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TOWARDS A DAMS SAFETY MANAGEMENT SYSTEM FOR ANGOLA

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Abstract. *Dams have contributed to the human development and have brought many benefits, such as delivering hydropower, irrigating agricultural fields, supplying drinking water, or just for navigational and recreational purposes. Nevertheless, dams are critical structures that raise multiple concerns and risks associated with the ecological, social and economic impact. Angola has a rich and complex network of water basins and dams that serves different strategic purposes as defined in its water resource management policy and respective strategic plan that, namely, considers relevant to build new dams and to better operate the existent ones. In fact, some of the most important dams in Angola are equipped with safety management information devices that perform data collection and storage for infrastructural analysis and reporting. However, many of these systems are currently in a critical condition. The civil war of 1975-2002 took a toll on dam safety measures and systems and most of them are outdated or malfunctioning. The dams that are presently under construction, like Matala, will already be equipped with safety management devices that are able to perform measurement of variables such as displacement and discharges, among others. Yet, new and adequate legislation must be created for all these efforts to effectively take place: the National Dam Safety Plan may provide the answer and framework to this state of affairs. Additionally, in this paper we assert that a more complex and integrated system can help to achieve this plan. Hence, the main contribution of this paper is the proposal of the gestBarragens-2, a next-generation Dam Safety Management System (DSMS), particularly fitting for the geographic and political context of Angola. This DSMS high-level architecture reflects our experience with the design, development and operation of a former DSMS in Portugal over this last decade, but also the state of art analysis and our own learning process, introspection and criticism. The gestBarragens-2 architectural view defines the complex integration of several subsystems in two complementary dimensions: the applicational and the technological. The applicational subsystems are mainly functional, while the technological subsystems provide cross-cutting features that are widely used in the DSMS as a whole.*

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1 INTRODUCTION

Dams have contributed to human development and have brought many *benefits* to societies such as delivering hydropower, irrigating agricultural fields, supplying drinking water, or just for navigational and recreational purposes [1]. On the other hand, dams are critical engineering structures that raise multiple *concerns and risks* associated with the ecological, social and economic impact [1,2,3]. Some of these risks are caused by acts of nature, e.g., earthquakes and excess or lack of precipitation that causes flooding or extreme drought. Other risks are due to human error, e.g. when dams are poorly planned, built or maintained, or just due to the deterioration of their structures. Hence, in spite of the growing experience in designing, building and maintaining dams, dam safety is a crucial issue of debate among national and international communities [4-7]. For example, the Dam Safety Committee, within the International Commission on Large Dams (ICOLD), defined a technical report with a set of goals and key requirements towards a *dam safety management system* (DSMS) [4], which have been followed and adopted by many countries.

Angola has a rich and complex network of water basins and dams that serves three main strategic purposes: provide drinking water to population, leverage agricultural irrigation, and increase the production of hydroelectric power [8-10]. The Angolan Government has developed a consistent water resource management policy over the years, focused primarily on the legal figure of their five-year plan applied to most of the strategic areas of intervention, which considers relevant to build new dams and to better operate the existing ones.

Some of the most important dams in Angola are equipped with safety management information devices that perform data collection and storage for infrastructural analysis and reporting. Cambambe, Capanda and Biopio are particularly significant in this matter. However, many of these systems are currently in a critical condition. The civil war of 1975-2002 took a toll on dam safety measures and systems and most of them are outdated or malfunctioning. Several dams are in risk and need an update and/or upgrade of their systems to ensure satisfactory levels of safety. The dams that are presently under construction, like Matala, will already be equipped with safety management devices that are able to perform measurement of variables such as displacement and discharges, among others. However, new and adequate legislation must be created for all these efforts to effectively take place: the National Dam Safety Plan may provide the answer and framework to this state of affairs. Additionally, we assert that a more complex and integrated DSMS system can help to achieve this plan by providing a set of technologies that allows a better management of the dams of Angola.

This paper is structured in 5 sections. Section 2 overviews the scenery of the Angolan dams, describing in particular its geographic and political/organizational frameworks. Section 3 describes the reality concerning the ownership and the national authority of dams in Portugal, and also introduces *gestBarragens*, which is a DSMS design and is developed by the National Laboratory for Civil Engineering (LNEC) and INESC-ID, and is currently supporting the majority of large concrete dams and stakeholders in Portugal [11,12]. Section 4 introduces *gestBarragens 2.0* (or just "*gestBarragens-2*" or "*gB*" for short) that is our proposal for the preliminary design of a next-generation DSMS, particularly fitting for the geographic and political context of Angola. Finally, Section 5 presents a general discussion of the related work and summarizes the conclusions of the paper.

The main contribution of this paper is the proposal of the gestBarragens-2, whose high-level architecture reflects our experience in the design, development and operation of a

DSMS like gestBarragens over this last decade [11,12], but also the state of art analysis [1-7] and our own learning process, introspection and criticism. The gestBarragens-2 architectural view defines the complex integration of several subsystems in two complementary dimensions. On the applicational dimension it integrates the following subsystems: gB-Core, gB-Monitoring, gB-Inspections, gB-Incidents and gB-Risks. On the technological dimension it integrates the additional subsystems: gB-CMS, gB-Documents, gB-GIS, gB-Alarms, gB-Reports&Alarms, and gB-Interop. The applicational subsystems are mainly functional, while the technological subsystems provide cross-cutting features that are widely used in gestBarragens-2.

