Computational system for the integrated management of construction and demolition waste

Sistema computacional para a gestão integrada de resíduos da construção e demolição

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Abstract

Knowledge of the qualitative and quantitative composition of waste is essential in order to propose alternatives and strategies for construction and demolition waste (CDW) management. Tools to support the integrated management of CDW have been of great help in identifying the best management alternatives. This article aims to develop a computational system (software) which supports the integrated management of CDW for Brazilian municipalities. The software was divided into four stages: knowledge acquisition (data collection), system structuring (system tools), coding and validation, all based on a case study. In conclusion, the computational tool developed and tested with a robust database for managing CDW in municipalities makes it possible to identify better management alternatives, considering the different realities of each municipality and each construction project.

Keywords: Decision support system. Solid waste. Software.

Resumo

Para a proposição de alternativas e estratégias de gerenciamento de resíduos de construção e demolição(RCD), é essencial a caracterização qualitativa e quantitativa dos resíduos. As ferramentas de apoio à gestão integrada de RCD tem sido de grande auxílio para identificar as melhores alternativas e estratégias. Este artigo tem como objetivo desenvolver um sistema computacional (software) que dê subsídios à gestão integrada de RCD para municípios brasileiros. O software foi dividido em quatro etapas: aquisição de conhecimentos (coleta de dados), estruturação do sistema (ferramentas do sistema), codificação e validação, a partir de um estudo de caso. Conclui-se, que a ferramenta computacional desenvolvida, testada com um banco de dados robusto, acerca da gestão de RCD em municípios, possibilita identificar uma melhor alternativa de gestão, considerando as diferentes realidades de cada município e de cada obra.

***Palavras-chave**: Sistema de apoio à decisão. Resíduos sólidos. Software.*

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Introduction

The construction industry is responsible for generating a series of environmental impacts, starting with the consumption of natural resources in the production chain, up to the irregular deposition of waste generated in construction and demolition (construction and demolition waste - CDW) (BOHNENBERGER *et al.*, 2018; SOUZA; RUDNICK; LUKIANTCHUKI, 2020; SANTOS; CABRAL, 2020; YAZDANI *et al.*, 2021).

One of the ways to reduce the impacts caused by CDW is through proper waste management and destination (SHI; XU, 2021). As pointed out by Caetano, Fagundes and Gomes (2018), it is essential to know the qualitative and quantitative composition of the waste in order to propose alternatives and strategies for CDW management.

However, several researchers have reported difficulty in obtaining reliable data on the CDW generation in terms of in determining its qualitative and quantitative composition (UMAR; SHAFIQ; ISA, 2018; VILLORIA-SÁEZ; PORRAS-AMORES; MERINO, 2020), since the methodology used for quantification and the construction process directly influence the CDW quantification (CAETANO; SELBACH; GOMES, 2016). The CDW amount and composition varies between regions and depends on local factors such as population, construction activity and materials, among others. In this case, decision support tools are of great help in obtaining reliable data and identifying the best CDW management alternatives (PAZ; LAFAYETTE; SOBRAL, 2020). With the increase in the knowledge level regarding construction waste, tools to help manage waste in construction projects and small and large municipalities were created.

In this sense, Banias *et al.* (2010) developed a web-based Decision Support system called the DeconRCM in order to assist construction companies, public agencies, engineers and individuals in the proper management of CDW. The system provides an accurate estimate of the amount of 21 different waste streams produced by renovation and demolition activities. Four types of construction are considered: residential, office, commercial and industrial.

Li and Zhang (2013) developed a web-based construction waste estimation system (WCWES) for the design of construction projects incorporating the concepts of dividing labor structure, quantity of material, classification of materials, waste levels and mass balance principles. The online analysis modules enable the analysis of construction waste from three dimensions: the waste source, waste flow and on-site storage.

Cheng and Ma (2013) presented the BIM (Building Information Modeling) technology, which is capable of simulating the planning, design, construction and operation of a building in order to promote a more accurate, concise and detailed quantification. Therefore, Wu *et al.* (2014) understand that the estimate of waste generation and its computer-aided management has good prospects for growth in the civil construction market.

More recently, You *et al.* (2020) proposed the use of multiple technologies to assist managers in supervising and managing construction waste in China. The system contributes to real-time monitoring of the waste disposal flow, identifying illegal practices and evaluating the performance of stakeholders. The study proposes the use of various equipment, such as face recognition, vehicle weight sensor, Global Positioning System, Mobile Communication Technology and Big Data Analysis, and the main objects monitored are construction sites, disposal facilities, vehicles and drivers.

The use of software as an aid to CDW management in Brazil has grown over the years, being developed both in the public and private sectors to improve the quality of municipal waste management.

Karpinski *et al.* (2008) developed a computational tool from the creation of a website to assist municipal managers in the implementation of the Municipal Civil Construction Waste Management Program (MCCWMP). The website has user registration features, registration of suitable areas for the implementation of landfills, registration of illegal disposal areas, registration of collecting companies and inspection agents. The system was tested in the municipality of Passo Fundo/RS, Brazil.

Gonçalves and Brandstetter (2013) created a virtual tool called RESPLAN, based on international methodologies to assist in creating Civil Construction Waste Management Plans (CCWMP) with maximum efficiency, seeking to reduce waste. The CCWMP development covers the stages of defining responsibilities, managing, and minimizing waste.

Oliveira *et al.* (2014) developed the Decision Support System (DSS) GIR@SSOL, built on the basis of bibliographic research and on-site observations of the collection and distribution process of CDW. The GIR@SSOL covers the following activities: identification of the points where the collection bins are located; definition of in which lots there are works in progress; estimating the working capacity (productivity) of bin transport companies and defining how many works do not have bin rentals. The tool has two subsystems, namely: a decision-making model subsystem, responsible for dimensioning the demands of the collecting units; and an interface subsystem, which facilitates interaction between users. The GIR@SSOL was validated in the municipality of Palmas/TO, Brazil.

Scremin, Castilhos Junior and Rocha (2014) developed a DSS for small municipalities. The system development took place in four stages. The first stage included knowledge acquisition, referring to CDW and decision support systems. Depending on the knowledge acquired, a conceptual model was established in the second stage, being expressed in the form of flowcharts which served as a basis for verifying the process logic. Once the conceptual model was established, they were then coded with the help of a computer technician in the third stage. The fourth and last stage was carried out during and after the system coding and refers to the previous evaluation of the developed system.

Paz and Lafayette (2016) developed an online DSS for managing construction waste on site, called the Construction Waste Management System (SIGERCON). The system has a database of 20 works in the city of Recife, which makes it possible to make adequate estimates for future works to be built in the city in relation to the total waste generation, generation by waste type, generation by work phase, and the management costs. The system also allows registering generators, transport and final destination of the waste.

Zanna, Fernandes and Gasparine (2017) developed the Solid Construction Waste Management System (SCWMS). The web system favors the control of waste generation and management throughout the work, by automatically generating indexes and reports. The tool allows filling out the Waste Transport Control online, and registering the transporters and final destination companies.

Therefore, it is understood that computational tools are of fundamental importance for waste management, as they propose to simplify the management process with strict control of activities such as transportation and final destination and enables developing waste reduction programs, consequently minimizing management expenses. In Table 1 is possible to see the main functionalities of the CDW management DSS developed in Brazil.

