Design of an environmental management information system for the Universidad Distrital

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ABSTRACT

This article presents the design, development and implementation of a software tool, serving as an alternative to the problems involving management, control and reporting of processes within the institutional plan for environmental management (known as plan institucional de gestión ambiental (PIGA) by its Spanish acronym) for the Universidad Distrital Francisco José de Caldas. The software is focused on carrying out such processes to the automation setting, based on the extreme programming (XP) Agile methodology that mainly centers on the continuous development of the customer requirements to offer a more assertive tool, in line with the plan institucional de gestión ambiental in Spanish (PIGA) processes. The result is a complete satisfaction of users and a highly usable, adaptable and efficient software, inherently optimizing and automating the environmental management processes of the PIGA program. This work delivers an applet that meets the design and implementation requirements of environmental management policies. The proposed tool manages to reduce process-related times by 97%, therefore, allowing to aim efforts in other missional functions and increase the overall value offer of the organization.

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1. INTRODUCTION

Organizations have the purpose to increase value offer and improve competitive advantages by cutting costs or delivering a differential product [1]. The current evolution of information and communications technologies (ICT), driven by different factors such as internet massification and technology accessibility has been positioned as strategic axes for value generation within organizations, leading to good practice manuals including information technology infrastructure library (ITIL) [1], control objectives for information systems and related technology (COBIT) [2] and the open group architecture framework (TOGAF) [3]. Thus, every organization that seeks to thrive should implement ICTs in processes to improve and increase value generation.

In the environmental sector, different ICT strategies have been used to increase value generation, such as environmental management information systems (EMIS), defined as "technical organization systems for the extraction, processing and deployment of relevant environmental information within companies" [4]. Such developments stemmed from the need to manage environmental information as a response to internal and external pressure in the form of regulations, consumers, stakeholders, activists and changes in commercial settings [4]. In the case of the environmental management system (or SGA by its Spanish acronym), encompassed within the institutional plan for environmental management (PIGA) of the

Universidad Distrital Francisco José de Caldas [5], [6], there was a need to improve inner operative processes and thus increase the availability of resources for missional processes, leading to increased value. The main cause behind this issue in the SGA derives from using Ms. Excel in inner processes. Although commonly useful for small and medium companies, it is not ideal for certain tasks.

The solution consists on an agile-based software [7], where the delivered designs are more accurate and closer to use as case scenarios, the requirements are formally specified and the product backlog is created to display a step by step view of the processes involved in the creation of the software tool. All these processes and developments are determined by the priority set during customer feedback. At the end of each product process defined in the backlog, partial results are shown that will become a software tool tailored to the requirements of the sistema de gestion ambiental-plan institucional de gestión ambiental in Spanish (SGA-PIGA) system. This tool can prove to be useful due to its usability and development for implementation projects within small and medium enterprises (SMEs) [8]. These companies have scarce resources to implement robust environmental management systems [9], which will promote organization's sustainable development [10].

Different research projects that developed computing tools for environmental management are reviewed. The first was developed in The United States, to assess the viability of developing environmental management systems in large-sized universities. The research concluded that the development of automated environmental management systems in large institutions involves various issues due to the variety of campus infrastructures, variety in environmental management policies and limited accessibility to relevant data. The authors claim that these systems must be developed and based on realistic project planning strategy, a proper selection of software technologies, an adequate design of the system architecture and the commitment of the administrative staff [11].

The second research was developed in Germany in Osnabruck University using Umberto® [12] software for environmental management and auditing [13]. The authors determined that the university contributes significantly in the consumption of fossil fuel resources and climatic change [14]. Another research developed the integrated multimedia environmental management system called SKYi to deliver data on space-time contaminants to establish the impact and reduction of environmental risk. The SKYi system also offers information on emissions, meteorology and topography, and field observation data from contaminants. The results of the model can be assessed through built-in statistical modules [15]. On this research was developed an air quality managemet system. The software architecture is based on a geographical information system (GIS) and a decision support system (DSS). The system includes a set of predictive models [16].