2 DAMS IN ANGOLA

The scenery of the Angolan dams offers a rich and complex reality, constantly evolving according to the geographical and political frameworks to which it belongs. Aiming to provide a straightforward account of both dimensions, we describe and then relate them within an institutional and regulatory context in this section.

2.1 Geographic framework

Angola has four different main watercourse areas: Atlantic, Zaire, Zambeze and Kalahari. The Atlantic area comprehends Chiluango, Zaire, Bengo, Cuanza, Queve, Catumbela and Cunene river basins. Zaire area is composed of Cuango and Cassai river basins. The Zambeze area widens to all the eastern Angola river basins, which overlaps the national boundaries of eight countries – Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. Kalahari area gathers Cubango river basin and its tributaries Cuchi and Cuito.

Within Angolan borders there are many superficial watercourses but, due to the scarcity of precipitation, most of them are only temporary. Therefore, it becomes urgent to design and to build hydric infrastructures that can store enough water supplies to cover the needs of the communities during the dry season, which takes around six to seven months and is known in Angola as “Cacimbo”.

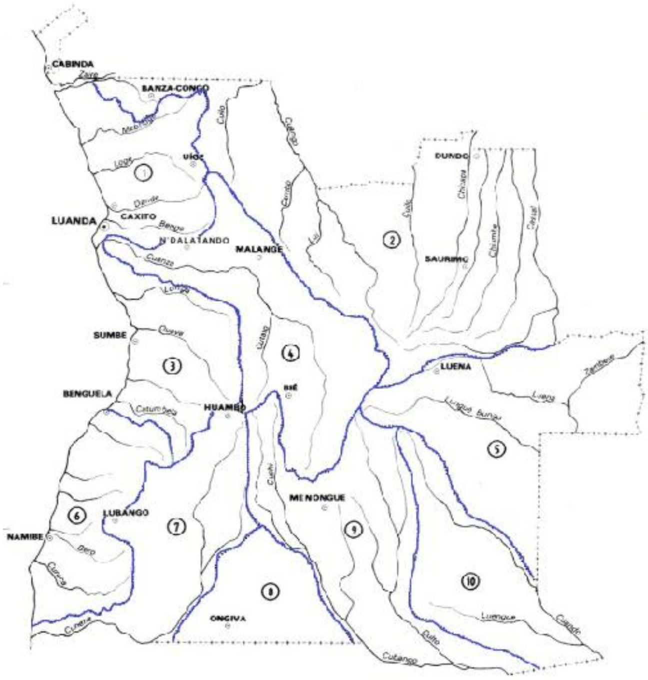

Figure 1: Main river basins in Angola.

Most Angolan rivers are born in the Central Plateau, Huambo region, also named as the “Large Springs Region”. Cuanza river is the largest among the watercourses that flow exclusively within Angolan borders [8]. It is born in Mumbué, municipality of Chitembo, in Bié province (near Huambo), in the Central Plateau. This river is 960 km long, crossing the provinces of Cuanza-Norte, Cuanza-Sul, Bié and Malange and flowing from South to North, into the Atlantic Ocean, southern to Luanda. The 2680 km long Zambeze river is another important watercourse. In fact, is one of the greatest in the African Continent. Cuanza and Zambeze have the most important river basins in Angola [13]. Both flow in locations where precipitation may vary from 400 to 1200 mm. Its volume depends more than 50% from precipitation. Angola is also the place where a significant amount of the Zaire river hydrographic systems are located, which is relevant since this is one of Western Africa’s largest river, around 4000 km long. Rich and complex, this hydrographic system (see Figure 1) enables Angola to shape a prosperous future, if the climate is favourable and, especially, if the authorities gradually improve their management skills in order to create a safer, more profitable and more sustainable national dam system.

2.2 The Dam Network in Angola

The dam network in Angola serves three main objectives: to provide drinking water supply to the communities, to enable agricultural irrigation and to be source of hydroelectric power generation. According to the Angolan Ministry of Energy and Water, Capanda, Cambambe, Biopio, Gove, Matala, Luachimo, Chicapa and Lomaúm are currently the most important dams generating hydroelectric power. The following group of twelve – Calueque, Cambumbe, Gandjelas, Quipungo, Chicungo, Chicomba, Calima, Dungo, Luinga, Quiminha, Neves and Sendi – is the most relevant when approaching the agricultural irrigation subject. *Drinking water* can be collected in most of them, if directed to drinking water treatment centres. On this particular matter is important to stress that the water consumption of the Angolan communities is low, as in 2002 daily *per capita* water consumption reached an average of 7,6 litres [14]. Currently, the communities still have to cope with various and delicate issues concerning drinking and irrigation water supply. That is why Calueque, Cuando and Ruacaná (Cunene province) dams and weirs have a critical role in providing drinking water not only to the region where they are implemented, but mostly to the capital of the country, Luanda. Each one serves as a rainwater collector, essential to water supply, and simultaneously regulate the volume of the water in the river flow.

On the second topic of *irrigation*, the above-referred twelve dams are the most relevant in volume. A good example is provided by Calenga, municipality of Caála, Huambo province, where 110 small weirs were built and/or upgraded during 2014, in order to help strengthening local agricultural activities,

The current state of the Angolan dam system concerning *hydroelectric power generation* is gradually improving. Electricity is still residual to the energetic matrix of the country, supplying 1.50 % [15] of the national energy consumption. Nevertheless, official forecasts point to a figure of 100 MW power generation from hydroelectric sources by 2025 [10].