Table 1 – **Main functions of decision support systems developed in Brazil**

	Author	Validation	Platform	Municipal CDW management			CDW management at construction sites		
				MWGE	MIDP	IWME	EWGC	TDR	WTC
1	Karpinski *et al.* (2008)	Passo Fundo/RS	Web		X	X			
2	Gonçalves and Brandstetter (2013)	-	Web				X	X	X
3	Oliveira *et al.* (2014)	Palmas/TO	Desktop		X	X			X
4	Scremin, Castilhos Junior and Rocha (2014)	Frederico Wesphalen /RS	Desktop	X		X			
5	Paz and Lafayette (2016)	Recife/PE					X	X	X
6	Zanna, Fernandes and Gasparine (2017)	-	Web					X	X

Note: MWGE - municipal waste generation estimate;
MIDP - Mapping of irregular deposition points;
IWME - installation of waste management equipment (Transshipment and Sorting Waste Areas – TSWA, Small Volume Receiving Units - SVRU, Landfills);
EWGC - estimate of waste generation in construction sites;
TDR - transport and destination registry; and
WTC - Waste transportation control.

In this sense, the experiences of using DSS in Brazil have been of great benefit, as they facilitate implementing integrated CDW management. However, there is a demand to develop a tool which integrates the different actors in CDW management, and which offers users several tools that enable estimating CDW generation, generating monthly reports, and dynamically importing and exporting data.

Therefore, this article aims to develop a computational system (software) which supports integrated CDW management for Brazilian municipalities, unifying the actions of stakeholders, streamlining procedures and allowing greater supervision by environmental agencies.

Method

The computer system developed was an extension of the system developed by Paz and Lafayette (2016), referring only to the CDW management module at construction sites (Module I). The system developed in this article used all the data collected from the diagnosis of municipal management and management at construction sites, as well as data from the literature, and has performance throughout the integrated CDW management cycle, as shown in Figure 1.

The development stages of SIGERCON were based on previous studies on the use of DSS in solid waste management, such as Massukado and Zanta (2006), Scremin, Castilhos Junior and Rocha (2014) and Paz and Lafayette (2016), and followed the steps as shown in Figure 2.

Knowledge acquisition

The knowledge acquisition stage aims to provide subsidies for its representation through models (SCREMIN; CASTILHOS JUNIOR; ROCHA, 2014). The necessary knowledge in the integrated CDW management was divided into three areas: municipal CDW management, CDW management at construction sites and CDW recycling.

Figure 1 – **Detailing of integrated CDW management software**

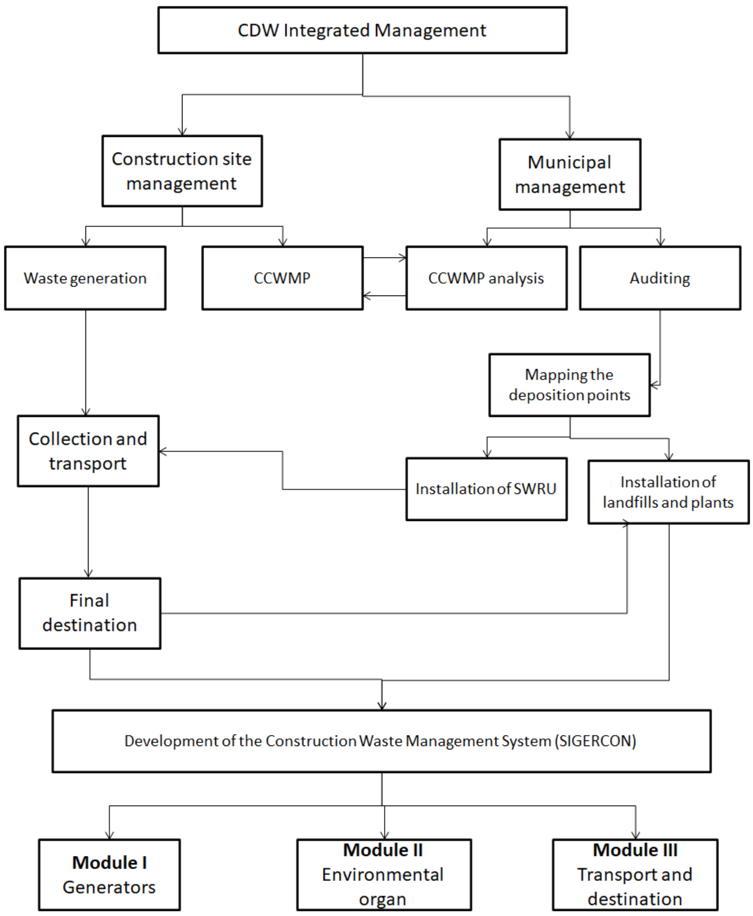
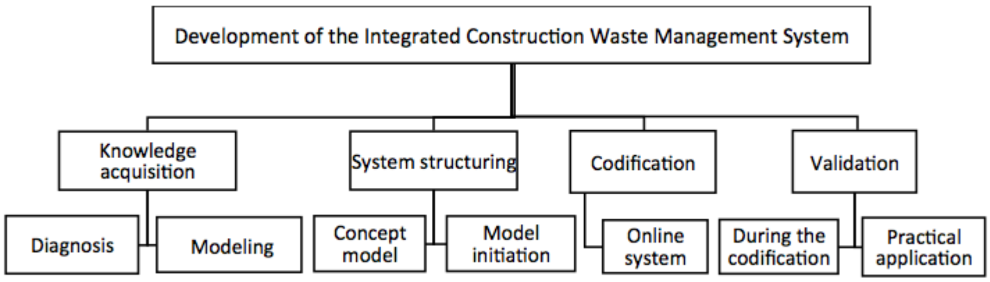


Figure 2 – **Detailing of the integrated CDW management software**



Source: Paz and Lafayette (2016).

The data obtained in this step in the literature survey referring to the qualitative and quantitative characterization of municipal waste, qualitative and quantitative characterization of construction waste, integrated waste management and recycling were organized according to the modules developed to be inserted into the system database.

System structuring

In the structuring phase of the system, the context of the problem is structured and organized based on the aspects deemed most relevant. Thus, the structuring and formalization of knowledge to develop SIGERCON is presented in this stage. The structuring was divided into two stages: construction of the conceptual model and the subsequent initiation of the model, in which the necessary knowledge and methods to attain the objectives proposed in the conceptual model presented above are addressed by flowcharts.

The conceptual model was developed based on the knowledge acquisition stage and the needs of users. The proposed solution is part of the possibility of incorporating the same knowledge model used by specialists in a computer program, enabling users who do not have in-depth knowledge of the area to attain the problem resolution by simply applying the software model correctly.

According to the needs observed in the knowledge acquisition stage, the needs to be minimized by using the software were established based on the following indicators:

(a) accurate estimation of CDW generation at each stage of the work;

(b) reduced irregular CDW deposition in the municipality;

(c) registration of waste generators;

(d) control of receipt and deposition of waste through systematic registration of its operation on a daily basis, which includes organized record filing;

(e) identification of the person/entity responsible for generating the transported waste(s), including address and contact telephone number;

(f) identification of the means of transport used and its responsible/driver; date(s) of collection and transportation of the waste(s);

(g) amount of waste received monthly in licensed areas;

(h) agility in issuing construction monitoring and inspection reports; and

(i) agility in the analysis and approval of CCWMP.

