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College of Science and Technology
School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

**Developing an Application to Support
the Monitoring of Compliance with
Zoning Regulations in Kigali City**

Thesis submitted to the University of Rwanda: College of Science and Technology,
in partial fulfillment of the requirements for the award of the Degree of Master of
Science in Geo-Information for Environment and Sustainable Development.

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Kigali, December 2024

DECLARATION

I declare that this thesis, submitted for the degree of Master of Science in Geo-Information for Environment and Sustainable Development, is entirely my own work and has not been previously submitted for any degree. All contributions are appropriately acknowledged, and no part of this work has been borrowed from external sources without citation.

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APPROVAL

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ABSTRACT

This thesis addresses the pressing issue of urban sprawl management in Kigali City, Rwanda, amidst rapid urbanization. As urban population growth outpaces rural growth, the city faces escalating pressure on infrastructure, housing deficits, and encroachment on agricultural lands. The enforcement of compliance to the Kigali Master Plan and zoning regulations has not effectively curbed the unauthorized urban expansion due to limited monitoring mechanisms. To address this challenge, the research proposes developing a tailored geospatial application to effectively monitor local communities' compliance to Kigali Master Plan and related zoning regulations. The study's objectives include exploring global geospatial solutions, identifying suitable models for Kigali, developing the application and evaluating its efficacy. The methodology involved a thorough review of literature on zoning regulation enforcement mechanisms, complemented by interviews with building inspectors in Kigali City which provided practical insights into the challenges of zoning compliance and guided the development of the application. The GIS-based application was developed using Survey123 Connect, WebApp Builder, and Dashboard on ArcGIS Online through Low-Code/No-Code process. The developed application integrates citizen-reported data with the Land Administration Information System, the Building Permit Management Information System, the National Spatial Data Infrastructure and the Kigali City Master Plan. Testing of the application confirmed its efficiency and effectiveness in addressing zoning compliance issues. Challenges included the limited availability of BPMIS data due to the lack of a current public API. The application's syntax, which classifies construction based on the reporter's location, may also miss multiple zones within a single land parcel. Furthermore, data quality could be compromised by weather conditions; however, this can be addressed with solutions like Continuously Operating Reference Stations. Overall, this study provides a robust framework for urban planning authorities to manage zoning compliance effectively amidst rapid urbanization and informal settlements, promoting sustainable urban development practices tailored to Kigali's unique dynamics.

Keywords: WebGIS, Application, Zoning Regulations, Compliance, Kigali City

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List of abbreviations

AGOL	ArcGIS Online
AI	Artificial Intelligence
API	Application Programming Interface
BLUIS	Bhubaneswar Land Use Intelligence System
BPMIS	Building Permit Management Information System
CoK	City of Kigali
CORS	Continuously Operating Reference Stations
COVID-19	Coronavirus Disease 2019
CSV	Comma-Separated Values
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information System
GlobalID	Global Identifier
GPS	Global Positioning System
ICT	Information and Communication Technology
LAIS	Land Administration Information System
ML	Machine Learning
NISR	National Institute of Statistics of Rwanda
NLA	National Land Authority
NLUDMP	National Land Use Development Master Plan
NSDI	National Spatial Data Infrastructure
NST1	National Strategy for Transformation 1
NYC311	New York City 311 (Call Center)
PDF	Portable Document Format
RLMUA	Rwanda Land Management and Use Authority
SaaS	Software as a Service
SDGs	Sustainable Development Goals
UAVs	Unmanned Aerial Vehicles

UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
UPI	Unique Parcel Identifier
URA	Urban Redevelopment Authority
WebGIS	Web-based Geographic Information System
WYSIWYG	What You See Is What You Get

1 INTRODUCTION

1.1 Background

In 2007, for the first time in history, the global urban population exceeded the global rural population, and since then the number of the world's city dwellers has continued to grow faster than the rural population (United Nations, 2018) leading to increased pressure on land for settlement activities (Weith et al., 2021). Today, 56% of the world's population (4.4 billion inhabitants) live in cities (World Bank Group, 2023), and towards the end of the Agenda for Sustainable Development in 2030, the share of the world's population living in urban areas is expected to reach 60 per cent, reaching more than two thirds (68 per cent) by 2050, the rate of urbanization being the highest in Asia and Africa (United Nations, 2018). The rapid urbanization process and inadequate urban planning lead to many issues such as increased pressure on urban infrastructure and resources, increase in housing deficits resulting in more people living in informal settlements, increased urban sprawl and loss of agricultural lands (Bah et al., 2018).

These issues are exacerbated by colonial-era legal frameworks that often do not fit current conditions, limiting effective urban planning and governance in many developing countries. This trend is exacerbated by contemporary land use governance systems characterized by gaps, mismatches, and dysfunctionalities, fostering unsustainable land use practices (Weith et al., 2021). Rapid urban population growth, especially in developing countries, presents a major challenge for governments and planning agencies, leading to spatial expansion beyond juridical limits (Mosammam et al., 2016). Consequently, urban population living in slums worldwide recently reached 23.5 per cent in 2018, corresponding to over 1 billion, with 80 per cent attributed to three regions: Eastern and South- Eastern Asia (370 million), sub-Saharan Africa (238 million) and Central and Southern Asia (227 million) (United Nations, 2024). In 2018, Rwanda counted 12,509,052 inhabitants, of which 17.2% were urban, and 61.3 percent of these urban population lived in informal settlements (UN-Habitat, 2024), and currently, more than 60% of Kigali's population are estimated to live in the informal settlement (City of Kigali, 2023b).

Important and capital cities in Africa were often the subject of grand master planning under colonial rule or involving prominent international planners or architects, and some of such plans were unchanged and were still in force until 2009 (UN-Habitat, 2009). Bamako, for example, had

its first master plan in 1981, which was not reviewed since 2015 because of uncertainties (SISSOKO, 2019), while Lagos has expanded beyond its state boundaries into another state on the northern corridor (Oyalowo, 2022). In 2006, Rwanda took a great step in land governance, by establishing the office of registrar of land titles (Ministry of Environment, 2019), followed by establishment of the National Land Center (Government of Rwanda, 2009), systematic land registration, and all the related developments, such as the establishment of the land administration information system and installation of CORS network to improve quality of land measurements (Ngoga, 2018). However, the effort has been put in land administration, leaving aside the land use component (Ministry of Environment, 2019), which was given due attention in 2020 by revising the National Land Use Development Master Plan (Government of Rwanda, 2021) and the Kigali Master Plan to provide a solid guidance for future physical urban growth (City of Kigali, 2020a).

Regulating land use is crucial to achieve sustainable land use, which in turn is a prerequisite for sustainable and resilient development (UN-Habitat, 2017). In fact, if not controlled, the current urbanization dynamics could hinder the development of the housing sector which could prevent the achievement of the Sustainable Development Goals (SDGs) 11, which aims to ensure access for all to adequate, safe, and affordable housing and basic services and to upgrade slums, as well as the achievement of the SDGs related to poverty and inequality (Bah et al., 2018).

The last few decades have seen development of new methods and techniques to monitor and analyze urban sprawl phenomenon and its consequences, where some scholars emphasize the spatial and temporal technologies such as GIS and remote sensing in combination with statistical techniques (Mosammam et al., 2016). The Rwanda NLUDMP also proposes the use of real-time monitoring technology linking the monitoring system to an updated high-resolution ortho-imageries (Government of Rwanda, 2021), but this is still not implemented. In Rwanda, detection of illegal constructions is done through manual master plans compliance inspection, which only concern parcels sampled among those that were given building permits (Rwanda Land Management and Use Authority, 2019).

Change detection, which is a process of identifying differences in the state of a geographic feature by observing it at different times (Singh, 2010), has largely proved to be effective and valuable tools for monitoring and estimating urban sprawl over a time period to examine the impacts and identifying the points of intervention and to direct growth away from sensitive ecological areas,

especially in developing countries (Mosammam et al., 2016). However, remote sensing cannot precisely prevent unauthorized construction (He et al., 2019), since it is limited by temporal resolutions (Spatial Post, 2023). This is mainly due to the fact that the long revisit period of most of the satellites is not conducive to the timely updating of illegal construction data (Li & Tan, 2020). Other limitations that come with the remote sensing in all its forms include high cost of high-resolution satellite imagery acquisition, specialized skills and equipment need, seasonal changes that can affect imagery quality and subjectivity in interpretation (Spatial Post, 2023).

Some cities have adopted new solutions that allow the public to report any suspicious land development, either through phone calls, or through online applications (New York City, 2024; Santee, 2024; Washington DC, 2024), while others are using web applications that leverage the latest GIS technologies, whereby suspicious constructions are reported together with their geographic coordinates (Rathod, 2018; The Times of India, 2019; Times of Malta, 2021) thus enabling the officials to quickly stop the ongoing illegal construction (The Times of India, 2019).

1.2 Problem statement

Due to limited mechanisms to evaluate the level of implementation of land use master plans, there have been many cases of non-compliance with the zoning regulations in Rwanda, which has resulted into uncontrolled urban growth, where implemented urban boundaries were 10 times bigger than the ones proposed by NLUDMP of 2011 (Rwanda Land Management and Use Authority, 2019). The Kigali Master Plan that was developed in 2013 (City of Kigali, 2013), has negatively impacted on the availability of affordable housing due to zoning regulations which obliged the use of high cost building materials and housing categories which were not affordable by low income people (Nyiransabimana et al., 2019). In 2019, Kigali Master Plan was revised and republished in 2020 together with the zoning regulations known as “*Zoning Regulations of the City of Kigali*” which aim to explain the proposed Zoning Plan and Development Control Regulations which would encourage and guide Public for implementation of the Kigali Master Plan and in the harmonic and balanced development of Kigali (City of Kigali, 2020c).