Currently, the most important dams equipped with power generation plants in working conditions are Capanda (Malange province), Hidrochicapa (Lunda-Sul province), Cambambe (Cuanza-Norte province) and Gove (Huambo province), many of them repaired or upgraded since the first decade of 2000. Most of them are part of the power generation and water supply and irrigation systems. Still under construction, Laúca dam (in Cuanza-Norte) is planned to become the largest in Angola, generating a potential of 2067 MW, four times the production of Capanda’s dam, one of the largest in the country. Additionally, several other dams are to be built or upgraded throughout the country until 2017, namely Baynes, Caculo

Cabaça, Jamba ya Oma, Jamba ya Mina, Luachimo, Chiumbe-Dala, Cambambe II Hidrochicapa II and the mini-hydro plants of Cunje and Cutato.

There are 77 river basins in Angola, although only 47 of them are suitable for hydroelectric power generation. These resources could generate electricity up to an amount of 18.000 MW but, currently, the existent infrastructure only allows to produce 4% of this value, near 800 MW. Despite the number and the power generation potential, many of these dams depend of the precipitation rates and, for that reason, may never work at their full capacity if medium and long-term climate conditions are not favorable.

2.3 Water resource management and dam safety planning

The Angolan Government has developed a consistent water resource management policy over the years, focused primarily on the legal figure of their Five-year plan, applied to most of the strategic areas of intervention. Within the National Development Plan 2013-2017 [15], the Angolan government names as a priority a policy to ensure the integrated management of water resources, by continuing the process of creating river basin management entities and developing strategic plans to each one. This means that the government aims to complete 22 strategic plans until 2017 [9]. To date, the management entities of Cubango, Cuvelai and Zambeze river basins are under conclusion; two river basins are presently managed by specific entities: GAMEK, in the case of the Cuanza river; and GABHIC, in the case of Cunene river.

The entity responsible for regulating the water resources in Angola at a national level is currently INRH. INRH is the institute for hydric resources management, subordinate of the Ministry of Energy and Water (MINEA). MINEA and the Ministry of Agriculture and Rural Development (MINADR) share attributions in the dam management regulation, according to the nature of each dam. Additionally, and according to the policies explained in the previous section, GAMEK and also GABHIC are responsible at an intermediate and regional level, concerning the river basins. Other 20 river basin management authorities will join them when the legislative processes are concluded.

Some dams and weirs belong to private entities and are mainly for agricultural purposes but, in some cases, are also being used for hydroelectric power generation.

From the power generation perspective, the entity in charge of the energy provision was, until last year, ENE, the state-owned electricity management company. But by the end of 2014 a deep reform took place. ENE was extinguished and its previous responsibility is now shared by new state-owned companies: ENDE, in charge of energy distribution, RNT, responsible for energy transport, and PRODEL, a new state-owned company for the management of energy production.

Despite the legislative work developed to provide a consistent legal framework, authorities acknowledge the need to regulate at a deeper level and provide the technicians and managers with a hands-on regulatory toolkit. Safety and energy management are two priorities for the Government and, therefore, in November 2014, the Ministry of Energy and Water announced the creation of a National Dam Safety Plan, aimed at identifying and managing critical safety issues on dams.

3 THE PORTUGUESE EXPERIENCE AND THE GESTBARRAGENS SYSTEM

In Portugal, the behavior of most large dams is being continuously monitored by sensors, such as plumblines and piezometers installed at strategic points [16,17]. Typically, a large concrete dam is monitored by hundreds to a few thousands of sensors. Sensor readings are collected either manually, by human operators using specific measuring devices, or automatically, by data acquisition units connected to the sensor network. After the acquisition process, the raw data follows a specific process and is transformed into engineering quantities (e.g. displacements, seepage) by specific algorithms that use a set of calibration constants.

According to the Portuguese Dam Safety Legislation [18], LNEC is responsible to keep an updated electronic archive of instruments data to support the analysis of the dam safety conditions. This Legislation also defines the duties and responsibilities of the different parties involved on dam safety, namely the Dam Owners, the National Dam Safety Authority, the National Latoratory for Civil Engineering (LNEC), the Civil Defense Authority and the Dam Safety Commission. In order to maintain this archive updated, the gestBarragens system was developed through a close collaboration among three Portuguese institutions (LNEC, INESC-ID and EDP – Portuguese Electricity Company) and is currently deployed in the organizational context of LNEC, EDP and other dam owners. It is a modular information system providing components to manage dam observations, visual inspections, and simulation models. It supports the management of technical documents and provides a set of analysis tools such as tabular and chart reports [19].

Figure 2 shows a simplified UML deployment diagram of the gestBarragens system, which also informs about the system's architecture. It 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. The reports are designed and implemented using MS Reporting Services 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.