In the University of Hertfordshire (UK), a research was developed to analyze ecological management software in the agricultural sector [17]. The software uses an expert system along with scoring and classification techniques [17]. Additionally, the system includes modules to simulate hypothetical scenarios. In the University of Thessaly (Greece), an environmental management information system was developed to establish a systematic method to manage environmental data and human resources of an environmental organization. The software manages information regarding human resources, environmental projects, protected species, environmental measurements of contaminants, and financial data [18].

In the University of Utah (United States), an online environmental management system was developed for agriculture. It can help producers in planning, controlling, monitoring, auditing and reviewing tasks to meet environmental policies [19]. In the University of Oldenburg a platform was developed for corporate environmental management information system (CEMIS) [20]. The platform has two main components, the workflow engine built using state chart XML (SCXML), and the green service mall conceived as a set of standardized web services [20].

Another project integrated a support system into the decision-making process of an environmental management system, which allowed people in charge of SMEs to easily implement clean productions and use renewable resources [21]. Lastly, a research project defined a formal framework for the design and development of an environmental management information system that operates with heterogeneous and large database. The framework is based on the ontological model of e-commerce (OntoTrader), that follows engineering guidelines driven by models and ontologies to separate the architecture from the implementation system [22].

As described in this section, different research ventures have led to software tools serving as support systems in environmental management, increasing the generation of value in organizations in which they have been used, particularly SMEs. These tools have been developed mostly in Europe and The United States, with no research on this topic found in Latin America. Indexing and abstracting services depend on the accuracy of the title, extracting from it keywords useful in cross-referencing and computer searching.

2. RESEARCH METHOD

The chosen methodology is experimental in nature [23]. The method used for the present study is comprised of three parts. The first part consists of a review of the related studies. The second part involves the development and implementation of an environmental management information system with agile methodology. The third part is an assessment of the implementation of the environmental management information system.

2.1. Review of related studies

The review of related studies is based on the PRISMA methodology [24], [25]. Two search equations were used: the first one is *"the environmental management information system"* and the second is *"environmental management system" and "software development".* The search was carried out in SCOPUS and ScienceDirect databases. The search was performed in the title, keywords and abstract sections. It only included articles published in scientific journals. After reviewing the articles, only 10 publications met the study criteria.

2.2. Development and implementation of the information system

The agile methodology was used in the development of the information system. This methodology establishes periodic meetings to show progress and receive approval on functionality when needed. The development is fast-paced where the client has a significant influence, thus, constant feedback is required from every person in charge of the development of previous modules, comparing results and making adjustments.

In order to carry the selection and prioritization of all project stages, a product backlog as shown in Table 1, was created to detail the different processes that must be executed to attain the determined goals. It is noteworthy that the processes found in the base of the backlog have higher priority levels. Consequently, they will be carried out before the processes described in the upper part of the backlog with lesser priority.

Table 1. Product backlog prototype

Project Stages
Development of the sustainable practice implementation
Development of the integral residue management
Development of the natural gas consumption module
Development of the fossil fuel consumption module
Development of the efficient use of energy module
Development of the efficient use of water module
Database creation
Prototype creation
Database prototype
Design of the project architecture

2.3. Design of the project architecture

Interviews were carried out with the entire SGA-PIGA staff members, seeking to obtain a detailed description of individual activities. Hence, the requirements were extracted and the development and system architecture were defined. The SGA-PIGA staff is made up of the environmental manager and seven environmental assistants. The modules were defined separately. An individual view was created to control all the facilities and academic terms of the system for all modules, except for the efficient use of water and efficient use of energy that have their own facility and period inputs. These modules have corresponding inventory segments to enter, organize and eliminate inventory. For each module, a report is filed automatically in the platform after entering the data for the corresponding module.