Available data on Kigali highlights the ongoing conversion of natural landscapes due to urban sprawl, emphasizing the urgent need for proactive urban management and strategic planning to mitigate these effects (Gilbert & Shi, 2023). Detecting land use change is done either by comparing

two different imageries via naked eyes or through joint land use inspections conducted once per year (Korea Land and Geospatial Informatix Corporation, 2019), or by field inspection done through the City's inspection division (City of Kigali, 2023a). Nevertheless, there are still several buildings being erected ignoring the master plan (KT Press, 2017), and fake construction permits on the market (Nsabimana, 2020). Hence, from 2003 to 2023, built-up areas in Kigali City have expanded from 48.59 km² to 238.07 km² (Gilbert & Shi, 2023).

Different researchers have suggested better ways of identifying land use change, including the use of Remote sensing together with other technologies such as UAVs or AI (Dr. Bhatta, 2010; Mosammam et al., 2016; Nshimiyimana et al., 2023; Rawat & Kumar, 2015; Solaimani et al., 2010), however, those methods cannot realize rapid and real-time monitoring of urban illegal constructions, which leads to the problem that illegal buildings' behaviors cannot be stopped in time (Li & Tan, 2020). There are other solutions adopted by different cities and countries that leverage the latest GIS technologies to allow the public to report suspicious land developments, (DuPage County, 2016; Longoni & Nivison, 2024; Times of Malta, 2021). Such GIS-based solutions could greatly improve how Kigali City enforces zoning regulations, but they haven't been implemented yet. If adopted, these tools would help authorities monitor compliance more effectively by providing timely alerts about possible illegal constructions, allowing for quicker and better-informed actions.

1.3 Objectives

The general objective of this research is to develop an application to support the monitoring of compliance with zoning regulations in Kigali City.

The specific objectives are:

1. To explore the existing geospatial solutions used in ensuring compliance with zoning regulations.
2. To identify potential geospatial model that best suits the features and requirements of Kigali City
3. To develop a geospatial application for monitoring compliance with zoning regulations in Kigali City
4. To evaluate the efficacy of the developed application

1.4 Research questions

This research sought answers to the following questions:

1. What are the latest geospatial solutions utilized globally for ensuring compliance with zoning regulations?
2. Which geospatial tool model is well aligned with the unique features and needs of Kigali City?
3. What technologies and tools can be utilized to develop a geospatial application for monitoring compliance with zoning regulations in Kigali City?
4. How effective is the developed geospatial application in aiding authorities to monitor and enforce compliance with zoning regulations in Kigali City?

1.5 Motivation

Rwanda's population was 13,246,394 inhabitants in 2022 and is projected to reach 17.4 (medium scenario) in 2035, and considering the current annual growth rate of 2.3%, the population in Rwanda may reach 22.9 million in 2050 with an Urban population projected at 7.9 M by 2035 and 15.2 M by 2050 (National Institute of Statistics of Rwanda, 2022). The built-up zones of Kigali have grown from 9,196.31 ha to 23,549.14 ha, corresponding to an increase of 256% from 2008 to 2017 (Rwanda Land Management and Use Authority, 2019). Currently, the City needs 18,000 affordable houses per year (Ntirenganya, 2024), while 60 per cent of the City's population lives in informal settlements that are subject to natural risks induced by climate change (Nkurunziza, 2024). If nothing is done, urban land will expand from 363.29 km² in 2015 to 637.97 km² in 2050 (Li et al., 2021).

Increase in land efficiency and innovative capacities is considered a need for Rwanda to reach an average GDP growth of 9.1% during the NST1 period for the country to reach upper middle-income status by 2035 (Government of Rwanda, 2017). Central to the achievement of Rwanda's ambitions to transform into a prosperous, food secure, knowledge-based economy, is the optimal use of land (Government of Rwanda, 2021). Real-time monitoring technology using accurate spatial data, integrated geo-information framework, Earth Observation tools, machine learning and Land Use Monitoring system will allow the Kigali City to promptly identify and apply corrective measures as needed (City of Kigali, 2020b; Government of Rwanda, 2021). There is need for a monitoring system linked to an upgraded Land Administration Information System, and Building

Permit Management Information System, all of them contributing to an interoperable environment capable of providing all necessary data for real-time analysis and warning (Government of Rwanda, 2021). The GIS-based tool suggested in this research would support the monitoring of compliance with zoning regulations, in near-real time, contributing to sustainable use of land resources in Kigali City.

1.6 Thesis structure

This thesis is organized into 5 chapters as shown in the figure below.

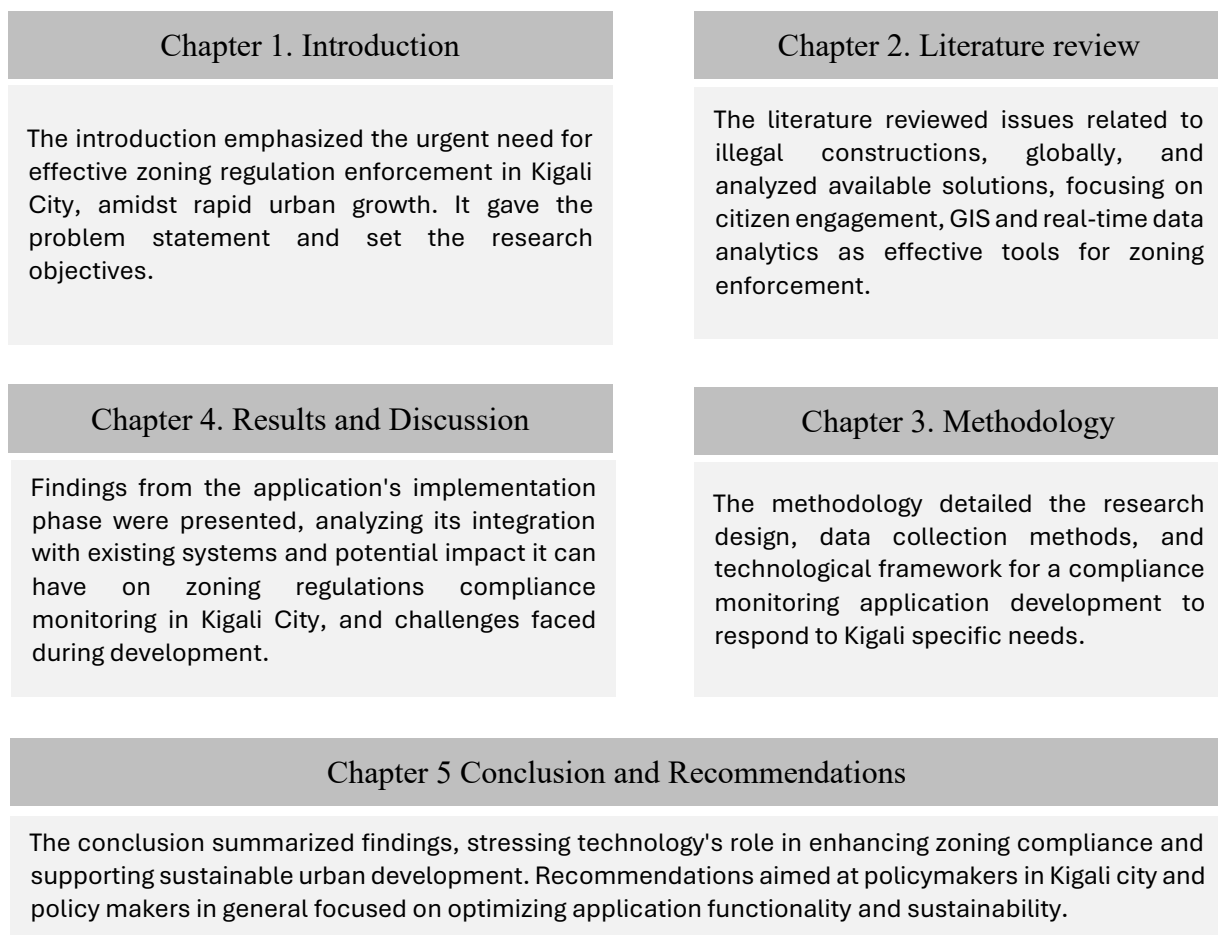


Figure 1-1: Thesis structure

2. LITERATURE REVIEW

This chapter explores critical aspects of urban development governance, focusing on compliance with zoning regulations and the challenges encountered by regulatory institutions. It delves into the prevalence of illegal constructions and the current methodologies used in monitoring them, highlighting the deficiencies in existing practices. The review underscores the necessity of adopting geospatial applications to enhance monitoring capabilities, providing a comprehensive overview of the current technological solutions employed for compliance monitoring. These discussions set the stage for understanding the complexities and deficiencies within urban development regulatory frameworks and the urgent need for innovative approaches to improve monitoring and enforcement mechanisms.

2.1 Relevance of compliance with zoning regulations

The global rise in urban populations and the escalating impacts of climate change are pushing cities towards greater sustainability and resilience, however this dual pressure is straining available land resources, posing significant hurdles in effectively meeting the diverse needs of urban communities (Maring & Blauw, 2018). Businesses benefit directly from sustainable land practices, accessing essential resources while contributing to local economies through employment opportunities and the provision of goods and services. Citizens, in turn, rely on sustainably managed land for food production, clean water, and other ecosystem services that support their livelihoods (Thiaw, 2022). Hence, the optimization of land use across various environmental and socio-economic contexts is crucial in minimizing land degradation and ensuring its sustainable utilization (FAO, 2024).

Unsustainable urban growth often stems from institutions not having the necessary resources or abilities to manage natural and environmental assets properly (Dentinho, 2011). In fact, once a city is built, its physical form and land use patterns can be locked in for generations, leading to unsustainable sprawl (World Bank Group, 2023). Controlling and managing urban land effectively, especially in rapidly expanding areas, is crucial to addressing various land use challenges including the formation of slums, increasing land costs, ensuring access to urban land for housing, managing incompatible land uses, addressing flooding, and tackling issues like overcrowding and congestion for promoting sustainable city development and safeguarding the

safety and health of urban residents (Ahmed & Dinye, 2011). Illegal buildings often pose significant risks. Many of these structures are unsafe due to bypassing local building regulations, avoiding professional architects, and using poor-quality or contaminated materials. As a result, these buildings are prone to collapse, leading to the loss of lives and property (Pharande, 2022). Illegal buildings also leads to reduction of tax revenues, strain infrastructure, impact the economy, and pose environmental risks (Aventior, 2020).