After defining the modules, we then proceeded to verify the difficulties of each user to establish the necessary tools to assist in solving the problems of each agent. The identification of difficulties was carried out through interviews with users, (generators, transporters, disposal companies and environmental agency, carried out from informal conversations, resulting in the generation of the conceptual model of the system.

The beginning of the model consists of defining the necessary system structuring to supply the needs identified in the conceptual model. Therefore, the system skeleton is developed, presenting the system's strategies to solve the identified problems.

In this step, we sought to insert the equations and features of each tool in the modules to achieve the intended objectives. The equations entered in the system were according to the literature survey and data collection (TESSARO; SÁ; SCREMIN, 2012; SCREMIN; CASTILHOS JUNIOR; ROCHA, 2014; KERN *et al.*, 2015; PAZ; LAFAYETTE, 2016; GULARTE *et al.*, 2017; FONSECA; RIBEIRO JUNIOR, 2018; PAZ; LAFAYETTE; SOBRAL, 2018; LAFAYETTE *et al.*, 2018; KERN *et al.*, 2018; TEIXEIRA *et al.*, 2020).

The system structuring was presented in this research through flowcharts using the Bizage Process Modeler software program for organizing the information.

System codification

The coding step of a DSS aims to transpose the developed conceptual model into a model developed by computer (digital). This step consists of coding the initiated model and building a friendly web-based interface to be accessed by the user to facilitate the access to system information and to obtain the results determined by the conceptual model (PAZ; LAFAYETTE, 2016).

The Module II and III coding was performed according to the system developed in Module I (PAZ; LAFAYETTE, 2016) in PHP language (Hypertext Preprocessor) and using the MVC model (Model-View-Control), being the most suitable for Web development as it facilitates the maintenance and possible system extensions. This contributed to integrate other modules to be developed. The jQuery library (Javascript) was also used to increase the system usability. The MySQL database was used for data storage, as it is a complete relational database system and because it is notably the most recommended for this type of application. A SIGERCON mobile application was developed as a complement to Module II as a control and inspection tool for the irregular CDW deposition.

The application was developed in hybrid architecture, meaning that they use elements from native and web applications (HUYNH; GHIMIRE; TRUONG, 2017). The application pages were developed using the Ionic Framework (open source tool for the development of multiplatform mobile applications). The Google Maps API was used to present the map of irregular deposition points, constituting an interface which enables communication between devices or systems. The purpose of the application is to allow complaints from anonymous users to be made, and to facilitate action from inspectors from environmental agencies to inspect irregular deposition.

The modules were coded separately and then the tools and the information used in each module were integrated, such as the construction project registry, transporters and final destination (Figure 3). This was because each module was created with the help of a different professional from the computing and information systems area, but using the same methodology.

System validation

Problems in the tool development and programming errors were identified and corrected in this step, such as problems with the logic, routine and appearance of SIGERCON. The work registration, transport and final destination, import and export of spreadsheets and presentation of graphics functions were analyzed at this stage. Thus, revisions and possible corrections of the system were performed for each release sent by the programmer.

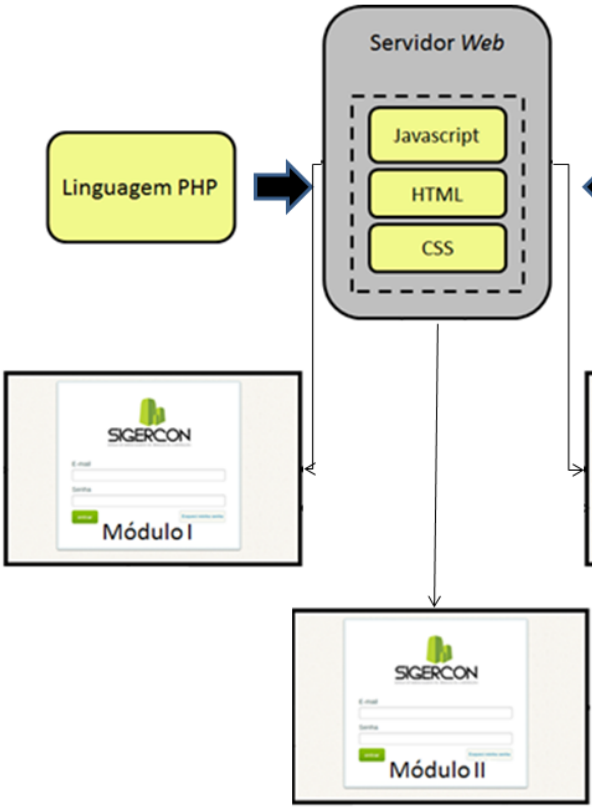
The system database was also validated, which corresponds to quantitatively characterizing CDW generation in the municipalities. In this sense, a correlation was made between the real data obtained in the diagnosis and the data estimated by the system. The integrated management system dimensioning for municipal management was validated in the municipality of Jaboatão dos Guararapes/PE, a municipality neighboring the city of Recife, belonging to the Metropolitan Region of Recife.

Finally, a conclusion from analyzing the agreement of the validation results was presented on the applicability and the importance of SIGERCON for integrated CDW management in Brazilian municipalities.

Results and discussion

The conceptual model of SIGERCON was established from the information collected in the diagnosis of municipal management and the CDW generation in construction sites covering the three modules of the system, with one module for each user who works in the CDW management to assist in the integrated management of wastes in Brazilian municipalities, according to the activities carried out by each one.

Figure 3 - **SIGERCON codification process**



The conceptual model definition started from the difficulties observed by users who work in CDW management, such as waste tracking, the issuance of periodic reports, knowledge of the waste volume to be generated before beginning the work, costs control, and increased material recycling rate.

In Table 2 is possible to see the needs observed in the diagnosis performed which compose the conceptual SIGERCON model.

Adequate tools were defined to meet the demands based on the user's needs which hinder implementing integrated CDW management, so that there is data integration.

After defining the conceptual model to be used in the system, data obtained in the knowledge acquisition stage was included. This knowledge was structured in the form of flowcharts based on the methodology used by Scremin, Castilhos Junior and Rocha (2014), which served as the basis for coding the system after initiation.

The structuring of Module I - Generators, as well as the system validation, was performed by Paz and Lafayette (2016), who divided the conceptual system model into 3 phases:

(a) phase 1: feneral description of the development;

(b) phase 2: Waste Management System dimensioning; and

(c) phase 3: project management.

Next, two main menus were developed for Module II - Environmental bodies/organs:

(a) Project: DSS tool used for dimensioning the necessary structure for adequate CDW management in the municipality, where the waste generated in the municipality is characterized and the Small Volume Receiving Units (SVRU) and recycling plants, which must be installed in the municipality, are dimensioned; and

(b) Management: menu used for daily control of integrated CDW management which allows the user to approve registrations for new users (construction companies, transportation and destination companies), view documents from these companies, monitor environmental licenses, and register irregular deposition points, eco-stations and Transshipment and Sorting Areas (TSWA).

