Enhancing an Arbovirus Control System with Georeferencing and Geolocation Resources

João S. Castanho
Departamento de Informática
Universidade Estadual de Maringá
Maringá, Brazil
joao.staub42@gmail.com

and

Felippe Fernandes da Silva
Departamento de Informática
Universidade Estadual de Maringá
Maringá, Brazil
felippefernandes10@gmail.com

and

Thelma E. Colanzi
Departamento de Informática
Universidade Estadual de Maringá
Maringá, Brazil
thelma@din.uem.br

and

Raqueline R. M. Penteado
Departamento de Informática
Universidade Estadual de Maringá
Maringá, Brazil
raque@din.uem.br

and

Guilherme Guerino
Colegiado de Ciência da Computação
UNESPAR Apucarana
Apucarana, Brazil
guilherme.guerino@ies.unespar.edu.br

Abstract

Diseases transmitted by Aedes aegypti, such as dengue, zika, and chikungunya, are a significant challenge for public health in Brazil. Geolocation and georeferencing are relevant resources for enhancing information systems that support the surveillance and control of such diseases. Despite its importance, many current methods of surveillance and control still rely on manual, paper-based processes that are slow and prone to spatial inaccuracies. This work presents the development and integration of specialized geoprocessing modules into the 'Controle Vetorial Paraná" system, a comprehensive technological solution designed to modernize entomological surveillance for the state of Paraná, Brazil. Rather than describing the entire platform, this article focuses specifically on these newly added georeferencing resources, which shift the operational focus from individual property addresses to block-based polygons, thereby overcoming the precision limitations of public geocoding services. Key features include polygon-based block registration, mandatory geographic validation of field visits, and dynamic heat maps for strategic decision-making. The proposed features were validated through user-centered design stages with health coordinators and endemic control agents. Results demonstrate that the transition to a polygon-based model, combined with a 35-meter GPS tolerance zone, significantly enhances the reliability of field data and streamlines the planning of blocking routes, providing a more precise and efficient tool for public health management. The experience reported in this work is valuable to a wide range of studies on the application of georeferencing features as extensions to existing information systems.

Keywords: geographic information systems, arboviruses, health informatics, user centered design.

1 Introduction

Arboviruses, such as dengue, zika, and chikungunya, transmitted by *Aedes aegypti*, represent a significant challenge for public health in Brazil [1, 2]. Effective control of these diseases depends on reducing the mosquito vector population, which proliferates in urban environments with stagnant water [3]. Measures such as environmental sanitation, the use of larvicides and insecticides, and regular inspections in residences and commercial establishments are fundamental to eliminating breeding sites and preventing outbreaks [4]. These actions are primarily carried out by Endemic Disease Control Agents (ACEs), in collaboration with Community Health Agents (ACSs), who identify focal points, apply chemical products, and guide the population on prevention [5]. The efficacy of these activities is crucial to containing the spread of arboviruses and reducing their impact on public health.

Regarding information systems in Brazil, the Ministry of Health carries out the monitoring and management of dengue and other arboviruses through two distinct information systems: Information System for Notifiable Diseases (SINAN) and National Dengue Control Program System (SisPNCD). SINAN aims to collect and process data on notifiable diseases across Brazil, thereby providing information for analyzing the morbidity profile and assisting decision-making at the municipal, state, and federal levels [6]. SisPNCD allows recording of sociodemographic data on affected individuals and monitoring of the disease's behavior in the region. However, access to SisPNCD alone is insufficient to support decision-making on preventive actions and the fight against arboviruses [7]. This inadequacy stems from the lack of integration between SINAN and SisPNCD, which prevents a unified view of epidemiological and entomological data. Furthermore, these systems lack georeferencing, making it difficult to identify precise geographic clusters of infestation or to plan field operations in a timely and optimized manner.

Furthermore, the primary method for vector monitoring is the Rapid Larval Index Surveillance for *Aedes aegypti* (LIRAa). LIRAa is a sample-based study conducted in households to identify areas with the highest concentration of mosquito breeding sites. This survey is conducted through stratified sampling, in which the municipality is divided into homogeneous sectors, and blocks are randomly selected for inspection. Within these blocks, approximately 20% of households are randomly selected for visits by ACEs, who record the presence of mosquito foci and the types of containers found. With the results obtained through LIRAa, local managers have the capacity to plan and direct their actions to combat the vector more effectively [8]; however, LIRAa is not an information system, but rather an epidemiological monitoring method based on sample surveys.

Submitting data to SINAN, SisPNCD, and LIRAa is mandatory for all Brazilian municipalities, although there is no integration among them. These systems present several limitations, ranging from how data is entered to the maintenance of historical records, and they provide limited information for the decision-making process. Currently, the use of these systems is restricted to generating national statistics. At the municipal level, managers generally rely on their own experience because these systems do not provide adequate support.

In this context, there are systems whose objective is to control actions to combat arboviruses [9, 10]; however, they do not use georeferencing, which enables precise identification of areas with higher concentrations of vectors and cases, thereby supporting timely planning of control actions. On the other hand, systems that do utilize georeferencing either do not include visit validation and route planning [11, 12] or are not intended for ACEs [12], who are the primary actors in carrying out arbovirus combat actions. In addition to academic and governmental initiatives, some Brazilian cities have adopted tools created by the private sector—solutions to which access is restricted and tends to be specific to the city that hires the service, preventing the consolidation of data to enable decision-making at the state or federal level.

This article is an extension of our previous work [13]. Our work proposes georeferencing functionalities within the context of an arbovirus control system, aiming to increase the efficiency of actions to combat these diseases. The aforementioned system, named ControleVetorial Paraná, was developed as part of an outreach project, with the objective of strengthening the fight against arboviruses across all municipalities in the state of Paraná, Brazil. This system allows for the monitoring and management of vector control actions carried out by ACEs and ACSs, including features such as basic registrations, property records, block registration with georeferencing, route control, management of various types of property visits, and the generation of management reports.

Thus, this article reports the development and validation of specialized functionalities utilizing geolocation[1] and georeferencing[2] that were designed and integrated as modular extensions into this arbovirus control system, which is divided into a web system and a mobile application. Rather than exploring the entire core platform capabilities, this text focuses strictly on the engineering and implementation of these new spatial components. In the mobile application, geolocation is used to validate the position of visits conducted by ACEs or ACSs, in addition to storing information regarding mosquito foci. In the web system, the georeferencing architecture comprises the registration of block areas—which are the units visited during city inspections—the visualization of blocking areas to prioritize actions, and the integrated visualization of endemic foci. We conducted an evaluation with end-users, focusing on data collection accuracy, error reduction, and agile identification of risk areas, which are critical to optimizing decision-making in entomological surveillance. This evaluation included improvement and validation stages, which enabled better acceptance of the developed system and the collection of suggestions that guided the progress of the work (Sections 3 and 4). Compared to our previous work [13], this article provides a broader and more in-depth background, more detailed results as well as a more extensive discussion of how our work stands in light of related work.

The main contribution is a modular georeferencing architecture integrated into an existing arbovirus control system, enabling block registration, GPS-based visit validation, and spatial delimitation of blocking areas. User evaluations confirmed improved efficiency in field workflows, and the broader social impact lies in enabling more targeted interventions against arbovirus transmission.

2 Background

This section presents the theoretical basis for the topics addressed in this work. It covers the primary concepts related to arboviruses and their control strategies, as well as the fundamentals of Geographic Information Systems (GIS), the Global Positioning System (GPS), geolocation technologies, and geographic databases. Furthermore, existing Brazilian computational systems aimed at monitoring and combating arboviruses are analyzed.

2.1 Geolocation Technologies

Geolocation technologies enable the structured identification and organization of spatial data, and, in this context, tools and standards for processing geospatial information have become prominent. A relevant example is **PostGIS**, an advanced spatial extension for PostgreSQL that clearly demonstrates how geometry concepts and spatial manipulation can be applied to relational databases. Originally developed as part of a research project on spatial database technologies by the company Refractions Research Inc., PostGIS has established itself as a robust tool for working with geospatial information. In alignment with the spatial data model defined by the Open Geospatial Consortium (OGC), it implements the principles established by this standard within PostgreSQL.

[1]Geolocation refers to the process of determining the real-world geographic location of an object or person using coordinates (latitude and longitude), typically captured via GPS or network signals.

[2]Georeferencing is the process of associating geographic coordinates with digital data, such as mapping these points onto a specific cartographic projection to allow spatial analysis within a Geographic Information System (GIS).

The standard developed by the OGC provides a model for geospatial data called Simple Features Access (SFA). This standard defines the fundamental Geometry type, accompanied by operations that manipulate and transform geometric entities. Geometry is an abstract type, where geometric values belong to its concrete subtypes, representing a variety of geometric shapes in different dimensions. These subtypes include the atomic types Point, LineString, LinearRing, and Polygon, as well as the collection types MultiPoint, MultiLineString, MultiPolygon, and GeometryCollection [14].

On the other hand, we have **geocoding** and **reverse geocoding**. Geocoding is the process of associating a pair of X and Y coordinates (latitude and longitude) with a location description by comparing specific information about the site with that found in a reference database [15]. The geocoding process encompasses the steps necessary to convert an input address, locate this address within the reference data, and identify the best candidate or candidates as reference points on the map. Despite the various applications of geocoding, several recurring challenges affect this process, often resulting in low matching rates. This, in turn, may require significant manual intervention by the user and can lead to inaccuracies and/or gaps in the generated spatial datasets [16].

Reverse geocoding is the process of converting geographic X and Y coordinates (latitude and longitude) into a human-understandable address or location name. This technique plays a crucial role in various situations, such as mobile device location applications and emergency call systems [17]. When a user provides GPS coordinates, reverse geocoding is used to convert them into a readable address, allowing the end user to understand their location intuitively. However, it is essential to note that reverse geocoding results are not always absolutely precise, as they may depend on estimates within predefined intervals. The accuracy of these results can vary depending on the quality of the available reference data and the interpolation methods used. Therefore, when implementing services that rely on reverse geocoding, it is fundamental to consider these limitations and choose the most appropriate approach for the project's specific needs [18].

The Google Maps Geocoding API [19] is a proprietary service offering high-precision geocoding. Nominatim [20] is an open-source alternative based on OpenStreetMap data, widely used in budget-constrained projects.

2.2 The *Aedes* Mosquito and Arboviruses

The mosquito genus *Aedes* is associated with the transmission of several arboviruses. Specifically, the *Aedes aegypti* and *Aedes albopictus* mosquitoes are of interest due to their relationship with infectious diseases such as dengue, zika, yellow fever, and *chikungunya*. These vectors can transmit four major arboviruses, significantly impacting public health. *Aedes aegypti* and *Aedes albopictus* prefer warm, humid climates and are predominantly diurnal mosquitoes. Favorable conditions, such as high temperatures and a high amount of rainfall, lead to the hatching of eggs within a few days [21].

Actions to combat *Aedes aegypti* and *Aedes albopictus* are fundamental to containing the spread of diseases transmitted by these vectors; for this control, several actions can be taken. One of the foundations of combating vector mosquitoes is environmental sanitation, which includes measures to reduce potential breeding sites, such as preventing water accumulation in containers that could serve as oviposition, protecting and covering useful containers, recycling or destroying useless containers, and eliminating natural breeding sites. There is also the use of insecticides and fogging; insecticides and larvicides are important measures in the fight against dengue vectors. Larvicides are applied to containers holding stagnant water to kill larvae, while insecticides are applied using nebulization machines or fogging trucks to eliminate adult mosquitoes in flight. Fogging is used in situations of high transmission, such as outbreaks or epidemics [4].