Land development is controlled through master plans which are essentially flexible, strategic blueprints for long-range planning that sets the stage for future development (Bui, 2024). Master plans are implemented through tools such as zoning regulations which are the bylaws dictating permissible land uses and development standards within specific areas to safeguard public safety and well-being while ensuring environmental conservation and cultural preservation (FasterCapital, 2024). In Rwanda, land development control is done through the National Land Use and Development Master Plan (NLUDMP) which is a comprehensive strategic framework aimed at guiding and coordinating spatial development throughout Rwanda, utilizing medium and short-term strategies to translate long-term aspirations into actionable plans. By establishing a structured hierarchy of planning levels—from Vision 2050 down to Kigali City, district, and local plans—the NLUDMP ensures alignment with national goals while addressing gaps in the current legal framework (Government of Rwanda, 2021).

City of Kigali (2020c) implements the Kigali Master Plan through the zoning regulations, which classify land uses into four categories:

Permitted Use: Permitted uses are activities or developments that align with the primary intent of a zoning code and are allowed without additional approval. These uses fit seamlessly within the designated zoning category and generally adhere to the overall planning goals of the area. However, even permitted uses must comply with supplementary regulations as applicable, such as Urban Design Guidelines, Heritage and Conservation guidelines, and specific overlay requirements to ensure contextual compatibility and adherence to broader regulatory frameworks.

Conditional Use: Conditional uses are those activities or developments that may have the potential to generate significant impacts, such as increased traffic, noise, or other effects on the surrounding neighborhood. These uses are not automatically permitted but may be allowed under certain

conditions following a thorough evaluation by the City of Kigali One Stop Centre. This assessment process ensures that any potential negative impacts are adequately mitigated and that the use is compatible with the surrounding area when specific conditions are met.

Prohibited Use: Prohibited uses encompass activities or developments that are deemed fundamentally incompatible with the designated zoning area. These uses are not allowed under any circumstances within the zone due to their potential to adversely affect the character or functionality of the area. For instance, Heavy Industrial Uses are prohibited in residential zones to prevent conflicts with the residential character and quality of life.

Overlay Zones: Overlay zones introduce an additional layer of regulation on top of existing zoning designations, offering greater flexibility and specificity in land use planning. These zones are superimposed over established zoning maps to address particular planning goals or protect sensitive areas. They allow for the imposition of supplementary restrictions or permissions and can modify the density and development incentives within their boundaries. Overlay zones can span multiple underlying zones and include areas such as Transit Overlay Zones, Airport Restriction Areas, and Urban Design Overlays. The regulations of an overlay zone are applied in conjunction with those of the underlying zoning, guiding development to meet both general and specific planning objectives.

During master plans implementation, robust compliance monitoring of zoning regulations is essential (FasterCapital, 2024). This oversight ensures that urban development adheres to sustainability principles of good urban governance endorsed by the United Nations which include the integration of sustainability across all facets of urban development, involving harmonizing the social, economic, and environmental requirements of both current and future generations, guided by a strategic vision aimed at achieving collective well-being (Metropolis, 2011; UN-Habitat, 2002).

2.2 Challenges faced by institutions in charge of ensuring compliance

In many countries, zoning regulations enforcement mechanisms suffer from inadequate monitoring systems, hampering effective oversight of regulatory compliance, while concurrently, certain public authorities face challenges in controlling non-compliant land developments due to constraints such as limited financial resources or political influences (Iban, 2020). The legal

structures under which this development control is to be enforced has been identified to be either too weak or inappropriate in addressing the myriad of problems of physical development (Ahmed & Dinye, 2011). Urban oversight is severely challenged by collusion between wealthy individuals and officials further facilitating illegal construction practices (Real Muloodi, 2022).

Allegations of bribery, conflicts of interest, abuse of public office and other similar offences are recognized as the most common forms of corruption in the planning and zoning sector (Pharande, 2022; Transparency International, 2017). This is worsened by informal developments that operate outside legal frameworks, exacerbated by their widespread scale and significant impact on vulnerable populations (JHA, 2021). Failure to enforce planning policies is among the factors that lead to cities sprawled growth (Bhatta, 2010) and unhealthy, disaster-prone and undocumented informal houses (Iban, 2020).

2.3 Illegal constructions and current monitoring practices

Voskresenskaya and Zhilskiy (2023) define illegal construction as an immovable property built on a land plot not designated for such use by law or legal regulations, including erecting structures without proper permissions from the landowner or authorities, or using land for purposes contrary to its intended use. According to the Thembisile Hani Local Municipality (2020), illegal land use occurs when a piece of land and/or building is used by an owner for a different use or under different conditions than specified or provided for in the land use scheme. Pharande (2022) defines illegal construction as any building or addition to an existing building which does not comply with the existing municipal or civil laws and has been built without proper permissions. Such buildings defy conventional urban planning regulations and flourish at the proximity to major cities (Romano et al., 2021). Illegal construction is often viewed as a negative phenomenon in modern societies because it contradicts the established rules and norms of each society. It is seen as a disruptive factor to achieving contemporary urban planning goals, which aim to preserve the natural environment and promote sustainable development (Šipetić et al., 2020).

Illegal construction is a key problem in daily urban management, which negatively impacts social harmony (Ding et al., 2024). This issue has become a global concern, significantly escalating over the past five decades due to rapid urbanization. This surge is primarily driven by the mass migration of rural populations to urban areas, creating sprawling informal settlements such as

slums and bidonvilles (Romano et al., 2021). For example, during the period from 2000 to 2005, the land area occupied by provincial capitals in China expanded by 90.15%, and from 2000 to 2010, the urban areas of China grew by 101.04%. This rapid urbanization has coincided with a significant rise in illegal construction activities, directly impacting urban governance and burdening municipal oversight authorities with increased responsibilities (He et al., 2019).

In India alone, in 2021, 36,486 houses were demolished, resulting in approximately 100 homes destroyed daily, which translates to about 567 people being evicted each day or 24 individuals losing their homes every hour, a punitive measure that has exacerbated the challenges faced by women, children, older individuals, and persons with disabilities (The Wire Staff, 2022). It is reported that municipal authorities occasionally tolerate citizens violating regulations, typically in turn for monetary fines (Ghalambordezfooly & Hosseini, 2023) and that numerous buildings have been erected through bribery of local civic authorities, a practice that inevitably comes to light over time which makes homeowners to face complete loss of their investments in these properties (Pharande, 2022).

Despite numerous examples of illegal building demolitions around the world, their occurrence persists, especially in undeveloped and developing countries (Šipetić et al., 2020). In developing nations, rapid population growth, poverty, and economic conditions are primary factors driving unauthorized land usage (Ghalambordezfooly & Hosseini, 2023). Hence, Egypt reported two million building violations between 2000 and 2017, prompting recent efforts to prosecute and demolish unlicensed constructions (Ahram Online, 2020). In Kampala, over 4,000 buildings lacking approved plans have contributed to structural failures, worsened by resources constraints exacerbated during the COVID-19 pandemic (Real Muloodi, 2022), while in Cameroon and Lagos, fatalities linked to unauthorized constructions have prompted urgent responses, emphasizing community reporting and swift demolitions to mitigate risks (TRT Afrika, 2023; Vanguard, 2024). Illegal construction in Lagos exacerbates homelessness and displacement, affecting millions. Demolitions often occur with inadequate notice, worsening living conditions and socio-economic challenges in both affluent and low-income neighborhoods, highlighting the need for a more balanced approach to urban development and housing (Uroko, 2024).

Kigali struggled with the 2013 master plan compliance due to a shortage of affordable housing near central areas. This gap led to increased unplanned settlements and congestion, highlighting

the need for the master plan update to plan more houses close to Central Business District to curb urban sprawl (KANAMUGIRE, 2019). It was reported that by 2017, Kigali offered a reward of fifty thousand Rwandan Francs to anyone who reported illegal construction, and had arrested 30 local leaders for related corruption, amidst a 300,000-unit housing deficit (Kalinda, 2017). Kigali's challenging terrain amplifies construction hazards, necessitating stricter oversight to prevent disasters like landslides exacerbated by climate change (Niyokwiringirwa, 2021; Reuters, 2017; Tabaro, 2023b). Illegally constructed houses in Kigali are routinely demolished (see an example on figure 2-1), yet criticism persists regarding the City of Kigali's oversight failures, allowing unchecked construction. This scrutiny suggests that timely intervention could have prevented these developments, potentially saving citizens significant costs (Kagire, 2023). Criticism primarily targets inadequate oversight in construction permit issuance and misplacement of buildings, prompting accountability concerns and emphasizing the need for learning from past errors (Tabaro, 2023a).



Figure 2-1: A hotel top floor being demolished
Source: Kagire (2023)

In some places within Kigali City, citizens have adopted "one-day" construction methods, masking new building work under old materials to evade oversight and reveal completed structures over weekends, bypassing regulatory checks (Hatangimana, 2022; Musoni, 2022; Umurerwa, 2015). Violating land use regulations can lead to hefty fines, legal disputes, and possible criminal charges. It can also cause environmental damage, reduce property values, and disrupt community harmony.

Additionally, it may result in project delays, increased costs, and damage to the landowner's reputation (Kayitare, 2023; Richard Stevens and Associates, 2023; Uroko, 2024).

2.4 Need for Geospatial application for monitoring compliance

Currently, numerous countries globally conduct manual inspections, leading to challenges in promptly and affordably identifying under-construction illegal buildings. This impedes timely intervention or enforcement of penalties. Administrative processes suffer from inefficiencies exacerbated by staff shortages, bureaucratic hurdles, and increased responsibilities, rendering universal inspector deployment impractical and elevating corruption risks (Aventior, 2020). There is need for implementing a technological solution, since the current method used by many countries consisting of field visits to detect illegal construction is outdated, proving inefficient in terms of time, cost, and workforce (JHA, 2021).

