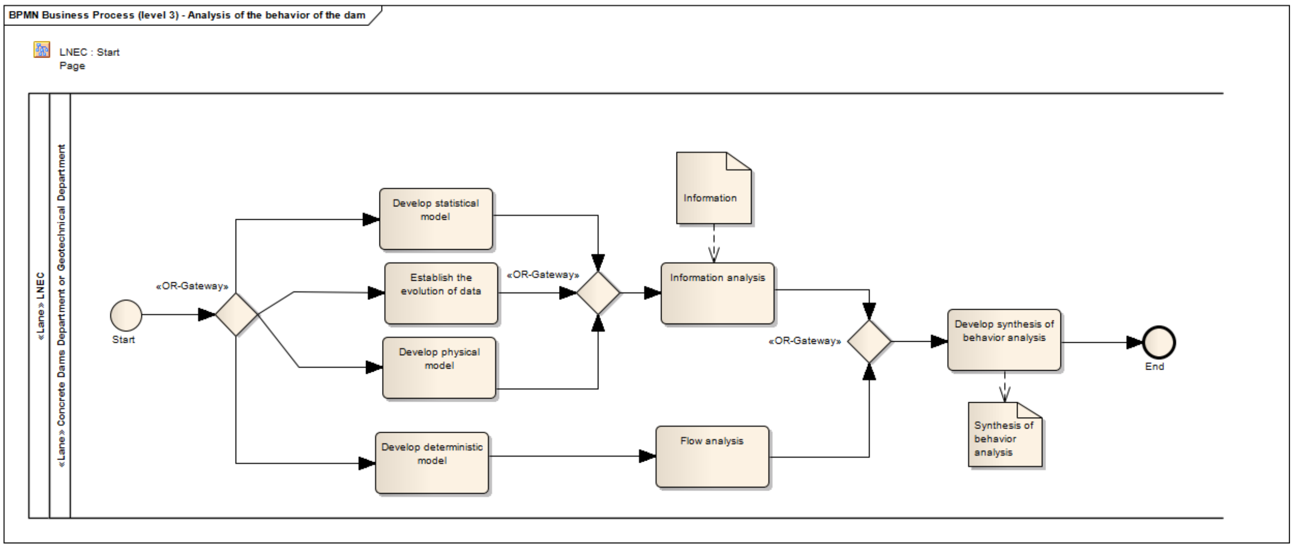


Figure 39: Analysis of the behaviour of the dam

9.2.3.3 Visual inspections

Before the civil engineer and the technician go to the dam site, the civil engineer analyzes the data of the behavior of the dam (as can be seen in the model business process level 1). At the dam site, the civil engineer visually analyzes the dam, and then prepares a summary of its findings. The technician checks when there are anomalies and collect the data and alert the civil engineer that there are anomalies. Finally, the civil engineer recommends the structure owner to correct the detected anomalies.

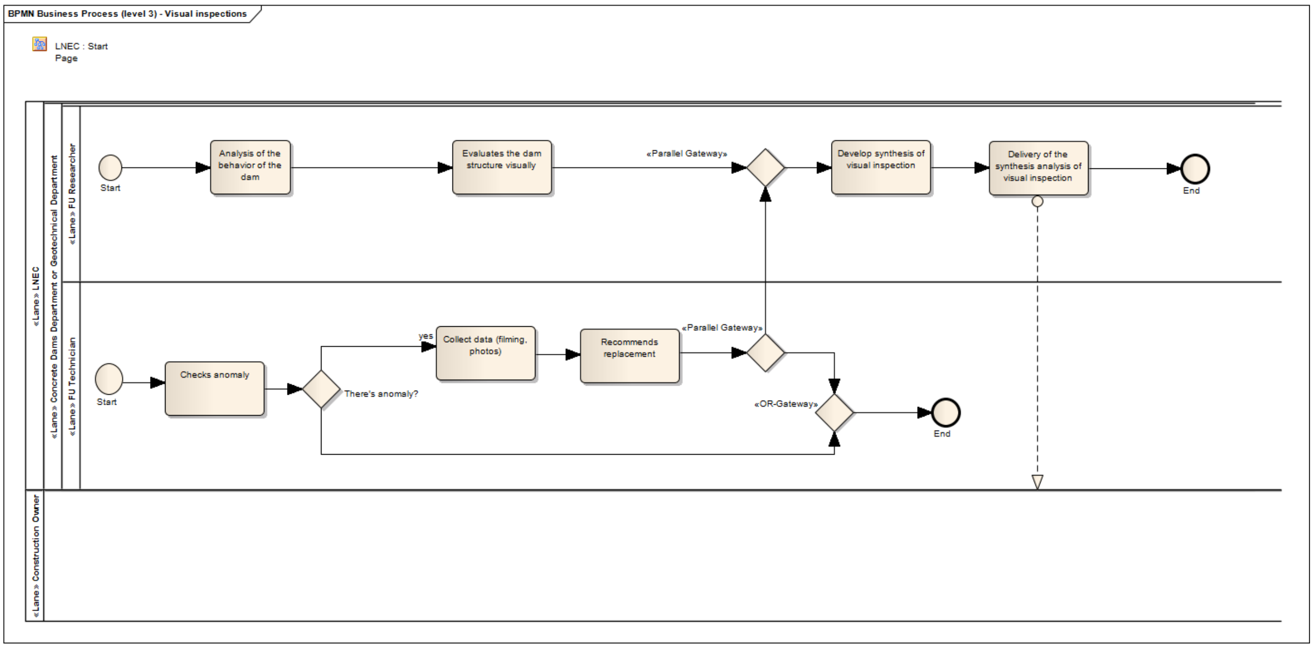


Figure 40: Visual inspections

9.2.3.4 Making a report of speciality

The department conducts an analysis of the behaviour of the dam through the study of physical measures or performs visual inspections, or both. Finally it makes a report of the conclusions of this study.

9.2.3.4.1 Check the emergency plan

The Authority receives the emergency plan from National Authority for Civil Protection and sends it to LNEC. Then, LNEC researchers analyze the plan and prepare a report, which is sent to the Authority to be considered in the final analysis. Based on that report, the authority verifies and potentially approves the plan.

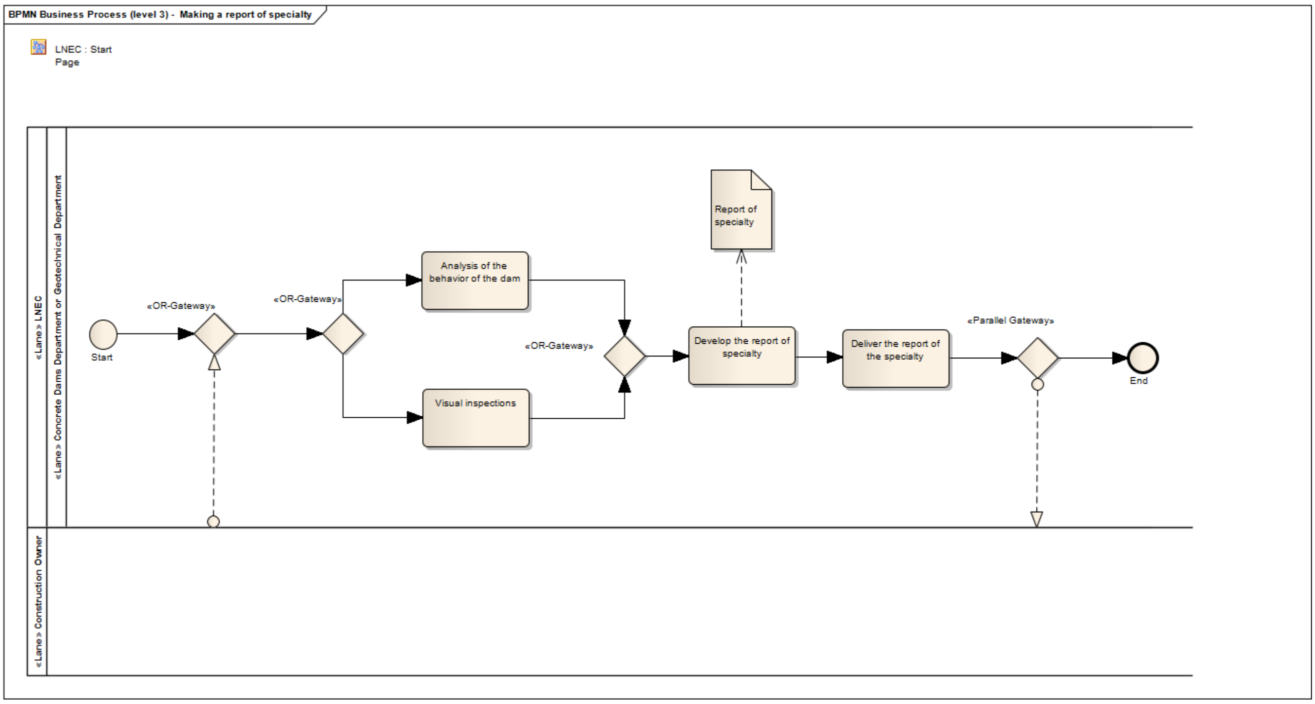


Figure 41: Making a report of speciality

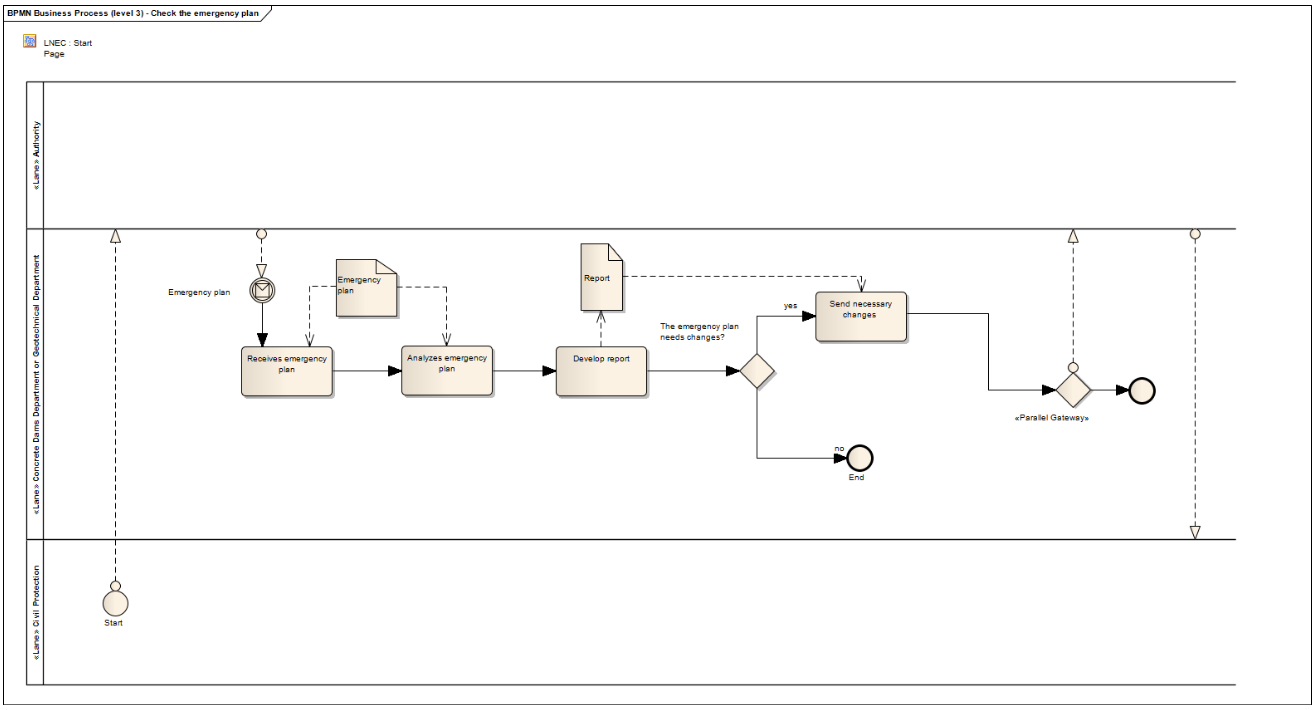


Figure 42: Check the emergency plan

9.2.3.5 Check the observation plan

The Authority receives the observation plane from the structure owner and sends it to LNEC for advice and technical analysis. LNEC researchers prepare a report to be sent to the Authority, which will be considered in the final analysis. Finally, the Authority verifies and potentially approves the observation plan.

9.2.3.6 Order to the supplier

The IT manager finds that it is necessary to replace / install a new component and contacts the vendor to purchase the component, after the supplier deliver the component to LNEC, the technician replaces / installs the software / hardware in the IT infrastructure.

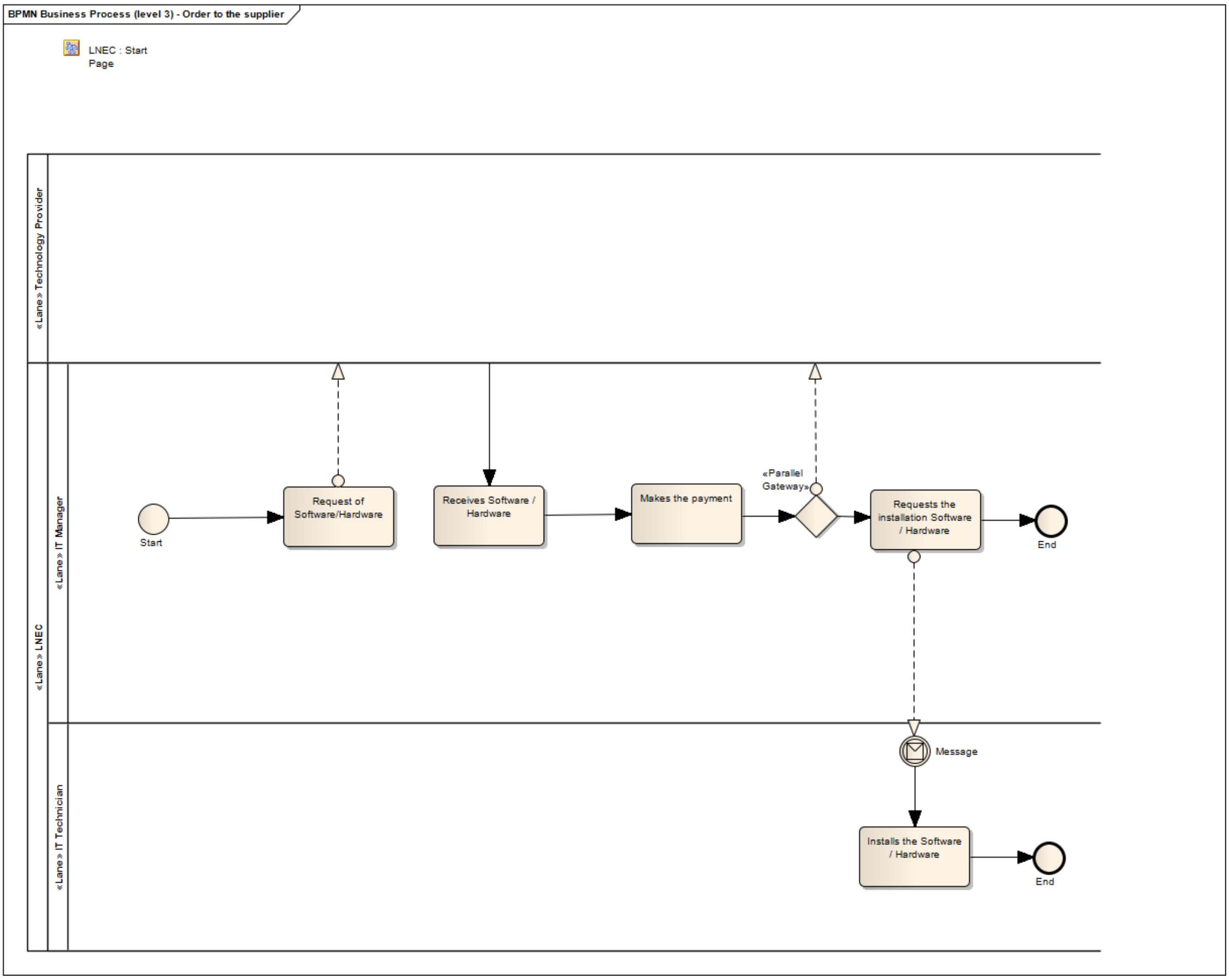


Figure 43: Order to the supplier

9.3 Application usage

This section identifies the services that are used within the scope of the processes listed in the previous section.