2.3 Brazilian Processes applied at the National Level

In Brazil, the primary method for monitoring *Aedes aegypti* is the Rapid Larval Index Surveillance for Aedes aegypti (LIRAa). LIRAa is a sample-based study conducted in households to identify areas with the highest concentration of mosquito breeding sites. With the results obtained through LIRAa, local managers have the capacity to plan and direct their actions to combat the vector more effectively [8].

The LIRAa Manual [22] highlights the importance of simplified sampling methods to facilitate the collection of relevant information for evaluating health programs, such as those for the control of dengue and other arboviruses. These methods are referred to as simplified because they enable estimates with acceptable errors and negligible biases in a rapid and cost-effective manner. The World Health Organization (WHO) and the Pan American Health Organization (PAHO) encourage the adoption of these methods for entomo-epidemiological surveys. Having an information system that provides indices quickly allows managers to direct actions toward critical areas and evaluate control activities more effectively, optimizing resources.

The National Dengue Control Program (PNCD), launched by the Ministry of Health in 2002, established the need for a methodology capable of generating timely data to support the fight against Aedes aegypti.

As a direct result of this requirement, the LIRAa methodology was developed, and its official manual [22] provides the technical guidelines for its implementation. This manual presents the fundamentals of the methodology, including criteria for strata[3] delimitation, action planning, sampling plans, and standardized forms, emphasizing the importance of specific actions based on the identified indicators and predominant breeding sites.

LIRAa, conducted nationally at the end of the year during the non-epidemic period, serves as a tool to guide control measures and social mobilization. The dissemination of results in the media has proven effective in gaining support from the population and sectors beyond healthcare in addressing the dengue problem within municipalities. LIRAa can replace traditional surveys, which typically present results only after the bimonthly work cycle [23]. However, it is important to emphasize that while LIRAa is an effective epidemiological monitoring method, it is not an information system by itself. Consequently, its execution depends on manual data collection and processing or its automation through specific software to ensure that indices are generated in a timely manner for decision-making.

Regarding national monitoring, the SINAN was created to collect and process data on notifiable diseases across Brazil, providing essential information for morbidity profile analysis and decision-making at all governmental levels [6]. While its online version allows for real-time data dissemination, it relies on extensive investigation forms where geographic data, such as residential addresses, are not mandatory, although they represent a potential source for georeferencing cases [24].

In a complementary way, the SisPNCD serves as the administrative platform for managing dengue control data, operating in both local and online modules to facilitate municipal reporting to state and federal authorities [25]. However, this system focuses primarily on sociodemographic data and administrative reports, and its isolated use is considered inadequate for providing a complete understanding of disease behavior or supporting detailed preventive actions in the field [7]. Ultimately, these national systems fall short for operational vector control: designed primarily for statistical surveillance, they lack the real-time geoprocessing capabilities required to direct local interventions effectively.

2.4 Computational Technologies and Systems for Arbovirus Prevention and Control

The primary strategy for reducing the incidence of dengue and other arboviruses is to control and eliminate the responsible vector. To achieve this, having a system that provides indices rapidly allows managers to direct actions toward critical areas and evaluate control activities more effectively, optimizing resources.

For agents to obtain information correctly, their location must be reported accurately. For this purpose, there are GIS, which are systems that perform the computational processing of geographic data, allowing for the retrieval of information based not only on alphanumeric attributes but also on their spatial location. These systems provide a unique perspective on the work environment of administrators, urbanists, planners, and engineers, integrating information from various fields around a common element: geographic location. Thus, data in a GIS must be georeferenced—that is, mapped onto the Earth's surface in a cartographic projection. GIS has several applications, including agriculture and cartography. One of its main uses is supporting the spatial analysis of phenomena [26].

An example of the use of GIS in arbovirus control was presented in the work by Barcellos et al. [27]. The authors conducted a study using GIS to analyze the spatial distribution of dengue cases and households with the dengue vector in the municipality of Porto Alegre, Brazil. The socio-spatial analysis enabled the identification of areas with higher concentrations of vectors and cases, providing valuable insights for planning control actions.

The Global Positioning System (GPS), a global radionavigation system that covers the entire Earth, supports the use of GIS. GPS enables global tracking by triangulating signals from at least four satellites. The system is composed of three segments: space, with 24 satellites distributed in orbit; control, responsible for supervision and corrections; and user, which includes GPS receivers for various applications. The versatility of GPS allows for applications in several areas, such as maritime navigation and topographic mapping. Its accuracy and reliability have been fundamental to technological advancement and the improvement of human activities, enabling the creation of innovative solutions that depend on precise position determination at any point on the planet [28].

There are several technological solutions developed by researchers focused on combating dengue in Brazil. Solutions such as Aedes em Foco [9] and SisVetor [10] prioritize the collection and visualization of inspection data, automating the registration of mosquito foci and monitoring activities. Aedes em Foco, developed for Cedro-CE, does not utilize georeferencing, which limits its capacity for dynamic spatial mapping. In contrast, SisVetor employs georeferencing for the planning and control of field teams; however, its implementation in

[3] In the context of LIRAa, a stratum (estrato) is a geographical grouping of blocks within a municipality, usually containing between 8,100 and 12,000 properties, used to ensure statistical representativeness during sampling.

pilot projects (Manaus-AM and Sete Lagoas-MG) does not detail the precision or integration of technologies such as GPS, restricting its replicability in contexts that demand real-time georeferencing or high granularity.

On the other hand, SIGDENGUE [11] and Vaza Dengue [12] aggregate municipal data with a focus on georeferencing. SIGDENGUE utilizes static shapefiles provided by the Municipality of Cascavel, Brazil, which limits its scope to that locality and prevents scalability to other regions without structural adaptations. Furthermore, this software does not include visit validation or visual route planning, thus not addressing the same scope as our proposal. Vaza Dengue, in turn, employs georeferencing via mobile devices to allow citizens to report mosquito foci and suspected cases directly on an interactive map, with colored markers indicating the type of notification. However, its purpose is oriented toward interaction with the population rather than systematic monitoring by ACEs, which reduces its applicability in contexts that require standardized institutional control.

The most related work to ours are the systems aforementioned. These solutions, although innovative, have limitations in geographic scope, technological precision, and target audiences, and differ from the georeferencing used in this work. In summary, Table 1 presents a comparison of the related work, highlighting their objective, the use of georeferencing, and how the georeferencing is utilized.

Table 1: **Synthesis of related work.**

Work	**Work Objective**	**End Users**	**Georefe-rencing?**	**Georeferencing Description**
Barcellos et al. [27]	Performs an analysis of the spatial distribution of cases and households with the dengue vector in the municipality of Porto Alegre.	Health managers and epidemiologists.	Yes	Uses GIS to identify areas with higher concentrations of vectors and cases.
Aedes em Foco[9]	Automates the registration of mosquito foci and monitoring activities in the municipality of Cedro - CE.	Health agents and municipal managers.	No	The system focuses on the collection and visualization of inspection data but does not use dynamic spatial mapping.
SisVetor [10]	Performs planning and control of field teams.	Field team supervisors and managers.	Yes	Employed in team control, but there are no details on the integration of technologies such as GPS.
SIGDENGUE [11]	Supports the management of dengue actions, focusing on notification, radius, and blocking activities.	Municipal health coordinators.	Yes	Uses static shapefiles for municipal mapping but does not include visit validation or visual route planning.
VazaDengue [12]	Allows citizens to report foci and suspected cases.	General population (citizens) and health managers.	Yes	Implements georeferencing through an interactive map with colored markers, where the population indicates the location of notifications.

Beyond the academic and governmental systems discussed above, some municipal health secretariats have also deployed public-facing dashboards displaying epidemiological and entomological data, typically including heat maps highlighting incidence levels by Basic Health Unit (UBS) [29, 10].

The existing dashboards and systems for Arbovirus Prevention and Control have several limitations, such as being typically designed for a single municipality, not being directed to the entire endemic disease control team, and not being easily integrated with national processes. Consequently, the strategic planning and execution of preventive measures to contain arbovirus outbreaks are severely hindered by the lack of real-time, georeferenced information at the municipal level. This fact motivates the development of the system Controle Vetorial Paraná, which is described in the next section.

Outside of Brazil, there are also computational solutions that rely heavily on GIS for vector control. In Colombia, a WebGIS system in Cali integrates socioeconomic and entomological data to generate vulnerability indices for resource targeting [30], while Singapore's NEA coupled Enterprise GIS with handheld field terminals for real-time block-level georeferencing [31]. Unlike these strategic mapping tools, the system proposed here fills an operational niche by embedding automated geographic validation directly into field agent workflows.

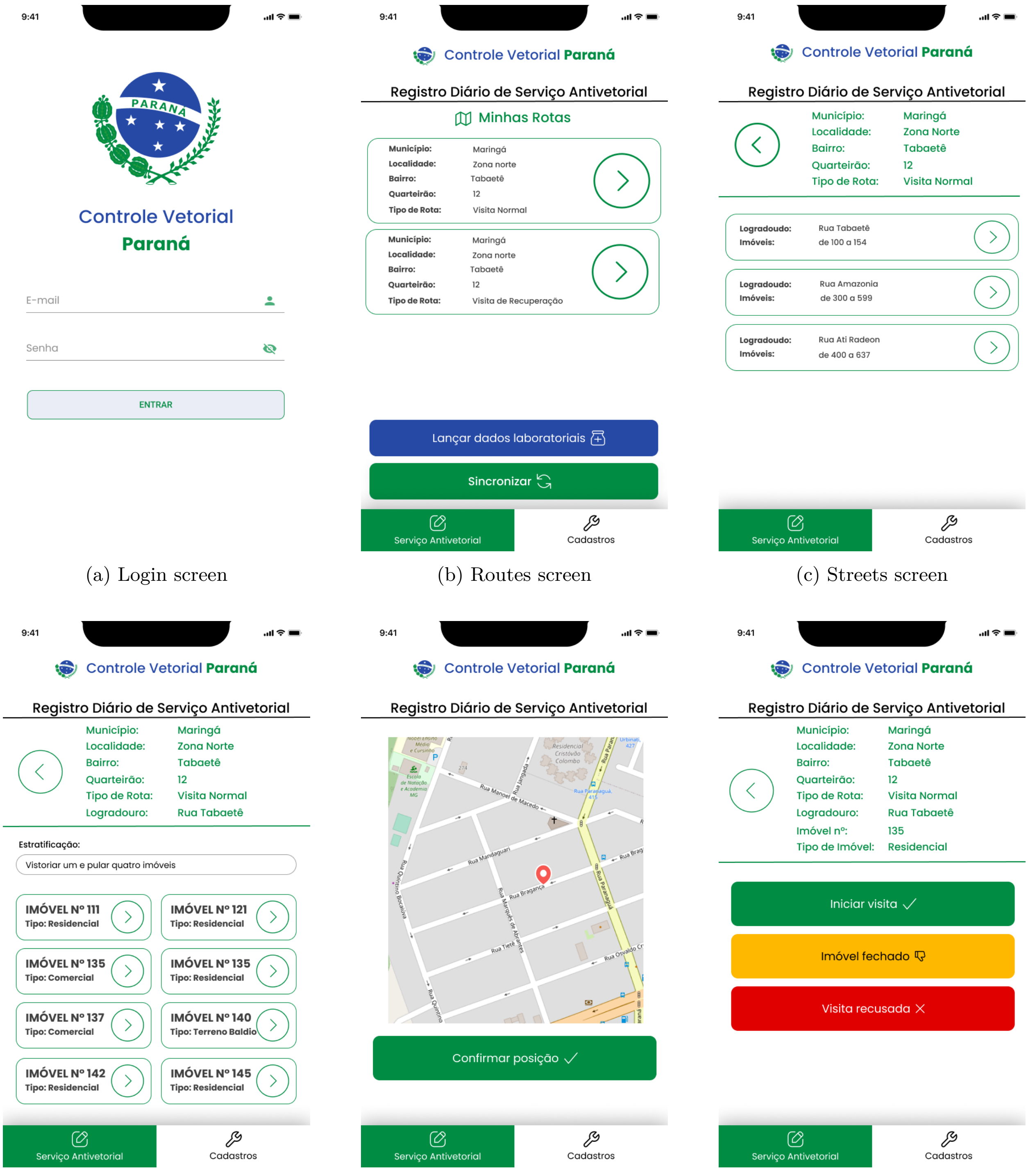
2.5 Controle Vetorial Paraná

The software discussed in this work is part of an outreach project developed at the State University of Maringá (UEM) in collaboration with the Paraná State Health Secretariat (SESA/PR). The primary motivation for this project stems from the critical public health situation in Paraná, which has consistently ranked among the Brazilian states with the highest number of dengue cases [32]. The complexity of managing outbreaks is further intensified by the circulation of multiple viral serotypes and the high volume of people crossing international borders. Current challenges include delays in case notification and the technical limitations of existing national systems, which hinder timely prediction and detection of outbreaks.