The National Land Use and Development Master Plan provides a list of measures required for its compliance, including technological advancements such as real-time monitoring tools, and a centralized national geoportal for accessing land use plans. It also advocates for incentivizing whistleblowers to report illegal constructions (Government of Rwanda, 2021). Geospatial applications play a crucial role in monitoring compliance, particularly in evaluating illegal land development. These technologies integrate spatial variables effectively, enabling the assessment of environmental violations. Common tools include remote sensing for capturing distant images, GPS for precise global positioning, and GIS for organizing and visualizing spatial data, facilitating the creation of detailed maps and charts (Schwartz-Belkin & Portman, 2023; Valdez et al., 2017).

2.5 Overview of existing tools for compliance monitoring

There are two types of enforcement, namely reactive, which responds to complaints from individual tenants or neighborhood residents, and proactive enforcement, which relies on systematic and planned inspections (House, 2021). While proactive models using technologies like aerial photography and satellite remote sensing are expensive, have a long cycle, and are impractical for frequent urban monitoring needs (Li & Tan, 2020), and difficult to administer, reactive regimes are efficient for agencies, focusing resources on active violations rather than random inspections. In fact, reactive regimes provide a platform for residents to voice concerns and for agencies to uncover hazards they might not otherwise identify (House, 2021). This is

facilitated by GPS-enabled devices, through which amateur citizens can generate and share geographical information quickly over the Internet (Ganapati, 2010).

2.5.1 Example of proactive compliance monitoring tools

2.5.1.1 Bhubaneswar Land Use Intelligence System (BLUIS)

The Bhubaneswar Land Use Intelligence System (BLUIS) of Bhubaneswar, the Capital of Odisha State in India, addresses critical challenges in Bhubaneswar, a rapidly expanding city, by monthly detecting and accurately monitoring land-use changes, enhancing transparency and accountability. By identifying encroachments on public lands early, the application helps control unplanned urban expansion that threatens sensitive ecosystems such as wetlands, water bodies, and forests. This proactive approach supports biodiversity conservation and sustainable resource management at local and regional levels. Additionally, the application mitigates financial losses associated with unauthorized developments, providing stakeholders with monthly, high-resolution satellite data for informed decision-making and efficient urban planning (Planet, 2020).

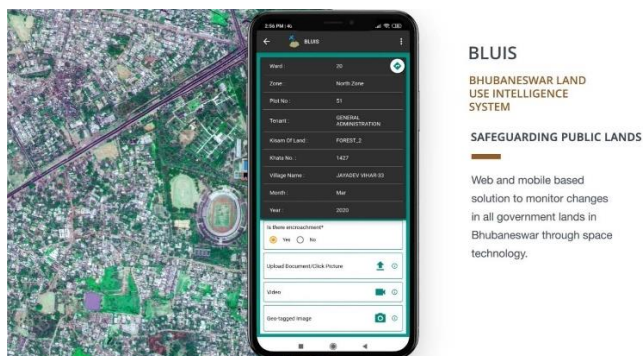


Figure 2-2:BLUIS mobile view

Source: BLUIS website, <https://bluis.odisha.gov.in/home>

BLUIS analyzes temporal changes in satellite imagery to identify new constructions, alerting officials for validation and action. It integrates a GIS dashboard for visualization and a mobile application for field validation, enabling efficient enforcement of land-use regulations.

Users

BLUIS serves as a critical tool for government officials tasked with monitoring and enforcing land-use regulations. Additionally, the system is used by citizens who report unauthorized land use changes through a dedicated mobile application.

General User Functions

The system's general user functions encompass monitoring land-use changes through integrated satellite imagery, providing alerts via both the GIS dashboard and mobile app for immediate action. The system also facilitates field validation of reported changes to ensure accuracy and compliance with regulations. Citizens can easily report unauthorized activities through the mobile application, fostering transparency and responsiveness in regulatory processes.

Main Features

Key features of BLUIS include the integration of high-resolution SkySat imagery for precise detection, bolstered by AI and ML algorithms that automatically classify and flag land-use changes. Alerts notify relevant authorities of unauthorized activities, facilitating swift responses. Geo-tagging of images and videos ensures location-specific validation, enhancing the effectiveness of enforcement efforts.

2.5.2 Examples of reactive compliance monitoring tools

2.5.2.1 City of Haysville: Citizen Problem Reporter

The ArcGIS Blog showcases Haysville, Sedgwick County, Kansas, as a case study where the adoption of Citizen Problem Reporter has revolutionized community engagement. (Longoni & Nivison, 2024). Citizens can report zoning violations as well as other issues, including animal problems, code enforcement violations, park and tree problems, street problems, and sewer and stormwater issues (City of Haysville, 2024). Implemented in 2021, this application has revolutionized how Haysville engages with its community, replacing slow and decentralized reporting methods with an intuitive online platform. Residents can now easily submit and monitor issues from any device, significantly enhancing efficiency and transparency.

The system automates report logging and directs tasks to appropriate departments, streamlining operations and optimizing resource allocation. Real-time monitoring empowers officials to prioritize effectively, ensuring prompt responses to urgent issues and maintaining oversight of long-term projects. This transformation has fostered greater trust and collaboration between the city government and its residents, promoting proactive community engagement and effective problem-solving (Longoni & Nivison, 2024).

Users

The Citizen Problem Reporter caters to a diverse range of users within the community, including residents and businesses alike. Its user-friendly design accommodates individuals of all technological backgrounds.

General user functionalities

For general users, the app offers intuitive functionalities designed to streamline the process of reporting and tracking various non-emergency issues. Users can submit new reports anonymously through a straightforward complaint form, review existing reports, and engage with the community by commenting and voting on submissions made by others. Authentication options via social media or ArcGIS Online credentials enable users to monitor the status of their own reports conveniently.

Main features

Key features of the app include automated logging and routing of reports to relevant city departments, ensuring prompt attention to submitted issues. Real-time monitoring capabilities empower city officials to prioritize tasks effectively, responding swiftly to urgent matters while maintaining oversight of ongoing projects. This comprehensive approach not only enhances administrative efficiency but also fosters transparency and trust between the local government and residents, promoting proactive community engagement and effective problem resolution.

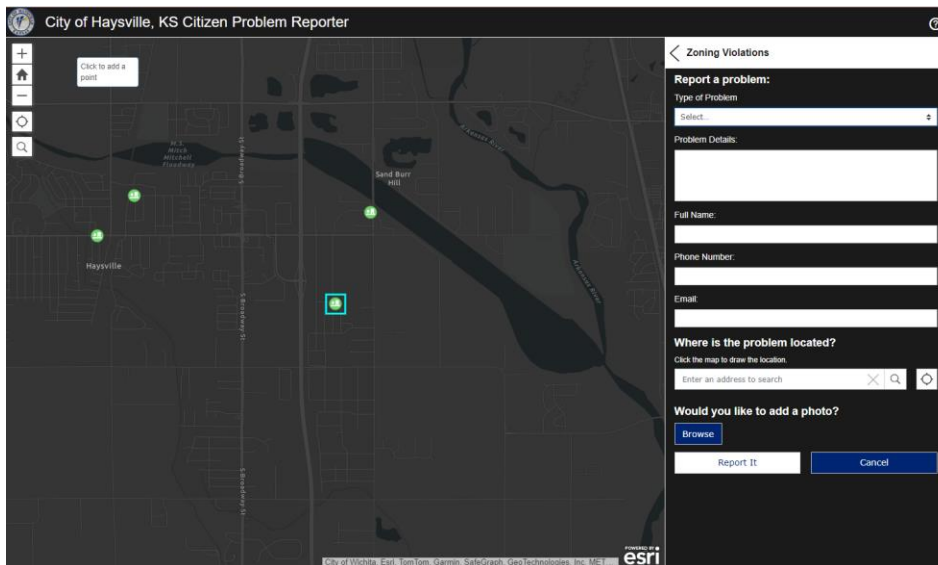


Figure 2-3: Citizen Problem Reporter, Zoning Violations form

Source: Reporter's website, <https://citizen-problem-reporter-haysville-ks.hub.arcgis.com/>

2.5.2.2 DuPage County, Illinois, USA: DuPage's Citizen Reporter

In DuPage County, Illinois, potholes are a significant issue, caused by moisture seeping into pavement cracks, which expands due to freezing and melting cycles exacerbated by heavy traffic. Potholes can range from minor nuisances to hazards that damage vehicles and endanger drivers. Each winter, the Illinois Department of Transportation spends millions filling these potholes across several counties, including DuPage (Chicago Tribune, 2021). Today, DuPage County enables citizen reporting of various issues such as forest preserve encroachment by building construction, illegal dumping in water bodies, road debris, pavement conditions and potholes through a GIS-based application. This application was developed in 2016 and powered by Esri technology, with its initial goal being for residents to help DuPage keep roads and trails safe and in good condition (DuPage County, 2016), and the application is seen as a win-win solution for taxpayers and road maintenance team (Sun-Times Wire, 2016).

Users

Users of the DuPage Problem Reporter include residents of DuPage County who report issues related to roadways, waterways and forest preserves. It is also accessible to various governmental agencies and crews responsible for addressing reported issues.

General User Functions

General functions for users include reporting issues via the application, viewing and tracking the status of their reports, uploading photos, and commenting on existing reports. Users can log in to track progress and receive updates on their submissions.

Main Features

The application allows users to submit complaints through a dedicated form with an interactive map providing the location of reported issues and their statuses. The application also sends notifications to users regarding the status of their reports. Through the application, various authorities are coordinated to ensure issues are addressed promptly.