2.4. Database prototype

In the definition of the product architecture, it is necessary to point out how information will be stored. A relational database can be built to avoid duplicity of information; thus, the first step was to build the relational model fulfilling the characteristics of the third normal form as shown in Figure 1. In Figure 1, the electrical inventory module is shown and how the faculty, luminaire, ballast, ignition, and period tables are related, thus avoiding duplication of data.

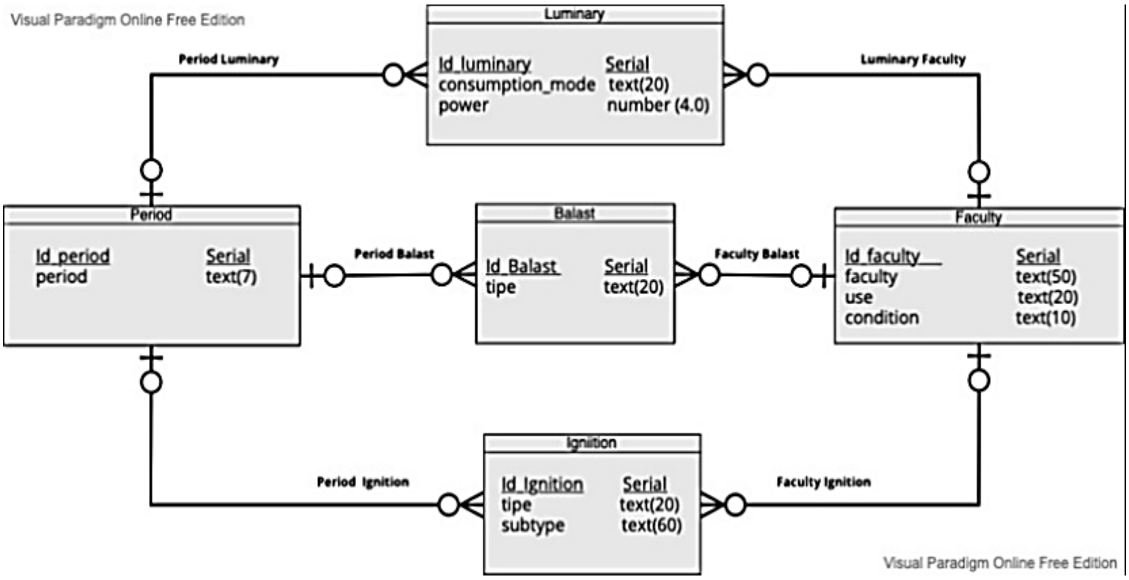

Figure 1. Relational model in third normal form of the electric inventory module

2.5. Creation of view prototypes

JAVA IDE Netbeans allows to graphically manipulate the disposition of elements in each application view. The final design is shown in Figure 2. An example of visualization of consumption indicators per person for six months is observed in Figure 2. The indicators used were the district environmental secretariat (SDA acronym in Spanish), Colombian technical standard 1500 (NTC acronym in Spanish) and technical regulation of the potable water and basic sanitation sector (RAS acronym in Spanish).