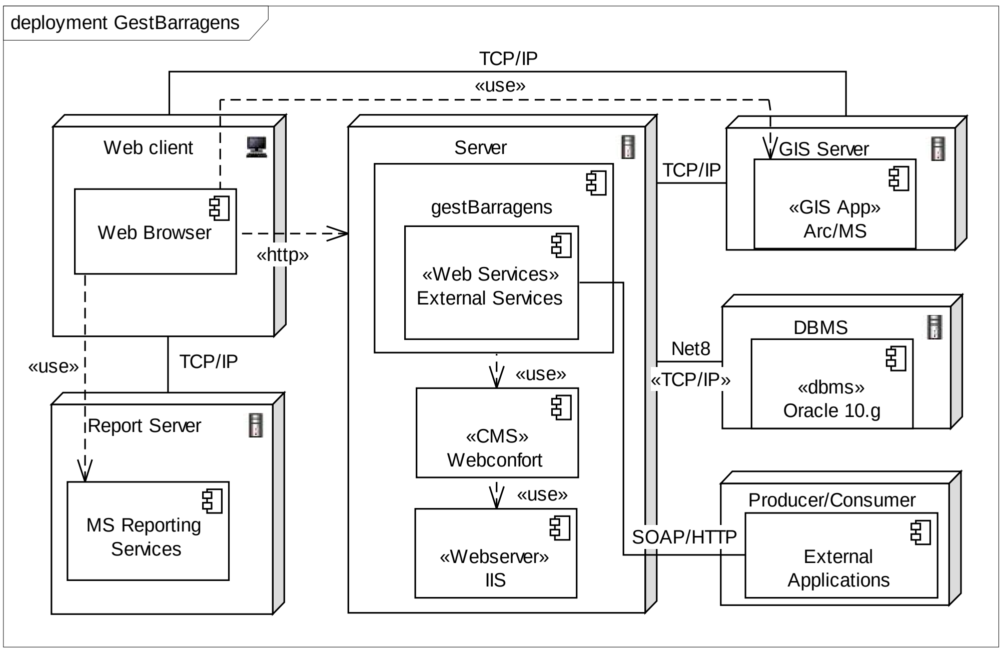

Figure 2: Deployment diagram of the gestBarragens system

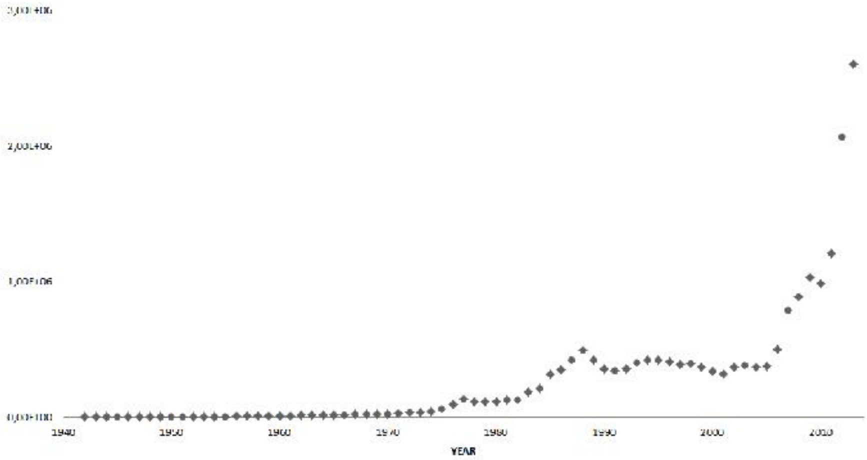

Figure 3: Sensor data acquisition per year

GestBarragens provides a number of solutions that are critical in the field of civil engineering, with the following key aspects: (*i*) *instrumentation*: it integrates new observation sensors, supports the dynamic management of new types of sensors, and manages metadata about sensors; (*ii*) *transformation process*: it manages the sensor specific algorithms to convert raw data (readings) into engineering quantities (results) using metadata properties, such as calibration constants; (*iii*) *management of multiple sensor types*: which supports a larger number of sensor types.

Currently gestBarragens manages 162 dams and supports 46 types of manual data acquisition sensors and 25 types of automatic data acquisition units. Additionally, gestBarragens manages the following total volume of data: 34200 manual data acquisition sensors, 514 automatic data acquisition units, 16.420.627 manual results and 5.482.426 automatic results. A recent investment in automatic data acquisition additionally leads to a higher frequency of data acquisition (Figure 3). The current growth rate is expected to stabilize or increase in the following years, since new large dams are currently under construction and the major dam owners are investing in new automated monitoring systems to further increase the real-time monitoring of critical infrastructures.

Figure 4 details information that 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 are reflected in the information's organization. In this way, the campaigns, measurements and results can be specialized in general observations or in geodesic observations. The relations between the concepts modelled in the domain diagram are the following: (i) each campaign has a set of readings from a certain instrument; (ii) each measurement is associated with one or more events; (iii) one measurement can generate one result (there can be several scalar values associated with one measurement); and (iv) 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).