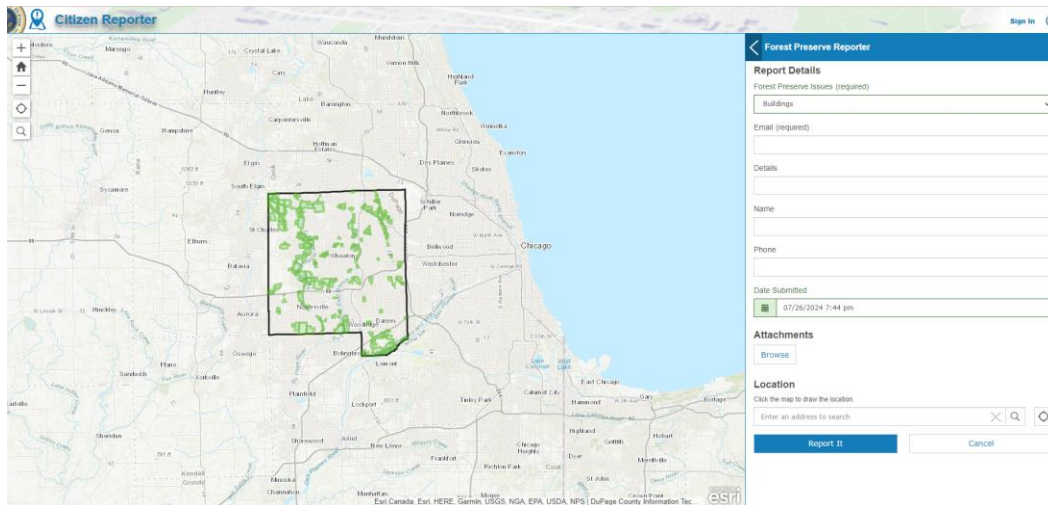


Figure 2-4: DuPage Citizen Reporter form (Forest Preserve/Buildings).

Source: <https://gis.dupageco.org/CitizenReporter/index.html#>

2.5.2.3 Other examples reactive compliance monitoring tools

Singapore: Feedback and Enquiry Form

The Urban Redevelopment Authority (URA) in Singapore harnesses GIS technology to enable citizens to report neighborhood issues, including illegal constructions, via a Feedback and Enquiry Form available on their website (Urban Redevelopment Authority, 2024). Integrated with an open-source GIS application featuring a map view, users can zoom and click to accurately mark the location of their complaint. The app also leaves space for details on the enquiry, and it is possible to attach files in addition to the details.

Trinidad and Tobago: DevelopTT

DevelopTT provides a range of online services related to land use and development permissions. Visitors can access the Public Application Register and submit unauthorized development complaints without logging in. Registered users gain access to all services, including planning permission service (Government of the Republic of Trinidad and Tobago, 2020). The platform includes other specific applications such as advertisement application for displaying signs, car rental correspondence for small rental facilities, and customs bonded correspondence for creating bonded storage areas. The complaint form includes fields for the complainant's information, offender details, nature of the complaint, and location plotting guide, allowing citizens to provide

detailed information about the unauthorized development precising its location on the interactive map.

New York City, USA: New York City 311 Call Center, NYC311

New York City offers a comprehensive 311 service, providing avenues for citizens to report various issues, including housing and building-related complaints (New York City, 2003). Citizens can report specific issues related to building construction, including work without permits, building conditions, and violations, providing detailed information about the problem, location, and individuals involved.

2.5.2.4 Data flow in a citizen-centric application

Citizen-centric solutions help cities collect reports for different sectors, including land use/zoning. As indicated in figure 2-5 below adopted from AFIFY et al. (2011), when the data reaches the system, the complaint is received by the appropriate department, which must verify the reported case, and take action. Reporters must sign up to be able to track the progress of their submitted reports.

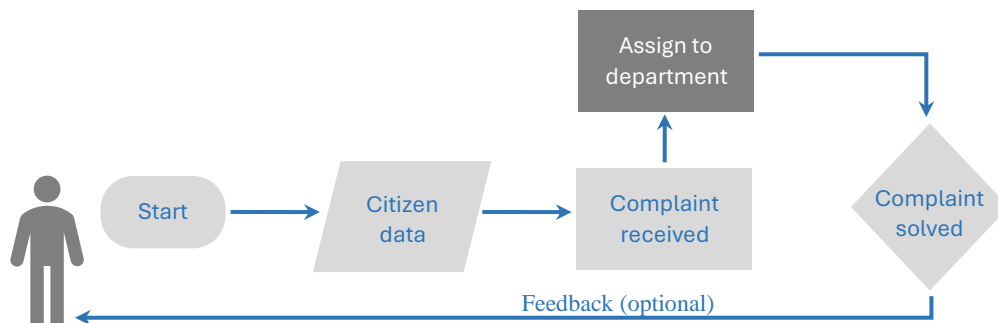


Figure 2-5: Complaint workflow.

Source: AFIFY et al. (2011)

2.5.3 Comparison between existing models

Table 2-1 below provides a comparative overview of various compliance monitoring systems used across different regions. Each system is evaluated based on key properties such as deployment model, technology used, anonymity level, number of questions, and mandatory entries. Darker green color indicates more preference of the property.

Table 2-1: Comparison between different land use compliance systems

Application	Citizens-centric	Web Browser	Geospatial technology	Total anonymity	Number of questions	Mandatory entries
Bhubaneswar Land Use Intelligence System (BLUIS)	No	Yes	Development	No	3	2
Haysville Citizen Problem Reporter	Yes	Yes	Low-Code/No-Code	Yes	7	1
DuPage Citizen Reporter	Yes	Yes	Low-Code/No-Code	No	6	1
Singapore Feedback and Enquiry Form	Yes	Yes	Development	No	16	11
Trinidad and Tobago Developtt	Yes	Yes	Development	Yes	15	2
NYC311	Yes	Yes	Development	Yes	21	2

Source: (City of Haysville, 2024; DuPage County, 2016; Government of the Republic of Trinidad and Tobago, 2020)

2.6 Relevance of a technological options in compliance monitoring in Rwanda

Over the years, Rwanda has demonstrated substantial advancement in the adoption of Information and Communication Technology (ICT), achieving a notable internet penetration rate of 60.4% and approaching 9.6 million mobile-cellular subscriptions by the close of 2019 thanks to extensive availability of 4G LTE, which spans 98.9% of the population (Ministry of ICT and Innovation, 2020). There are also strategic initiatives such as the "irembo" platform, facilitating online access to 98 government services, and others such as the National Spatial Data Infrastructure and Land Information Management System facilitating access to land use and land ownership information respectively (Government of Rwanda, 2019; Ministry of ICT and Innovation, 2020; Sabiiti, 2021).

Central to these developments is the implementation of the Smart Rwanda Master Plan, a comprehensive framework aimed at transitioning Rwanda into a knowledge-based economy (Ministry of ICT and Innovation, 2020). The Kigali Master Plan Zoning Regulations recommends a participatory and bottom-up approach to involve and engage the citizens in the designing and monitoring process of the master plans and related regulations (City of Kigali, 2020c). Given Rwanda's robust mobile and internet infrastructure, including widespread broadband accessibility; the development of an application to support the monitoring of compliance with zoning regulations in Kigali City holds promising potential for achieving effective oversight and regulatory enforcement.

3. METHODOLOGY

In this section, the systematic approach undertaken to develop an application aimed at facilitating the monitoring of zoning regulations in Kigali City is detailed, including a comprehensive literature review and the application of various technical methodologies.

3.1 Description of the Study Area

Kigali City is the capital of Rwanda, founded in 1907, located in the center of the country (City of Kigali, 2023), and currently, Kigali alone is home to approximately 1.7 million inhabitants (NISR, 2022). As Rwanda's financial and administrative hub, Kigali accounts for over 40% of the Gross Domestic Product (GDP) and attracts large numbers of rural migrants (UrbanShift, 2024). As the most urbanized province in Rwanda, Kigali's built-up areas have increased from 25km² in 1987 to 115 km² in 2018, causing a decline in adequate housing (Manirakiza et al., 2020). Currently, only 42.4% of private households are classified as modern planned urban housing, while 40.1% are classified as spontaneous housing (NISR, 2022), which is an indication of lack of compliance with zoning regulations.