The project's main objective is to provide a robust technological solution for entomological surveillance and vector control, centralizing management for all 399 municipalities in Paraná within a single platform. The developed system, named **Controle Vetorial Paraná**, was conceived through an integrated architectural approach consisting of two main components:

- **Web Application:** Developed for management and administrative oversight, it allows for the registration of blocks with high-precision georeferencing, route planning, and the generation of detailed reports in PDF and XLS formats.
- **Mobile Application:** Specifically designed for field use by Endemic Control Agents (ACEs). It enables the registration of various types of activities, such as property(residence or business establishment) visits, focal treatments, blockages, strategic point inspections, and both light and heavy Ultra-Low Volume (ULV) applications.

Targeting health managers and field agents, the system addresses the critical gap in data integration by allowing the export of files specifically formatted for submission to national systems like SINAN and SisPNCD. This ensures that while local management gains speed and precision through geoprocessing, national statistical obligations are still met. Furthermore, the solution underwent usability evaluations to ensure that the interface and workflows were appropriate for agents' operational routines, minimizing errors during data collection and enhancing the overall effectiveness of vector control strategies in the state [13]. Complementing the technical validation, the web interface designed for coordinators underwent a structured heuristic evaluation based on Nielsen's principles. This study, guided by the Design Science Research Methodology (DSRM), involved 72 participants who performed guided tasks to identify potential interface limitations. The evaluation confirmed positive perceptions regarding the system's consistency and visual organization, while providing critical feedback to refine error prevention and navigation flow. Such iterative assessments ensure that the Controle Vetorial Paraná system remains a user-centered tool, capable of supporting complex public health workflows with high usability and operational efficiency [33].



(a) Login screen (b) Routes screen (c) Streets screen

(d) Property screen (e) Map screen (f) Entomological visit screen

Figure 1: Excerpts of the mobile application prototype.

To sustain this integrated architecture, the technological stack was selected to ensure scalability and native support for geospatial data. For the back end, Java was chosen with the Spring Boot framework, working alongside a PostgreSQL database with the PostGIS extension for storing and manipulating spatial geometries. On the other hand, for the web front-end, the Angular framework was adopted to provide a dynamic administrative interface. Complementarily, Android was defined for the mobile version to ensure the necessary performance for field data collection.

Excerpts of screen prototypes developed for the mobile application are presented in Figure 1, specifically highlighting the geolocation features compatible with the functionalities developed in the first improvement stage (see Section 3). As the system was developed to be used in Brazil, the text of all screens are in Portuguese. Figure 1a illustrates the login interface, where the field agent enters their email and password to access the system. Following authentication, Figure 1b displays the list of available service routes within the "Serviço Antivetorial" (Anti-vector Service) module.

To accommodate field reality where connectivity is often intermittent or absent, the mobile application operates in an offline-first capability. During initial synchronization at the local health office via internet connection, the system downloads all assigned routes and block geometries to the device's local storage. Consequently, field validation runs entirely offline; the local device captures coordinates from the native GPS and executes the Ray Casting algorithm on the cached block polygon. Internet connectivity is strictly required only at the beginning of the shift to fetch data and at the end of the day to synchronize and upload completed daily vector logs to the centralized database.

Upon selecting a specific route, the details are shown in Figure 1c, which includes the public spaces (logradouros). Subsequently, when a location is selected, the screen in Figure 1d is displayed, listing the properties situated at that address. After selecting the property to visit, the agent is directed to the screen shown in Figure 1e, where GPS-based geographic position confirmation is required. Once confirmed, the agent has access to the visit type options, as indicated in Figure 1f.

Data governance is enforced through a Role-Based Access Control (RBAC) model that segregates users into three profiles: Field Agents, Supervisors/Coordinators, and Operators. Each profile has access restricted to their operational scope. All client-server communications are encrypted via TLS/HTTPS to protect geospatial data in transit.

3 Methodology

In this section, we describe the method adopted to develop the work, which consists in adding georeferencing and geolocation resources to enhance the **Controle Vetorial Paraná** (see Section 2.5) system. In summary, we adopted a user-centered methodology that included three stages of development of the georeferencing functionalities, whose resulting versions were validated by experts, as illustrated in Figure 2.

To include georeferencing, the methodology of this work was divided into six stages, which took place sequentially, as described below:

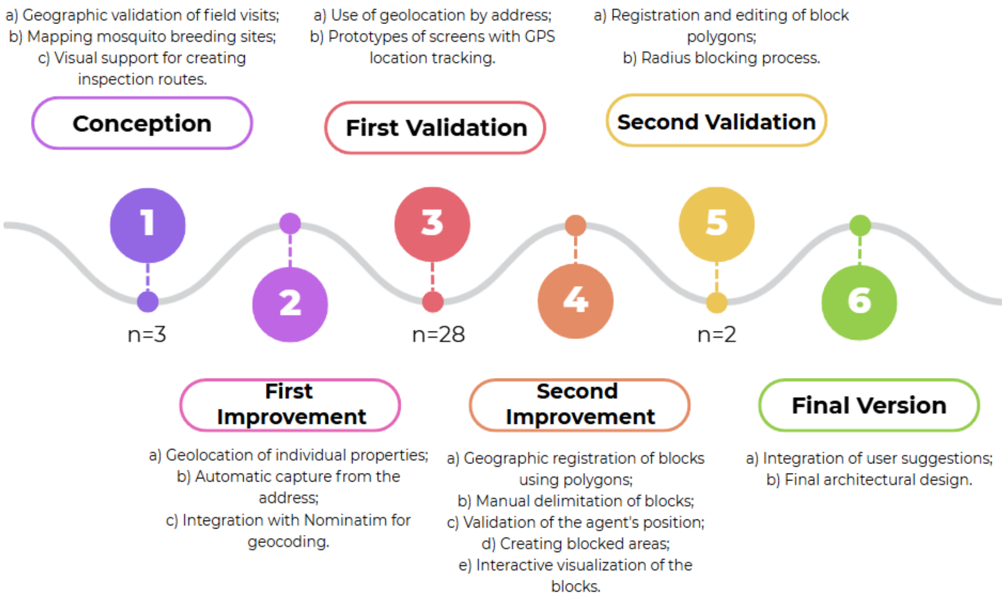


Figure 2: Stages of the Work Development.

1. **Conception:** This stage focused on understanding the problem domain through two complementary activities: interviews with health surveillance managers (N = 3) at the health department, and a literature review covering scientific articles, theses, and official Ministry of Health documents. Existing technologies already deployed in the system were also inventoried;

2. **First Improvement:** This stage focused on the registration and consultation of geographic points associated with each property, where vector inspections would be performed. In this stage, latitude and longitude coordinates for each property were captured and stored, obtained from the corresponding address data. The same technologies already employed in the system were used, along with a free georeferencing service;

3. **First Validation:** In this stage, a preliminary validation of the system was conducted. Endemic Disease Control Agents (ACEs), along with supervisors, coordinators, and arbovirus technicians (N=28) from one of the state's regional health offices, were invited to evaluate the initial prototypes. In this first validation, the participants live and work in three different cities. Ethical issues, anonymity, and consent were ensured through an Informed Consent Form (ICF). The form was completed by all participants, and the result of this evaluation culminated in an adjustment of the development strategy, driving a change of focus in the GIS project;

4. **Second Improvement:** In this stage, the geographic registration of a block and the geographic validation of the ACE in the field were implemented, based on the block area. In addition to this registration, geospatial queries were developed to identify a blocking area for arbovirus cases. Following Ministry of Health protocols [22, 23], a new dengue notification triggers a 300-meter blocking radius for larval surveys and focal treatment, and a 150-meter radius for insecticide application.;

5. **Second Validation:** This stage focused on validating the block registration functionality by developing a user manual alongside a simplified version of the registration interface made available to end-users. Due to project constraints and the specific period in which this evaluation was conducted (January), field teams faced significant seasonal high demands and reduced availability. Consequently, a Key User sampling strategy was adopted. We invited a municipal health coordinator and a field supervisor ($N = 2$) who had previously participated in the first validation stage. This drastic reduction in sample size from the first phase ($N = 28$) to the second ($N = 2$) was a deliberate methodological choice: since coordinators and supervisors are directly responsible for strategic planning, workflow definition, and overseeing regional teams, they possess the necessary technical competence to validate the web application's usability and effectively act as legitimate representatives of their respective field agents.

6. **Final Version:** This stage of the work corresponds to the final implementation, integrating user suggestions collected in the previous stage along with other improvements.

Finally, it should be clarified that, in response to an urgent demand from the Brazilian State of Paraná, this work did not undergo approval by an Ethics Committee, as it constitutes an institutional action for the improvement of health management processes. Furthermore, due to the nature of this work, which falls into the category of public opinion research with non-identifiable participants, as established in Circular Letters No. 17/2022 and No. 12/2023 from CONEP, this research is exempt from Ethics Committee review. Thus, all ethical aspects were respected, including anonymity and formal consent through the ICF.

4 Results

This section presents the results of each stage described in Section 3. The georeferencing and geolocation functionalities developed in this work were integrated into the web system and mobile application of the **Controle Vetorial Paraná** ecosystem (see Section 2.5). These capabilities were developed as modular components embedded directly into the platform's pre-established technological stack, which naturally bounded the selection of libraries, geospatial tools, and verification algorithms. The specific technologies employed in each development stage are detailed in their respective subsections.

4.1 Conception

The design of the geoprocessing features in this work was guided by three fundamental requirements: geographic validation, precise foci mapping, and support for creating inspection routes. The first requirement aimed to ensure the integrity of field data by using geolocation to validate the actual position of the agent at the time of the visit. The second requirement involved the systematic recording of the geographic coordinates of identified mosquito foci, enabling the generation of heat maps and spatial analyses to direct vector control actions. Finally, the third requirement consisted of an interactive map to provide visual feedback to coordinators during the strategic planning of visit routes.