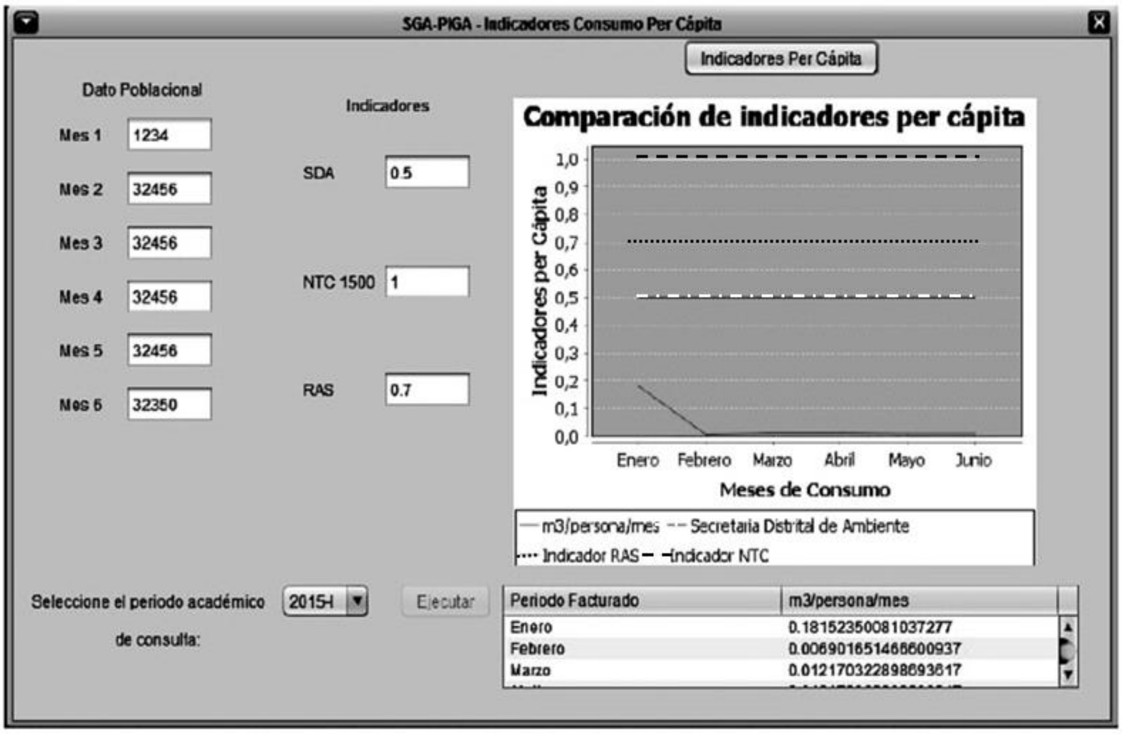

Figure 2. Final disposition of the elements in the Trend Per Capita window

2.6. Database creation

The physical models are created once the relational models have been designed for each module in the database. In contrast with the relational model, the physical model includes technical specifications between entities through foreign keys and common attributes as shown in Figure 3. These diagrams are useful given that the detailed database description generates a structured query language (SQL) script automatically processed in the PostgreSQL database, avoiding an unpractical manual process. The resulting script of the physical model for electric inventory module is shown in Figure 4.