9.3.1 Acquisition of readings

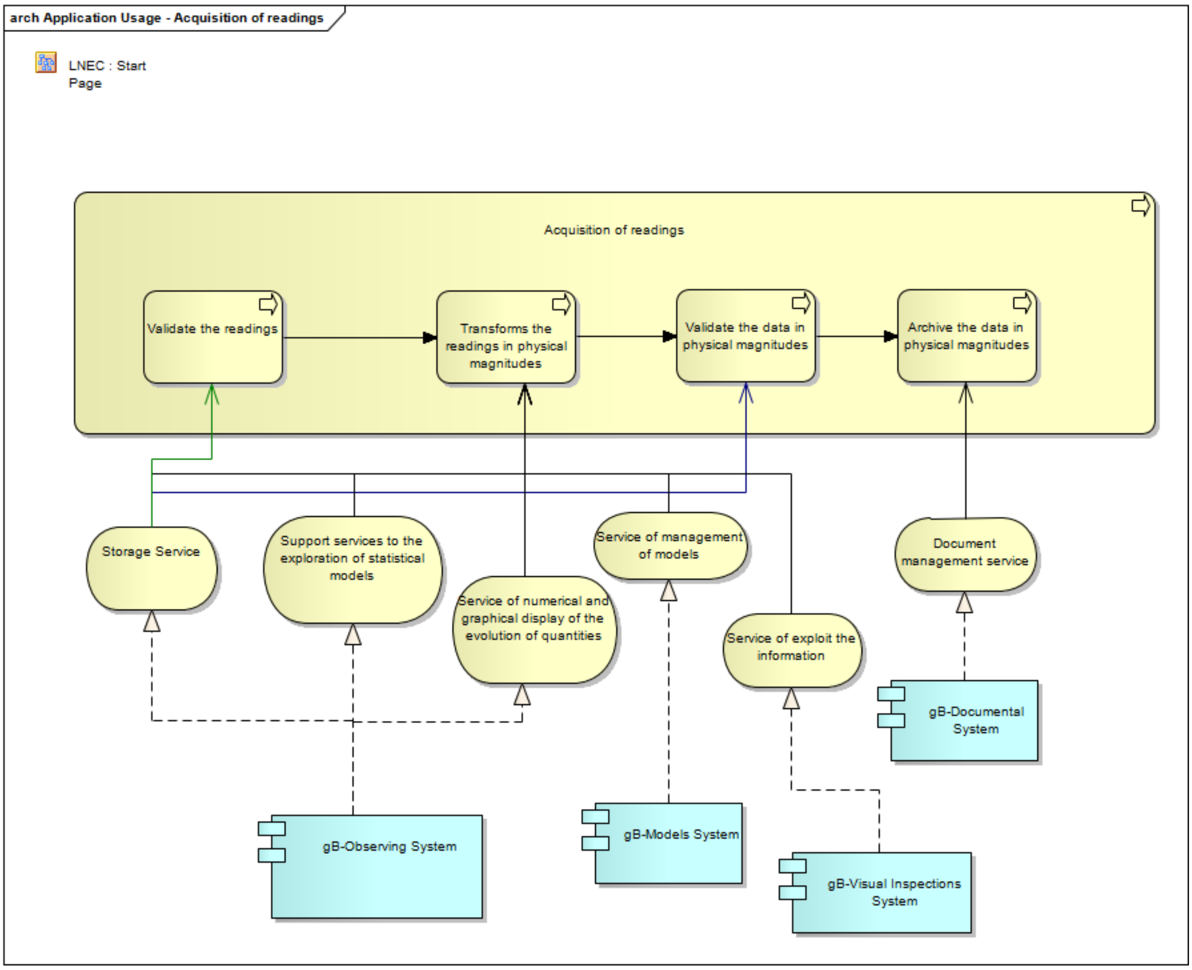


Figure 44: Application usage - Acquisition of readings

9.3.2 Analysis of the behaviour of the dam

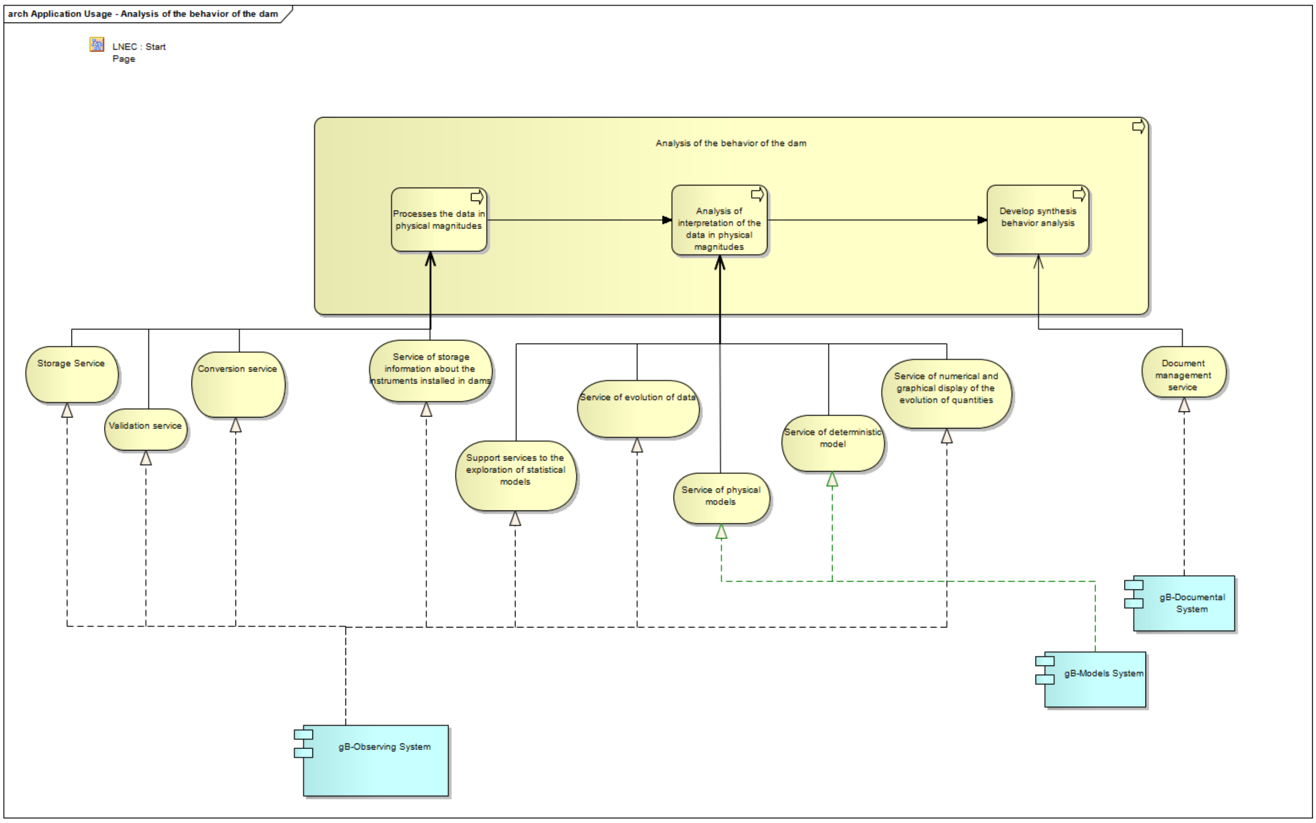


Figure 45: Application usage - Analysis of the behaviour of the dam

9.3.3 Visual Inspections

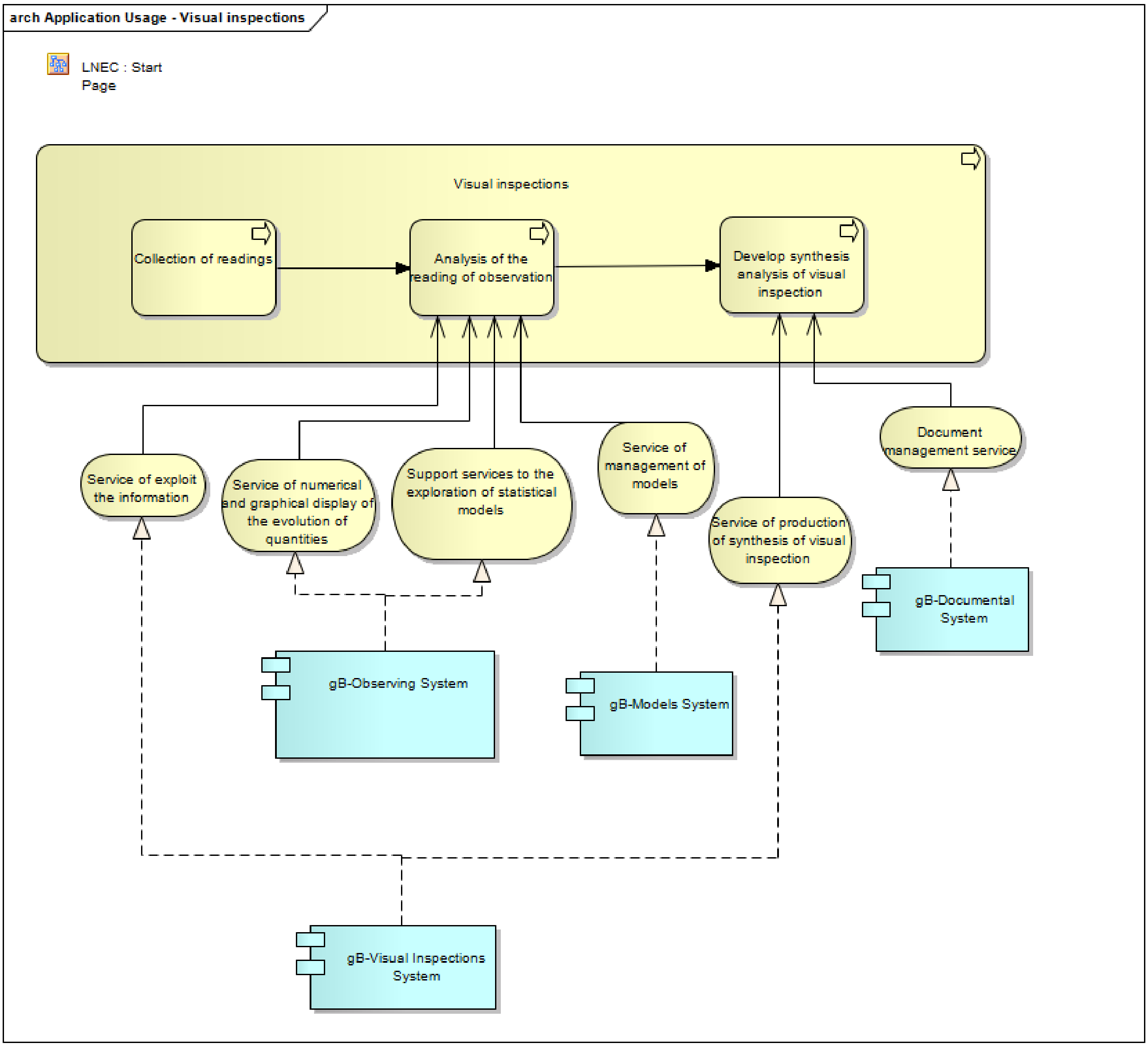


Figure 46: Application usage - Visual Inspections

9.3.4 Making a report of specialty

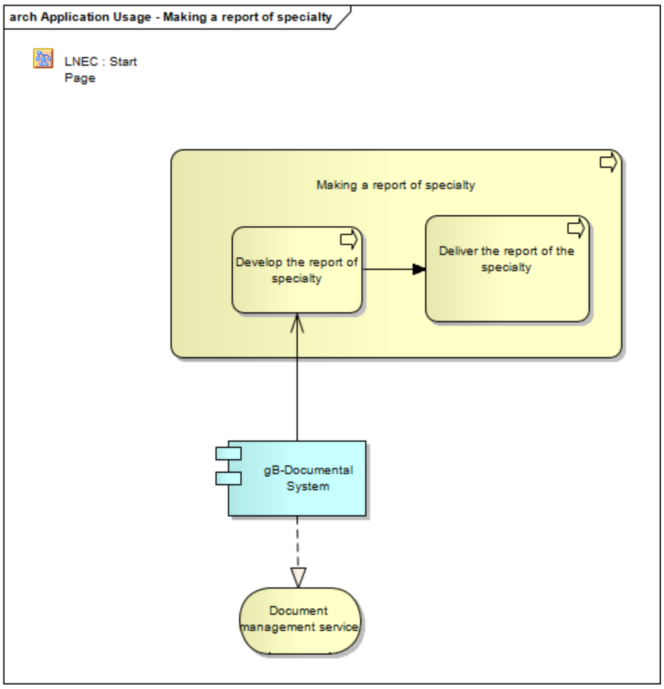


Figure 47: Application usage - Making a report of specialty

9.3.5 Checking/approval of the emergency plan

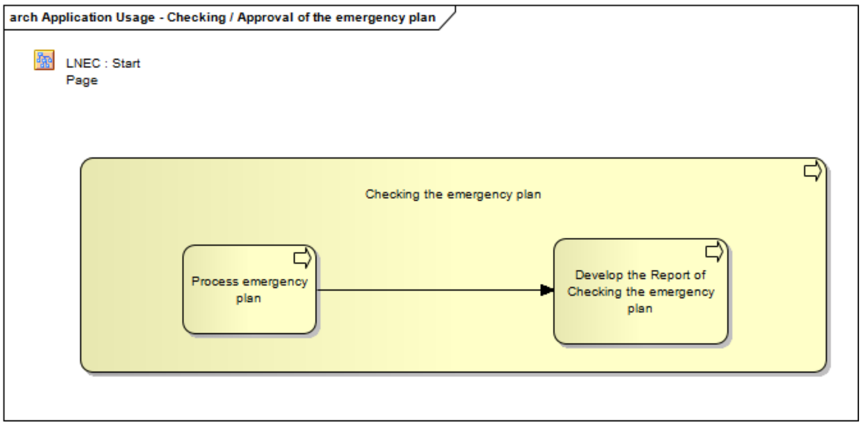


Figure 48: Application usage - Checking/approval of the emergency plan

Checking / approval of the observation plan

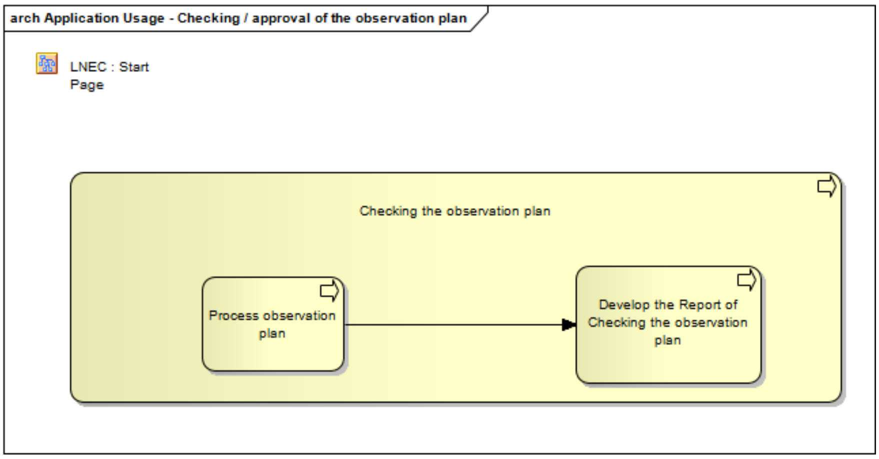


Figure 49: Application usage - Checking / approval of the observation plan

9.3.6 Order to the supplier

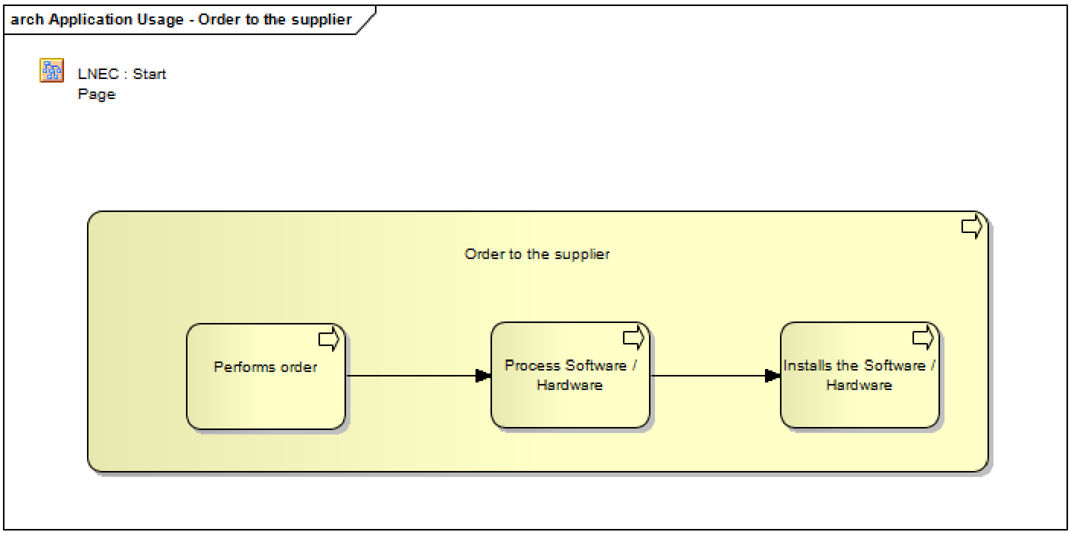


Figure 50: Application usage - Order to the supplier

9.4 Application cooperation

This section identifies systems and information flows between system components.