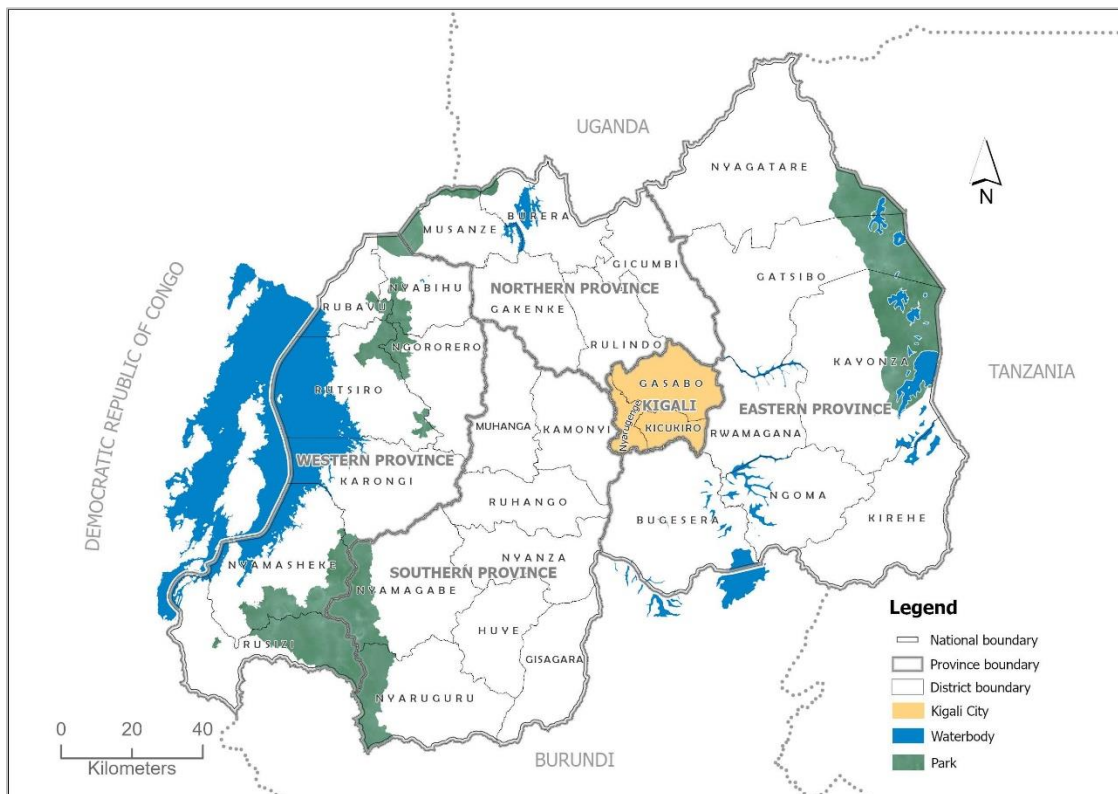
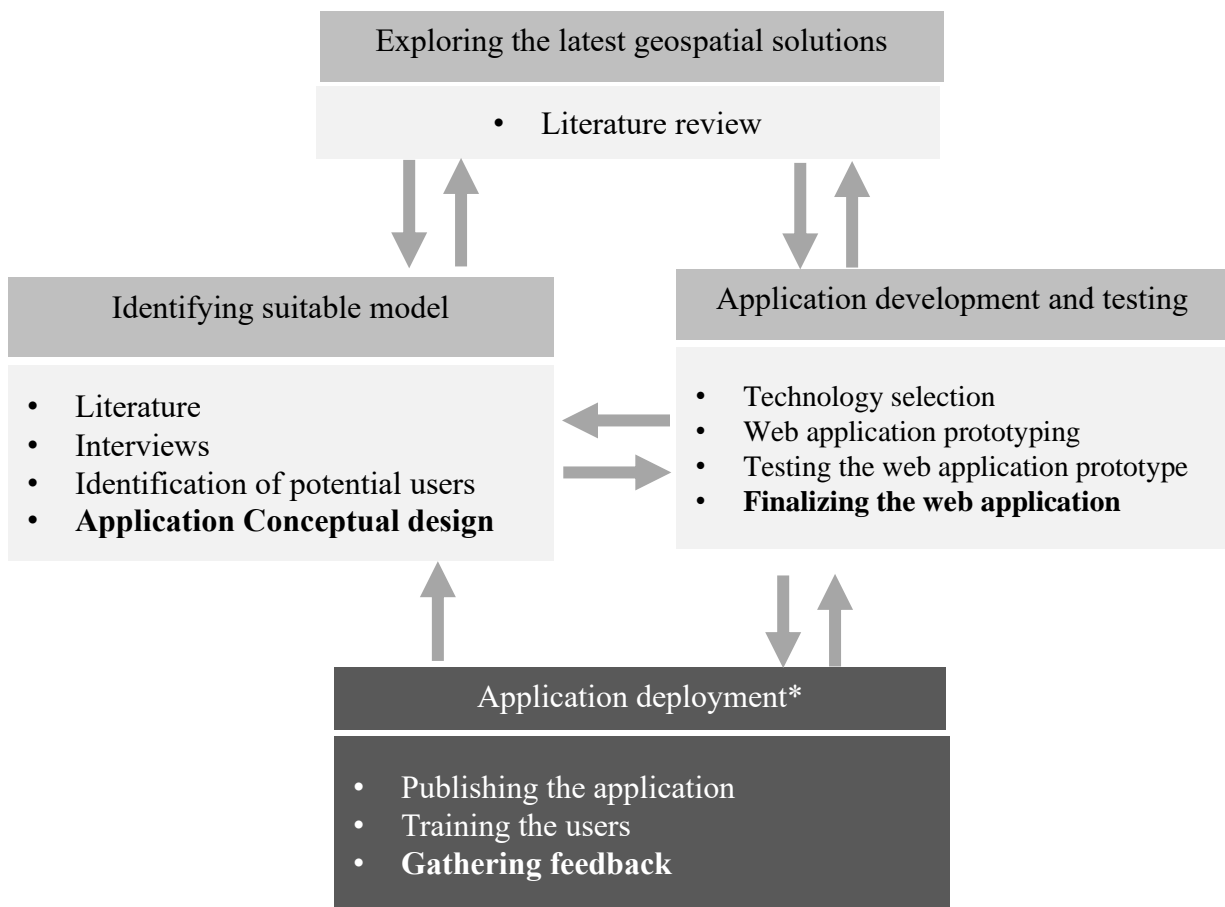


Figure 3-1: Kigali City location map.

Source: <https://nsdi-rla.hub.arcgis.com/>

3.2 Research framework

To achieve the objectives outlined in this research, a comprehensive and iterative methodology was employed, encompassing four key phases aligned with the specific objectives as indicated below in the research framework. The research involved exploring the latest geospatial solutions through a literature review and interviews to identify a suitable model and understand user needs. This informed the conceptual design of the application, which was then developed into a web application prototype. After iterative testing and refinement, the application was finalized for deployment, ensuring it effectively met the identified requirements.



*Not part of this research

Figure 3-2: Research framework.

3.3 Exploration of existing GIS-based compliance solutions

The literature review explored the background and methodologies employed in similar urban contexts globally. This included examining case studies where digital tools have been successfully integrated into urban planning and governance, aiming to draw insights applicable to the development of an innovative monitoring application for Kigali City.

3.4 Identification of potential geospatial model for Kigali City

The choice of the model for Kigali City integrated extensive stakeholder engagement, careful hardware and software needs evaluations and selection of a hosting environment that will ensure effectiveness and sustainability.

Users and their roles: Interviews were conducted for understanding the diverse user roles and gathering insights into their specific operational needs and current challenges, to ensure that the application design and functionality directly address the practical requirements of zoning compliance monitoring in Kigali City.

Hardware considerations: This was pivotal in determining the infrastructure needed to support the application's robust performance and accessibility. Factors such as system scalability, devices to be used and compatibility with existing city infrastructure were carefully assessed to ensure seamless integration and efficient data management while minimizing financial implications.

Software selection: Guided by the need for a scalable, user-friendly GIS platform, capable of real-time data integration and analytics. The choice prioritized functionalities like mapping, visualization, and mobile compatibility to enhance usability for stakeholders across different levels of expertise. Evaluating both commercial and open-source options allowed us to balance reliability, flexibility, and cost-effectiveness.

Functions: Functional requirements were identified through interviews and a comprehensive review of Kigali City's zoning regulations and current challenges related to illegal constructions. These insights were instrumental in translating user needs into specific technical and operational functionalities essential for effective zoning compliance monitoring.

Host of the application: Key considerations included scalability to handle future needs, robust data security measures, and seamless integration with Kigali's existing applications, enhancing operational efficiency and community impact.

3.5 Developing the compliance monitoring application for Kigali City

The development of the application was done in two main steps:

Application design: Based on the insights gained from the needs assessment, we proceeded with the application design phase. This involved translating the identified needs into functional and technical requirements for the application.

Application Development through No-Code/Low-Code process: We adopted the No-Code/Low-Code approach to develop our solution that integrates reported cases and other relevant content. This method allowed for rapid development and customization of the application without extensive coding.

3.6 Evaluating the efficacy of the developed application

The application testing methodology encompassed three stages:

Integration testing: This was done on the data collection application to ensure seamless communication between it and critical databases, crucial for accurate data retrieval and analysis related to urban development and zoning compliance.

User Acceptance Testing: This test was conducted to evaluate the application's usability, friendliness, and effectiveness in monitoring zoning compliance. This phase involved talking to testers for feedback on their experience while using the application.

Performance Testing: This test assessed the application's performance under diverse conditions to ensure it could handle real-time gathering without delays or system failures.

4 RESULTS AND DISCUSSION

This chapter presents the outcome of the research and application development efforts aiming at enhancing urban regulatory oversight in Kigali City. The overall objective of this thesis has been to develop a robust application that addresses the critical need for effective monitoring and enforcement of zoning regulations amidst rapid urbanization. This chapter encapsulates the outcomes of implementing the application within the context of Kigali's dynamic urban landscape, aiming to improve compliance reporting mechanisms and regulatory transparency. This chapter also explores the challenges encountered during implementation.

4.1 Current compliance monitoring practices in Kigali City

Organizational Structure: Through interviews with Kigali City's personnel involved in building inspection, it was revealed that building inspection falls under the jurisdiction of the Vice Mayor in Charge of Infrastructure, who supervises the Inspection Division. This division is headed by the Chief Inspector, overseeing four Senior Inspectors. One of these senior inspectors is the Building Senior Inspector who directly coordinates the inspectors from the districts' inspection units. This consists of three building inspectors who collaborate with additional inspectors assigned to various sectors, with one inspector per sector.

Field Inspections: Inspections within Kigali districts aim to verify reported cases and ensure compliance with building permits in specific sectors. Districts report their findings to Kigali City's Inspection Division through the Building Senior Inspector. Kigali City has also an internal dashboard which contains building footprints that get updated every three months through a local contract.

Reporting Illegal Constructions: Citizens, including Youth Volunteers and informants known as "*ijisho ry'umuturanyi*" report illegal constructions by submitting evidence via photos and phone calls to local leaders and security organs at various levels. Reports often reach city officials, with the mayor sometimes being the first to receive alerts. Coordination with enforcement (inspectors) teams involves guiding them to the reported sites using landmarks, although there's a noted need for an application supporting location and UPI transmission.

Operational Flexibility: Inspectors' daily activities are planned rather than adhering to a regular calendar. This flexibility allows them to proactively monitor areas of concern within the city.

4.2 Needed enhancements

Citizen involvement is essential in identifying and reporting illegal constructions. However, the existing reporting process heavily depends on landmarks for navigation to these sites, which can lead to confusion and delays in response. This underscores the necessity for a GPS-enabled application that provides accurate location tracking, thereby streamlining the inspection process. The proposed application should include critical features such as photo uploads and location tagging, enabling citizens to submit clear and actionable evidence of violations. Additionally, this application will enhance the flow of information between inspectors, facilitating prompt task dispatch and coordination among team members. Furthermore, instead of receiving raw alerts from citizens, managers should receive verified and confirmed reports to ensure that they are acting on reliable information. A user-friendly interface for managers will help in monitoring reports, tracking progress, and making informed decisions. By integrating these features, the application can significantly enhance the effectiveness of illegal construction reporting and inspection in Kigali City.