Table 2 - **Conceptual model with observed needs**

Modules	User needs
Module I - Generators	- to develop Civil Construction Waste Management Plans (CCWMP) based on CDW generation indicators; - to register CDW collections and generate automated manifests; - to register the reuse of waste in the projects; - to register the training carried out in the projects; - to monitor costs of CDW management; - to conduct statistical analysis of generation and costs arising from CDW management; - to receive reports sent by transporting and final destination companies.
Module II - Environmental bodies/organs	- to control the amount of waste collected in public places; - to evaluate and approve the CCWMP through a computerized system; - to register and monitor environmental licenses for generators, transporters and final destination of waste; - to map the irregular deposition points of CDW in the municipality; - to locate suitable areas for structuring the site for sorting collected waste.
Module III - Transport and Final destination	- to register the trucks used in waste collection; - to register the performed CDW collections; - to automatically prepare reports of waste movement; - to automatically develop destination certifications.

The "Project" menu was developed based on previous studies such as those by Scremin, Castilhos Junior and Rocha (2014), in which the integrated CDW management structure is dimensioned which the municipality must adapt to.

The menu has the tools for "Characterization" of waste, "Ecostations" and "Processing plants". The waste "Characterization" tool automatically estimates the current population of the municipality and the daily generation of CDW (t/day) from the data initially registered in the "Management" menu. The population estimated is performed according to Equation 1:

$$\mathrm{Pop_{pres}} = \mathrm{Pop} * (1 + \mathrm{R_{ag}}^{(\mathrm{Y_{cu}} - \mathrm{Y_{lc}})}) \qquad \text{Eq. 1}$$

In which:

Pop_{pres}: population in the present year;

Pop: population of the last census;

R_{ag}: annual growth rate of the municipality;

Y_{cu}: current year; and

Y_{lc}: year of the last census.

The estimate of the current daily generation of CDW in the municipality can be performed by the DSS through two alternatives:

(a) alternative 1: there is no data available on the amount of waste collected at ecostations, streets or irregular CDW deposition points (The system will alert you that the estimate may be uncertain in this case); and

(b) alternative 2: there is data available on the amount of waste collected from ecostations, streets and irregular deposition points.

In case there are no data available on the amount of waste collected in the municipality, the calculation is performed considering only the average municipal per capita generation rate, from the database of the system of other Brazilian municipalities, according to Equation 2:

$$\mathrm{G_{CDW}} = (\mathrm{Pop_{pres}} * \mathrm{G_{PC}})/1000 \qquad \text{Eq. 2}$$

In which:

G_{CDW}: Daily CDW generation in the municipality (t/day); and

G_{PC}: Per capita CDW generation (kg/inhabitant.day).

On the other hand, when the monthly data referring to CDW collection from ecostations, streets and irregular deposition points are registered in the system, the system only performs the sum of the data, according to Equation 3:

$$G_{CDW} = Q_{eco} + Q_{cm} + Q_{id} \qquad \text{Eq. 3}$$

In which:

Q_{eco}: Quantity of waste collected at eco-stations (t/month);

Q_{cm}: Quantity of waste collected on the streets of the municipality (t/month); and

Q_{id}: Quantity of waste from irregular deposition points (t/month).

After estimating the total waste generation in the municipality, the system will calculate the amount of waste per class, according to CONAMA Resolution No. 307 (BRASIL, 2002) and the generation by type of material. The percentage of each class and material used in the system's database was based on previous research (TESSARO; SÁ; SCREMIN, 2012; LIMA; CABRAL, 2013; FARIAS; FUCALE; GUSMÃO, 2016; CÓRDOBA *et al,* 2019; ROSADO *et al*., 2019).

If the user already has data on the municipality's CDW composition, the system allows data to be entered for the estimate. If the user does not have data, the system uses the database indicators. Concrete, mortar, fine material, soil, brick, wood and metal were considered regarding the estimated materials.

After estimating the amount of waste generated in the municipality, the system performs an assessment of the eco-stations required to carry out the sorting, collection and proper disposal of CDW from small generators. In this case, three alternatives are considered:

(a) alternative 1: the municipality does not have eco-stations;

(b) alternative 2: the municipality has eco-stations < the necessary minimum; and

(c) alternative 3: the municipality has eco-stations > the necessary minimum.

The calculation of the minimum amount of eco-stations (Q_{me}) required in the municipality used by the system is based on Equation 4, proposed by Scremin (2007), which considers the urban area of the municipality (A_u) and the catchment radius of the catchment basin eco-stations (R_{ab}):

$$Q_{me} = \frac{A_u}{(\pi \times {R_{ab}}^2)} \qquad \text{Eq. 4}$$

In the case of Alternative 2 in which eco-stations below the minimum quantity already exist, the system calculates the number of new eco-stations (Q_{ne}) to beinstalled using Equation 5:

$$Q_{ne} = Q_{me} - Q_{ecurr} \qquad \text{Eq. 5}$$

In which Q_{ecurr}: Current quantity of eco-stations.

After calculating the minimum quantity, the system calculates the number of inhabitants (N_{hab}) per ecostations, according to Equation 6:

$$N_{hab} = Pop_{total}/Q_{me} \qquad \text{Eq. 6}$$

Regarding the economic aspect, the system calculates the installation cost (C_i) and the operation cost (C_o) of the eco-stations. Equation 7 presents the calculation of the installation cost and Equation 8 presents the calculation of the operating cost:

$$C_i = Q_{me} * C_{ui} \qquad \text{Eq. 7}$$

$$C_o = Q_{me} * C_{uo} \qquad \text{Eq. 8}$$

In which:

C_{ui}: Unit installation cost (R$/ecostation); and

C_{uo}: Unit operation cost (R$/ecostation).

Finally, the number of bins (Q_c) needed to collect and store all the waste to be delivered to the eco-stations is calculated, according to Equation 9[1]:

$$Q_c = \left(\frac{Cap}{7.6}\right) * Q_{me} \qquad \text{Eq. 9}$$

In which Cap: Capacity to receive CDW from eco-stations (t/day).

The system proposes the installation of a public waste processing plant for the correct disposal of CDW Class A. In this case, two alternatives are foreseen:

(a) alternative 1: the municipality does not have a public CDW plant; and

(b) alternative 2: the municipality has at least one public CDW plant.

The crusher capacity was initially calculated for the plant dimensioning considering 8 hours of plant operation, and 80% of the amount of Class A waste sent to the plant (considering the contamination of a portion of the CDW with other classes and irregular deposition), according to Equation 10:

$$C_c = \left(\frac{Gca}{8}\right) * 0.8 \qquad \text{Eq. 10}$$

In which:

C_c: Crusher capacity (t/h); and

G_{ca}: Class A waste generation

Equation 11 presents the calculation of the minimum required area (A_n) for the plant installation, in which a rate of 500 m^2/t.h of crushed CDW was used:

$$A_n = C_c * 500 \qquad \text{Eq. 11}$$

In economic terms, cost compositions related to the implementation, operation, and maintenance of CDW plants were used according to the crushing capacity of the plant, based on previous studies (ESGUÍCERO; BATTISTELLE, 2016; GULARTE *et al.*, 2017; KUHN *et al.*, 2017) Only the plant's operation and maintenance costs were considered for alternative 2.