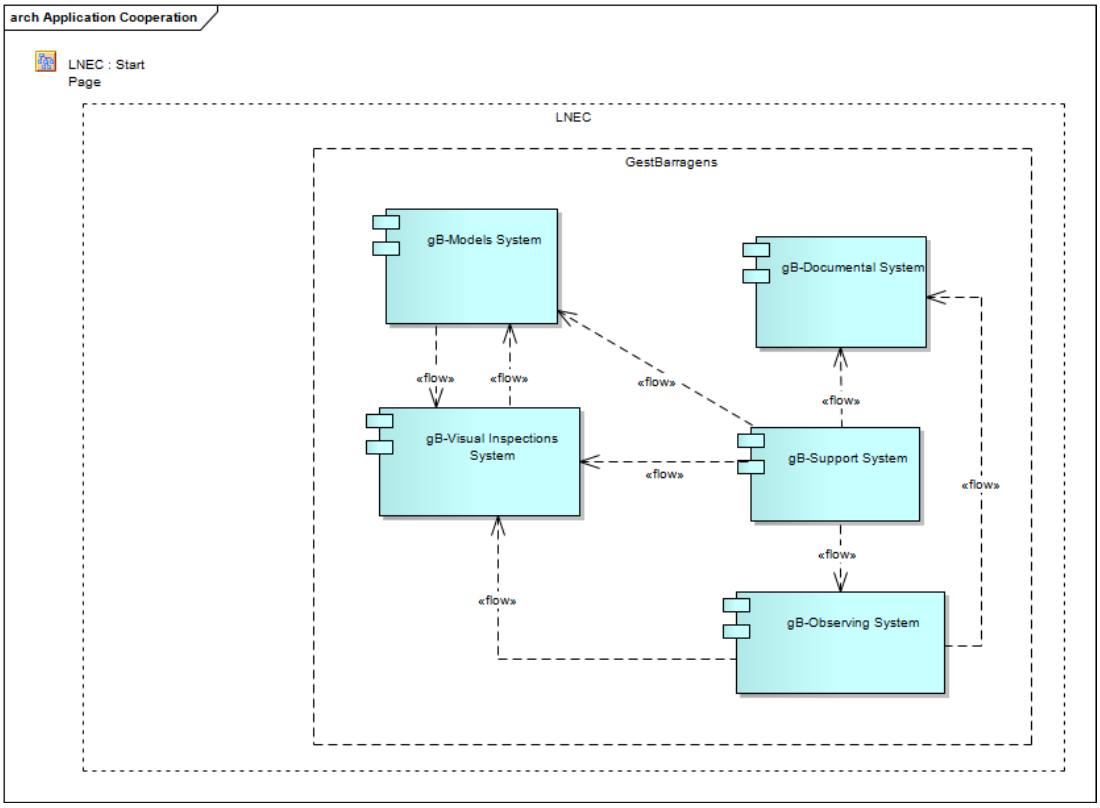


Figure 51: Application cooperation

9.5 Application structure

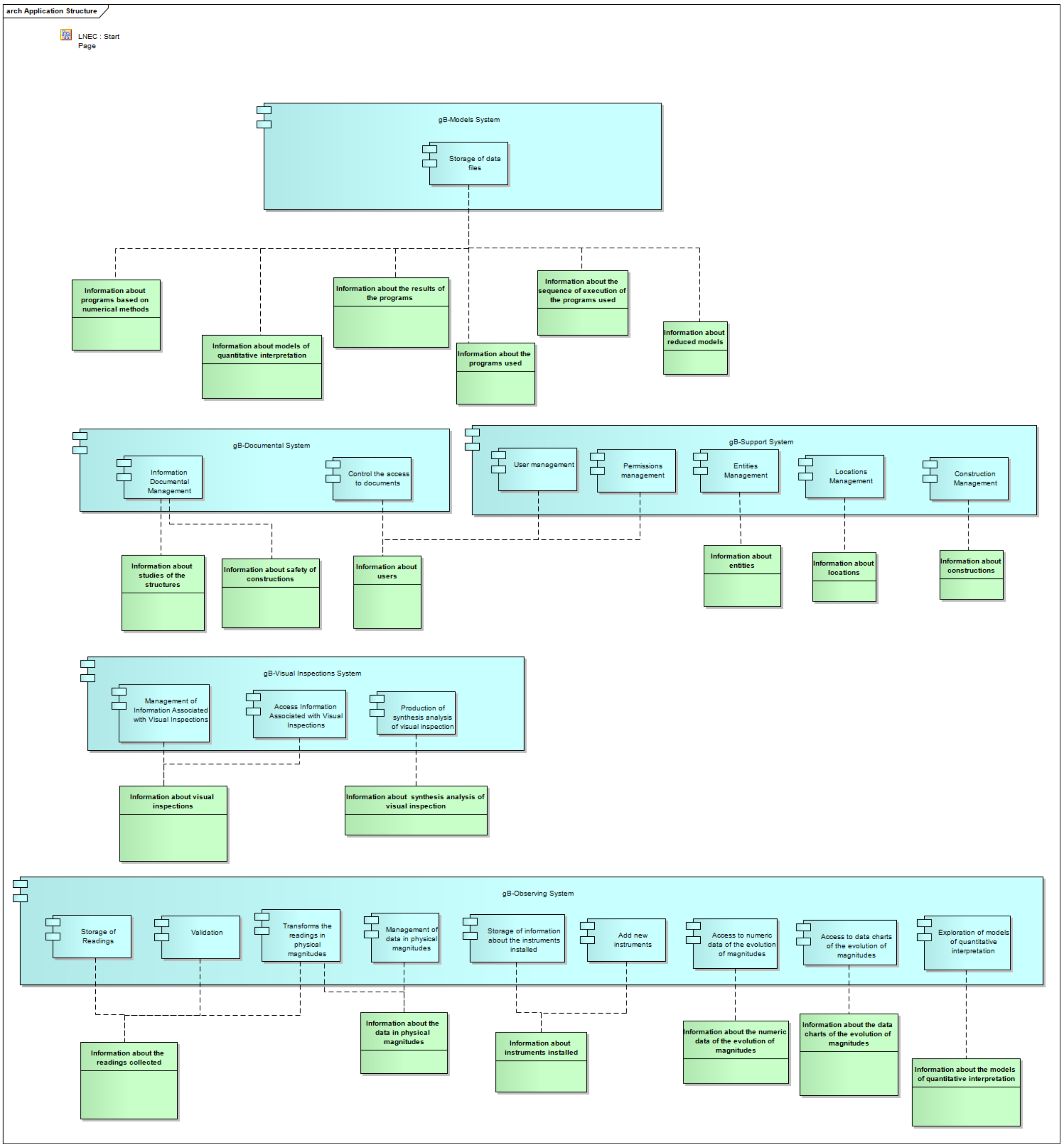


Figure 52: Application structure

9.6 Application behaviour

9.6.1 Gb-Suport and Gb-Observation system

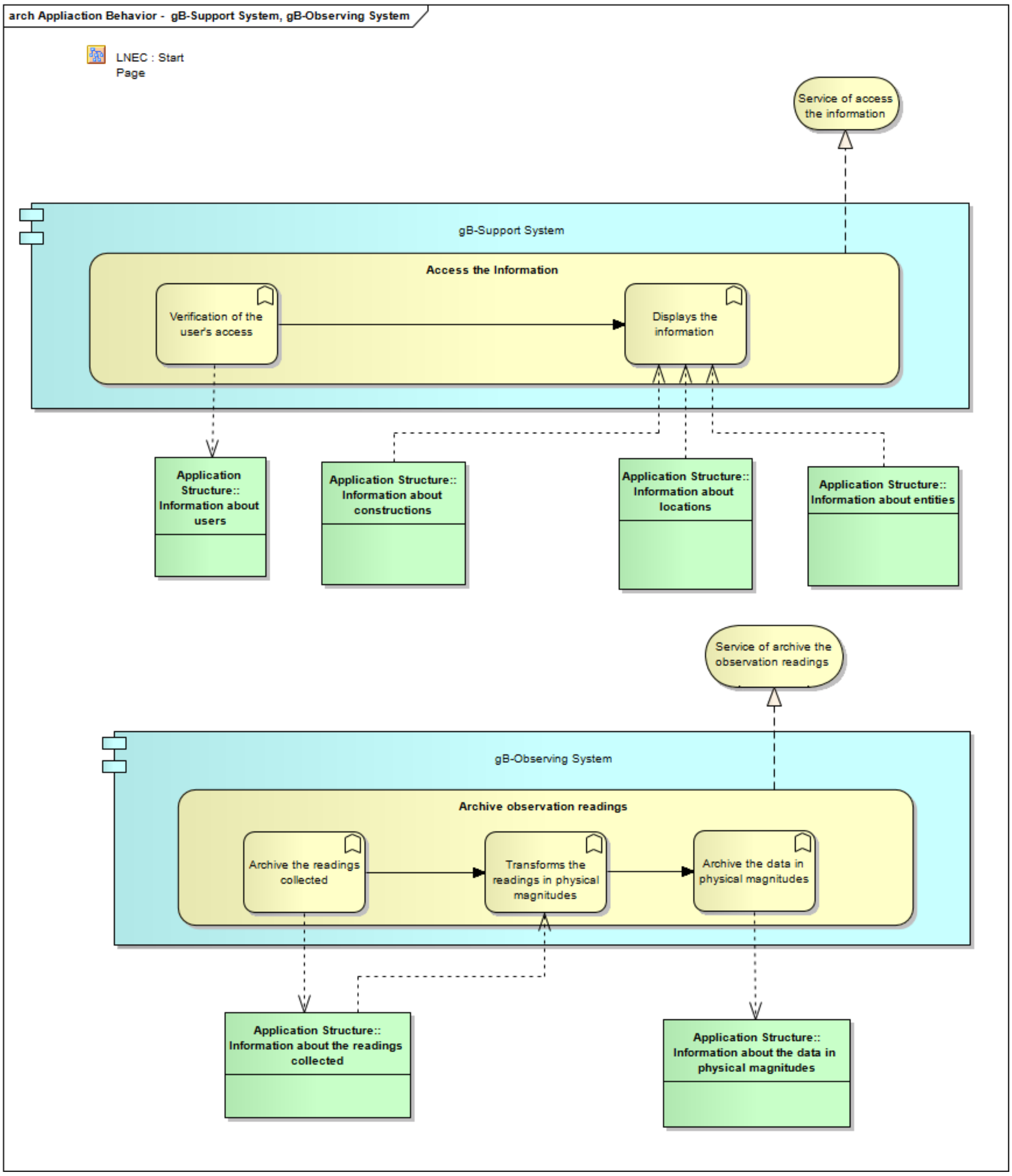


Figure 53: Application behaviour - gbSupport and gb-Observing systems

9.6.2 gB-Documental, gB-Visual-Inspections, Sistema gB-Models

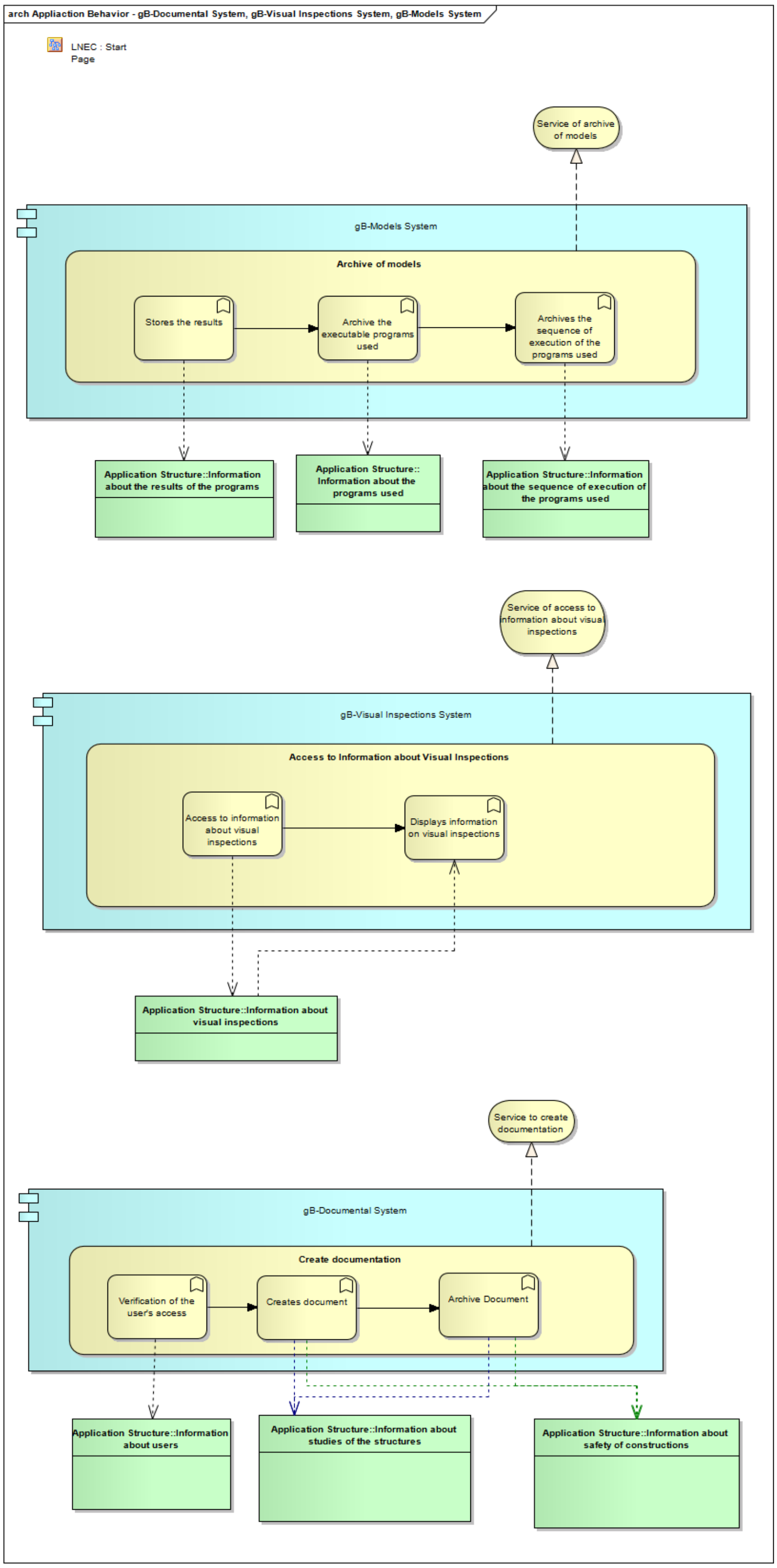


Figure 54: Application behaviour - gb-Documental, gb-Visual Inspections and gb-Models systems