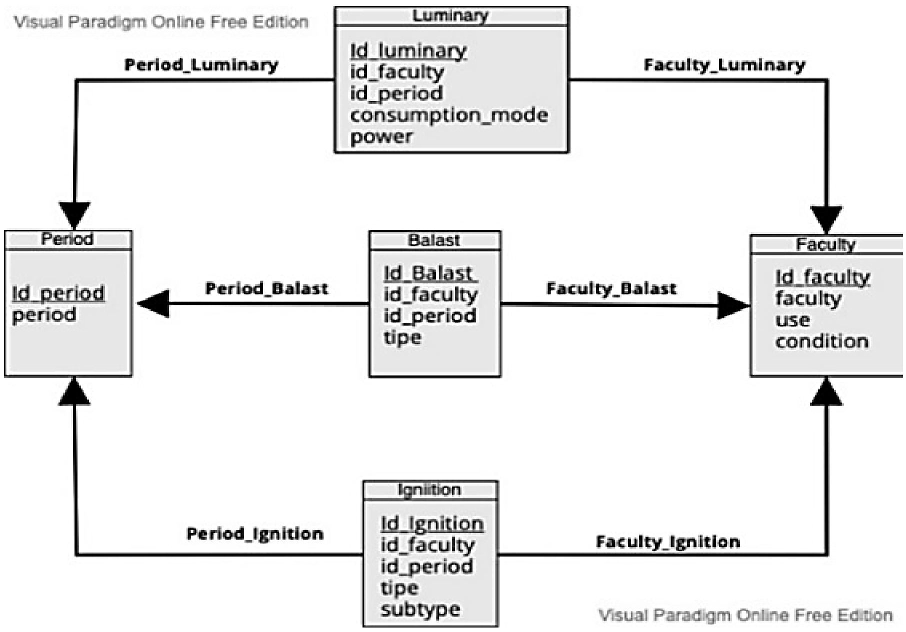

Figure 3. Physical model of the electric inventory module

```
/*==============================================================*/
/* DBMS name:      PostgreSQL 8                                 */
/* Created on:     19/08/2016 4:39:48 p. m.                     */
/*==============================================================*/


/*==============================================================*/
/* Table: BALASTO                                               */
/*==============================================================*/
create table invelectrico.BALASTO (
   ID_BALASTO           SERIAL               not null,
   ID_FACULTAD          INT4                 null,
   ID_PERIODO           INT4                 null,
   TIPO                 TEXT                 not null,
   constraint PK_BALASTO primary key (ID_BALASTO)
);

/*==============================================================*/
/* Index: BALASTO_PK                                            */
/*==============================================================*/
create unique index BALASTO_PK on invelectrico.BALASTO (
ID_BALASTO
);
```

Figure 4. Partial view of SQL generation script for the electric inventory module

2.7. Creation of modules

The components of each module are presented. Table 2 describes the efficient use of water module. Table 3 describes the efficient use of energy module. Table 4 describes the module for integral residue management. Table 5 describes the natural gas consumption module. Table 6 describes the automotive park fuel consumption module. Lastly, Table 7 describes the sustainable practice implementation module.

Table 2. Efficient water usage module

Component	Description
Water and sewage billing	The water and sewage billing invoices are stored digitally and generated by the company providing the public service (Water, Sewage and Public Cleaning services in Bogotá).
Billing record	The different values of the invoice are registered as consumption (m^3), residential fee, non-residential consumption and total payment of aqueduct and sewage utilities. These are used to calculate daily and monthly consumption.
Inventory records of hydraulic points in each facility	This contains the inventories per facility of the various hydraulic devices, and the ones with low consumption are marked.
Charts	The charts allow comparative analysis of installed low-consumption elements VS conventional elements.
Tables and data	The module can build different tables which are assembled. Certain types of data are chosen for subsequent analyses. A compound table is delivered of the inventories according to each facility or divided into owned, total or leased facilities

Table 3. Efficient energy usage module

Component	Description
Energy consumption invoice	The invoices emanated from the billing process are digitally generated and stored by the company providing the utilities (Grupo Energía de Bogotá).
Invoice record	The different values of the invoice are registered such as kilowatt / h, value of kW/h and total consumption value. These are used to calculate daily consumption and daily value.
Inventory records of energy facilities in each facility	This contains the inventories per facility of the various lighting devices and source type.

Table 4. Automotive park fuel consumption module

Component	Description
Ordinary residues	The data of the public cleaning invoice is registered as well as the cubic meters of garbage and cost.
Recyclable residues	The data delivered by the association of recyclers ASODIG is recorded, where the different recyclable materials and amounts are shown.
Pathogenic residues	The Ecocapita invoice is recorded including the type of residue, its amount and total cost.
Chemical residues	The Ecoentorno invoice is recorded including the type of residue, its amount and total cost.

Table 5. Integral residue management module

Component	Description
Natural gas invoices	The natural gas invoice data is stored digitally by the company providing the public service.
Records and tables	The consumption of the natural gas is recorded, including its value, fixed fee and total monthly payment. The tables can be reviewed per faculty as well as the total consumption of the campus.

Table 6. Natural gas consumption module

Component	Description
Fuel consumption invoice	The invoices are stored digitally per fuel consumption. The university sends a report each semester of the various invoices generated including consumption values, cost per gallon, kilometrage and type (oil or gas).
Records and tables	The values of fuel consumption, cost per gallon, kilometrage and type (oil or gas) are recorded. A report can also be generated which displays the different vehicles of the campus, the total consumption of each vehicle, total costs, average consumption and travelled kilometrage.