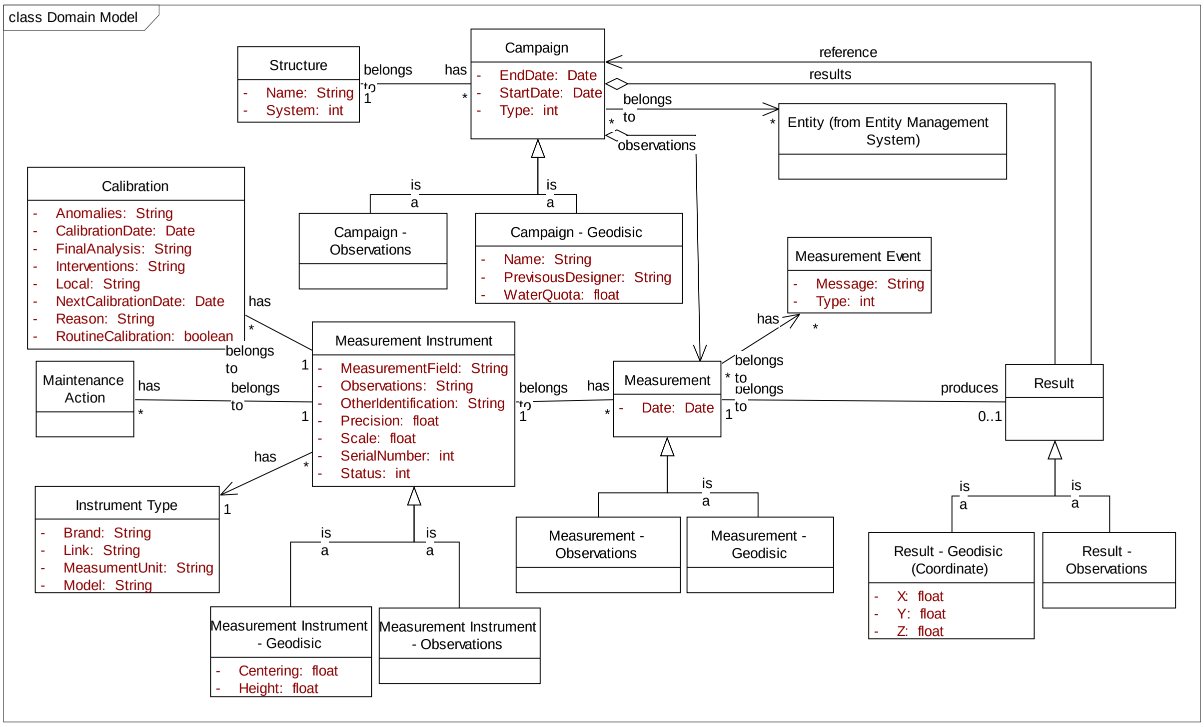

Figure 4: Domain Structure Diagram

4 HIGH-LEVEL ARCHITECTURE OF GESTBARRAGENS 2.0: A DAM SAFETY MANAGEMENT SYSTEM FOR ANGOLA

As introduced in the Section 3, gestBarragens was defined as an integrated dam safety management system for concrete dams, which supports the following major processes: manual and automatic monitoring of physical readings from the instrumentation systems installed in dams; visual inspections made by human intervention; management documents and digital assets associated to dams; and fault detection in the observed data, which can result in decisions to ensure the safety of dams [12,19].

The gestBarragens-2 is a comprehensively dam safety management system, particularly fitting for the reality of Angola and in accordance with its specific requirements and business goals, as introduced in Section 2. GestBarragens-2 results from the knowledge and experience to design, develop and operate gestBarragens in the Portuguese reality over the last decade.

However, gestBarragens-2 aims to overcome several technical limitations of gestBarragens, particularly in what concerns its programming technologies, development and support platforms. In particular, gestBarragens-2 should provide new features and technologies, such as a new CMS system, a new reporting and dashboards platform with the production and visualization of graphic models, integration with geographic information system, integration with mobile applications, and interoperability mechanisms with physical systems, as well as software applications developed by third-parties. Figure 5 illustrates the top-level architecture of gestBarragens-2 with its major subsystems. Some of these subsystems (shown to the left of the figure) are considered “applicational modules”, while others are more “technological or infrastructural modules” (shown to the right of the figure). There are many interdependencies among these subsystems and, in general, technological subsystems support the majority of the applicational subsystems.

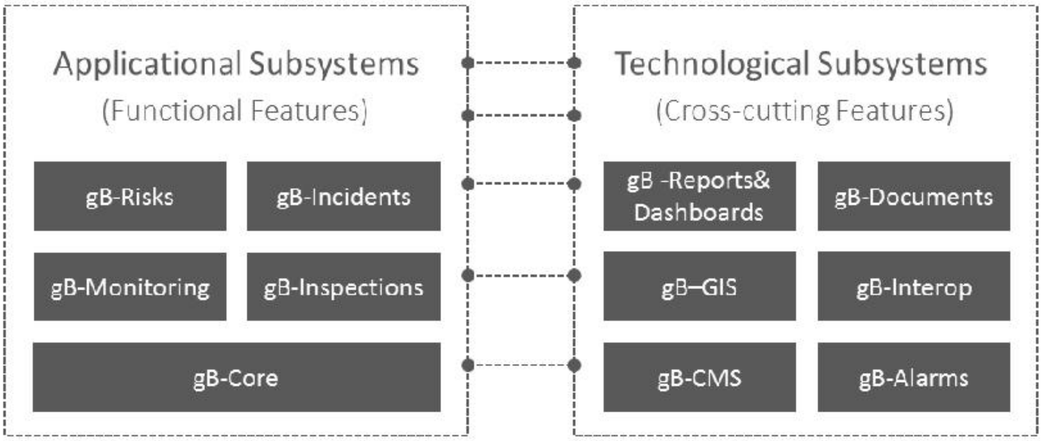

Figure 5: gestBarragens-2 – top-level architecture.

4.1 Applicational Subsystems

As depicted in Figure 6, gestBarragens-2 involves the following applicational subsystems: gB-Core, gB-Monitoring, gB-Inspections, gB-Incidents and gB-Risks. gB-Core is the core framework on which the others depend. gB-Monitoring is an important subsystem, mostly common to every dam safety management system. gB-Monitoring includes the gB-Models, considered as a (sub)subsystem specialized in providing flexible analysis models. gB-Inspections allows the management of visual inspections that might occur as routine or in exceptional situations. gB-Incidents provides a data repository with all information and historical events that have occurred during the dam lifecycle. Finally, gB-Risks support all activities related to the risk management of each dam, and has a strong interdependency with other subsystems.