9.7 Infrastructure

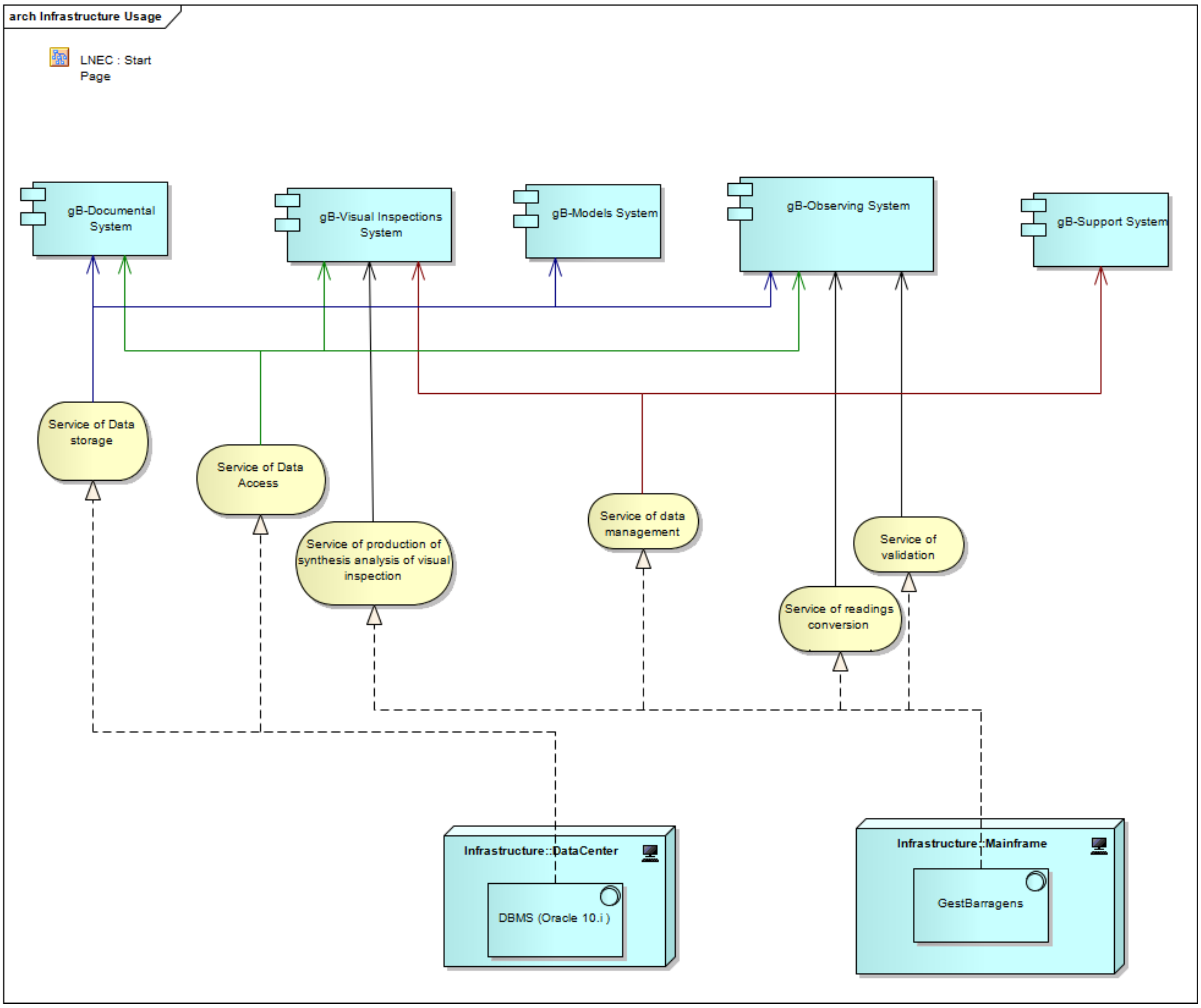


Figure 55: Infrastructure

9.8 Implementation & Deployment

9.8.1 gB-Support System

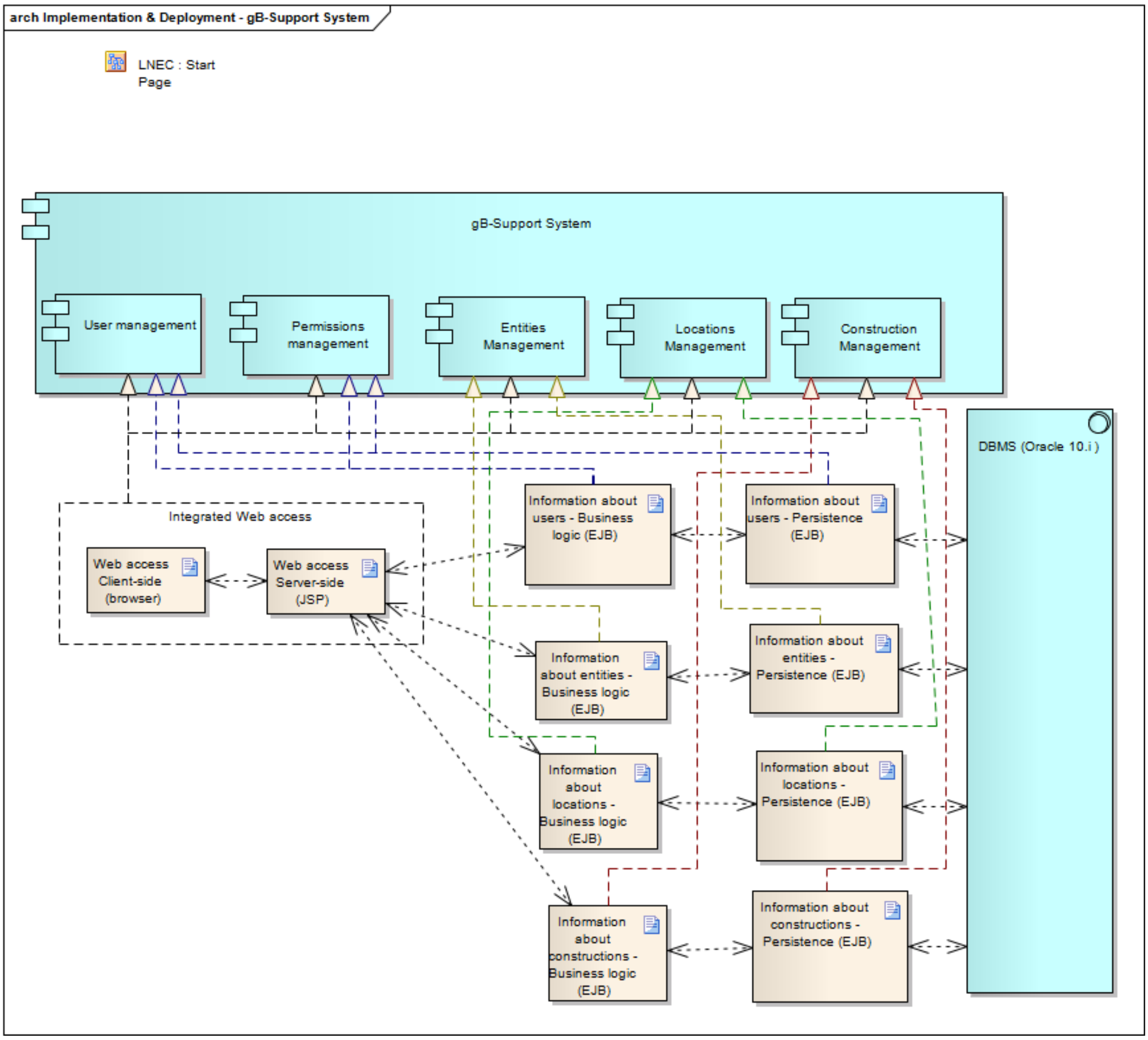


Figure 56: Implementation & Deployment - gB-Support system

9.8.2 gB-Observing System

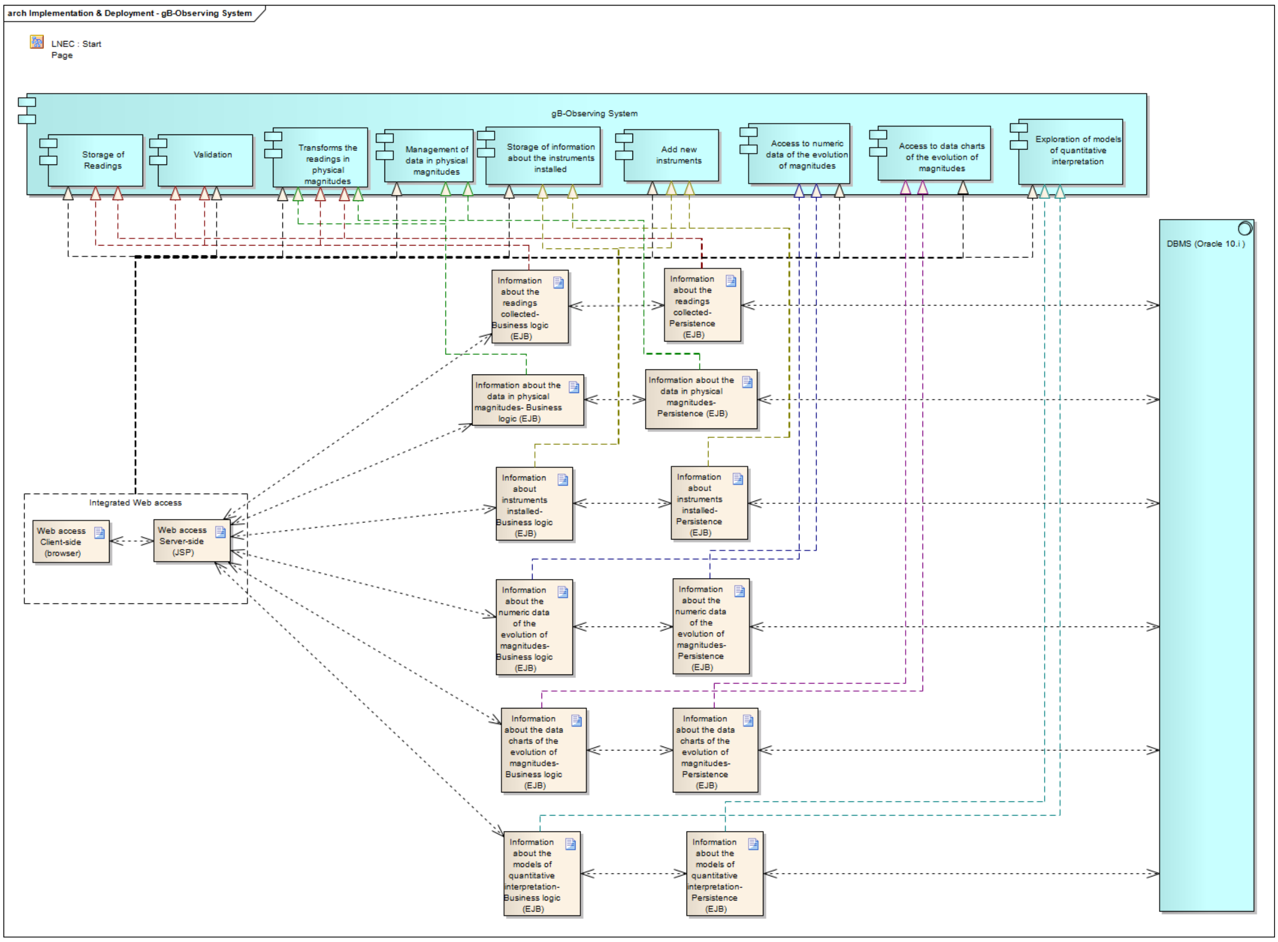


Figure 57: Implementation & Deployment - gb-Observing system

9.8.3 gB-Visual Inspections System

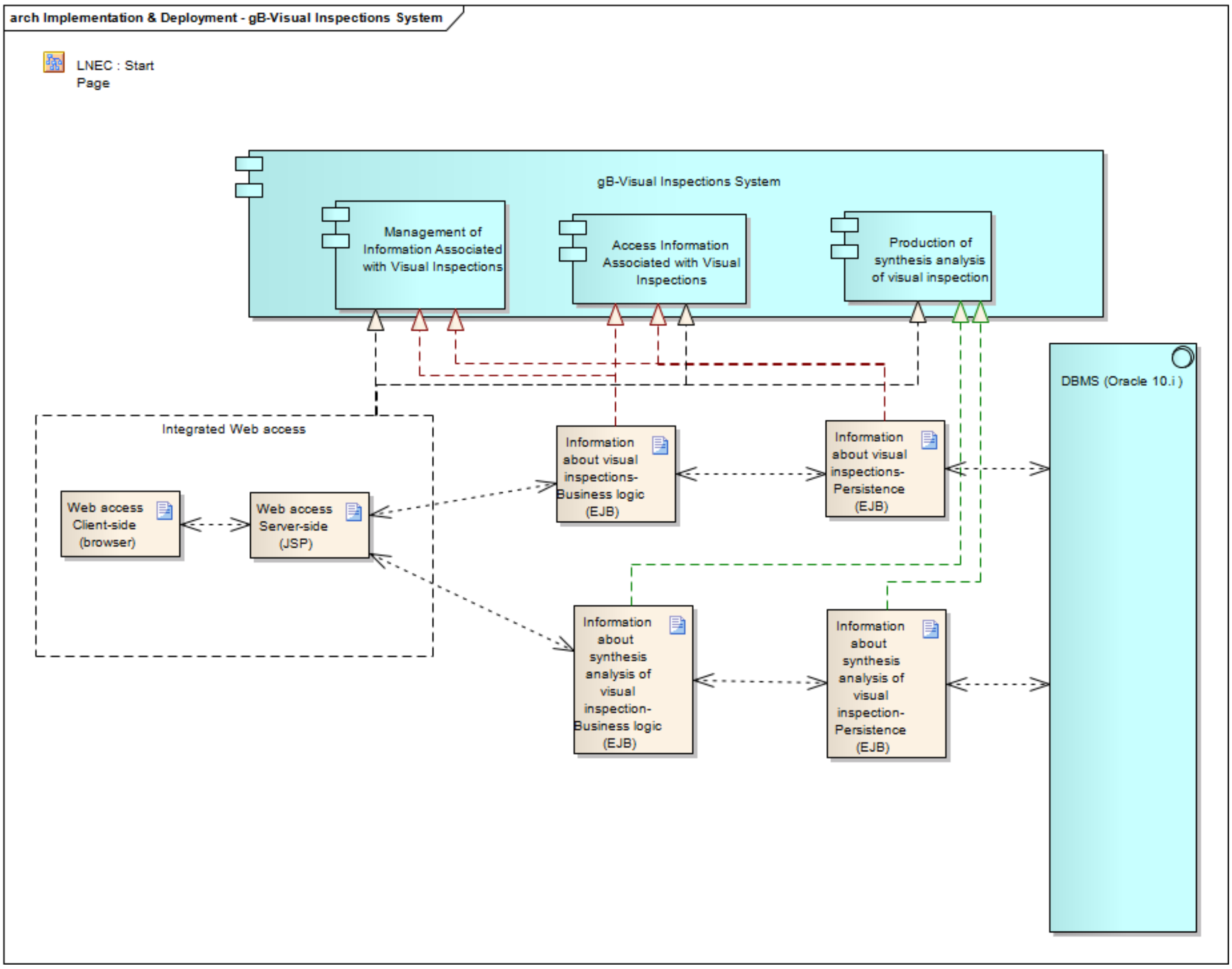


Figure 58: Implementation & Deployment - gB-Visual Inspections system

9.8.4 gB-Models System

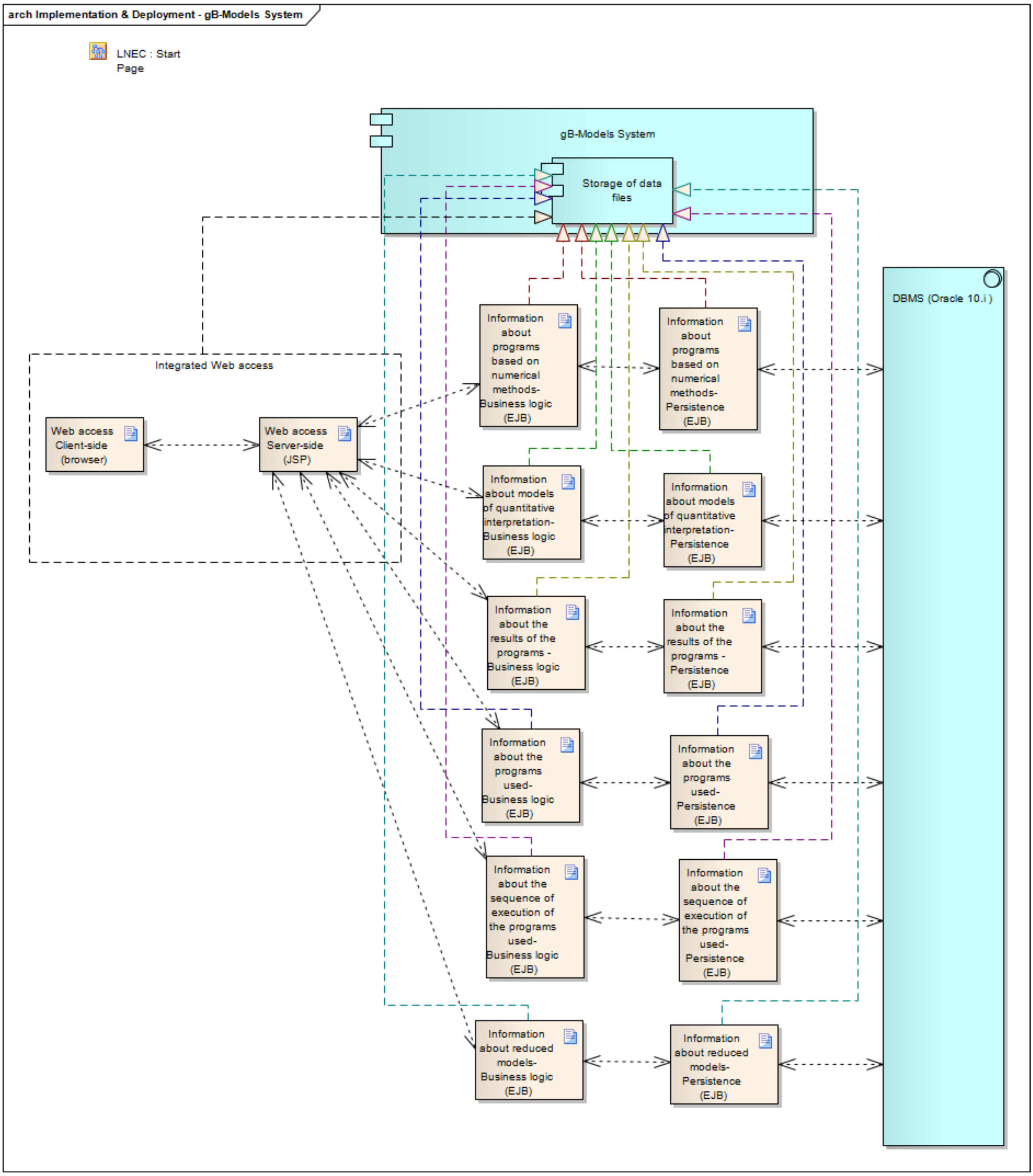


Figure 59: Implementation & Deployment - gB-Models system

9.8.5 gB-Documental System

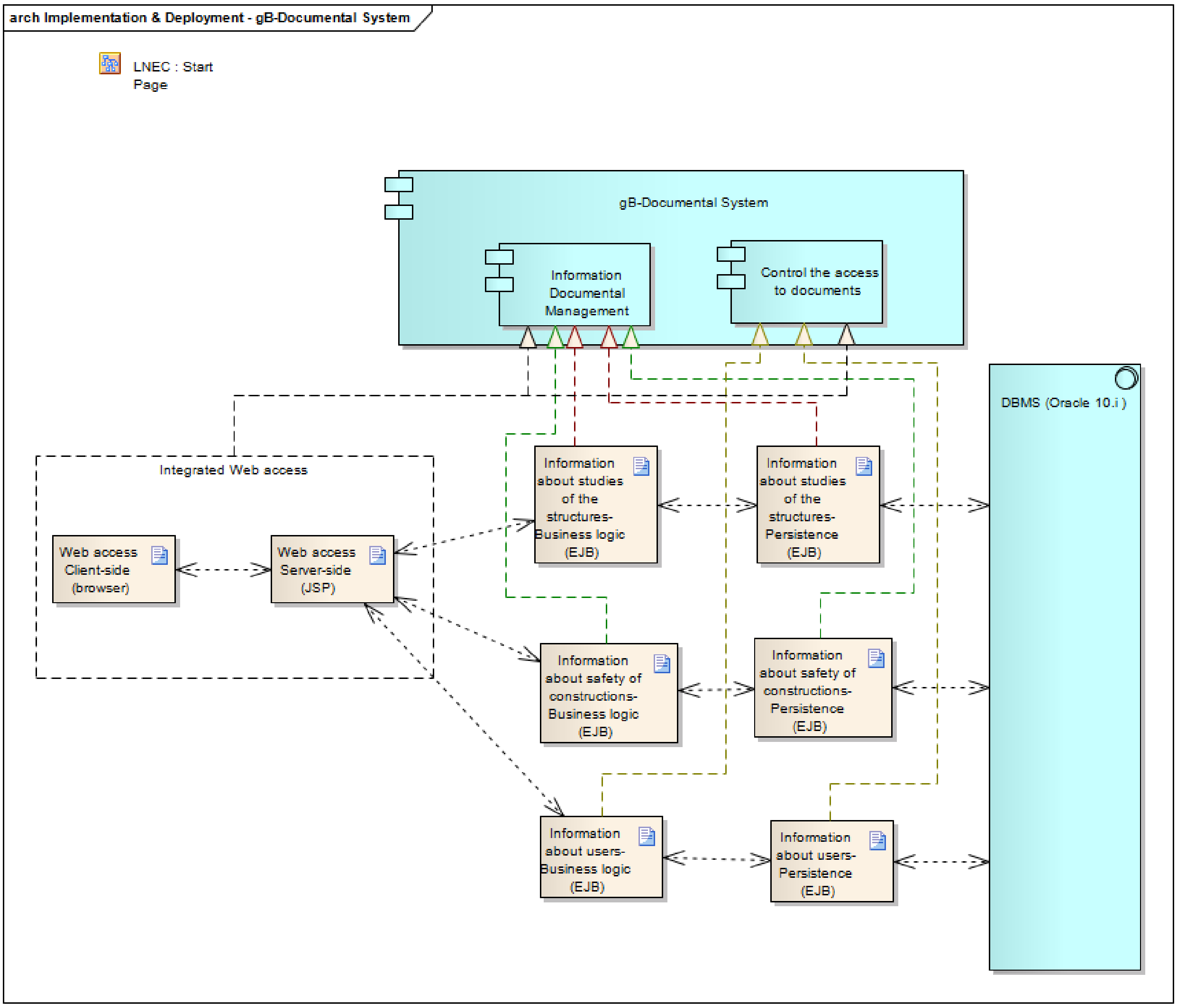


Figure 60: Implementation & Deployment - gB-Documental system

10 Appendix – Instrumentation used in the processes

10.1 Plumb line

This type of device allows the observation of horizontal displacements in concrete and masonry dams.

The plumb line represents a vertical axis through a wire of high strength steel, and the quota is set at a high point of the structure (straight plumb line), or fixed in a deep point of the foundation (inverted plumb line). In the first case, the wire is tensioned by the action of a weight of about 600 N, which allows obtaining, at the points where it is accessible, the displacement of the attachment point in respect to these points, i.e. the relative displacements. In the second case, the wire, strained by the action of buoyancy of the water contained in a reservoir on a floating device immersed in it, gives, at points where it is accessible, relative displacements of the point mooring depth of the foundation that since the point is considered fixed, correspond to absolute offsets.

Passing the wire through the body of the dam is done through tubes with a diameter such that it allows free movement of the wire. The passage through the foundation is provided by boreholes that give continuity to the tubes that pass through the body of the dam.