4.3 Proposed Kigali City's model

Considering Kigali City's mandate and structure and the existing inspection workflow, we have chosen to implement a model similar to one implemented by Haysville, as it was the best compared to other presented models (see table 2-1). The model adapted for Kigali is indicated in figure 4-1 below.

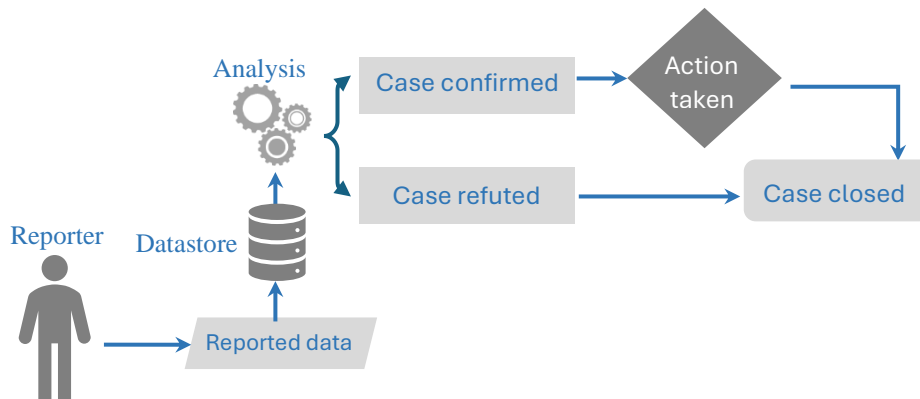


Figure 4-1: Proposed model

In this model, reported cases go directly to the central storage, where analysts within districts work with inspectors to follow up on cases that are likely to be illegal. Both information of analysis and action taken will inform decision makers at City level through dedicated applications as indicated in section 4.4.

4.4 Technology choice

4.4.1 Software

To allow multiple submissions of records by many people while keeping a good performance, ArcGIS WebGIS was selected as the best technology behind our web GIS Application after comparing it with an alternative open source, as indicated in table 4-1 below. According to GISKernel Technologies Pvt Ltd (2023), high cost is the most highlighted limitation in the use of ArcGIS WebGIS, such as ArcGIS Enterprise; however, the City of Kigali has already acquired ArcGIS Enterprise with perpetual licenses (ESRI, 2021; Surbana Jurong, 2020), making it an advantage.

Table 4-1: Comparing ArcGIS Enterprise and Opensource Stack.

Criteria	ArcGIS Enterprise	Open-Source Stack
<i>License Cost...</i>	Higher	Free
<i>Ease of Use...</i>	User-friendly	Varied
<i>Customization...</i>	Extensive	Highly customizable
<i>Integration...</i>	Seamless integration	Varied
<i>Scalability...</i>	Flexible	Dependent on Setup
<i>Community Support...</i>	Large	Active
<i>Maintenance and Updates...</i>	Regular	Community-driven
<i>Features and Functionality.....</i>	Rich	Diverse
<i>Licensing and Legal Issues...</i>	Proprietary	Open-source
<i>Industry Adoption...</i>	Wide	Growing

Source: GISKernel Technologies Pvt Ltd (2023)

ArcGIS Enterprise serves as the core GIS software, facilitating mapping, analytics, and data management for Esri's suite and custom applications (ESRI, 2023b). On the other hand, AGOL has some important advantages over the ArcGIS Enterprise: individuals can create maps and applications utilizing the high-performance and scalable features integrated within the universally accessible ArcGIS Online platform, which also undergoes automatic updates, eliminating the need for organizations to schedule downtime for upgrades (ESRI, 2023a).

Table 4-2: Differences between AGOL and ArcGIS Enterprise.

Features, Capabilities	ArcGIS Online	ArcGIS Enterprise
Is SaaS	✓	
Is software		✓
Gets updated automatically	✓	
Can be installed on chosen infrastructure		✓
Can be behind a firewall		✓
Has a consumption-based pricing model	✓	
Has a core-based pricing model		✓
Can share content within an organization	✓	✓
Can share content with another authorized organization	✓	✓
Can share content with the public	✓	✓
Integrates with all other Esri software and apps	✓	✓
Enables Esri-managed, hosted services	✓	✓
Enables user-managed, referenced services		✓
Has advanced server roles with special capabilities		✓
Allows for management of users, groups	✓	✓
Can visualize and analyze data	✓	✓
Can create custom web apps	✓	✓

Source: ESRI (2023a)

Other important feature that was considered while selecting ArcGIS Online is its capability to run on any device connected to internet, regardless the hardware specifications (ESRI Bangladesh, 2024). It is for this reason that a username was acquired from the National Land Authority’s AGOL organizational account and used to develop our application. Other differences between AGOL and ArcGIS Enterprise are indicated in table 4-2 above. ArcGIS Online (AGOL) is a Software As a Service (SaaS), a complete, cloud-based solution, offering smart, data-driven styles and intuitive analysis tools that deliver location intelligence and the ability to make maps and apps to share the insights with an organization or the public (Szukalski, 2024).

4.4.2 Hardware:

While AGOL runs on any device with an internet connection (ESRI Bangladesh, 2024), ArcGIS Enterprise requires 12 GB of free disk space on the system drive for files staging and log files writing, plus 30 GB+ of free disk space on the installation drive, and 60 GB or more on each machine in the deployment for the production system (ESRI, 2024).

4.5 Application development

In total, three components, namely data collection application, case analysis application and data visualization application, were developed to respond to the needs of users' categories following the figure 4-2.

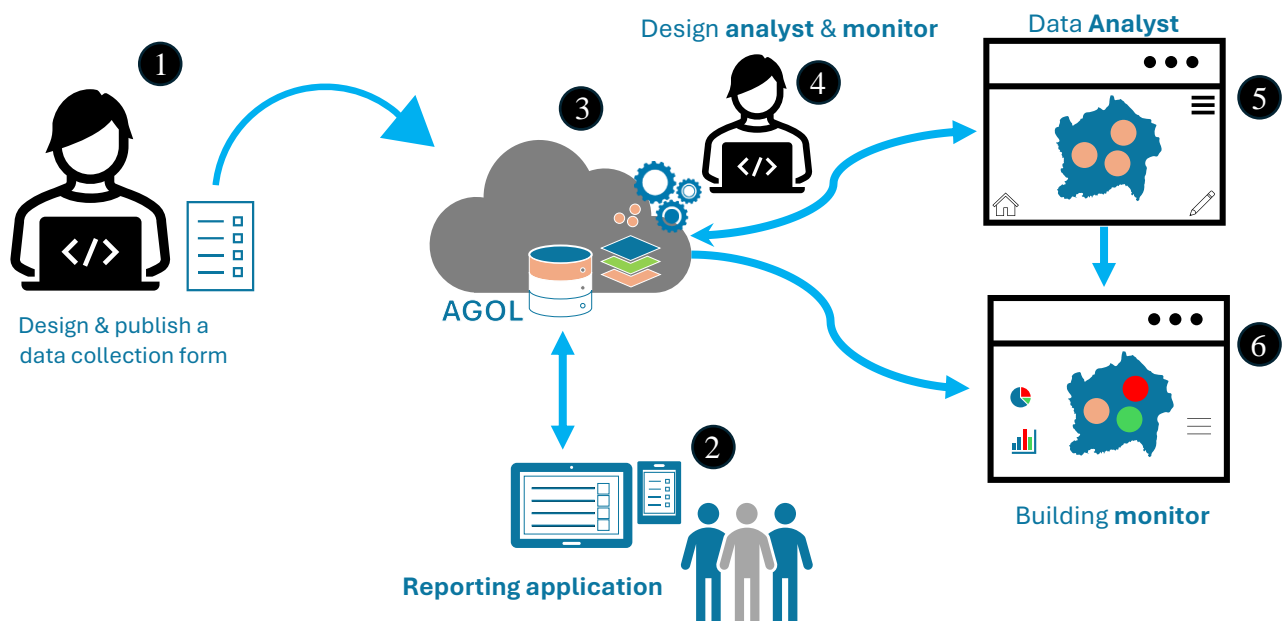


Figure 4-2: Application development: steps and components

Source: adapted from <https://www.blog.esri.com/simplify-your-data-collection-efforts-with-arcgis-survey-123/>

(1) Design and publish a data collection form: This step was completed on desktop using Survey123 Connect (section 4.4.1).

(2) Reporting application: Once the data collection form was published, it became our Reporting application, accessible through a web browser and compatible with mobile devices (section 4.4.1).

(3) AGOL: ArcGIS Online, a Software As a Service (SaaS), a complete, cloud-based solution, with analysis tools that deliver location intelligence. All our files are hosted on NLA’s AGOL (section 4.3.1).

(4) & (5) Design analyst & monitor: Within AGOL, Case analyst application and Building monitor were developed through easy and user-friendly steps without necessity of coding (section 4.4.2 & 4.4.3).

The data collection form which was designed within Survey123 Connect was published to ArcGIS Online (AGOL). When the data collection form was published, it came with a form, and two hosted layers: “reference”, and “results” layers. The form is accessed by reporters through their mobile devices connected to the internet. The data they collect feed both reference and results layers. The results layer is used to design “Case analyst” and “Building monitor” applications. The steps taken to build all the components described above are indicated in the following sections.

4.5.1 The Reporting Application

The reporting application interface, “Reporter”, was designed to be as simple as possible (see figure 4-3), to allow quick and anonymous reporting. This application is based on ArcGIS Survey123 Connect, with only two entries visible: Location (Mandatory), and a photo (optional) and accessible from the following link: <https://arcg.is/01L4TT1>. The location of the reporter was set to be the same location as the reported cases, to avoid the need for map reading skills. This makes the application open to non-GIS people. Reporting is always done on the field, through a GPS-enabled device. With only two entries, this application can be used by anyone with a smartphone, with or without knowledge in map reading. In our case, any citizen can report illegal construction activities. In addition, a user-friendly guide was designed to provide comprehensive instructions for users, facilitating seamless navigation and utilization of the application.