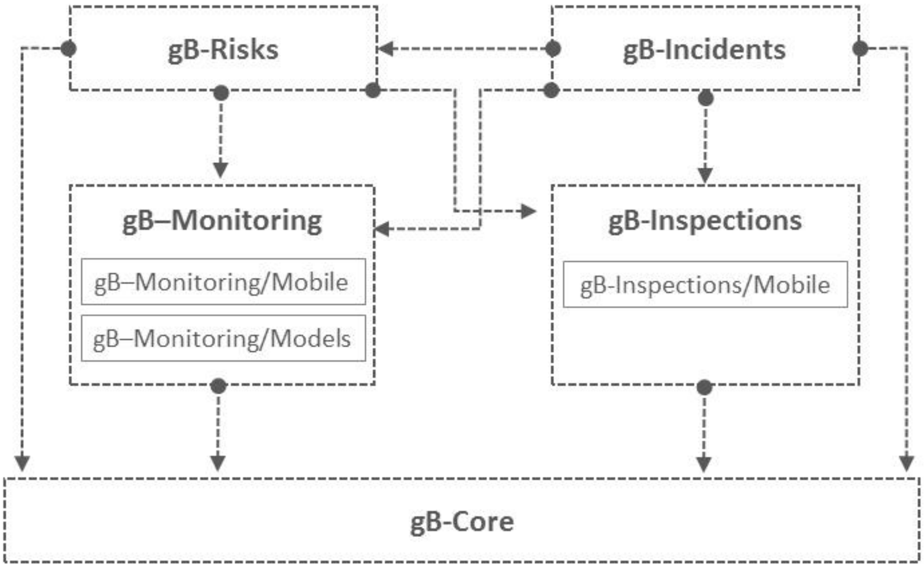

Figure 6: gestBarragens-2 – applicational modules and main dependencies.

gB-Core: General Management and Support. The gB-Core subsystem involves the management and configuration of common features, including, for instance, the information management that is transversal to other applicational modules, such as the management of dams, organizational entities, and geographic related entities. A *dam* (or more generally "engineering work" or "engineering structure") is composed by several elements (e.g., dam foundation, underground works, dam reservoir), and each element can comprise several sub-elements (e.g., the element “underground works” can be composed by surge shafts, inlets, caves). One can associate organizational entities to the dam (e.g., dam owner, public authority) as well as to its elements (e.g., engineer and builder organization). It can also be associated with each dam information on the water line (and watershed), the production center, and the corresponding overall geometry. *Organizational entities* allow the management of individuals and organizations, with a variety of attributes and classifiers, and also the possibility to associate individuals to organizations and vice versa; it is yet possible to provide particular individuals with a system user account. *Geographic related entities* allow the definition of a common set of types and elements of geographic nature that can later be associated with both organizational entities and dams. The following types are defined: Region or Province, County, Town and District, but also Watershed and Water Line. Note that these types are alphanumeric, but allowing the establishment of associations with counterpart, such as geographic information to be kept in gB-SIG.

gB-Monitoring: Dam Monitoring System. The gB-Monitoring subsystem supports the management of instrumentation and safety monitoring networks, their monitoring campaigns, treatment and validation of the information monitored and the analysis of the results. In particular, gB-Monitoring supports the following activities: configuration of meta-information of the dams, respective monitoring systems and reading instruments; the reading and validation of values, manual or automatically read from the instruments of the monitoring system; conversion of reading values into engineering quantities values; the generation of quantitative interpretation models, i.e. models of the dam’s elements that show numerical and graphical evolution of quantities (readings and engineering quantities according to various criteria). By default, gB-Monitoring provides the most relevant interpretation models in an integrated way supported by the gB-Reports&Dashboards. However, gB-Monitoring allows the design and production of other models in the most flexible way, by providing interoperability features supported by the gB-Models subsystem (see below).

gB-Monitoring/Models: Mathematical Model Management System. The gB-Monitoring/Models (or just gB-Models) resorts to gB-Documents subsystem to provide the management of files used by other specialized applications (eventually developed by third parties). These applications allow the calculation of mathematical models that evaluate the safety analysis of the dam’s physical structure. gB-Models enables the storage of multiple files such as (input and output) data files, executable files, and settings and configurations files. gB-Models gives particular support to mathematical models. A *mathematical model* has descriptive attributes (e.g., text, images, model type) and an associated set of executable programs, a set of data files, which are used by those executable programs. It has also several parameters that are used during the execution of those applications to generate numeric and graphic files.

gB-Inspections: Inspection Management System. The gB-Inspections subsystem supports the management and exploration of information related to the visual inspections with the purpose of detecting or confirming anomalies and problems in the dam’s elements. gB-Inspections provides previous and post inspection reports, which are specific to the type of site inspected. Additionally, gB-Inspections uses the gB-Documents to provide a folder with images, videos and documents for each inspection. A *visual inspection* complements the safety analysis obtained from the monitoring system installed in the dam. An inspection may be routine, expert inspection or exceptional, and is performed by a set of individuals (i.e., the inspectors) *in loco*, where some relevant sites, i.e. elements and sub-elements, are examined. There are different types of inspection depending on the type of the dam, the elements and sub-elements examined, and the types of occurrences (e.g., leaks, deposits, fissures, joint movements).

gB-Incidents: Incidents Management System. The gB-Incidents subsystem allows the registration of all significant events occurred in a dam over time, as well as all activities involved in the resolution or mitigation of the respective incident. This subsystem allows the registration of all relevant events since its design phase and construction, along with the operation and maintenance phases. An *event/issue* has a date of occurrence and closure, an associated state (e.g., incident analysis, ongoing treatment, solved, closed), a title and description, the name of the responsible entity and other individuals involved, and a documents' folder (kept in the gB-Documents subsystem) with all the files that are relevant to the respective process.