When the shape of the dam does not allow the placement of a vertical tube from the foundation up to the highest quota of the dam, and therefore the installation of one plumb line, using a set of inverted plumb line + straight plumb line. Then, is mounted on two shafts with the same two vertical plumb lines, one straight and one reversed, and is done with the coordinometer lower base of the straight plumb line as close as possible to the upper base the inverted plumb line. With this device you can relate the relative displacements of the plumb line provided by straight plumb line, with the data for the inverted plumb line and thus obtain the absolute components of the displacements.

In accessible locations the passage of the plumb line (visit galleries, niches, platforms or walkways within the structure), are placed welded parts of the structure, coordinometer bases, where you can place your measuring device - optical coordinometer - which allows to obtain the rectangular coordinates of the wire in the measuring plane.

To control the operating conditions of the coordinometer or enable the use of another device, it settles at the base of coordinometer and is also rigidly connected to a reference structure, designated the reference cone, which is embodied with a point which has the same movements as the neighboring base. Readings corresponding to the cone thus always have the same value for the same device, unless there are observation errors.

Description - The first five characters are the name of the plumb line where the first three define the type of the plumb line, inverted (IPF) or right (FPD) and The Other two the number of the wire.

Block - Block of the dam where the plumb line is located.

Code - The code identifying the base coordinometer in the computer system.

OE - Indicates whether this device code is part of the expedite observation.

Rf - Factor convention for radial displacement which is related to the position of the base coordinometer (Fig. 1)

Ft - Factor convention for tangential displacement which is the position of the base coordinometer (Figure 61).

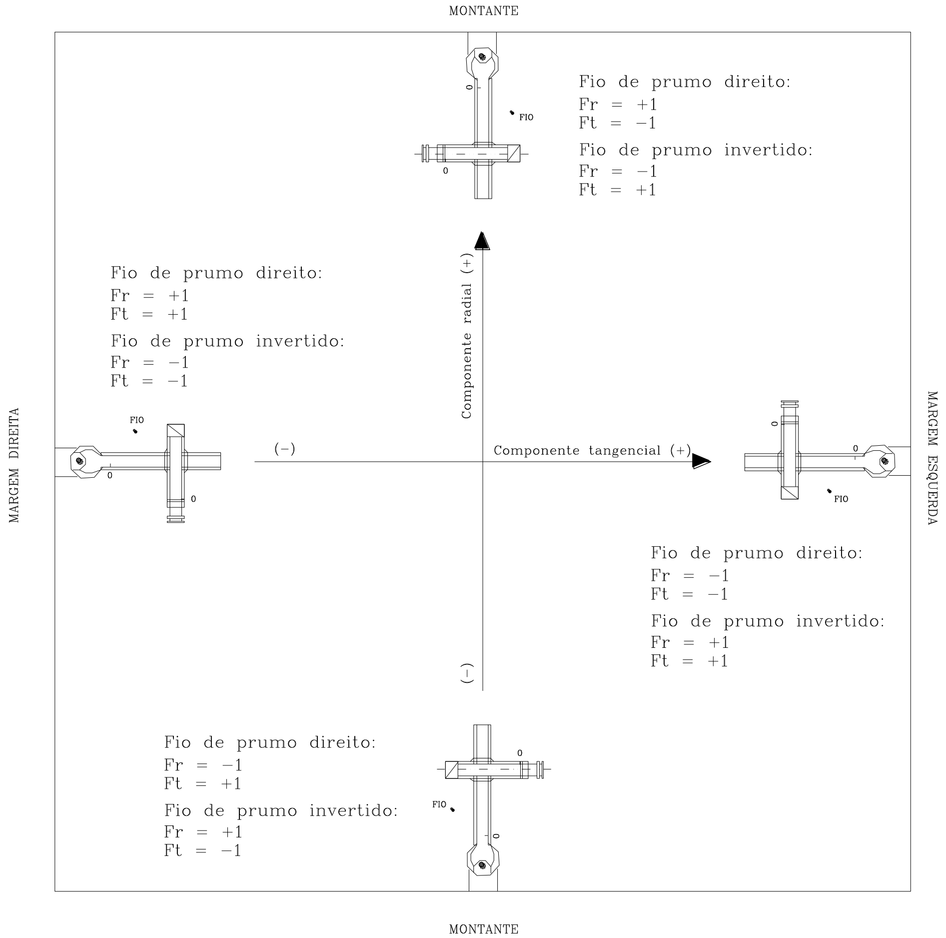


Figure 61: Possible arrangements of base coordinometer factors and their convention

Quota - Coordinometer quota location of the base.