Most of the computational solutions studied for combating arboviruses do not incorporate georeferencing in the same way adopted in this work (see Section 2). This article aims to provide a different approach, specifically directed at ACEs, who are responsible for inspection visits. The interviews showed that it is of paramount importance for the system to validate the agent's location at the time of the visit, thereby providing security and accurate storage of this information. This practice proves extremely useful for mapping the foci of the transmitting mosquito in the city, enabling a more effective response in the fight against arboviruses.

To achieve this purpose, a property registration was initially designed to include a geolocation field. Furthermore, during the in loco visit, the ACE had to confirm the geographic location of the property to be inspected.

4.2 Architectural Design and Interface Contracts

To ensure scalability, modularity, and native support for complex geospatial data handling, the georeferencing functionalities were structured around key architectural decisions, concrete interface contracts, and standard software engineering components.

The ecosystem follows a decoupled Client-Server architecture pattern, separating the presentation layers from the core business logic. Figure 3 illustrates the high-level block diagram of the system component interactions.

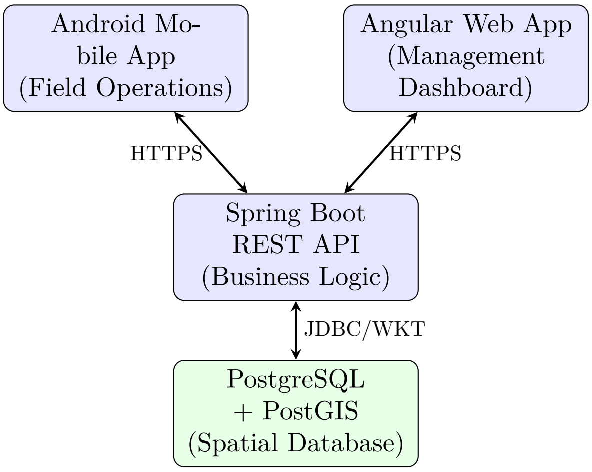


Figure 3: High-level architectural block diagram of the georeferencing modules.

Three major architectural decisions (AD) guided the system enhancement:

- **Spatial Extension Integration:** Choosing the PostgreSQL relational database accompanied by the PostGIS spatial extension. This decision was driven by the need to natively store geometric `Polygon` and `Point` entities, enabling high-performance topological queries (such as containment and radial expansions) directly through database functions.
- **Backend Decoupling with Spring Boot:** Implementing the backend services using Java and Spring Boot. This framework provides robust asynchronous capabilities for heavy data parsing, modular REST controller mappings, and smooth integration with spatial drivers.
- **Offline-First Synchronization Architecture:** An internal SQLite database on the mobile client caches route data and block geometries, enabling spatial validation to run entirely offline (see Section 4.7.1).

4.3 First Improvement

Figure 4 presents the use case diagram for the main registrations of the system as a whole. The geolocation functionality is related to the **Manage Property** use case, which includes the **Request Geolocation** use case.

Based on the conception of the idea regarding geolocation, the development focused on property registration, considering that to register a property, it is necessary to provide the system with all its information, making it possible to use a georeferencing service to capture the property's latitude and longitude at the time of registration.

When registering a property, the system implements an automated geolocation workflow in which, after the registration data is filled out in the management interface, the address data is sent—at the time of submission—to the Nominatim geocoding service. This service returns the corresponding geographic coordinates (latitude and longitude), which are then automatically linked to the property record and stored along with the other information. In this way, each registered property is georeferenced systemically, despite the precision limitations inherent to the service used, ensuring that spatial location is an integral part of its fundamental data.

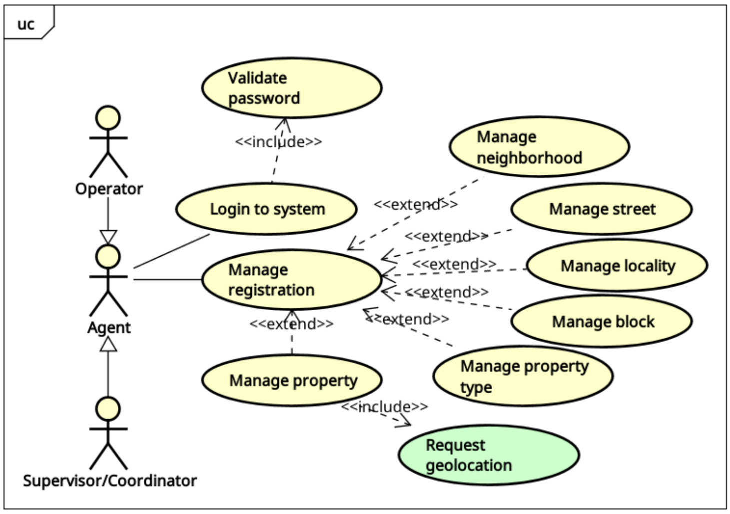


Figure 4: Use case diagram of property management.

4.4 First Validation

This section details the initial evaluation phase of the system, primarily focusing on gathering preliminary perceptions of integrating geoprocessing into field routines. The objective of this stage was to validate whether the automatic address-based geocoding strategy met end users' operational expectations and to identify potential usability bottlenecks or technical limitations before large-scale implementation.

4.4.1 Manual Validation of Nominatim

The adoption of the Google Maps Geocoding API was ruled out due to its paid licensing model, which made its use unfeasible within the budget constraints of this project. As an alternative, the free Nominatim service was selected; however, before its final implementation, it was necessary to conduct manual tests to assess whether its precision would be sufficient for the critical demands of vector control.

After registering the property location with the Nominatim service, the authors conducted a manual test to evaluate the service's precision in identifying a specific property's location. This procedure involved comparing the property's actual location, obtained via the free version of Google Maps[4], with the first response from the Nominatim service[5].

During the test, each address was submitted to the Nominatim service, and the first result obtained was used for analysis. In contrast, the actual location of the property was obtained manually through Google Maps, where the address was entered into the site and its geographic coordinates were captured manually.

The empirical results revealed significant inaccuracies: across 18 tested sample addresses extracted from typical local urban pathways, the average error between the point returned by the free service and the actual coordinates was 431 meters, with a standard deviation of 720 meters. These outcomes were discouraging for the service's viability, particularly given the high standard deviation observed in queries involving longer thoroughfares. To illustrate this behavior while preserving data privacy, specific tested locations were anonymized: control tests on standard, shorter urban pathways (anonymized as Street 1 and Street 2) showed acceptable errors of 18 meters and 66 meters, respectively, whereas a test conducted on a major, long commercial thoroughfare (anonymized as Avenue 1) revealed an exorbitant error of 2,334 meters.

The Nominatim validation highlighted significant practical and technical limitations in the system's original approach, which relied on individual address geocoding to automatically register each property's latitude and longitude. This property-level approach presented two key problems: (i) the Nominatim service showed unacceptable precision errors, as demonstrated above; and (ii) the approach required internet connectivity at registration time—a significant barrier given that agents frequently operate in areas with limited or no coverage. Even capturing coordinates via GPS during a first visit would not resolve this, as the registration itself would lack a spatial reference prior to that visit.

[4]https://www.google.com.br/maps/preview
[5]https://nominatim.openstreetmap.org/ui/search.html

4.4.2 Evaluation with Participants

The first improvement reported in the previous section was validated by endemic disease control teams. During this validation, the mobile application screen prototypes involving the use of georeferencing were presented, such as those presented in Figure 1. Subsequently, a questionnaire designed for data collection was introduced. The questionnaire contained two questions regarding the use of georeferencing/geolocation. These questions are:

- **Question 1:** *Is the use of geolocation a useful tool in the fight against arboviruses?* [This question was evaluated using a 5-point Likert scale, ranging from 'strongly disagree' to 'strongly agree'];
- **Question 2:** *What suggestions or ideas would you have to improve the effectiveness of geolocation in the context of combating arboviruses?* [This was an open-ended question].

The evaluation was conducted with two endemic disease control teams, totaling 28 participants. The questionnaire was answered by 23 agents, 2 supervisors, 1 coordinator, 1 technician, and 1 biologist, all involved in endemic disease control and affiliated with the State Health Secretariat. The collected data are important for validating the functional prototype and providing valuable insights into the application's effectiveness and usability across different roles in the context of endemic disease control.

From the 28 respondents, 92.4% (N=27) identified as female, while 3.6% (N=1) identified as male, with ages ranging from 24 to 69 years. Regarding the participants' length of service at the Health Secretariat, most participants reported having worked for more than five years (75%; N=21), while 14.3% (N=4) reported having between two and five years of service, 7.1% (N=2) reported between one and two years, and only 3.6% (N=1) indicated less than one year of service.

Regarding Question 1, 10 participants strongly agreed (35.7%), while 17 agreed (60.7%), and only 1 (3.6%) disagreed that geolocation is a useful tool for their daily work. These data highlight the widespread perception that geolocation/georeferencing is a valuable tool for most professionals involved in the fight against arboviruses.

The responses collected from the participants to the open-ended question (Question 2) were fundamental in guiding the development toward a solution aligned with operational reality, i.e., the problems highlighted in Section 4.4.1. In addition to confirming the technical problems previously mentioned, the participants responses pointed toward the actual operational unit of work in the field: a block instead of a property. Among the responses, the following ones stood out, evidencing the block is the main unit during field work:

- **P1:** *"Separate by blocks and sides"*;
- **P2:** *"It is not necessary to open the geolocation for every property entry, only when going to the block"*;
- **P3:** *"Keep a map in evidence showing the highest index of foci and sick people, where the most critical points can be seen"*;
- **P4:** *"Our work is by blocks; we always start on side one of the block and follow sides 2, 3, and 4, also identified by street names"*;
- **P5:** *"We work by block and close all 4 sides; we work on 4 different streets within a single block"*;
- **P6:** *"The management level of maps, such as geolocation of cases, found foci, and, in the future, registration with ovitraps could be considered, taking into account the new Ministry of Health guidelines"*;

Based on these responses, it became evident that the management of routes and actions in the fight against arboviruses is structured at the block level, rather than by individual properties. This insight, coupled with the precision and feasibility issues of address geocoding, led to a strategic shift: the proposal to replace the individual geographic registration of properties with the geographic registration of block areas.

This new approach resolves the previous limitations: (a) the block area can be registered manually and accurately by a supervisor in an environment with good connectivity (web version), using mapping tools; (b) once registered, the block polygon serves as a robust reference for validating the agent's location (via the mobile device's GPS, without the need for real-time internet) and for the automatic delimitation of blocking areas. This suggestion was approved by the professionals present during the validation.

Furthermore, the questions highlighted the demand for visualization tools, reinforcing the plan to automatically collect the agent's geographic position during visits, without the need for map confirmation, to feed the generation of heat maps, thereby assisting in the identification of priority areas for combat actions. The following quotations evidence the kinds of visualization tools participants consider interesting to add in the system:

- **P7:** *"I believe that, at a management level, it would be interesting to have information such as the locations where outbreaks were found by agents, perhaps a heatmap with layers such as located outbreaks and suspected and/or positive patients"*;
- **P8:** *"I believe this will improve and assist agents in creating work routes, which will facilitate and improve fieldwork. At a management level, it would be interesting to monitor the routes taken by agents during the day and/or visits, in order to evaluate performance and correct visit techniques"*.

4.5 Second Improvement

Following the results of the first validation, a second implementation cycle was initiated to enhance the system's georeferencing capabilities.