gB-Risks: Risk Management System. The gB-Risks subsystem supports the risk management associated with a dam. The risk is an event that has a probability of occurring and, if it occurs, it might have a positive or negative impact for the stakeholders, in particular for the population and for decision-makers and technicians who, directly or indirectly, are responsible for the occurrence or consequence of these events. Some risks are associated with natural causes, e.g., earthquakes, which can cause damage to dams or bridges; or excess or lack of rainfall, which can cause flooding or extreme drought), but others are due to human error, e.g. dams that are poorly planned, constructed or maintained. gB-Risks supports the following activities: (1) identification of the most significant risks concerning the dam; (2) assessment of its impact, by the analysis of their probability of occurrence and its result, and the consequent prioritization; (3) definition of risk treatment measures, typified by prevention, share or transfer, mitigation, or acceptance strategies; and (4) monitoring, control and communication of the risks. A *risk* has a set of relevant properties, including its title and description, the entities responsible for its treatment (risk owners) if it occurs, its impact level (determined on the basis of the probability and consequence assigned), as well as risk treatment measures, including mitigation plans or emergency plans. In addition, each risk should have a documents' folder (kept in the gB-Documents subsystem) with all the files that are relevant to the process.

4.2 Technological Subsystems

On the technological dimension gestBarragens-2 integrates subsystems that provide cross-cutting features used extensively by the others; these subsystems include gB-CMS, gB-Documents, gB-GIS, gB-Alarms, gB-Reports&Alarms, and gB-Interop.

gB-CMS: Administration and Content Management System. The gB-CMS is the subsystem responsible for the administration and management of cross-cutting issues to the support and operation of the system as a whole, namely by providing the following features: content management, safety/authorization, auditing, and applicational configuration. *Content management* supports in particular the management of different types of Web pages and components, and other aspects related to multi-language, or visual layouts and themes. *User Management, permissions and access control* allows to establish a secure policy and access control according to a flexible system of roles, which enables to satisfy multiple organizational and functional requirements. In addition, any user can be associated with roles, and a role can be associated with multiple users. *Auditing and logging* allows the continuous processing of operations carried out on the main objects (e.g., dams, inspection, risks and events) and provide multiple analyses of these operations in the form of reports and dashboards. Finally, *configuration and definition* features allow the configuration of a large number of objects and system parameters to adjust the system to multiple requirements.

gB-Documents: Document Management System. The gB-Documents subsystem enables the management of all documents and digital assets relating to the dams, namely technical reports and studies, legislation and regulations, visual inspection reports, photos, videos, etc. gG-Documents supports several features, such as the following ones: *Setting mechanisms*, e.g., management of several types/classifiers (e.g. associated with the classification of people, organizations or documents); use of a recycling folder mechanism (recycle bin); or configuration of system roles. *Folder management* features, such as hierarchical management of document folders, with several folders per dam. *Document management* features, which allow the registration, classification, upload dissemination, controlled access and download of documents. *Search and access to documents* features, for access and consultation of documents, e.g., by browsing in the hierarchy of folders or by keyword searching. Each *document* is defined by title and may have a publication date and an id, keywords, relevant observations, authors and publishers. A document may have a file associated in a digital format, or simply a reference to the physical or electronic external location. The association of authors and publishers to the document is not mandatory, and it may correspond to entities (individuals or organizations) formally registered in the system or simply to names without previous record and process in the system.

gB-GIS: Geographic Information System. The gB-GIS is implemented on a GIS platform (Geographic Information Management) that supports navigation functionalities and geographic information visualization at two levels: macro e micro. The *gB-GIS/Macro* allows the geographical visualization of dams in panoramic terms and within country maps and watersheds, allowing an easier and more intuitive user experience, and an overview analysis of the security and risk dimensions of a selected set of dams. On the other hand, *GB-GIS/Micro* allows geographical visualization of the location and internal environment of each dam in particular, including the display of the physical geometry of the work elements, and of the geodetic and instrumental observation networks. The GB-GIS/Micro also allows the analysis and visualization of results obtained by observation systems, the results of the quantitative interpretation models and also the results of mathematical models by means of diagrams and drawings (for example, stress diagrams obtained in the different observation points of the dam structure). The gB-GIS/Micro can be used independently or integrated in gB-Monitoring as an exploration tool of the quantities calculated from the observations.

gB-Alarms: Alarm & Monitoring System. The gB-Alarms subsystem allows the definition and management of alarms based on predefined conditions of the state of one or more structural elements of a dam. When these conditions are checked, the alarm goes off and can notify, via email or SMS, the entities responsible for their analysis and monitoring. gB-Alarms is mostly used by gB-Monitoring and gB-Risks subsystems.

gB-Reports&Dashboards: Reporting and Dashboards System. The gB-Reports&Dashboard subsystem allows a flexible definition and management of reports and dashboards and their dynamic deployment and visualization in multiple web pages throughout the system. Reports and dashboards improves the user's awareness towards their activities, by not only providing an overview of the activity (e.g., for at-glance analysis) but also enabling a more detailed view in order to let users identify the root causes of problems and take appropriate actions. Dashboards have a certain number of prerequisites, such as: helping to define and present the most important information or tasks in a comprehensible manner; provide the ability to act upon the data; highlight problems with alerts; show progress and time series; and should be customizable with colors, charts, key metrics, etc. In addition, they should be specifically customizable based on the following operations: drill down, filters, comparison, alerts, export and print, text-based summary, tagging, and annotations. Some of the most relevant dashboards of gB-Reports&Dashboard are defined for the following objects: dams, water basins, dam, dam element, dam sub-element and instrument. These dashboards should show the overall risk level, the number of incidents per type, etc.