For this dimension, the implementation costs related to equipment acquisition (C_{ea}), land acquisition (C_{la}), vehicle acquisition (C_{va}), earthworks, containments and civil works (C_{cw}), environmental licensing (C_{el}) and opening a company (C_{oc}).

In relation to the operation, labor production costs (C_{lp}), personal protective equipment (C_{ppe}), fuel (C_{fu}), inputs (C_{in}), administrative expenses (C_{ae}), revenue tax (C_{rt}), and maintenance costs (C_{main}) were considered.

A total of eight management tools were established in initiating the "Management" Menu: Municipality, Construction Companies, Projects, Transport, Final Destination, Irregular Points, Ecostations, and Transhipment and Sorting Areas (Figure 4).

All information related to the municipality using the system is registered in the "Municipality" tool, such as population data, demographic growth rate, urban area, companies responsible for collecting CDW, the quantity of waste collected and licensed area.

The "Projects" tool aims to monitor the CDW management of the construction sites located in the urban area of the municipality. It is possible to analyze the CCWMP and partial and final reports sent for each work using this tool, in addition to controlling the environmental licenses and demolition and construction permits issued by the agencies responsible for this activity (Figure 5).

It is possible to register all the mapped irregular CDW deposition points in the "Irregular points" tool, where it is possible to monitor the situation of each point in relation to the location, terrain topography, disposed waste classes, type of road, type of pavement, occupation of the area and accessibility, and it is also possible to attach an image of the location. Thus, the points considered most critical and therefore priority for collection and recovery of the area are identified.

[1]For the calculation, the average storage capacity of 7.6 t of CDW in a bin with a volume of 6 m^3 was considered, thus obtaining a density of 1.26 t/m^3, which was the mean value obtained by the 2900 bins registered in the 20 analyzed construction works.

Figure 4 - **Module II management menu home screen**

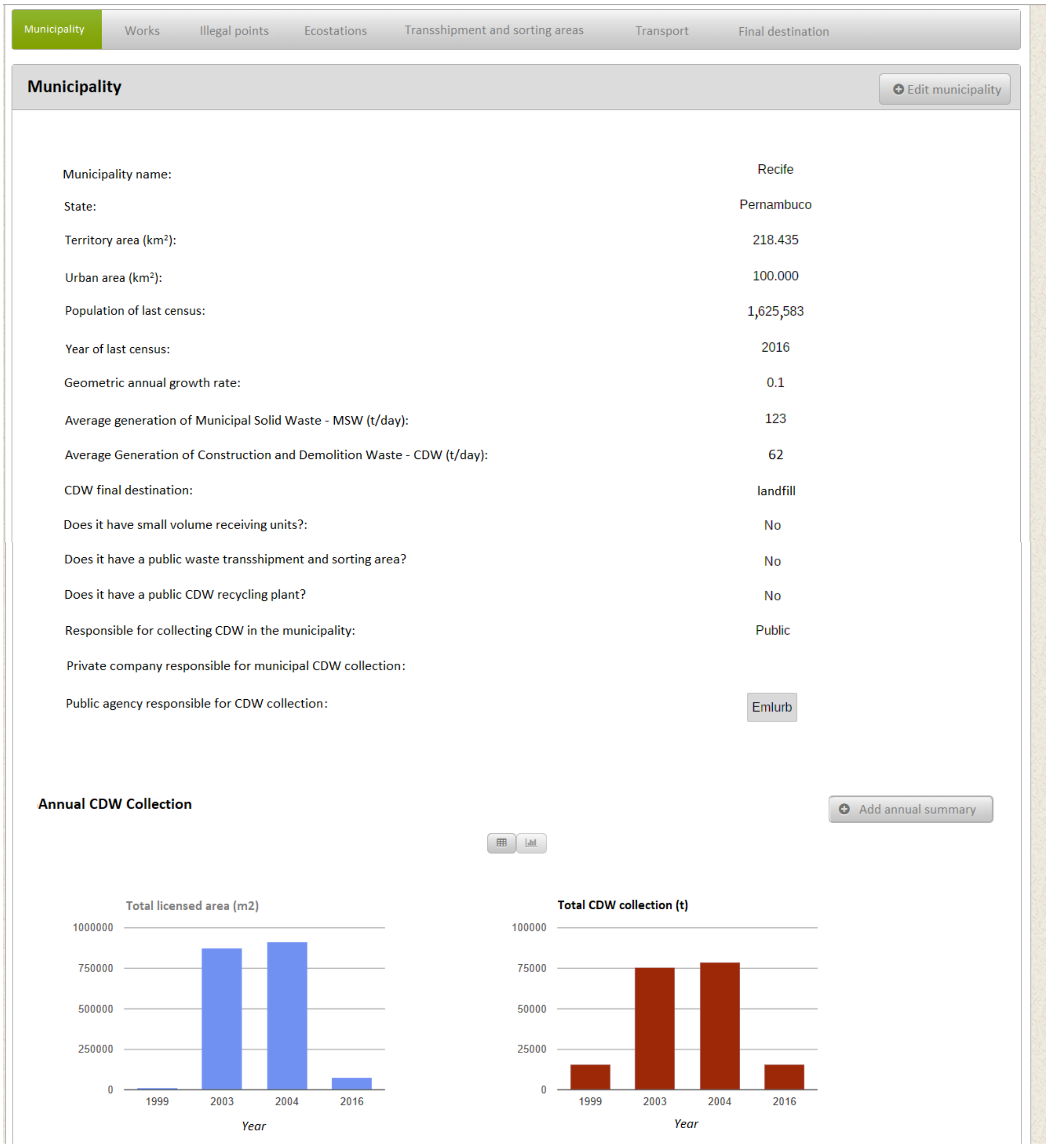
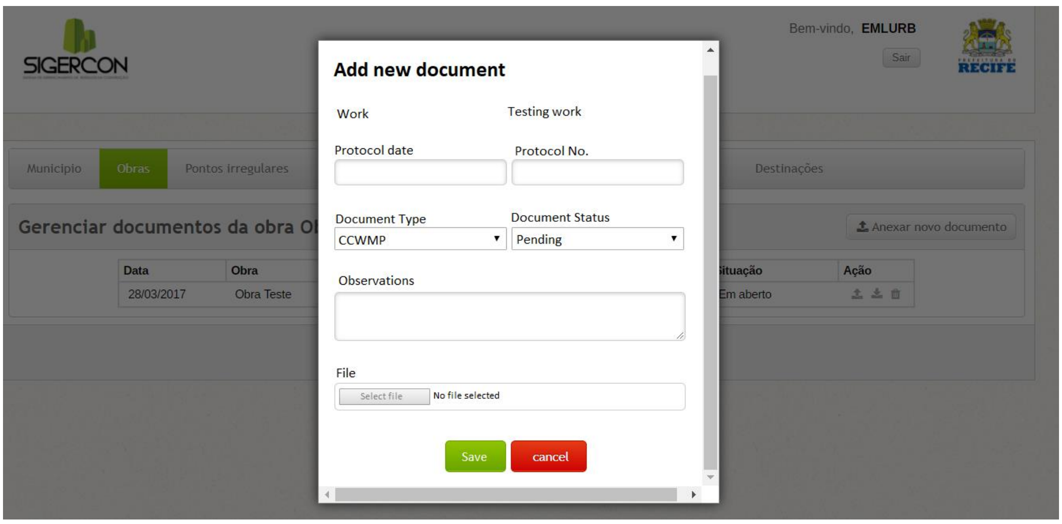


Figure 5 – **Project CCWMP analysis tool**



The “Ecostations” and “Transshipment and Sorting Areas” tools have the same structure, where it is possible to register this equipment (for sorting waste from small and large generators, respectively) in relation to the address, geographical coordinates, daily operational capacity and waste classes received, in addition to controlling the flow of CDW in and out of each area.