4.5.1 Manage Block Improvement

Based on the results of the first validation, the second implementation stage for the project improvement began. After gaining a deeper understanding of how visit routes are defined, it was possible to implement a functionality in the system designed to assist coordinators in choosing the best route using visual resources. To achieve this, the registration of the specific area for each block was incorporated into the system. At the time of a block's registration, it is necessary to select the corresponding physical area. The updated registration use case diagram is presented in Figure 5, where the **Manage Block** and **Select Geographic Area of the Block** use cases can be observed.

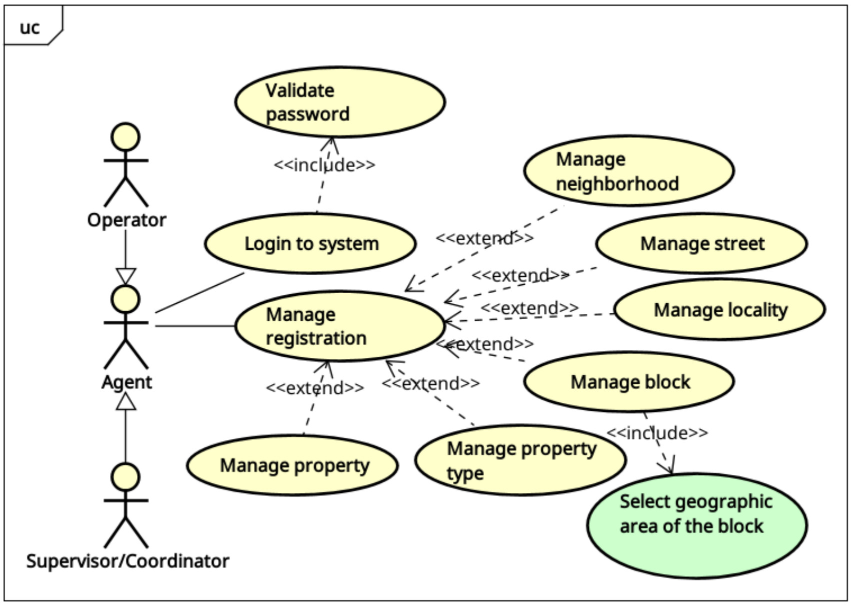


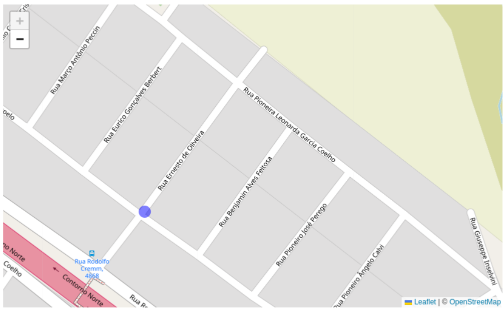
Figure 5: Use case diagram of updated registration.

This implementation of georeferencing functionalities in the system is structured based on the operational unit of the block, abandoning geocoding by individual addresses. To perform this registration, the Leaflet library[6] was used, which enables the use and manipulation of maps. Block registration was implemented using the Leaflet library integrated with OpenStreetMap[7], both open-licensed solutions consistent with the project's zero-cost cartographic requirements.

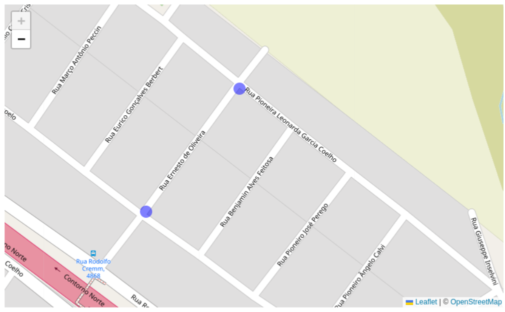
Selecting a block on the map requires a sequence of clicks by the system user to delimit the desired area. The parts of Figure 6 illustrate this process. When new points are added, they connect to the first and last points, always forming a polygon that is initially triangular with three points. As more points are added, the polygon adjusts to completely cover the total selection of the block. The ability to edit the geometry is illustrated in Figure 7, where Figure 7a shows the initial state of the polygon before the adjustment, and Figure 7b demonstrates the result after a specific vertex has been moved by the user. This functionality allows the coordinator to refine the polygon edges to ensure that the digital area precisely matches the physical boundaries of the block on the map. The functionality has two additional buttons to improve user

[6]https://leafletjs.com/reference.html
[7]https://www.openstreetmap.org/

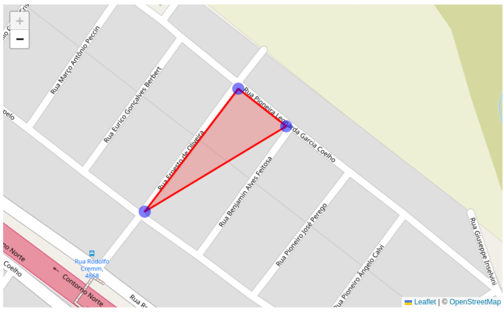
autonomy during selection: one allows undoing the last point created, and the other allows clearing all points.



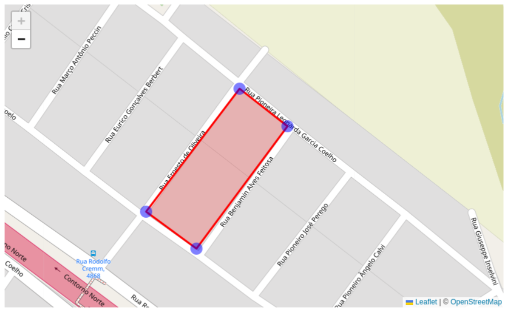
(a) First point



(b) Second point

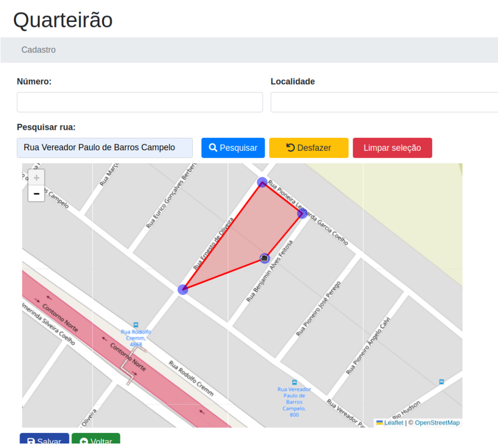


(c) Third point

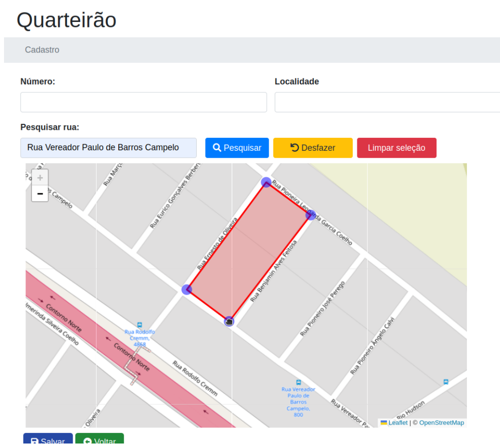


(d) Fourth point

Figure 6: Selection of a rectangular block.



(a) Selected point being moved.



(b) Selected point at final location.

Figure 7: Moving a point during Block registration.

The technical process for delimiting a block on the map is based on dynamic geometry logic. As demonstrated in Figure 6, the procedure begins with an initial click to establish the starting vertex (Figure 6a). This process is repeated sequentially; in this example, through three additional clicks (Figures 6b, 6c, and 6d). It is essential to note that the visual representation of the area as a closed polygon occurs upon the insertion of the third point (Figure 6c), at which point the system automatically connects the last point to the first, forming the minimum geometry required for spatial validation.

This functionality was developed based on the feedback collected during the first validation, with the objective of digitally reproducing the analog route-planning process used by coordinators in their routine. Figure 8 illustrates the type of physical map employed in the field, upon which the ACEs' routes are traditionally defined. The proposal was to integrate this cartographic resource into the system, providing the user responsible for planning with intuitive visual feedback aligned with their consolidated operational practices.

Figure 8: Map representing a section of the city used in route planning.

4.5.2 Blocking Area Delimitation

In epidemiological surveillance, vector blockade (locally referred to as blocking area) is an emergency tactical intervention triggered by a newly reported arbovirus notification. It requires rapid spatial containment to prevent disease transmission. Rather than referring to user account restriction (lockout), a blocking area in this context defines a geographic buffer zone centered on the notification source. To support this, a feature was developed that allows coordinators to click a notification point and automatically establish a 150-meter radius (for localized insecticide nebulization) or a 300-meter radius (for active larval surveys and focal treatment), visually rendering all urban block polygons within this radius for immediate route enforcement.

To facilitate the blocking process (depicted in the use case diagram in Figure 9), a functionality was developed that allows the user to visualize blocks on the map and select a specific notification point to define the blocking area. This feature is critical when receiving new dengue notifications, whether suspected or confirmed. The coordinator can define a blockade area and visualize all the blocks contained within it, thus assisting in delimiting the intervention zones. Within this interface, the user can also select additional blocks by clicking them, with immediate visual feedback on the operational load of each area.

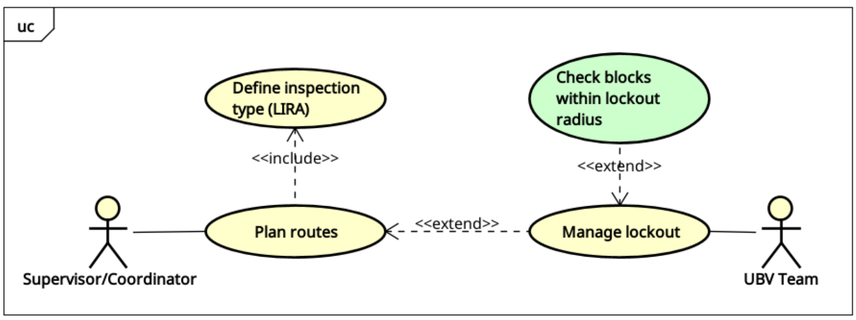
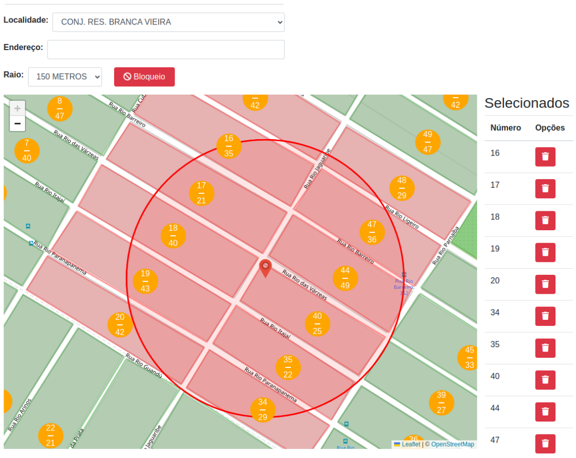
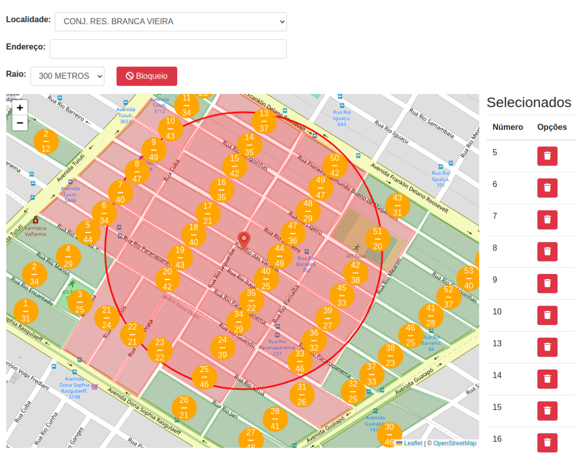


Figure 9: Use case diagram of blocking process.