α - Angle between the correct tangential direction and the incorrect tangential direction, which is the "side origin" of the right angle to the tangential direction and the adopted conventional sense, i.e. counter-clockwise (Figure 62).

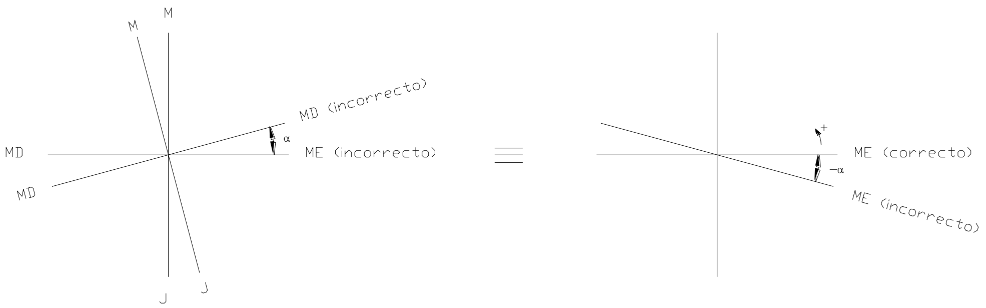


Figure 62: Plumb Lines. Angle between the correct tangential direction and the incorrect tangential direction

RF_i – Initial radial wire reading.
$RF_{Máx}$ – Maximum limit for validation of the radial reading to the wire.
RF_{Min} – Minimum limit for validation of the radial reading to the wire.
TF_i – Initial tangential reading to the wire.
$TF_{Máx}$ – Maximum limit for validation of the tangential reading to the wire.
TF_{Min} – Minimum limit for validation of the tangential reading to the wire.
RC_i – Initial radial cone reading.
$RC_{Máx}$ – Maximum limit for validation of the radial cone reading.
RC_{Min} – Minimum limit for validation of the radial cone reading.
TC_i – Initial tangential cone reading.
$TC_{Máx}$ – Maximum limit for validation of the tangential cone reading.
TC_{Min} – Minimum limit for validation of the tangential cone reading.

Data

The readings provided by this type of device in a given time n, are as follows:

RF_n – Radial reading to the wire at time *n.*
RC_n – Radial reading to the wire at time *n*
TF_n – Tangential reading to the wire at time *n*
TC_n – Tangential reading to the wire at time *n*

Algorithm

The expressions for calculating the radial displacement (*DR*) and tangential (*DT*) in each of the points of measurement are as follows:

$$DifR = \left[\left(RF_n - RF_i\right) - \left(RC_n - RC_i\right)\right] Fr$$

$$DifT = \left[\left(TF_n - TF_i\right) - \left(TC_n - TC_i\right)\right] Ft$$

$$\mathbf{DR = \left(DifR\ Cos\ \alpha - DifT\ Sin\ \alpha\right) x\ 10 \qquad (mm)}$$

$$\mathbf{DT = \left(DifT\ Cos\ \alpha + DifR\ Sin\ \alpha\right) x\ 10 \qquad (mm)}$$

10.2 Displacement Base

Displacement bases are designed to measure the surface (floors and ceilings of galleries, the lower base of the ornament of the crown and downstream), the movements of joints or cracks and are constituted by three studs duly anchored in concrete, forming together an equilateral triangle, arranged so that two of its sides pass through the gasket.

From the measurement with a Marion displacement type, the variation of distance from the sides of the triangle, determining the opening, closing and sliding movement (in the upstream, downstream, to the bases and placed on a horizontal plane - crown towards the foundation for the bases placed on the vertical plane.

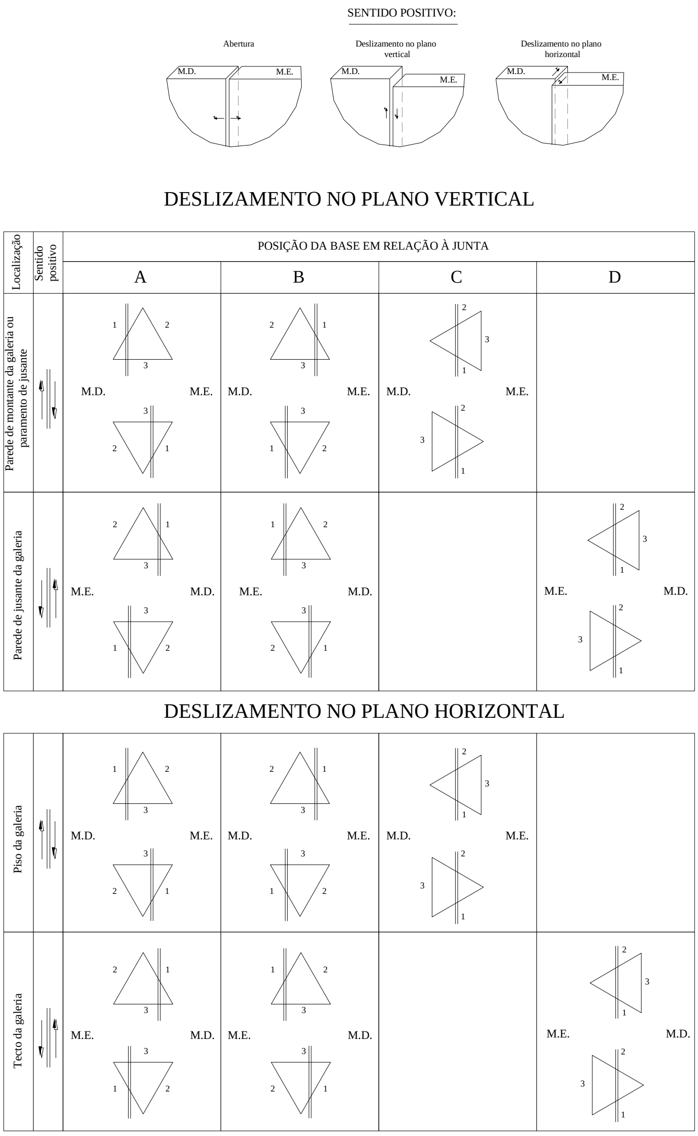


Figure 63: Position of the bases in relation to the joint displacement

Base – Number base.
Position – Position the base over. In Figure 63 is depicted the positions of possible installations, and their conventions.
Code – Code identifying the basic displacement in the computer system.
Joint – Joint of the dam where the base is installed.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota based on the location of the joint.
$L1_i$ – Initial reading of side 1.
$L1_{Máx}$ – Maximum value for validation of the side 1 reading.
$L1_{Min}$ – Minimum value for validation of the side 1 reading.
$L2_i$ – Initial reading of side 2.
$L2_{Máx}$ – Maximum value for validation of the side 2 reading.
$L2_{Min}$ – Maximum value for validation of the side 2 reading.
$L3_i$ – Initial reading of side 3.
$L3_{Máx}$ – Maximum value for validation of the side 3 reading.
$L3_{Min}$ – Maximum value for validation of the side 3 reading.
LI_i – Initial reading of invar.
$LI_{Máx}$ – Maximum value for validation of the invar reading.
LI_{Min} – Maximum value for validation of the invar reading.

Data

The readings provided at the time n, for this type of device are as follows:

$L1_n$ – Reading of side 1
$L2_n$ – Reading of side 2
$L3_n$ – Reading of side 3
LI_n – Reading of invar

Algorithm for calculation of results

The calculation of the opening (Δ y) and sliding (x Δ) on the displacement base is obtained by the following expressions:

Bases type A or B

$$\Delta y = -\left[(L3_n - L3_i) - (LI_n - LI_i)\right] 2 \qquad \textbf{(mm)}$$

$$\Delta x = -\frac{1}{\sqrt{3}}\left[\left((L3_n - L3_i) - (LI_n - LI_i)\right)2 - \left((L1_n - L1_i) - (LI_n - LI_i)\right)\right] \qquad \textbf{(mm)}$$

Bases type C or D

$$\Delta y = -\frac{1}{2\sqrt{3}}\left[(L1_n - L1_i) - (LI_n - LI_i) + (L2_n - L2_i) - (LI_n - LI_i)\right] \qquad \textbf{(mm)}$$

$$\Delta x = \frac{1}{2}\left[\left((L1_n - L1_i) - (LI_n - LI_i)\right) - \left((L2_n - L2_i) - (LI_n - LI_i)\right)\right] \qquad \textbf{(mm)}$$

Regarding the bases of type B and D, the calculation of the slip includes signal inversion.

10.3 ELECTRIC RESISTANCE CARLSON JOINT READERS

Joint gauges are intended to measure closures and openings of contraction joints, and have a constitution similar to that of electrical resistance strain gauges. They consist of bellows in its central zone, while ensuring an appropriate deformation of the outer wall, allows to absorb any movements between the sliding block.

The schema of the connections and methods are the ones suitable for reading the Carlson electrical resistance strain gauges.

Meter – Designation of the meter in the observation plane.
Joint – Contraction joint where the meter is installed.
Code – Code for identification of the strain gage system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota location of the device on the joint.
R_0 – Total resistance at a temperature of °C. Constant supplied by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Constant supplied by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum limit for validation of the relationship of the resistances.
r_{Min} – Minimum limit for validation of the relationship of the resistances.
σ – Variation of the opening by ten thousandth of a variation in the resistance. Constant supplied by the manufacturer.

Data

Algorithm for calculation of results

The temperature values (*T*) and aperture (Δy) are obtained through the following expressions:

$$T = (R_n - R_0)\Delta_t \qquad \text{(ºC)}$$

$$\Delta y = (r_n - r_i)\sigma \qquad \text{(mm)}$$

where,

R_n – Reading of the total resistance at the time *n*.
R_0 – Total resistance at a temperature of ºC
Δ_t – Temperature range in ° C per ohm of resistance variation
r_n – Reading of the ratio of the resistances at the time *n*
r_i – Initial reading of the resistance relations.
σ – Variation of opening by ten thousandth of a variation in the resistance

10.4 ELECTRICAL RESISTANCE THERMOMETERS

The measurement of temperature is effected by dams apparatus specially designed for this purpose, such as thermoelectric couple and electric resistance thermometers. But Carlson type devices (gauges, joint meters, tensiometers, pressure gauges and iclinometers), and also allow obtaining it.

The electrical resistance thermometers are essentially made of a wound and non-inductive resistance and, enclosed in a metal cylinder.

Thermometer – Number of the thermometer in the observation plane.

Block – Block where the thermometer is placed.

Code – Code identifying the thermometer into the computer system.

OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota location of the device on the block.

R_0 – Electrical resistance at a temperature of °C. Constant supplied by the manufacturer.

$R_{Máx}$ – Maximum limit for validation of the resistance.

R_{Min} – Minimum limit for validation of the resistance.

Δ_t – Temperature range in ° C per ohm resistance change. Constant supplied by the manufacturer.

Data

Algorithm for calculation of results

The calculation of the temperature at the time *n* (T_n) *is* obtained by the expression

$$T_n = (R_n - R_0)\Delta_t \qquad \text{(ºC)}$$

where,

R_n – Reading of the electrical resistance at the time *n*

R_0 – Electrical resistance at a temperature of ºC

Δ_t – Temperature range in °C per ohm of resistance variation

10.5 FOUNDATION EXTENSOMETERS

The measurement of displacement in the foundation points is made through the foundation extensometers.

The extensometers are made of wire or metal rods (or by fiber optic cables) installed in boreholes run through the foundation. They generally are installed with multiple anchors in the same hole, which allows to measure the extensions between the various sections.

The measurement of displacement between the various anchorage points and fixed head structure read is carried out manually through a precision deflectometer or automatically by means of suitable devices.

Extensometer – Extensometer number in the observation plane.
Position – Position of the anchor into the hole. If it is a simple extensometers the value is 1, otherwise the value varies between 1 and the existing number of anchors.
Code – Code identifying the device into the computer system.
Block – Block where the gage is placed.
OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota location of the device on the block.
Length – Length of the foundation extensometer.
LI_i – Initial invar reading.
$LI_{Máx}$ – Maximum value for the validation of the invar reading.
LI_{Min} – Minimum value for the validation of the invar reading.
LF_i – Initial reading of the wire or rod.
$LF_{Máx}$ – Maximum value for the validation of the wire or rod reading.
LF_{Min} – Minimum value for the validation of the wire or rod reading.
K_1 – Conversion from inches to millimetres. If the readings used in deflectometer are graduated in mm K_1 then assumes the value 1.0, if it is graded in inches the value of K_1 is equal to 25.4.
K_2 – Indication of the calculation of the various anchorages.

Data

Algorithm for calculation of results

The calculation of the time displacement *n* (D_n) *is* obtained by the expression

$$D_n = \left[\left(LF_n - LF_i \right) - \left(LI_n - LI_i \right) \right] K_1 \qquad \text{(mm)}$$

where,

LF_n – Reading of the wire or rod at the time *n*
LF_i – Initial reading of the wire or rod
LI_n – Invar reading at the time *n*
LI_i – Initial invar reading
K_1 – Conversion factor of the displacement in mm

10.6 DRAINS

The control flow of drainage in the foundation of the dam is carried out through the holes of the drainage network (drainage) (Figure 64).

Figure 64: Foundation drain

The flow measurement in each well is carried out with containers of different volumes depending on the checked output. The filling time is measured with a stopwatch, thereby obtaining the flow rate.

The drained and infiltrated flow over a given area of the dam are conducted to a tank, totalizing spout, where they are manually or automatically measured by a flow meter (flow meter). (Figure 65)

Figure 65: Totalizing spot

Drain – Number of the drain in observation plane.
Block – Block where the drain is located.
Code – Code identifying the device into the computer system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota of the mouth of the drain.
$Flow_i$ – Minimum value for validation of the flow reading.
$Flow_{Máx}$ – Maximum value for validation of the flow reading.

Data

Algorithm for calculation of results

The calculation of the flow at the time *n* (C_n) is obtained by the expression

$$C_n = (V_n / t_n) 60 \qquad \textbf{(liters per minute)}$$

where,

V_n – Volume reading at time *n*
t_n – Time reading at time *n*

10.7 PIEZOMETERS

The uplift measurement is carried out by piezometers consisting of one or more piezometric chambers of pressure connection, located in holes drilled in the foundation (Figure 66). The pressures are measured in nanometers installed at the end of the respective piezometric tube, which can be read directly or automatically by the pressure sensor (Figure 67). The pressure gauges are provided with a three-way tap, thus allowing acting as drain.

Figure 66: Piezometer in the foundation

Figure 67: Pressure gauge with automatic collection

Piezometer – Number of the piezometer in the observation plane.
Block – Block where the piezometer is installed.
Code – Code identifying the device into the computer system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota gauge.
$Flow_i$ – Minimum value for validation of the flow reading.
$Flow_{Máx}$ – Maximum value for validation of the flow reading.
$SPressure_i$ – Minimum value to validate the reading of uplift.
$SPressure_{Máx}$ – Maximum value to validate the reading of uplift.

Algorithm for calculation of results

As already mentioned, the piezometers, in addition to measuring the underpressure can also act as a drain. The calculation of the flow has already been mentioned, while the percentage of load at the time *n* piezometer (*% load*) is obtained by the following expression

$$\%C\arg a = \left[SP_n / \left(NI_n - C_m\right)10\right]100 \qquad (\%)$$

where,

SP_n – Uplift reading at the time *n*
NI_n – Water level in the reservoir at the time *n*
C_m – Gauge quota

10.8 TEMPERATURES AND LEVELS

The variations of air temperature in the vicinity of the dams are recorded through thermography which read the maximum and minimum temperature with a thermometer, placed in the weather station (Figure 68). Most of the Portuguese dams have weather stations, where in addition to measuring the air temperature also measures or records the moisture content, precipitation, evaporation, wind speed and direction (Figure 69). Currently there are meteorological stations that allow the automatic collection of all these quantities.