In addition, there are the “Transport” and “Final Destination” tools in which the registration of these users is approved, as well as the control of licenses and other documents of the companies.

The system also presents the locations of all data registered in the system which have geographic coordinates in the form of a dynamic map (projects, irregular deposition points, SVRU/TSWA, destination areas).

All registered data that have a geographic location (projects, irregular deposit points, SVRU and TSWA are sent to the “Monitoring” menu, where it is possible to perform spatial analyzes, as shown in Figure 6.

Finally, Module II has the “Denunciations” tool, where information about the irregular CDW deposition points sent by the population and inspectors of the environmental agency through the SIGERCON mobile application which is compatible with Android and iOS smartphone operating systems is recorded. In Figure 7 is presented the initial tutorial and login screens (in the case of inspectors) in the system.

For the general population, just click on “I want to make a complaint” to make a provisional registration of irregular deposition points. The application will request access to the Smartphone’s camera and the current location.

The initiation of the SIGERCON mobile application is related to the needs of environmental agencies to map the irregular CDW deposition points, to visualize the information dynamically and systematically update the database by the contribution of the whole society. With this structure, the application has two tools: one for the inspectors, and another for anonymous complaints. Society may provide anonymous reports, just needing to fill in the data related to the size of the waste pile (small, medium, or large), the surroundings (close to houses, schools, hospitals, shops, vegetation, rivers) and types of waste (rubble, organic and/or pruning).

The registration of the points involves a description of the waste pile size (small, medium or large), the characteristics of the surroundings (house, school, hospital, commerce, vegetation, river), and the types of waste observed (rubble, organic or pruning). Upon completion of the registration, the complaint is made available at the inspector’s login and on the web system to confirm the irregular deposition. After confirmation, the data is sent to the monitoring map (Module II) for registration.

It is necessary to have access to the GPS location data of the smartphone to be able to map the irregular deposition points so that the coordinates are sent to the web system. The application also allows the points to be photographed for further analysis by the module II manager. The same process occurs for the inspectors of environmental agencies, who in addition to registering the points, can also view the complaints on a map in the application itself.

Figure 6 – **Monitoring Menu – Module II**

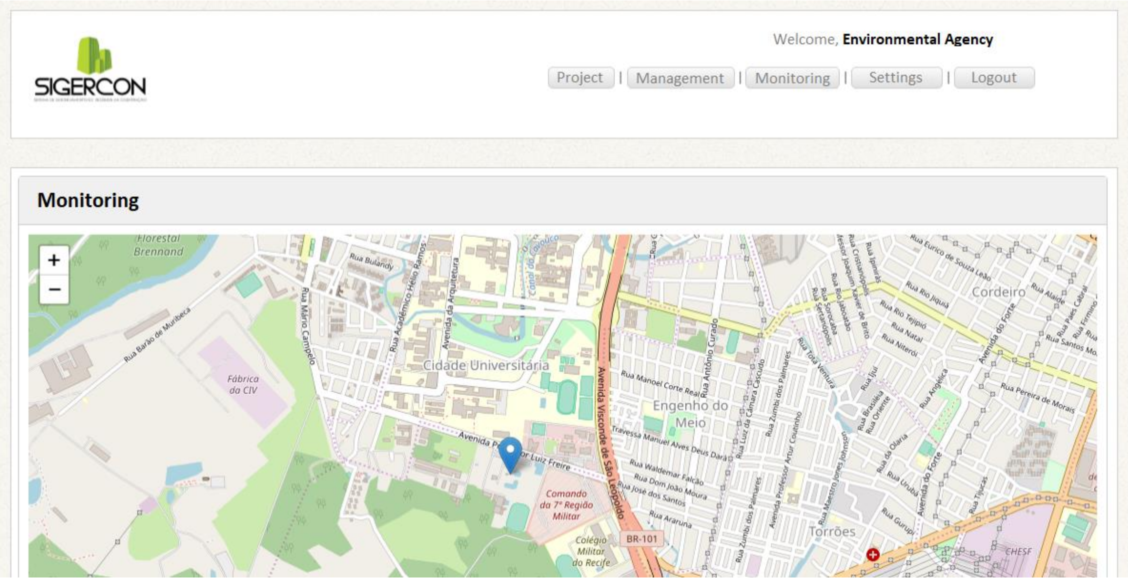
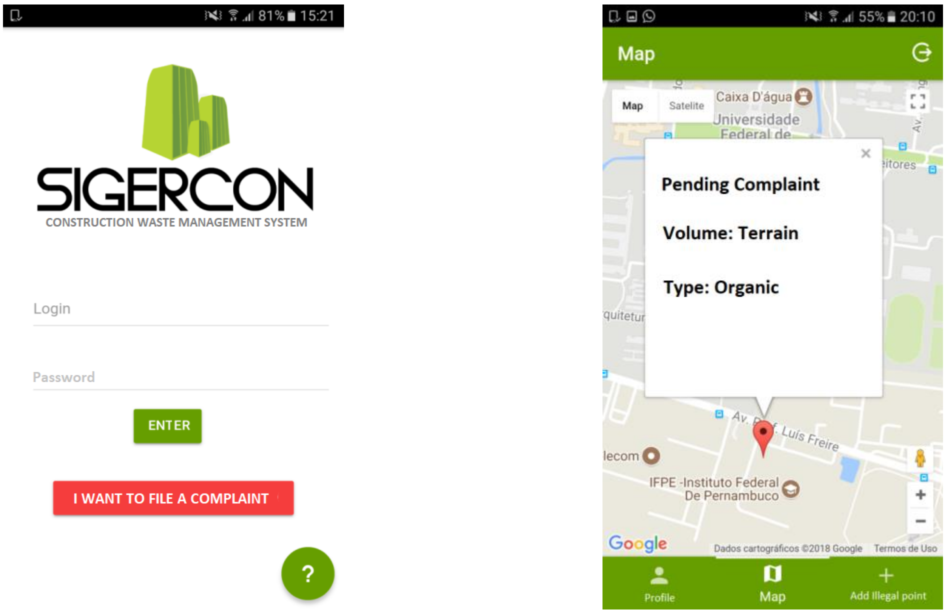


Figure 7 - **SIGERCON mobile application - Module II**



The initiation of Module III aimed at transport companies and final destination of CDW was performed only considering the “Management” menu, since the need to implement a design tool was not identified.

The following tools from Module III were implemented: Company data, projects; destination; waste collection; reports; statistical analysis and economic analysis.