The screenshot in Figure 10a illustrates the area delimited by a 150-meter radius, while Figure 10b illustrates the screenshot after delimiting a case's blocking area within a 300-meter radius. On this screen, the user responsible for the operation can add or remove other blocks from the blocking list as needed. In this scenario, the user registering a blocking route retains full autonomy to modify the list of blocks included in the route before finalizing the operational plan.



(a) 150-meter blocking area.



(b) 300-meter blocking area.

Figure 10: Block area.

4.6 Second Validation

To validate the functionalities developed in the second improvement, two professionals from the Health Secretariat participated in the evaluation: a coordinator and a supervisor. These participants were selected based on their extensive experience in managing arbovirus control actions. The coordinator is responsible for the strategic management of regional teams, while the supervisor directly oversees route planning and the inspection of Endemic Control Agents (ACEs) at the municipal level. The objective of this validation was to obtain additional suggestions and validate usability through user comments. All information described regarding block registration was consolidated into a user manual, which was made available to the participants. The manual contained a brief introduction on the importance of the block registration functionality [8].

The manual provided instructions on how to register the geographic area of the block and specified the requirements for performing such registration in the system. To this end, users were advised to use a computer with a mouse for a better block selection experience, and to be connected to the internet to save data.

This manual was provided along with a simplified version of the block registration screen (Figure 11). Using this simplified version, the participants (P1 and P2) were asked to perform the task of registering a block's geographic area. In this regard, P1 expressed: *"I found the alternative of selecting blocks interesting because it is the unit used to plan field actions."* Meanwhile, P2 considered the functionality easy to use and proposed two additional suggestions:

- **Suggestion 1:** Include the number of properties a block has and display this information on the map;
- **Suggestion 2:** Automatically add the city name when searching for a street to center the map.

4.7 Final Version

Based on the improvement feedback from the participants who interacted with the functionality, **Suggestion 1** was implemented. Consequently, it became possible to register the number of properties in a block and visualize both the block number and the quantity of associated properties on the map, as illustrated in Figure 12. In this excerpt of screenshot, each block have a yellow circle displaying two distinct numbers: the top number serves as a unique identifier (code) for the block, while the number below represents the total quantity of properties it contains. This visual representation is similar to the one used in the manual process without the system, as shown in Figure 8, ensuring consistency with traditional field methodology.

[8]The user manual is available at https://figshare.com/s/addc9b84fec60a5e868b.

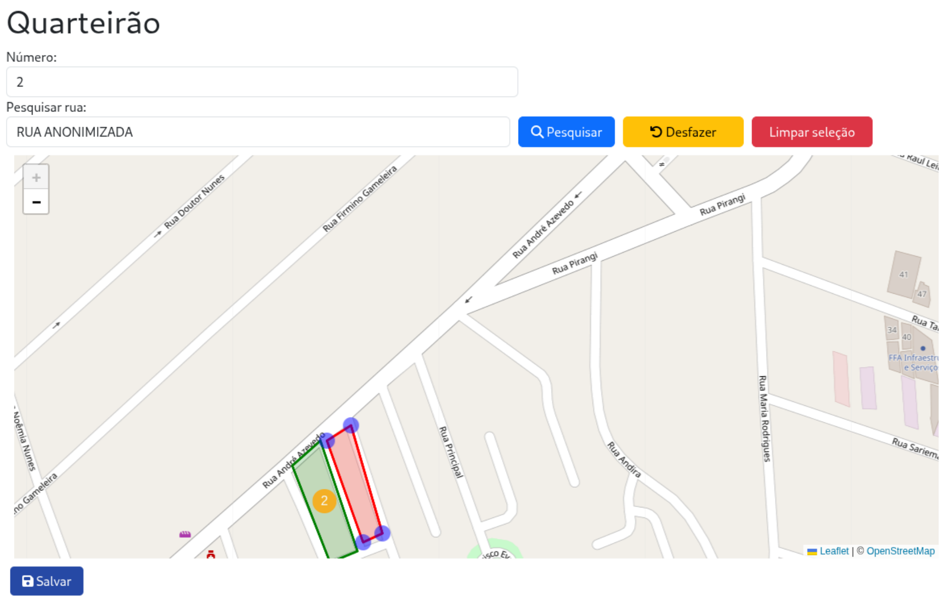


Figure 11: Block registration — simplified version.

Figure 12: Excerpt of the screenshot showing the blocks on the map in the final version.

The geographic validation of the visit is a process to ensure the reliability of the data collected in the field. This validation occurs at the exact moment the ACE records the service, comparing their current GPS position with the block's geometry, which is expanded by 35 meters to account for signal variance. The interaction flow required for this verification, from authentication to location confirmation, is depicted in the use case diagram presented in Figure 13. This functional model ensures that the daily anti-vector service record is only persisted if the agent is within the spatial tolerance zone defined by the block's polygon.

The selection of a 35-meter tolerance buffer is not arbitrary but mathematically and empirically supported by recent mobile health (mHealth) and global positioning research. In dense urban landscapes, physical barriers trigger severe multipath errors, reflecting satellite signals off multi-story buildings and degrading horizontal positioning accuracy [34].

To enable this verification from a computational perspective, the areas designated for visits are stored in the system as polygonal geometries. Furthermore, the blocks designated for visits by the agents have their areas stored in the system through geometry—specifically a polygon, as detailed previously. Using a geospatial query, the area of this polygon can be expanded, as illustrated in Figure 14. In this figure, it can be observed that the original area of the polygon, Figure 14a, on the Figure 14b was expanded by 35 meters, resulting in the area on the right side of the figure. This expanded area was employed to validate the agent's position during their activities. This validation is performed using the Ray Casting algorithm, which checks whether a point is contained within a polygon. In this case, the point is the agent's geographic

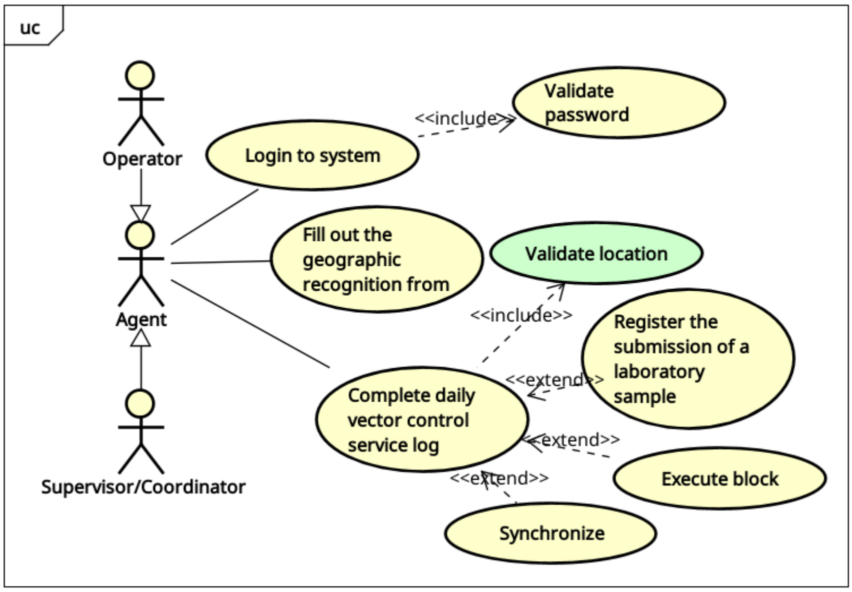


Figure 13: Use case diagram of entomological inspection.

(a) City block polygon.

(b) Expanded city block polygon.

Figure 14: Polygons representing the block and its expanded area.

position, and the polygon is the expanded area of the block.

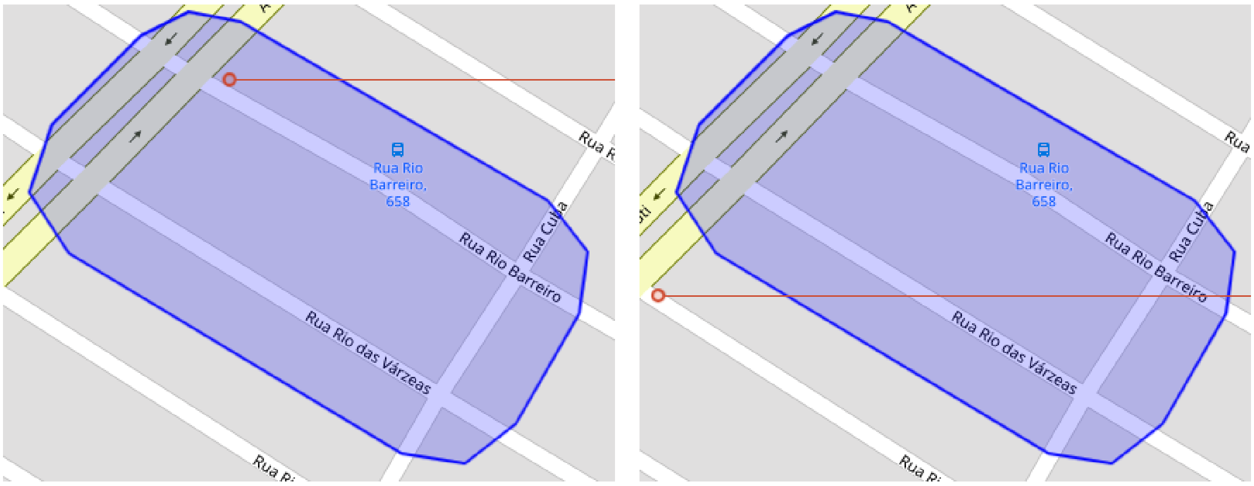
4.7.1 Geographic Validation Algorithm: Ray Casting

To perform the geographic validation of the agent, the Ray Casting algorithm (also known as the crossing number algorithm or the Even-Odd Rule) was selected. This algorithm is widely used in computer graphics and GIS to determine whether a given point is located inside or outside a polygon.

The principle of the algorithm is to trace an imaginary ray from the point in question (in this case, the agent's coordinate) in an arbitrary direction, typically to the right and horizontal. Next, the number of times this ray intersects the edges of the polygon is counted. If the number of intersections is odd, the point is located inside the polygon; if it is even (or zero), the point is outside.

The choice of this algorithm is due to its computational efficiency $O(n)$, where n is the number of vertices of the polygon, and its robustness in handling complex polygons, whether convex or concave. This fits perfectly with the irregular shapes of urban blocks.

Upon analyzing the pseudocode for the Ray Casting algorithm (Algorithm 1), the logic for spatial validation can be described through its variables. The boolean variable *inside* is initialized as false and has its state toggled whenever a horizontal ray, starting from the *point* (x_p, y_p), intersects an edge of the *polygon* defined by vertices i and j. The condition on line 4 checks if the y_p coordinate lies between the y_i and y_j



(a) Point inside polygon.　　(b) Point outside polygon.

Figure 15: Polygons representing the block and its expanded area.

ordinates, while the mathematical expression (derived from the linear equation) determines if x_p is to the left of the edge. If the final count of intersections is odd, *inside* returns true, confirming that the agent is within the block boundaries.