Figure 68: Weather shelter

Figure 69: Weather station

Measurement of the water level of the reservoir is made visually on a scale installed on the upstream either automatically through a linear meter.

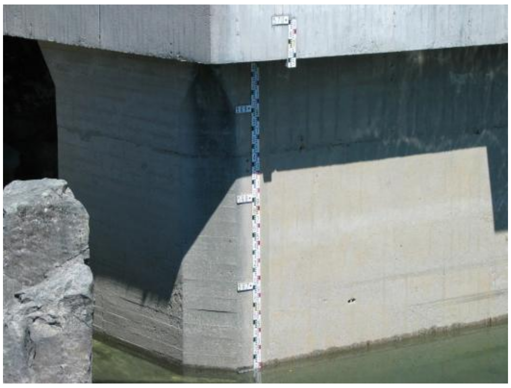


Figure 70: Linear scale

Figure 71: Automatic collection of the level

Location – *Location of the weather station.*

OE – Indicates whether this device code is part of the expedite observation.

TMáx – Maximum temperature for validation.

T_{Min} – Minimum value for validation of the temperature reading.

$NM_{Máx}$ – Maximum value for validation of the level of the lake.

NM_{Min} – Minimum value for validation of the level of the lake.

$NJ_{Máx}$ – Maximum value for validation of the water level downstream.

NJ_{Min} – Minimum value for validation of the water level downstream.

Data

Algorithm for calculation of results

In such apparatus there are no calculations, the readings obtained are transferred directly to the database.

10.9 WIDE BASE EXTENSOMETERS

The measurement of extensions within the foundation of the dam was carried out with large base extensometers. With the advent of foundation extensometers this type of device is no longer used.

This device comprises a Carlson joint meter to which is screwed a steel rod. The complete set, with a length of approximately 2 m, is protected by a jacket of copper sheet 0.3 mm thick, filled with grease.

The schema of the connections and methods are the ones suitable for reading the electrical resistance strain gauges Carlson .

Group – Group number of strain gauges.
Position – Position of the gage in the group..
Code – Code for identification of the strain gage in the computer system.
Block – Block group placement of the extensometers.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota group location of the extensometers.
R_0 – Total resistance at a temperature of ° C. Constant supplied by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit to validate the reading of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Constant supplied by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum limit for validation of the relationship of the resistances.
r_{Min} – Minimum limit to validate the reading of the ratio of resistors.
ε_1 – Change in length by ten thousandth of a variation in the resistance. Value obtained in the laboratory before the installation of the extensometer.

Data

Algorithm for calculation of results

The expressions for calculation at the time *n*, of the temperature (T_n) and extension (ε_n) in each of the extensometers are as follows:

$$Tn = (R_n - R_0)\Delta_t \qquad \text{(ºC)}$$

$$\varepsilon n = (r_n - r_i)\varepsilon_1 \qquad (\times 10^{-6})$$

where,

R_n – Reading of the total resistance at the time *n*
R_0 – Total resistance at a temperature of ºC
Δ_t – Temperature range in ° C per ohm of resistance variation
r_n – Ratio of the resistances reading at time *n*
r_i – Initial reading of the resistance relations
ε_1 – Variation of the extension ten thousandth of a variation in the resistance

10.10 ACOUSTIC EXTENSOMETERS

The placement of the vibrating string extensometers to determine the extensions on the concrete in concrete dams has been unusual in Portugal, and was only applied to the Salamonde, Venda Nova and Castelo de Bode dams.

The vibrating string extensometers are fundamentally constituted by a vibrating string steel of 0,3 mm diameter, firmly attached at both ends of the extensometer. The rope is excited by an electro-magnet which also serves to capture the string vibration. Thus, any deformation of the concrete surrounding the unit will vary the tension to which the rope is subjected, and hence its natural frequency of vibration.

Measuring the frequency of the rope was made by the following reading devices: Maihak, Télemac and Electron. Currently, the measurements are performed with a digital readout device that directly provides the period of vibration of the string.

The information contained in the 2nd group of the support table for the acoustic extensometers, Is as follows:

Group – Group number of extensometers.
Position – Position of the extensometer in the group.
Code – Code for identification of the extensometer in the computer system.
Block – Block group placement of the extensometers.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota group location of the extensometers.
F_i – Initial string vibration frequency.
$T_{Máx}$ – Maximum limit for validation of the extensometer string period reading.
T_{Min} – Minimum limit for validation of the extensometer string period reading.
GF – Constant for transformation of the frequency of the string in length.
K – Calibration constant.

Data

The reading provided by this type of device is the period of vibration of the string (*T*) per cycle in seconds x 10^{-7}.

Algorithm for calculation of results

The expression for calculating the length (ε_n) at the time *n*, for each of the extensometers are as follows:

$$\varepsilon_n = -\left(\left(1/T_n\,100\right)^2/\,1000\,GF - F_i\right)K \qquad (\times 10^{-6})$$

where,

$$GF = 0.1\,L^2\,10^{-3} \qquad (\mu\varepsilon/F^2)$$

T_n – Period of vibration of the string at the time *n*
L – Length of the extensometer string in inches

10.11 ACOUSTIC JOINT METERS

This device is based on the use of a vibrating string connected to a speed reducer system of the joint movement and consists essentially of two cylinders and a sealed sleeve.

The support table, data file and calculation algorithm format are the same as the acoustic extensometers, changing only the result of the value obtained, which is expressed in millimetres, so there is no need to repeat what was described above.

10.12 TENSIOMETERS

The direct measurement of tensions in concrete is carried out by electrical resistance Carlson type tensiometers which working principles are described in various publications. The tensiometers differ from the extensometers because of the changes in length that are converted into voltages by appropriate methods, while tensiometers measure, with some approximation, the compressive tension, independent of the deformations. The schema of the connections and methods are the ones suitable for reading the Carlson electric resistance extensometers. The information contained in the 2nd information group of the support table of the Carlson tensiometers) is as follows:

Group – Group number of tensiometers.
Position – Position of the tensiometer group (designation is the same as for the extensometer).
Code – Code for identification of the extensometer in the computer system.
Block – Block of the dam where the extensometer is located.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Location quota of extensometer in the block.
R_0 – Total resistance at a temperature of ° C. Value provided by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Value provided by the manufacturer.
T_i – Initial temperature.
$\Delta\sigma$ – Variation of the voltage in *kg/cm²* for ten thousandth of a variation in the resistance. Value provided by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum reading for validation of the relationship of the resistances.
r_{Min} – Minimum reading to validate the reading of the relationship of the resistances.
C – Correction factor of the voltage due to temperature, and is given by:

$$C = -\left[\left(80\frac{T}{D} + 6,7\right)10^{-6} - K\right] E\ F \quad \text{Kg/cm}^2 / 1^{\circ}\text{C}$$

where:

T – Thickness of the mercury layer. Value provided by the manufacturer.
D – Thickness of the diaphragm. Value provided by the manufacturer.
E – Effective modulus of the concrete elasticity.
K – Coefficient of thermal expansion of concrete.
F – Dependent factor on the device. Value provided by the manufacturer

Data: The readings provided by this type of device in a given time *n*, are as follows:

R_n – Reading of the total resistance at the time *n*

r_n – Reading of the ratio of the resistances at the time *n*

Algorithm for calculation of results: The expressions for the calculation of the magnitudes provided by this type of equipment, temperature (T_n) and tension of the concrete (σ_n), in time *n* are as follows:

$$T_n = (R_n - R_0)\Delta_t \qquad (ºC)$$

$$\sigma_n = (T_n - T_i)C + (r_n - r_i)\Delta_\sigma \qquad (Kg/cm^2)$$

10.13 PRESSURE GAUGES

The measurement of the concrete pore water pressure is carried out by pressure gauges of the Carlson electrical resistance type which constitution and working principles are described in various publications.

The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Meter – Name of the pressure gauge.
Block – Block of the dam where the pressure gauge is installed.
Code – Code identifying the device into the computer system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota location of the pressure gauge on the block.
R_0 – Total resistance at a temperature of ° C. Value provided by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Value provided by the manufacturer.
T_i – Initial temperature.
$\Delta\pi$ – Variation of pressure in kg/cm2, for ten thousandth of a variation in the resistance. Value provided by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum reading for validation of the relationship of the resistances.
r_{Min} – Minimum threshold to validate the reading of the ratio of resistors.
ρ – Temperature correction factor, i.e. the change in the ratio of resistors for each 1 ° C of temperature. Value provided by the manufacturer.

Data

The readings provided by this type of device in a given time *n*, are as follows:

R_n – Reading of the total resistance at the time *n*

r_n – Reading of the ratio of the resistances at the time *n*

Algorithm for calculation of results

The expressions for the calculation of the magnitudes provided by this type of equipment, temperature (T_n) and pressure in the concrete pores (P_n), at the time *n* are as follows:

$$T_n = (R_n - R_0)\Delta_t \qquad \textbf{(ºC)}$$

$$P_n = [(T_n - T_i)\rho + (r_n - r_i)]\Delta\pi \qquad \textbf{(Kg/cm}^2\textbf{)}$$

10.14 THERMOCOUPLES

The thermocouples are devices that allow measuring the temperature of the concrete, and its constitution and principles of operation described in several publications.

The reading of this type of device is made with a digital potentiometer, which gives directly the value of the observed temperature (Figure 72).

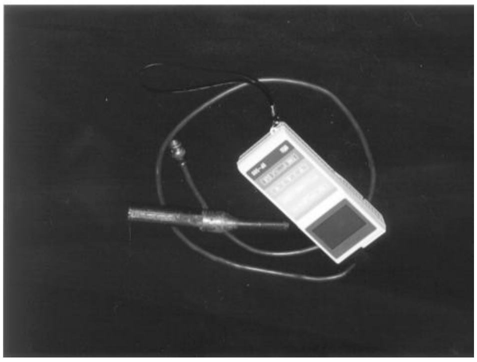


Figure 72: Thermocouple and potentiometer

The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Par – Title of the pressure gauge.

Block – Block of the dam where the pressure gauge is installed.

Code – Code identifying the device into the computer system.

OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota location of the device on the block.

$T_{Máx}$ – Minimum limit for validation of temperature.

T_{Min} – Minimum limit for validation of temperature.

Data

As stated, the readings provided by this type of device in a given time *n* corresponds to the observed temperature in ° C.

Algorithm for calculation of results

Since the reading of the device corresponds to the magnitude observed, there is no place for the implementation of any calculation for determining the value of the temperature observed at time *n* (T_n).

10.15 INCLINOMETERS

The measurement of the rotations in the first Portuguese dams was carried out by bubble level inclinometers and its use was abandoned. Currently, the device used is an electrical resistance inclinometer, type Carlson, which can be embedded in concrete, and which consists of a transducer sensitive to the slope of a plumb line capable of producing an electrical signal proportional to the angle of inclination (Figure 73)

Figure 73: Inclinometer Carlson

The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Inclinometer – Designation of the inclinometer (A4).
Block – Block of the dam where the inclinometer is installed.
Code – Code identifying the device into the computer system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota location of the device on the block.
R_0 – Total resistance at a temperature of ° C. Value provided by the manufacturer.
$R_{Máx}$ – Maximum limit for validation of the total resistance.
R_{Min} – Minimum limit for validation of the total resistance.
Δ_t – Temperature range in ° C per ohm resistance change. Value provided by the manufacturer.
r_i – Initial reading of the resistance relations.
$r_{Máx}$ – Maximum reading for validation of the relationship of the resistances.
r_{Min} – Minimum threshold to validate the reading of the ratio of resistors.
Δ_ϕ – Variation of the rotation in degrees, ten-thousandth of a change in the ratio of the resistances. Value provided by the manufacturer.

Data

The readings provided by this type of device in a given time n, are as follows:

R_n – Reading of the total resistance at the time *n*

r_n – Reading the ratio of the resistances at the time *n*

Algorithm for calculation of results

The expressions for the calculation of the magnitudes provided by this type of equipment, temperature (*Tn*) and rotation (*ϕn*), in time *n* are as follows:

$$T_n = (R_n - R_0)\Delta_t \quad \text{(ºC)}$$

$$\varphi_n = (r_n - r_i)\Delta_\phi \quad \text{(grados)}$$

10.16 FLOW CELL

The deformability of concrete dams is evaluated from laboratory tests and tests "in situ". With respect to these, the tests are performed by flow cells.

Figure 74: Set of flow cells

The test principle is to subject to pressure, concrete cylinders limited by interior part of the cells through a pad of steel filled with oil, connected to the outside by a tube through which is applied such pressures. In the cylinder axis is installed a extensometer, of Carlson type, for measuring the flow deformation, since the pressure is maintained by nitrogen bottles.

Figure 75: Flow cell

Each group of cells is accompanied by a correcting device which allows the flow tests to deduce the variations of the concrete volume from the extensions observed through the cell.

The schema of the connections and methods are the ones suitable for reading the electrical resistance Carlson extensometers. The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Group – Designation of a cell group.

Position – Position of the cell. 3 - Vertical, 11 - corrector.

Code – Code identifying the cell in the computer system.

Block – Block of the dam where the cell is located.

OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota location in the cell block.

R_0 – Total resistance of the temperature ° C, the strain gauge placed in the cell. Value provided by the manufacturer.

$R_{Máx}$ – Maximum limit for validation of the total resistance read on the gage placed in the cell.

R_{Min} – Minimum limit for validation of the total resistance read on the gage placed in the cell.

Δ_t – Variation of the temperature in ° C per ohm resistance change of strain gauge placed in the cell. Value provided by the manufacturer.

T_i – Initial temperature.

ε_2 – Correction of the extent due to the variation of 1 ° C temperature, strain gauge placed in the cell. Value provided by the manufacturer.

r_i – Initial reading of the relation of the resistances read on the extensometer placed in the cell.

$r_{Máx}$ – Maximum reading for validation of the relationship of the resistances read on the extensometer placed in the cell.

r_{Min} – Minimum threshold to validate the reading of the relationship of resistances read on the extensometer placed in the cell.

ri_i – Initial reading of the reverse resistance ratio of extensometer placed in the cell.

$ri_{Máx}$ – Maximum reading for validation of the inverse relationship of the resistance read on the extensometer placed in the cell.

ri_{Min} – Minimum threshold to validate the reading of the inverse relationship of the resistance read on the extensometer placed in the cell.

ε_1 – Variation of the extension by ten thousandth of the variation in the resistance of an extensometer placed in the cell. Value provided by the manufacturer.

Data

The readings provided at the time *n*, for this type of device are as follows:

P_n – Reading at the time *n*, pressure to which the cell is subjected

R_n – Reading at the time *n*, the total resistance of the extensometer placed in the cell

r_n – Reading at the time *n*, the ratio of the resistance of the extensometer placed in the cell

ri_n – Reading at the time *n*, the ratio of the inverse of the resistance of the extensometer placed in the cell

Algorithm for calculation of results

The expressions for the calculation of the magnitudes provided by this type of equipment, temperature (*Tn*) and extension (εn) at time *n* are the following;

$$T_n = (R_n - R_0)A_t \quad (ºC)$$

$$\varepsilon_n = (T_n - T_i)\varepsilon_2 + [(r - r_i) + (i_i - ri)/2]\varepsilon_1 \quad (x10^{-6})$$

10.17 PRECISION GEOMETRIC LEVELING

The levelling accuracy is the determination of height differences between points in the structures and fixed points (or with known displacements) using equipment (levels of precision and invar sights) and special operating techniques.