The “Waste Collection” is used to accompany requests for collection from projects/works. When the construction project registers a bin exit, the carrier receives a notification of this collection, can view the data and generate a Waste Transport Control (WTC), if necessary.

The reporting tool is used by transportation and disposal companies to generate the monthly and annual reports needed by customers and the environmental agency. The reports are generated automatically according to the data registered in the “Waste Collection”.

In the “Statistical Analysis” and “Economic Analysis” tools the user can follow the information related to the collected/treated waste, as well as the revenue obtained by this activity. It is also possible to generate a report of these tools for internal user control.

The three SIGERCON modules were integrated after coding according to what was established in the Conceptual Model. In Table 3 is shown the data which are sent between the modules.

Each work registry carried out by the generator is sent to the environmental agency for monitoring. The environmental agency should initially analyze and approve the CCWMP of the project so that the collection registration tools, purchase of recycled aggregates and reuse of waste are released. The environmental agency must approve the final report at the end of the project so that the project management is completed.

The transportation and waste disposal companies will receive all collections that are registered by the generator with the respective WTC in the system. The registration must be analyzed, and the WTC approved so that the waste can be collected. These companies must send reports to the environmental agency monthly.

The first stage of SIGERCON validation was performed during the software coding, in which revisions and bug fixes were carried out. The functionality of the information flow between the system modules, as well as the application, was then tested at the end of the programming.

A comparison of the system tools with the guidelines established by the Municipal Law Project no. 10/2016, which institutes the Urban Cleaning and Management Code of Solid Waste in the Municipality of Recife was conducted as a way of verifying the applicability of SIGERCON to the reality of the users in the city of Recife. This project, which is under discussion in the City Council, regulates the existing instruments and introduces new instruments for the control and inspection of CDW, as well as a series of requirements for generators, transporters and the final destination companies.

Table 3 – **Integration of the SIGERCON Modules**

Receive / Send	Module I – Construction company	Module II – Environmental bodies/organs	Module III – Transporter
Module I – Generator		- Request access (Main screen) - Send the works which have been registered (Manage Works) - Sends licenses and reports	- Sends registration of each waste collection (Waste Collection)
Module II – Environmental bodies/organs	- Approves registration - Sends messages - Approves CCWMP - Approves Partial Reports - Approves Final Reports		- Approves Registration - Approves reports
Module III – Transporter	- Sends monthly reports (Reports)	- Request access (Main screen) - Sends documents (Company data) - Sends monthly and annual reports (Reports)	

Among the novelties established by the code, the requirement to send partial reports by the construction companies for construction projects lasting more than one year stands out to renew the CCWMP. The report must contain the activities carried out to comply with what was defined in the project's CCWMP. Using the system, a CDW generation report will be generated automatically, and it will be possible to attach and submit the reports for approval to the environmental agency.

We also verified the validity of the weighing tickets and the requirement for proof of delivery of recyclable materials in the final report of the CCWMP. The tool for attaching documents also promotes control of weighing vouchers and tickets.

In addition, more requirements were established to prove the residues which are reused in the project so that it is necessary to register the reuse of the material through photos, and submit projects which prove the need for use. In this sense, the system promotes the control and organization of documents related to reusing waste.

The project tool for the municipality of Jaboatão dos Guararapes/PE was used to validate the system database in order to compare the estimated data of the model with the reality of the municipality. The system estimated the waste generation in the municipality by class and material from the registered data (Figure 8).

Considering that the municipality does not have ecostations for sorting waste from small generators or a beneficiation plant, the DSS dimensioned the quantity and the cost of the ecostations (Figure 9) and the dimension and the cost of the beneficiation plants.

Considering a reception capacity of 30 t/day of waste, and with a coverage radial area of 1.5 km, the need to install 14 ecostations in the municipality of Jaboatão dos Guararapes was estimated, with an installation cost of almost R$ 8 million (US$ 2.1 million).

A plant with a 25 t/h crusher for the final destination of CDW was estimated by the system at an installation cost of just over R$ 2 million (US$ 530,000), and maintenance cost of R$ 670,000 (US$ 177,000/year).

An SIG project was developed from the data obtained by the DSS to plan the integrated management of the CDW in Jaboatão dos Guararapes. In Figure 10 is possible to see the location of the 14 proposed ecostations based on the 101 irregular CDW deposition points mapped by Santos *et al*. (2015), while in Figure 11 is presented the proposal for the location of the CDW beneficiation plant, considering the criteria established in this research.

It was found that there are only two recommended areas in Jaboatão: one in the Muribeca neighborhood, with 95 ha, and the other in the Muribequinha neighborhood, with 240 ha. Both areas are favorable considering that the DSS proposed a minimum area of 12.3 ha. However, it was proposed to implement the plant in Muribequinha due to its greater proximity to the irregular CDW deposition points.

Thus, it was observed that the output data from the DSS of Module II favored planning integrated CDW management in the municipality by presenting viable alternatives for the collection, transportation and final destination of the waste.

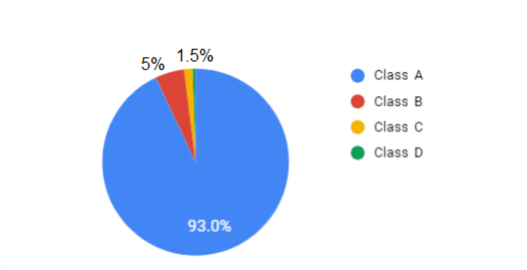
Conclusions

This study aimed to develop a computational system (software) which supports integrated CDW management for Brazilian municipalities, unifying the actions of stakeholders, streamlining procedures and allowing greater supervision by environmental agencies.

Figure 8 - **Estimation of waste generation by class and type of material in Jaboatão dos Guararapes/PE**

Waste generation by class

Class	Percentage (%)	Quantity generated (t)
Class A	93	389.43
Class B	5	20.94
Class C	1.5	6.28
Class D	0.5	2.09



Waste generation by type of material

Component	Percentage (%)	Quantity generated (t)
Concrete	20	83.7
Mortar	16	67.0
Fine material	17	71.1
Soil	22	92.1
Brick	22	92.1
Wood	2	8.4
Metal	1	4.2

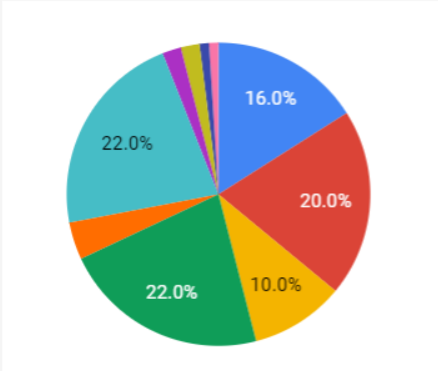


Figure 9 - **Dimensioning of ecostations for the municipality of Jaboatão dos Guararapes/PE**

Dimensioning of ecostations network

Coverage radius	1.5
Minimum amount of ecostations	14
Municipality situation	Alternative 1 The municipality does not have ecostations
Capacity to receive CDW in ecostations (m³/day)	30
No. of inhabitants / ecostation	51227
Unit cost of installing an ecostation (BRL/unit)	500,000
Cost of installation of ecoestations (BRL)	6811816
Unit cost of maintaning an ecostation (BRL/unit)	50,000
Monthly maintenance cost (BRL/month)	681,182
Dimensioning the amount of skips per day	58