Algorithm 1 Ray Casting Algorithm - Point-in-Polygon Check

Require: *polygon*: list of vertices $(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)]$
Require: *point*: coordinate (x_p, y_p) to be tested
Ensure: **true** if point is inside polygon, **false** otherwise

1: $inside \leftarrow false$
2: $j \leftarrow n - 1$
3: **for** $i \leftarrow 0$ to $n - 1$ **do**
4:     **if** $((y_i > y_p) \neq (y_j > y_p))$ **and** $(x_p < (x_j - x_i) * (y_p - y_i)/(y_j - y_i) + x_i)$ **then**
5:         $inside \leftarrow \neg inside$ ▷ Flip the logical state (inside/outside)
6:     **end if**
7:     $j \leftarrow i$
8: **end for**
9: **return** *inside*

Upon analyzing the algorithm's operation, three key points were highlighted:

- The polygon is represented by a list of n vertices, assuming that the first and last vertices are the same (closed polygon).
- The condition on line 7 of Algorithm 1 checks whether the horizontal ray starting from the point crosses the edge defined by vertices i and j. The mathematical expression is an adaptation of the parametric line equation.
- The state of the boolean variable *inside* is toggled with each detected crossing, implementing the "even-odd" logic.

Within the context of the system, the input polygon is the expanded geometry of the block (converted from WKT to a list of coordinates), and the point consists of the latitude and longitude captured by the agent's device GPS at the moment of the visit. The function returns true if the agent is within the block's boundaries, allowing the visit to proceed, or false, signaling a potential location inconsistency.

The practical application of the Ray Casting algorithm for spatial validation is demonstrated in Figure 15. Specifically, Figure 15a illustrates the scenario where the agent is successfully validated, as the point (highlighted in orange) is contained within the boundaries of the block's polygon. Conversely, Figure 15b presents a situation where the point lies outside the delimited area, which would lead to the system denying the visit registration. In both cases, the line extending from the orange point represents the projected "ray" used by the algorithm to count intersections with the blue polygon's edges and determine the user's location.

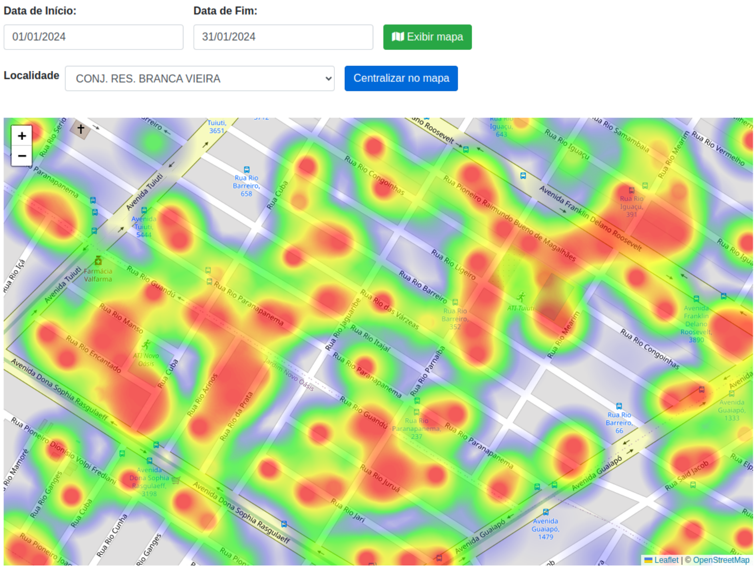


Figure 16: Enlarged heat map.

4.7.2 Technical and Interface Validation

To complement the user-centered evaluations and ensure software quality, the proposed georeferencing functionalities underwent a rigorous technical validation phase executed by a Quality Assurance (QA). This process consisted of executing formal, documented test cases designed around user stories, explicitly specifying the execution steps, input data, and expected behavioral outputs. E2E testing validated the complete data lifecycle for block management: the QA engineer verified that polygons drawn and edited on the Leaflet map interface were correctly serialized to WKT format, transmitted via the REST API, and persisted in the PostGIS database.

Geotargeting Core Logic Testing: The core mathematical validation, concerning the Ray Casting algorithm implementation and the 35-meter GPS tolerance buffer, was verified through controlled scenario testing. The QA process utilized predefined coordinates to test boundary limits:

1. Coordinates simulating an agent positioned strictly inside the block boundaries (expected and confirmed output: true).
2. Coordinates simulating an agent within the 35-meter expanded variance buffer zone (expected and confirmed output: true).
3. Coordinates simulating an agent strictly outside the allowed tolerance perimeter (expected and confirmed output: false).

4.7.3 Geographic Validation Results and Applications

The block registration functionality provided additional benefits, such as simplifying route creation within the system, providing a visual representation of block boundaries as blocking areas, and enabling the geographic validation of agents during field visits using the delimited block area. When performing a visit through the application, in addition to collecting all the information required to complete the visit form, the latitude and longitude of the location where the visit occurred are also recorded. These data are essential for validating the agent's precise location. Based on the persistence of this information, it was possible to develop a heat map (Figure 16) showing the incidence of mosquito foci throughout the city. This map offers a valuable visual representation for identifying areas with higher mosquito concentrations and guiding appropriate control and prevention strategies.

To create the map, a query is performed to retrieve all points (latitude and longitude) corresponding to mosquito foci. These points are incorporated into the map, allowing the user to visualize them. For testing purposes, 30,000 points representing mosquito foci were registered. Figure 16 presents an enlarged version of a map for better visualization, showing a zoomed-in view of a specific location, as the original map contains all 30,000 points across the city.

5 Discussion

This work encompasses distinct **benefits**. Firstly, the work resulted in the implementation of a geographic registration for blocks, allowing the agents responsible for combating dengue—the system's users—to perform this task efficiently. This geographic registration is a crucial tool, as it enables the definition of visit routes and facilitates the visualization of city locations on a map. Furthermore, the registration enables geospatial queries of blocks within a defined blocking area. All these functionalities were developed aiming at increasing ease of use for the users, streamlining the process of defining and executing routes, and validating the geographic position of the agent performing field visits.

In comparison with the analyzed systems, such as Aedes em Foco [9] (restricted to the municipality of Cedro due to local public policies) and SIGDENGUE [11] (dependent on specific shapefiles from the municipality of Cascavel), the approach proposed in this work stands out for its flexibility and broad applicability. Furthermore, the development of a user manual differentiates this solution from others, such as control panels and dashboards, which lack public documentation, thereby limiting their accessibility and replicability.

Finally, this work's distinguishing factor lies in addressing georeferencing as its primary functionality, making it more efficient compared to SisVetor [10] and Vaza Dengue [12]. Given the above, it is noted that existing regional systems consist of solutions tailored to the needs of each municipality or micro-region. However, some remained only as proposals, and others did not advance beyond the initial implementation. None of these systems cite the use of georeferencing in the manner required for the project in question, making it unfeasible to leverage knowledge from existing studies. This justifies the proposal of the present work, whose methodological procedures have been presented.

A second contribution of this work lies in the transformation of the operational workflow performed by ACEs in the field work. This was achieved through the support of user-centered design and its stages—such as conception, validation, implementation, and testing—ensuring the digital solution mirrors the practical reality of the agents. In summary, Table 2 presents a detailed comparison between the current manual process conducted by ACEs and the proposed system, highlighting the improvements in precision and efficiency. By adopting **Controle Vetorial Paraná** (see Section 2.5) in the field work, all the aspects described in Table 2 will be achieved, providing the identification of precise geographic clusters of infestation and supporting to plan field operations in a timely manner.

Table 2: **Comparative Table: Current Manual Process vs. Proposed Digital System.**

Aspect	Current Manual Process	Proposed System
Workflow	Often manual and analog, resulting in slow processes prone to errors.	**Integrated digital solution**, consisting of web system and mobile application to replace the analog workflow.
Operational Unit	Focus on sampling (LIRAa) or individual property and notification records.	**Structured on the block as operational unit**, aligned with the teams' actual routine.
Georeferencing	Non-existent in some systems, static (shapefiles) or with low precision.	**Dynamic and with higher precision**, using GPS coordinates and the Ray Casting algorithm for polygon delineation.
Visit Validation	Based strictly on manual reports in forms, without physical presence verification mechanism.	**Mandatory geographic check-in**, which conditions the visit registration to detecting the ACE's position within the block polygon.
Route Planning	Based on managers' experience.	**Intuitive visual feedback** for route creation and block area definition.
Decision Making	Limited by lack of integration between systems.	Supported by **dynamic heat maps** and geospatial queries that identify critical areas in real time.

During the development of this work, we faced two main **difficulties**: (i) involving multiple agents in conducting the validation studies, and (ii) understanding the specific domain, as it involves a high level of complexity. Thus, the proposal presented in this work is valuable as it provides a georeferencing solution that is tailored to the daily routines of the end users.

Despite the comparisons, the solution presented here has some limitations, namely: (i) the georeferencing functionalities were used and tested with addresses from a single city and by users from that same city; (ii) it cannot be categorically stated that the block expansion used to validate the agent's position will be sufficient, as in urban centers with many tall buildings, this technology tends to present some failures. These limitations need to be properly evaluated and addressed in future studies. Additionally, **Controle Vetorial Paraná** is currently a fully validated and certified functional system awaiting official state-wide production roll-out. Hence, it was not possible to collect real-time operational telemetry. Thus, quantitative performance metrics, such as actual time saved during daily route planning, end-to-end API response times under multi-municipal stress load, or exact field registration error reductions, remain unmeasured at this stage. Gathering these empirical indicators is heavily dependent on institutional deployment schedules and has been formally established as the primary focus of our future work (Validation at Scale).

Ultimately, despite the existence of monitoring dashboards and consolidated registration systems, primary field data collection still presents critical technological gaps in several municipalities, especially regarding georeferencing precision and the reliable validation of ACE activities. Unlike the other systems listed in Table 1 (see Section 2.3), our system is directed to endemic control agents (ACEs), supervisors, and managers providing integrated management of vector control with spatial validation of field activities. The system integrates geolocation into its lifecycle based on three main requirements identified during this research: **(1) geographic validation of the ACE during the visit**; **(2) visual feedback at the moment of route creation**; and **(3) storage of the geographic position of visits**. The dynamic georeferencing uses block polygons and GPS validation via the Ray Casting algorithm. To ensure scalability and robust spatial processing, the system was built upon a technological stack comprising Java with Spring Boot for the backend, a PostgreSQL database with the PostGIS extension for spatial data management, and an interface developed with Angular and Android SDK. Geographic manipulation and visualization are supported by the integration of Leaflet, Nominatim, and OpenStreetMap libraries.

6 Conclusion

This work resulted in the development and integration of georeferencing and geolocation resources into the arbovirus control system, focusing on block registration, geographic validation of ACE visits, and the storage and visualization of endemic foci. The primary contribution was the improvement in identifying infestation areas and creating blocking routes, increasing the system's precision and effectiveness, and providing a visual resource for route generation. These functionalities directly address the limitations of existing systems, which do not provide adequate support for municipal-level decision-making, nor do they use georeferencing to optimize field operations.

As lessons learned, the initial difficulties regarding domain complexity stand out, as well as the need for greater user involvement from the beginning of the development process. However, the adoption of user-centered methodologies ensured the system's alignment with the real needs of ACEs and ACSs, who are the primary actors in combating arboviruses. The evaluation demonstrated that the integration of georeferencing and geolocation not only improves operational efficiency but can also contribute to the reduction of disease transmission, benefiting the population through targeted preventive actions.