gB-Interop: Interoperability Management System. The gB-Interop subsystem provides several features to support the interoperability of the system as a whole, involving the interoperability with a multitude of devices and reading instruments as well as with different software applications. Figure 7 shows the distributed and federated multi-instance model of gestbarragens-2, which suggests the variety of software applications and devices involved and the respective classes of interoperability. First, the interoperability and communication that exist at each dam local instance, namely the communication between the devices and the local server instance, and the synchronization between gestbarragens-2/mobile applications and again the local server instance. Then, in a second stage (see Figure 4), the synchronization established between local instances and the national-wide central instance.

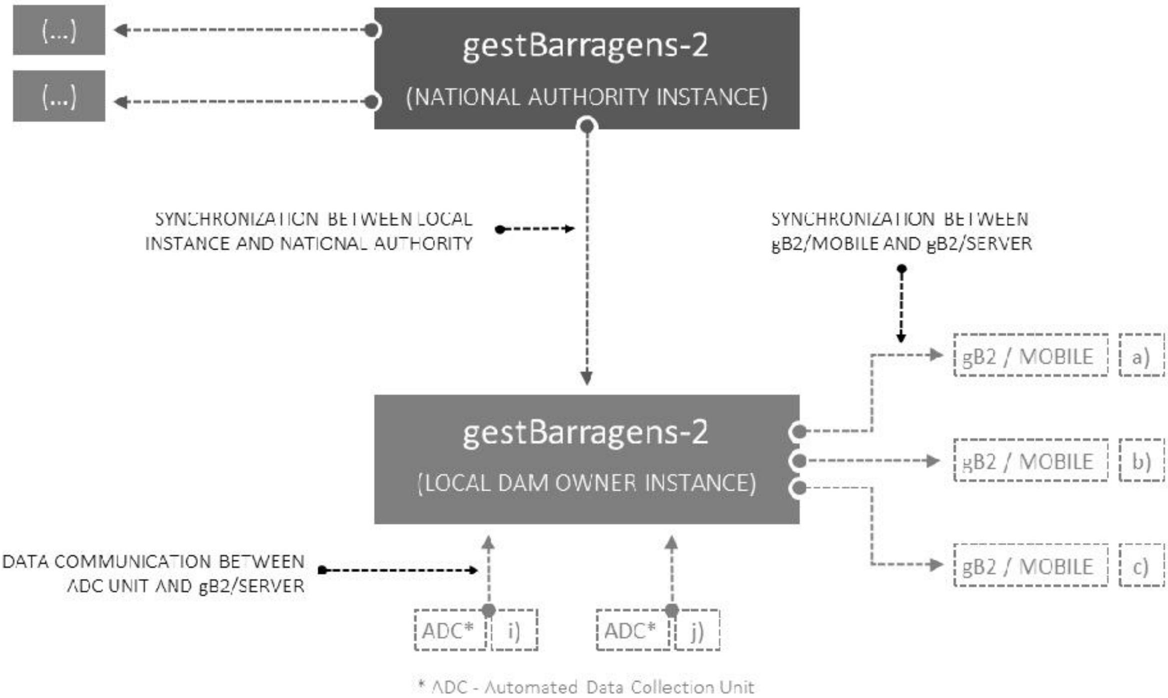

Figure 7: gestBarragens-2 – distributed and federated multi-instance model.

5 CONCLUSION

Angola has a rich and complex network of water basins and dams that serves different strategic purposes as defined in its water resource management policy and respective strategic plan that, namely, considers relevant to build new dams and to better operate the existing ones. Some of the most important dams in Angola are already equipped with safety management information devices that perform data collection and storage for infrastructural analysis and reporting. However, many of these systems are currently in a critical condition, due to deterioration and the consequences of the civil war of 1975-2002 and, as a result, most of them are outdated or malfunctioning. The dams that are presently under construction, like Matala, will already be equipped with safety management devices that are able to perform structural deformation measurement of variables like compression and humidity, among others. However, in order to better manage and support the safety of dams, we assert that a more complex and integrated system should be developed.

Hence, the main contribution of this paper is the proposal of the gestBarragens-2, a next-generation Dam Safety Management System (DSMS), particularly fitting for the geographic and political context of Angola. This DSMS high-level architecture reflects the experience with the design, development and operation of a former DSMS in the Portuguese context over this last decade, but also the state of art analysis and the learning process, introspection and criticism. The gestBarragens-2 architectural view defines the complex integration of several subsystems in two complementary dimensions: the applicational and the technological. The applicational subsystems are mainly functional while the technological subsystems provide cross-cutting features that are widely used in the DSMS as a whole.

Over the last decades several DSMSs have been developed with the purpose of handling and storing data concerning dam safety [3,5,7]. Most of these systems provide real time interpretation systems connected to data acquisition units and databases to handle the off-line management of information and its interpretation, which correspond to the features included in the gB-Monitoring subsystem. Other systems also provide visual inspection support and correspond to the features included in the gB-Monitoring subsystem. However, as far as we are aware of, none of them provides an integrated and cohesive package of features like the ones stated in this paper.

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