Table 7. Sustainable implementation practice module

Component	Description
Record of the tree-based format in each facility	Each tree located in different facilities of the university is registered as well as their current status and whether they require special treatment.

2.8. Assessment of the environmental management system

In order to assess the environmental management system, the processing times before and after the implementation were compared and the improvement rate was determined. Before the implementation of the environmental management system, the processes were developed in Ms. Excel. The users of the system were asked one month after the implementation, the reduction of times in the processes.

3. RESULTS AND DISCUSSION

In order to approach the development of the architectural design, use case scenarios were defined including interviews with the PIGA staff and served as the basis for the design of the first stage of the product backlog. The use cases were input validation for facilities and terms, extended report and extended data validation. The use cases are described in this section.

3.1. Use case of input validation for facilities and terms

The user must first enter the data for facilities and terms. Then, the application validates the input format captured from the keyboard. If it is correct, it is stored in the database and then edited as shown in Figure 5 and detailed in Table 8.

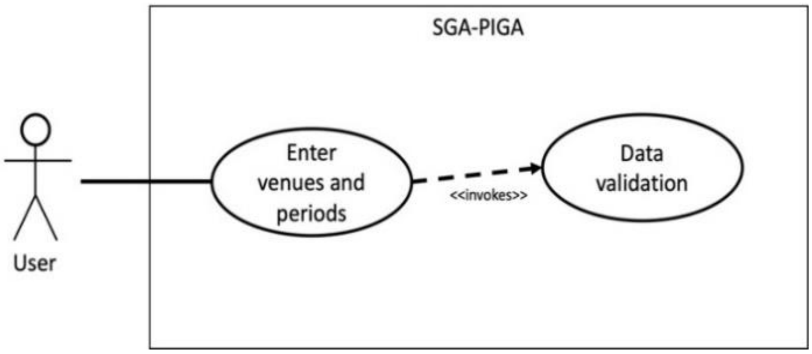

Figure 5. Use case of input validation for facilities and terms

Table 8. Description of the use case scenario for input (facilities and terms)

RF- 01	Facilities and terms	
Related requirements	RI-02 Information regarding facilities and academic terms.	
Description	The system must behave as described in the following use case when someone enters a new facility or term.	
Pre-condition	The requesting user is not authenticated and has access to the tool.	
Post-condition	The facilities will appear in all the system interfaces mentioned in step 2 and can be associated to any academic term.	
Exceptions	Step	Action
	1	If the user tries to add a facility that is already in the system, an error message is displayed and the facility will need to be modified.
	2	If the user tries to add an academic term in which the date is out of the date ranges included in the system, it will display a message error and ask the user to try again.

3.2. Use case of extended report

The generation of reports, once all the consumption data is stored for each module, the user must press the corresponding button and choose a specific location for the document (a Word format is created for easy edition). This process is homologous for each module in the application as seen in Figure 6 and detailed in Table 9. Reports are generated on the water consumption, hydraulic inventory, fuel consumption, conventional and unconventional waste, trees, electricity consumption and electrical inventories modules.