As future work, the expansion and consolidation of the system are proposed across three main fronts: operational optimization, functional expansion, and validation at scale.

Operational Optimization: Plans include implementing the automatic calculation of optimized routes for visits and blocking actions, utilizing shortest-path algorithms (such as Dijkstra's, as applied by Oliveira [35]). This functionality, integrated with the geographic delimitation of blocks, will determine the ideal visitation sequence or the most efficient route through public thoroughfares, minimizing agent displacement and maximizing coverage.

Functional Expansion: The intention is to develop more elaborate geospatial dashboards to visualize the vector situation and arbovirus cases by region, facilitating real-time identification of risk areas. Additionally, the development of a mobile application aimed at the general population is envisioned. This app would allow voluntary symptom reporting, provide a preliminary guideline-based diagnosis, indicate the nearest Emergency Care Unit, and alert users to outbreaks in the region. Such a tool would create a direct feedback channel with the community, enhancing participatory surveillance and household preventive actions.

Validation at Scale: To consolidate the contributions, a new round of evaluation will be conducted with a larger number of participants from different profiles (field agents, supervisors, and coordinators) and various regions. The objective is to validate the system's scalability, its adaptability to different urban contexts, and its perceived impact on operational efficiency and decision-making.

Finally, the geographic block registration resulting from this work is not limited solely to combating arboviruses; it can also be implemented in other areas, such as urban planning. With this technology, cities can map their neighborhoods accurately, enabling geospatial queries about occupied areas. Furthermore, this tool can contribute significantly to analysis and decision-making across various fields, including urbanism, territorial management, and sustainable development.

Acknowledgments

The authors thank CAPES (Funding Code 001) and CNPq (Grants 404027/2023-7 and 306774/2025-9) for financial support.

References

[1] C. O. de Souza Fernandes, D. R. A. de Souza Fernandes, R. V. M. Baracat, P. T. de Melo Silveira, and G. de Oliveira Braga, "Arboviroses emergentes e reemergentes no brasil: dengue, chikungunya e zika," Brazilian Journal of Implantology and Health Sciences, vol. 6, no. 8, pp. 5036–5048, 2024, in portuguese.

[2] L. F. Q. Moreira, A. J. da Rocha Reis, and A. K. R. Segundo, "Wing-based identification of dengue vector mosquitoes using convolutional neural networks," IEEE Latin America Transactions, vol. 24, no. 1, pp. 53–63, 2026.

[3] M. T. S. Faria, N. R. S. Ribeiro, A. P. Dias, U. A. F. Gomes, and P. M. Moura, "Saúde e saneamento: uma avaliação das políticas públicas de prevenção, controle e contingência das arboviroses no Brasil," Ciência & Saúde Coletiva, vol. 28, pp. 1767–1776, 2023, in portuguese.

[4] A. L. N. Ribeiro, "Análise das políticas públicas de combate à dengue," Master's thesis, Universidade Federal de Santa Maria, Santa Maria, 2013, in portuguese.

[5] L. S. França, C. M. A. d. Macedo, J. d. J. P. Lima, J. M. Silva, M. B. Almeida, and S. N. Sales, "O que está errado? percepção dos agentes comunitários de saúde e endemias sobre o combate ao aedes aegypti1," Enfermería Actual de Costa Rica, no. 38, pp. 61–74, 2020, in portuguese.

[6] J. Laguardia, C. M. A. Domingues, C. Carvalho, C. R. Lauerman, E. Macário, and R. Glatt, "Sistema de informação de agravos de notificação em saúde (sinan): desafios no desenvolvimento de um sistema de informação em saúde," Epidemiologia e Serviços de Saúde, vol. 13, no. 3, pp. 135–146, 2004, in portuguese.

[7] D. F. d. Sousa and S. P. d. C. Prestes, "A mediação do sistema de informação aliada ao uso do painel epidemiológico no controle da dengue," in Anais do Seminário de Inovação em Saúde Pública. Belém: Universidade Federal Rural da Amazônia, 2023, in portuguese.

[8] L. R. Carvalho, "Três ensaios sobre a dengue no município de pedro leopoldo: um estudo sobre o liraa," Ph.D. dissertation, Universidade Federal de Minas Gerais, 2023, tese (Doutorado em Economia), Programa de Pós-Graduação em Economia, in portuguese. [Online]. Available: http://hdl.handle.net/1843/50583

[9] A. Monteiro, C. Cavalcanti, E. Lima, J. Neto, I. Coelho, G. Paillard, G. Gomes, F. Junior, H. Pequeno, M. Castro et al., "O programa aedes em foco como elemento de combate a arboviroses," in Anais do XX SBCAS, 2020, pp. 238–249, in portuguese.

[10] UNB. (2026) Software sisvetor: Módulo gestor e aplicativo de campo. Universidade de Brasília. Acesso em 27 de janeiro de 2026, in portuguese. [Online]. Available: https://sisvetor.sds.unb.br/

[11] C. B. Rizzi, A. L. Brun, G. Galante, and R. L. Rizzi, "Sigdengue: Um sistema de informação para o acompanhamento e gestão de ações sobre dengue com enfoque às atividades de notificação, raio e bloqueio," iSys-Brazilian Journal of Information Systems, vol. 9, no. 1, pp. 101–117, 2016, in portuguese.

[12] S. Fiorini, L. Sousa, D. Cedrim, A. Garcia, D. Saade, I. Moraes, and L. Frajhof, "Vigilância entomológica da dengue, zika e chikungunya: Uma solução baseada em redes sociais e dispositivos móveis," in Anais do XVI Workshop de Informática Médica. SBC, 2016, pp. 2567–2576, in portuguese.

[13] J. Castanho, T. E. Colanzi, F. F. da Silva, R. Penteado, and G. Guerino, "Georeferencing as support in an arbovirus control system: Development and validation," Centro Latinoamericano de Estudios en Informática (CLEI), 2025, to appear.

[14] PostGIS Development Group, PostGIS 3.4.0dev Manual, PostGIS Project, 2023, acessado em 15 de agosto de 2023. [Online]. Available: https://postgis.net/stuff/postgis-3.4.pdf

[15] L. Sanglard, K. K. Garcia, and W. M. Ramalho, "Use of geocoding techniques for epidemiological surveillance in the federal district, brazil: a case study using dengue," Geospatial Health, vol. 20, 2025.

[16] P. A. Zandbergen, "A comparison of address point, parcel and street geocoding techniques," Computers, Environment and Urban Systems, vol. 32, no. 3, pp. 214–232, 2008.

[17] M. Hysenaj, "From" here" to nearby: A python-spring boot pipeline for smartphone geolocation, reverse geocoding, and real-time place discovery in web gis," in 2025 6th International Conference on Communications, Information, Electronic and Energy Systems (CIEES). IEEE, 2025, pp. 1–4.

[18] A. Danalet, B. Farooq, and M. Bierlaire, "A bayesian approach to detect pedestrian destination-sequences from wifi signatures," Transportation Research Part C: Emerging Technologies, vol. 44, pp. 146–170, 2014.

[19] Google, Geocoding API overview, Google, 2023. [Online]. Available: https://developers.google.com/maps/documentation/geocoding/overview

[20] Nominatim, Manual do Nominatim 4.3.0, openstreetmap, 2023. [Online]. Available: https://nominatim.org/release-docs/latest/

[21] O. W. Lwande, V. Obanda, A. Lindström, C. Ahlm, M. Evander, J. Näslund, and G. Bucht, "Globe-trotting aedes aegypti and aedes albopictus: risk factors for arbovirus pandemics," Vector-Borne and Zoonotic Diseases, vol. 20, no. 2, pp. 71–81, 2020.

[22] MINISTÉRIO DA SAÚDE, Manual do Levantamento de Índice Rápido do Aedes aegypti para Dengue (LIRAa) 2013, 2013, acesso em 11 de setembro de 2023, in portuguese. [Online]. Available: https://www.gov.br/saude/pt-br/centrais-de-conteudo/publicacoes/svsa/dengue/manual_liraa_2013.pdf

[23] ——, "Diretrizes nacionais para prevenção e controle de epidemias de dengue," Secretaria de Vigilância em Saúde. Departamento de Vigilância epidemiológica, 2009, acesso em 11 de setembro de 2023, in portuguese.

[24] ——, Ficha de Investigação Dengue e Febre de Chikungunya, Sistema de Informação de Agravos de Notificação, 2016, acesso em 09 de setembro de 2023, in portuguese. [Online]. Available: http://portalsinan.saude.gov.br/images/documentos/Agravos/Dengue/Ficha_DENGCHIK_FINAL.pdf

[25] MINAS GERAIS, "Secretaria de estado de saúde de minas gerais. dengue (sispncd)," 2022, acesso em 09 de setembro de 2023, in portuguese. [Online]. Available: http://vigilancia.saude.mg.gov.br/index.php/dengue/

[26] G. Câmara, C. Davis, A. M. V. Monteiro, and J. D'alge, "Introdução à ciência da geoinformação," São José dos Campos: INPE, vol. 345, 2001, in portuguese.

[27] C. Barcellos, A. K. Pustai, M. A. Weber, and M. R. V. Brito, "Identificação de locais com potencial de transmissão de dengue em porto alegre através de técnicas de geoprocessamento," Rev. Sociedade Brasileira de Medicina Tropical, vol. 38, pp. 246–250, 2005, in portuguese.

[28] J. V. E. BERNARDI and P. M. B. LANDIM, "Aplicação do sistema de posicionamento global (gps) na coleta de dados," DGA, IGCE, UNESP/Rio Claro, Lab. Geomatemática, Texto Didático, vol. 10, no. 31, p. 2002, 2002, in portuguese.

[29] LONDRINA. (2026) Dashboard arboviroses. Autarquia Municipal de Saúde de Londrina. Acesso em 27 de janeiro de 2026, in portuguese. [Online]. Available: http://datastudio.google.com/u/0/reporting/a0e44fa8-253f-4dea-a35b-XXXXX

[30] S. Kienberger, M. Hagenlocher, E. Delmelle, I. Casas et al., "A webgis tool for visualizing and exploring socioeconomic vulnerability to dengue fever in cali, colombia," Geospatial health, vol. 8, no. 1, pp. 313–316, 2013.

[31] L. Eisen and R. J. Eisen, "Using geographic information systems and decision support systems for the prediction, prevention, and control of vector-borne diseases," Annual review of entomology, vol. 56, no. 1, pp. 41–61, 2011.

[32] O Globo. (2024) Dengue: os 10 estados com maior alta da doença em 2024; veja ranking. Acesso em: 3 fev. 2025. [Online]. Available: https://oglobo.globo.com/saude/noticia/2024/01/31/dengue-os-10-estados-com-maior-alta-de-dengue-em-2024-veja-ranking.ghtml

[33] J. Castanho, M. Sato, J. Barbosa, G. Leal, R. Balancieri, A. Amaral, G. Guerino, and T. Colanzi, "Heuristic evaluation of a web-based system for arbovirus control in brazil's public health context," Centro Latinoamericano de Estudios en Informática (CLEI), 2025, to appear.

[34] K. Merry and P. Bettinger, "Smartphone gps accuracy study in an urban environment," PloS one, vol. 14, no. 7, p. e0219890, 2019.

[35] E. F. d. Oliveira, "Um sistema para cálculo de rotas de caminho mínimo utilizando pgrouting e dados do openstreetmap," Universidade Federal de Uberlândia, Relatório Técnico, 2021, in portuguese.