Figure 10 **- Location of the proposed ecostations for the municipality of Jaboatão dos Guararapes/PE**

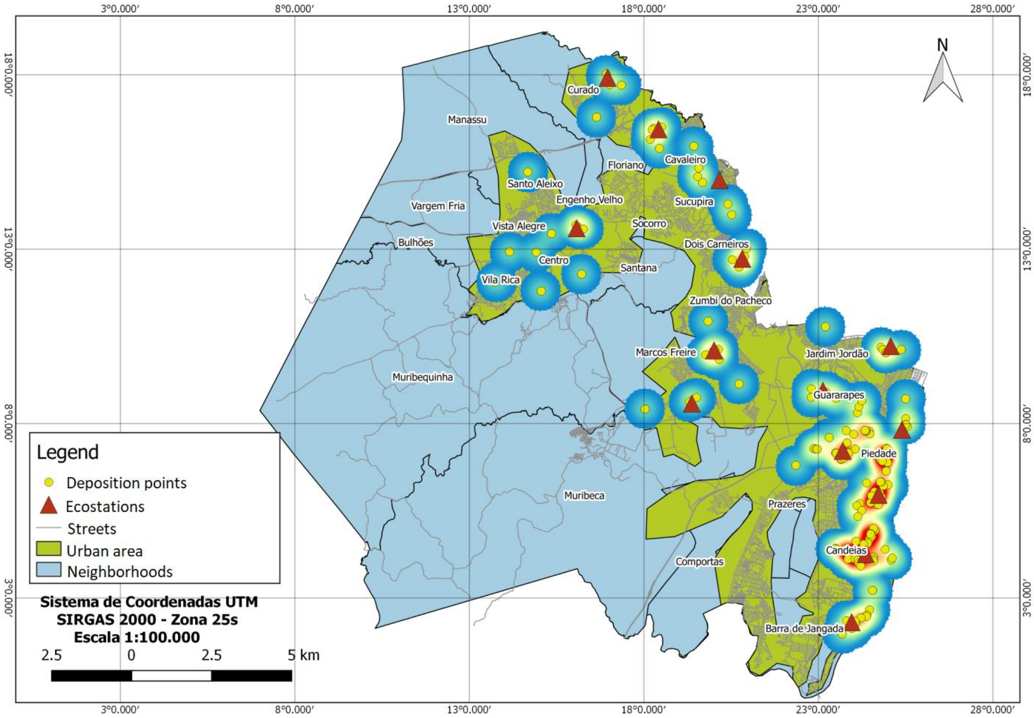
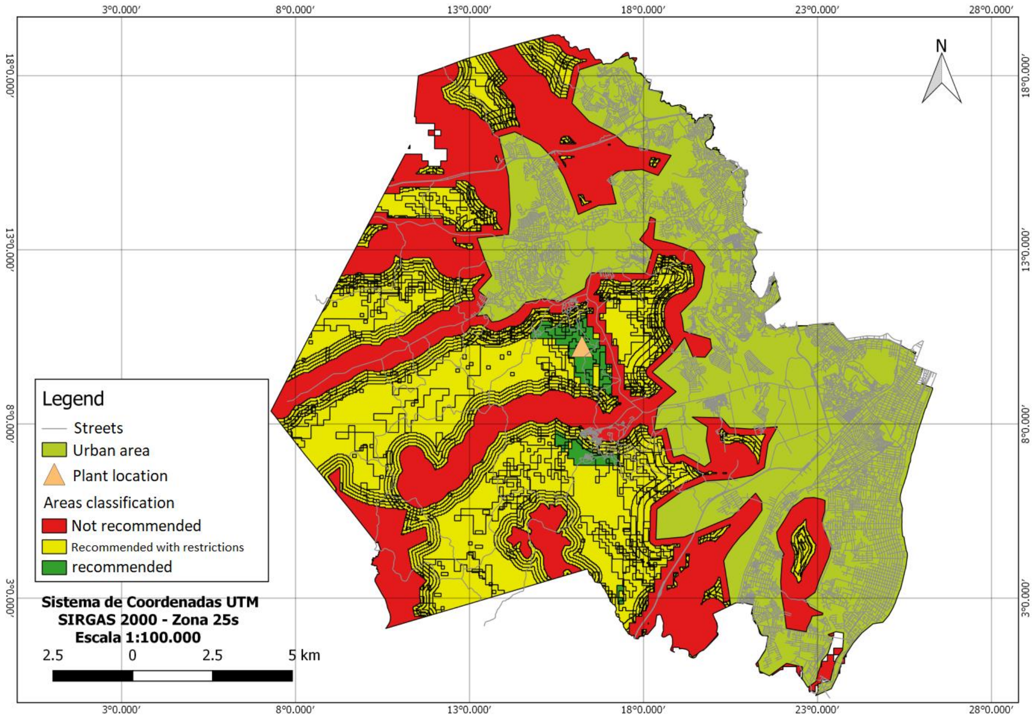


Figure 11 **- Classification of areas and location of the proposed plant for the municipality of Jaboatão dos Guararapes**



Based on the tests and validation of its modules and application in the municipality of Jaboatão dos Guararapes, it was concluded that SIGERCON favors the implementation of an integrated CDW management system in Brazilian municipalities considering the specificity of each municipality and each region. This was made possible by the inclusion of information from several municipalities and studies already carried out, in the database of the system.

When integrating an expert system into the waste management process, it was observed that the data estimated by the system were more accurate than the estimated generation in the CDW management projects of the new works.

The system favors integrated management considering the political dimension, as it helps in complying with laws and standards, as well as in implementing good practices and viable solutions for waste (economic dimension). Regarding cultural and social issues, the socio-environmental impacts are reduced from irregular CDW deposition, and it helps in implementing environmental education programs, allowing society to participate more effectively in CDW management, and in the inspection and disposal of waste in ecostations.

The expansion of SIGERCON to three modules involving municipal management and transporters together with management at construction sites favors an integration of data, as well as control of the necessary documentation to comply with the federal and municipal CDW management laws. The system makes it possible to conduct activities which are currently manual to be quicker, such as analysis and approval of CCWMP, registration and control of construction projects, transporters and final destination companies, preparation of collection reports and filling in the waste transport manifest.

In addition, the system has great potential for city governments which have a limited number of professionals and few managers with technical knowledge about the management of construction waste, as the software enables automation of several processes which would require a larger team.

The implementation of the irregular deposition monitoring application also streamlined the inspection and collection activities of the illegally disposed CDW. It was also possible to include society in general as actors in the waste management process, expanding the capacity for monitoring and mapping waste.

With the measures foreseen in the Metropolitan Solid Waste Plan based on Federal Law No. 12,305/2010 (BRASIL, 2010), the integrated management of CDW in the Metropolitan Region of Recife can become a reality, reaching the various actors that operate in the system such as generators, transporters, urban cleaning agencies and society.

Therefore, it is concluded that the computational tool developed and tested with a robust database for CDW management in municipalities enables identifying better management alternatives considering the different realities of each municipality and each construction project. However, it is necessary to expand the system's database so that it is calibrated and takes into account the different realities of Brazilian municipalities.

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