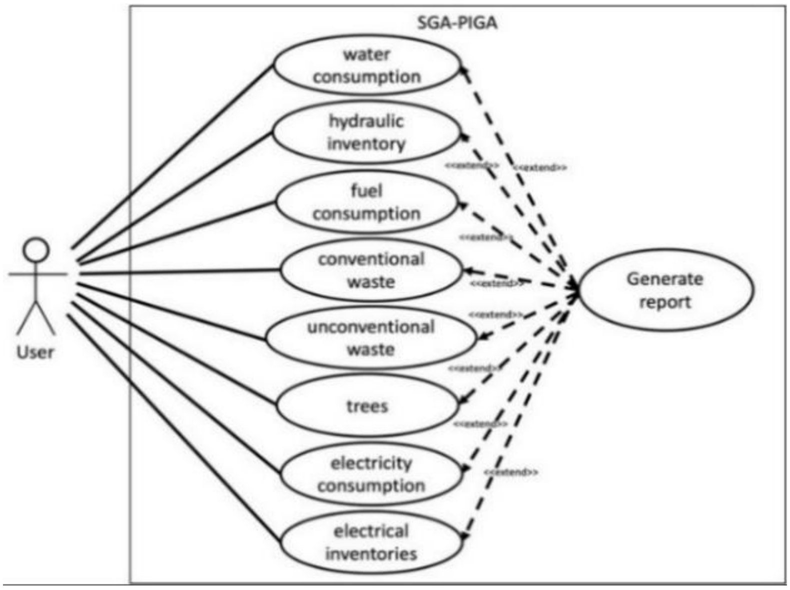

Figure 6. Use case of extended report generation

Table 9. Use case description of extended report generation

RF- 02	Report generation	
Related requirements	RI-02 Generate all the previous calculations in each module	
Description	The system must behave as described in the following use case when someone tries to generate a report.	
Pre-condition	The requesting user is not authenticated and has access to the tool.	
Post-condition	.DOCX files are generated of the reports in each module	
Exceptions	Step	Action
	1	If the user tries to generate the report of a module that has incorrect calculations, it will not be generated properly and the user will be asked to perform direct calculations in the application.

3.3. Use case of extended data validation

The inputting process of data requires a previous validation with the public services invoices and the information provided by the physical resource office of the Distrital University, and the inventory tables delivered by each faculty. The user then proceeds to digitalize the data, categorizing it in terms of facility, academic term and faculty for each corresponding module. The application validates all the numeric and alphanumeric formats of each record and, in case of an error, the user is asked to correct it. The procedure is shown in Figure 7 and detailed in Table 10. Once the use case scenarios are established in terms of the PIGA requirements, the next phase is the coding process by developing business rules and a graphical interface.

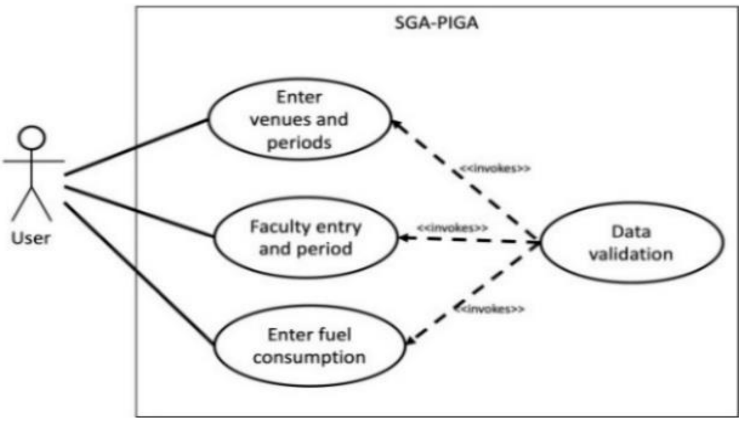

Figure 7. Use case of extended data validation

Table 10. Description of the use case of extended data

RF- 03	Extended data validation	
Related requirements	RI-03 Review of the input data in each module	
Description	The system must behave as described in the following use case when the user tries to edit, add or delete data from the tool	
Pre-condition	The requesting user is not an authenticated user and has access to the tool	
Post-condition	The data is edited, added or deleted depending on the chosen action.	
Exceptions	Step	Action
	1	The entered data is validated and in case of overwritten or redundant data, the information is not stored correctly and the user is requested to enter it once again.

3.4. Graphical interface

Building the graphical interface required the Java swing libraries to design interfaces and the Jfreechart library that delivers statistics included in the final reports of each module. Figure 8 shows the access menu of all modules and the user's manual. All the facilities and academic terms are added in this window. These can be edited and deleted when required as shown in Figure 9.