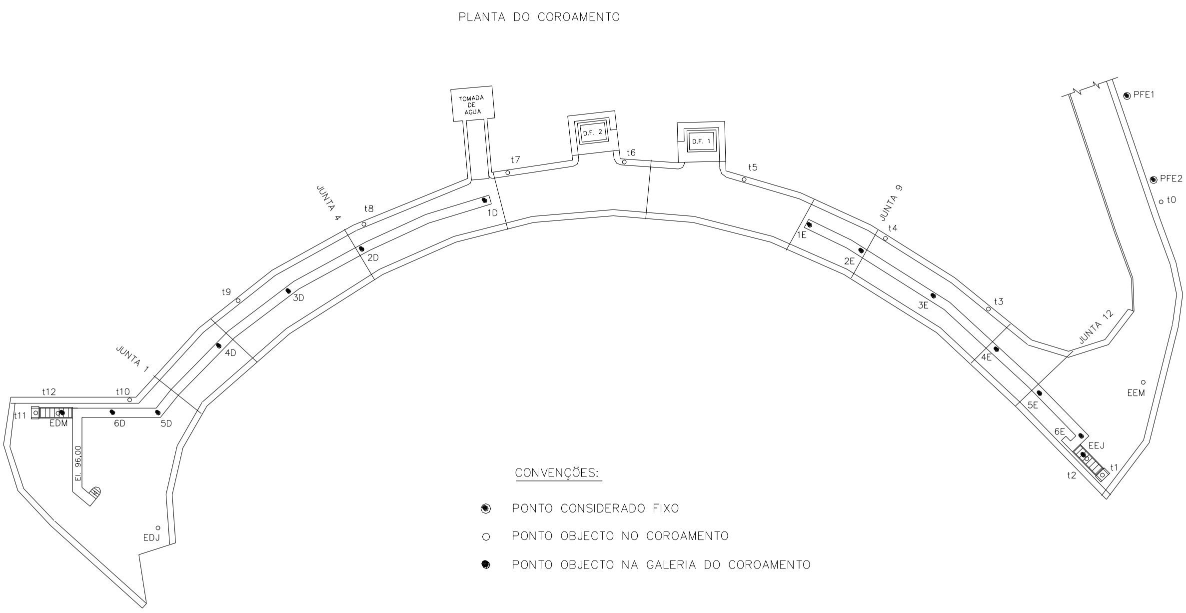


Figure 76: Precision geodetic network

The variation between seasons, the differences in quotas in relation to fixed points, allows for shifts in the vertical direction.

Currently data of this type of device is not treated in gestBarragens. It is pre-processed and calculated in a different department that sends the final displacements to the gestBarragens system, which only makes a transfer to the database of the obtained results in the applied geodesy group.

The support information is as follows:

Point – Point Designation.
Block – Block of the dam where point is located.
Code – Code identifying the point in the computer system.
OE – Indicates whether this device code is part of the expedite observation.
Quota – Quota point location in the block.
$D_{Máx}$ – Ceiling to validate the observed shift.
D_{Min} – Minimum limit for validation of displacement observed.

Data: The value that appears in the "main individual information," referring to this type of device, corresponds to the observed displacement in *mm*.

Algorithm for calculation of results: Since data of this type of device is not calculated in GestBarragens, we do not describe the respective calculation algorithm.

10.18 GEODESIC SHIFTS

The horizontal displacements of the structure can be observed through a plumb wire or by geodetic methods. The geodetic method most used in Portugal is the external triangulation network.

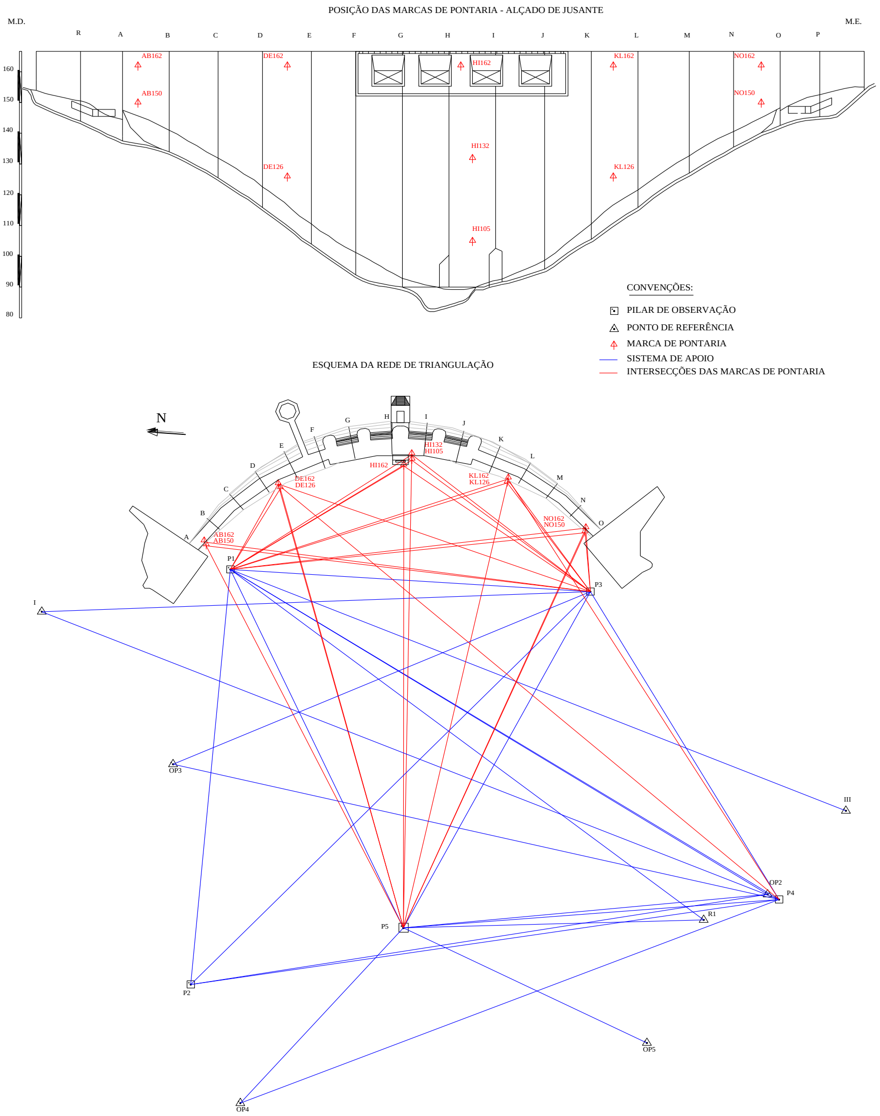


Figure 77: Triangulation network

The exterior triangulation networks consist of sets of vertices materialized by pillars with adequate foundation and aiming targets placed at points of the structure and in solid foundation.

The observation of the network is the measurement of linear and angular values, according to rules and operating sequences previously planned, using appropriate equipment (distance meters, theodolites). The results are set, validated and converted into displacements, according to a suitable mathematical model.

The data in this type of equipment are treated at the centre for applied surveying, and the results are transferred to gestBarragens.

The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Brand – The brand name of the aim or point to measure.

Block – Block of the dam where the tag is located.

Code – Code identifying the point in the computer system.

OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota location of the tag in the block.

$DR_{Máx}$ – Ceiling to validate the observed radial displacement.

DR_{Min} – Minimum limit for validation of the radial displacement observed.

$DT_{Máx}$ – Ceiling to validate the observed tangential displacement.

DT_{Min} – Minimum limit for validation of the tangential displacement observed.

Data

The values that appear in fields in the "information leading individual", referring to the readings of this type of device, match the observed radial and tangential displacements in *mm*.

Algorithm for calculation of results

Since data of this type of apparatus are not calculated in GestBarragens, we do not describe the respective calculation algorithm.

10.19 Convergence meter

Such device allows the measurement of points of similarities between the structures. Its application is most common in tunnels and caves. In 21 is depicted the layout of a measuring section for convergence in a tunnel.

The information contained in the 2nd information group of the support table for this type of equipment is:

Section – Section Name of convergence.
Block – Location of the section.
Code – Identification Code of the section.
OE – Indicates whether this device code is part of the observation.
Quota – Quota location of the section.
LP_i – Initial default reading.
$LP_{Máx}$ – Ceiling to validate the pattern reading.
LP_{Min} – Minimum limit for validation of the pattern reading.
F_i – Number of the start hole of the tape.
LF_i – Initial reading of the tape.
$LF_{Máx}$ – Maximum limit for validation of tape reading.

LF_{Min} – Minimum limit for validation of tape reading.
T_i – Initial Ambient temperature.
$T_{Máx}$ – Maximum ambient temperature for validation.
T_{Min} – Minimum limit for validation of temperature.
η – Coefficient of thermal expansion of the tape.
Length – Length of the tape.

Data: The readings provided at time *n*, for this type of device are as follows:

LP_n – Standard Reading
F_n – Reading of the hole of the tape
LF_n –Tape measurement
T_n – Ambient Temperature

Algorithm for calculation of results: The expression for calculating the convergence at the time $n(C_n)$ is:

$$C_n = (F_n\, 12.5 + LF_n) - (F_i\, 12.5 + LF_i) - (T_n - T_i)\,\eta\, l/1000 - (LP_n - \eta) \quad \text{(mm)}$$

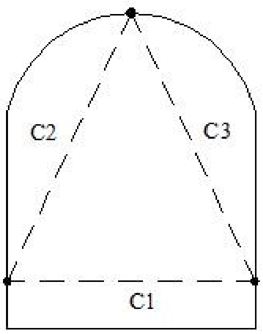


Figure 78: Measuring section convergences

10.20 THREE-DIMENSIONAL BASES

The three-dimension bases (Figure 79) are intended to measure the surface (galleries or base underside of ornament downstream), the joint movements or cracks in three directions.

Figure 79: Three-dimensional base

Measurements of variations, according to the three directions are carried out with a measuring device. The information contained in the 2nd information group of the support table for this type of equipment is as follows:

Base – Base number.

Position – Position of the base in relation to the joint.

Code – Code identifying the basic sensor in the computer system.

Joint – Joint of the dam where the base is installed.

OE – Indicates whether this device code is part of the expedite observation.

Quota – Quota based on the location of the joint.

$L1_i$ – Initial Reading of side 1.

$L1_{Máx}$ – Maximum value for validation of the Reading of side 1.

$L1_{Min}$ – Minimum value for validation of the Reading of side 1.

$L2_i$ – Initial Reading of side 2.

$L2_{Máx}$ – Maximum value for validation of the Reading of side 2.

$L2_{Min}$ – Minimum value for validation of the Reading of side 2.

$L3_i$ – Initial Reading of side 3.

$L3_{Máx}$ – Maximum value for validation of the Reading of side 3.

$L3_{Min}$ – Minimum value for validation of the Reading of side 3.

Data

The readings provided at the time n, for this type of device are as follows:

$L1_n$ – Reading from side 1

$L2_n$ – Reading from side 2

$L3_n$ – Reading from side 3

Algorithm for calculation of results

The displacements according to the three directions, Δ_n, ΔH_n, ΔN_n, observed at the time *n* are given by the following expressions:

$$\Delta_n = -(L3_n - L3_i) \quad \text{(mm)}$$

$$\Delta H_n = -(L2_n - L2_i) \quad \text{(mm)}$$

$$\Delta N_n = -(L1_n - L1_i) \quad \text{(mm)}$$

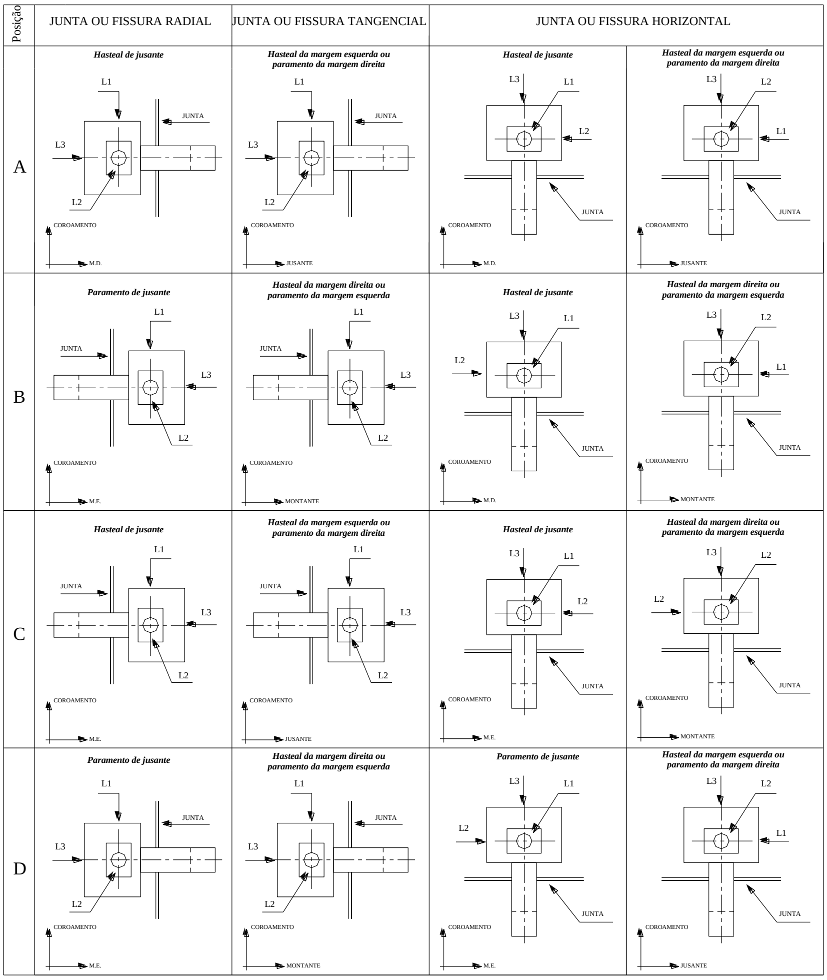


Figure 80: Three-dimensional bases - signs convention

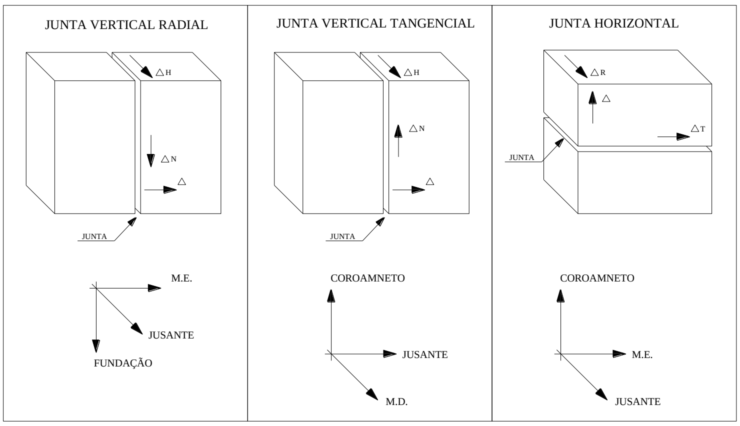


Figure 81: Three-dimensional bases. Base position in relation to the joint and conventions for the positive direction of motion

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