Figure 8. Main interface of the SGA-PIGA program with access menu

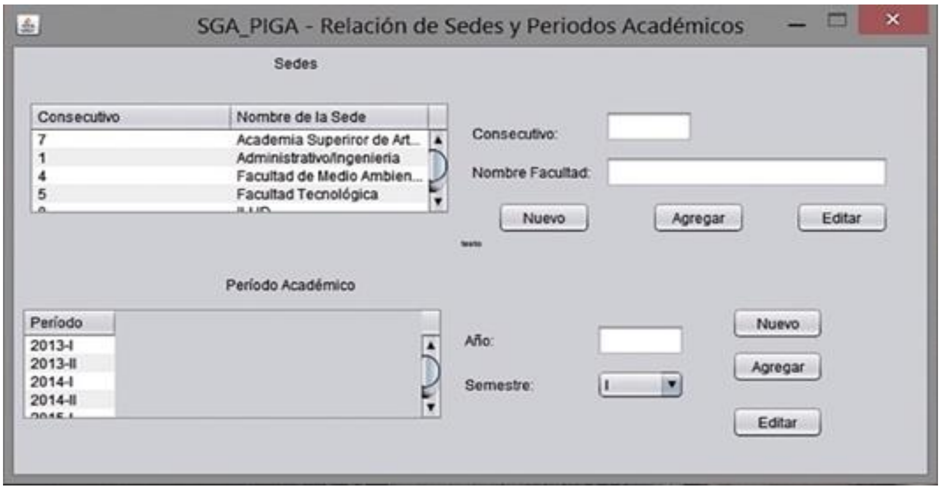

Figure 9. Facilities and academic terms for all modules except for water and energy

3.5. Cost

In terms of human resources, the software development cost was $0 US since it was developed using free software JAVA, as it is the result of undergraduate program work. Besides, the project manager is a professor at the Universidad Distrital and his time fees are also of no cost as these are included in the monthly income. As such, human resources costs represent no fees. On the other hand, the expenses incurred are related to consumable items like stationery, toners, and pens. Public utilities (water, power supply), and transportation which added to approximately $300 US.

Regarding maintenance costs, the software was delivered to the systems advisory office (SAO) which is in charge of the University's software development, maintenance, and management. The delivery of the software included the training of an engineer of the SAO. The engineer has two hours a week to deal with the system requirements of the environmental management information system, which has a weekly fee of $50 US and it is charged to SAO without affecting the department´s total budget.

3.6. Evaluation

After the implementation of the tool, the input and recording times of the data are optimized as well as the statistical analysis and specific generation of reports in each module. On the other hand, the dispersion, duplicity and loss of information have been avoided by using a centralized database, only managed through the application. All the requirements were declared by the SGA-PIGA office and optimized, thus simplifying the digitalization of the information and its disposal in the final reports. Once the application went into production phase, the following information was obtained. Report generation in the SGA is separate for each module. The corresponding times for these processes changed drastically as shown in Table 11.

As seen in Table 11, the optimization of report generation time and information management in the new tool is notorious. A reduction of 97% was achieved. These results in higher flexibility time margins in the SGA-PIGA system so that the staff can perform other activities within the organization.

Table 11. Results of report generation

Type of tool report	Excel	Information system	Time reduction (hours / %)
Hydraulic points inventory	32 hours	1 hour	31 h / 96.88%
Aqueduct analysis and report	16 hours	30 minutes	15.5 h / 96.88%
Sustainable practice report	40 hours	1 hour	39 h / 97.5%
Energy inventory report	40 hours	1.5 hours	38.5 h / 96.25%

4. CONCLUSION

The development of the environmental management information system resulted in cutting times for various processes, which allowed staff members of the SGA-PIGA department to increase the available time for other missional activities and increase overall value. The design and development of a relational database to handle information regarding the administrative staff of the institution is highly beneficial for the customer, bearing in mind that the persistency of information is structured and visible for all app users. This means that staff members can both use information in administrative decision-making processes and have an information repository to be used in the future. To develop the prototype, different tools and technologies were used. The software is open source and the frameworks are commonly seen in the current work environment.

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