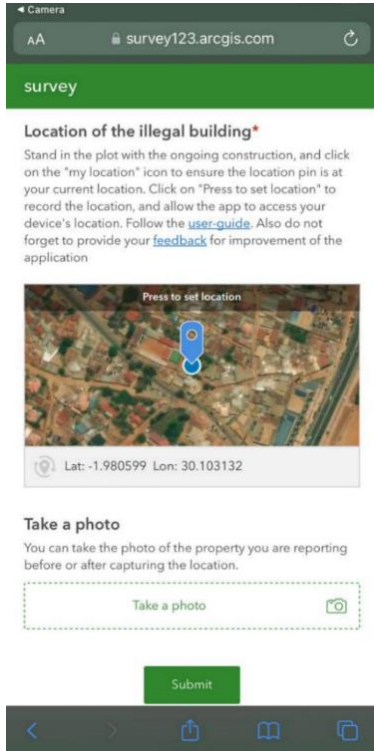


Figure 4-3: Screenshot of the Reporter's interface

The data collection application includes questions detailed in table 4-3, most of which are not visible to the reporter. Once the form is published, it generates two primary hosted layers: the reference layer and results layer. The latter is used to develop a web map and the dashboard (section 4.4.3).

Table 4-3: Screenshot of the reporting application questions lists within Survey123 Connect

type	name	label
geopoint	location	Location of the illegal building
hidden	x	Longitude
hidden	y	Latitude
hidden	village_url	Village Layer
hidden	json_villages	JSON
note	province_name	Province
note	district_name	District
note	sector_name	Sector
note	cell_name	Cell
text	village_name	Village
text	zone_info	Zoning
text	permit	Permitting
image	photo	Take a photo

The Reporting application collects 8 important entries (see table 4-3 above) as follows:

1. **location** and **x & y**: “location” (geopint), collects a single GPS coordinate of the location where the reporter is standing, while x&y (hidden) visually provides the Latitude and Longitude which was set to be used to allow navigation through Google Street View.
2. The first two (village_url and json_village) introduce the village layer link which was used by the other 5 to extract the administrative information using `pulldata("@layer","getRecordAt"...) and pulldata("@json"...) syntaxes.`
3. The first of this group provides zoning information from Kigali Master Plan layer, while the second provides information on permitting status. They both use `pulldata("@layer","getValueAt"...) syntaxes.`
4. Provides capability to capture an image of the reported house using the device’s camera.

4.5.2 Case Analyst Application

The Case Analyst Application allows officials to assess cases against BPMIS and zoning layers in a layered environment and to make necessary edits which directly feed into the dashboard enabling authorities to initiate enforcement actions promptly. This application is available at <https://arcg.is/Of8PTG>.



Figure 4-4: Screenshot of the Case Analysis interface

The needed functionalities of the Case analyst application were added through *ArcGIS Web AppBuilder*, which is a user-friendly, what-you-see-is-what-you-get (WYSIWYG) tool enabling the creation of web applications without coding (Coughlin, 2022). Through the popups, we have added the possibility for the users to navigate to the location of a reported case through Google Street View. This gives an idea of what the area looks like, especially in case reporters did not capture photos.

The following Arcade expression which serves to link to Google Street View images from points features in ArcGIS Online (Harvard University, 2024) was used on the cases popups:

```
5. var PointGeometry = Geometry($feature);
6. var ArcadeX = PointGeometry.x;
7. var ArcadeY = PointGeometry.y;
8. var ArcadeSr = PointGeometry.spatialReference.wkid;
9. var Latitude, Longitude;
10. function AuxSphereToLatLon(x, y)
11. { Console ("Converting...");
12. //Converting Mercator sphere coordinDRates to latitude and longitude:
13. var rMajor = 6378137;
14. var shift = PI * rMajor;
15. Longitude = x / shift * 180.0;
16. Latitude = y / shift * 180.0;
17. Latitude = 180 / PI * (2 * Atan(Exp(Latitude * PI / 180.0)) - PI / 2.0);
18. }
19. if (ArcadeSr == 4326) { Console("4326 Spatial Reference - No Conversion
    Necessary"); Latitude = ArcadeY; Longitude = ArcadeX; else if (ArcadeSr == 102100)
    { Console("102100 Spatial Reference - Conversion Necessary");
    AuxSphereToLatLon(ArcadeX, ArcadeY);}else { Console(ArcadeSr + " Spatial
    Reference is not supported - currently works with Web Maps where the basemap is in
    WGS84 (4326) or Web Mercator Auxiliary Sphere 102100");}
20. var url = "http://www.google.com/maps/@?api=1&map_action=pano&viewpoint=" +
    text(Latitude) + "," + text(Longitude);
21. return url;
22. var PointGeometry = Geometry($feature);
23. var ArcadeX = PointGeometry.x;
24. var ArcadeY = PointGeometry.y;
25. var ArcadeSr = PointGeometry.spatialReference.wkid;
26. var Latitude, Longitude;
27. function AuxSphereToLatLon(x, y)
28. { Console ("Converting...");
29. //Converting Mercator sphere coordinDRates to latitude and longitude:
30. var rMajor = 6378137;
31. var shift = PI * rMajor;
32. Longitude = x / shift * 180.0;
```

```

33. Latitude = y / shift * 180.0;
34. Latitude = 180 / PI * (2 * Atan(Exp(Latitude * PI / 180.0)) - PI / 2.0);
35. }
36. if (ArcadeSr == 4326) { Console("4326 Spatial Reference - No Conversion
    Necessary"); Latitude = ArcadeY; Longitude = ArcadeX; else if (ArcadeSr == 102100)
    { Console("102100 Spatial Reference - Conversion Necessary");
    AuxSphereToLatLon(ArcadeX, ArcadeY);}else { Console(ArcadeSr + " Spatial
    Reference is not supported - currently works with Web Maps where the basemap is in
    WGS84 (4326) or Web Mercator Auxiliary Sphere 102100");}
37. var url = "http://www.google.com/maps/@?api=1&map_action=pano&viewpoint=" +
    text(Latitude) + "," + text(Longitude);
38. return url;

```

Adding functionalities: Needed functionalities were added through “Widgets”. Legend, layer list, edit, filter, zoom slider, home, search, basemap and info widgets were used (see figure 4-5).

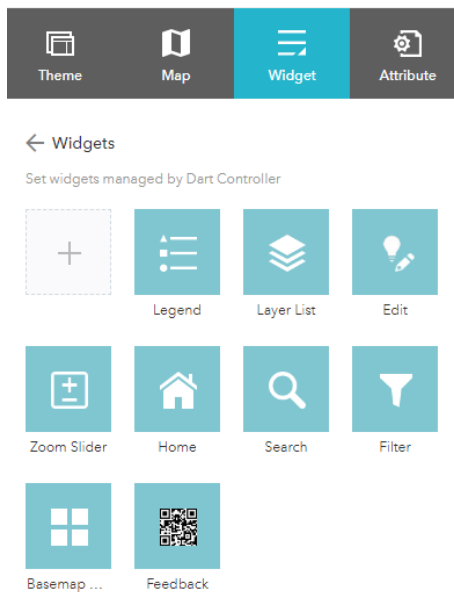


Figure 4-5: Screenshot of the list of selected widgets

4.5.3 The Building Monitor

The Building Monitor offers insights into reported cases, providing real-time data on the total number of reported cases, with updates on confirmed violations and actions taken. By aggregating information from the case analyst app, the building monitor facilitates informed decision-making and prioritization of enforcement efforts. The dashboard is accessible from the following link: <https://t.ly/xZ98v>.

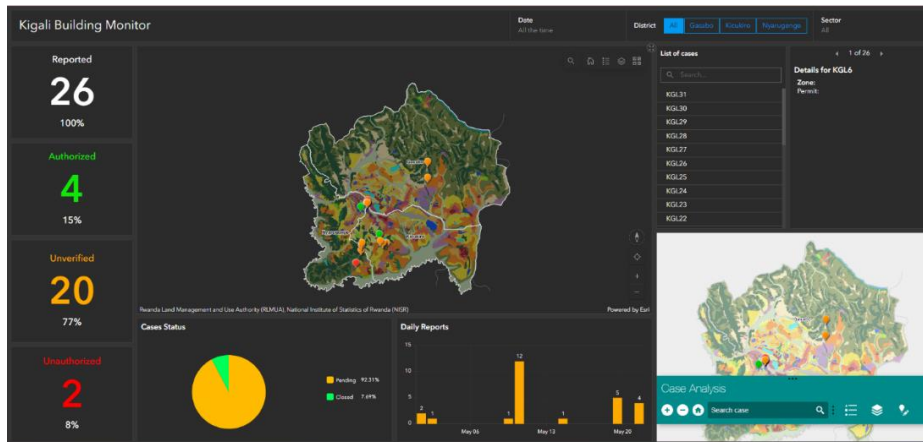


Figure 4-6: Screenshot of the Building Monitor interface.

This application provides insights into the reported cases, including the total number of reported cases, the conclusion (whether the reported case was confirmed as illegal or not), action taken and the status. The dashboard will inform the managers of the cases' status through graphs, numbers, interactive map and other elements, providing a clear insight in a friendly way. While designing a dashboard is a drag-and-drop process, the dashboard also offers possibilities for advanced configurations by incorporating Arcade expressions especially on lists, tables and indicators.

The following is a modified expression by Acunto (2024), which was used on the list to highlight cases that are collected on the day the dashboard is being viewed (`CreationDate<=Today()`), to ensure they are given due attention:

```

var color = []
var emoji=When($datapoint.CreationDate<=Today(),':warning:', '')
if($datapoint.CreationDate >=Today()){
  color= "#FF0000"
} else {
  color=""
}
return {
  //textColor:",
  eicon:emoji,
  backgroundColor: color,
}

```

The records fulfilling the `CreationDate<=Today()` will be highlighted in red colour.

4.6 Application evaluation

The link to Reporter was shared to various testers who used it to capture some cases, to prove the app was working and assess its accuracy. Through the Survey123 Website, reported cases can be visualized in many formats, such as table (figure 4-7), shapefile, CSV, or a pdf. Report.

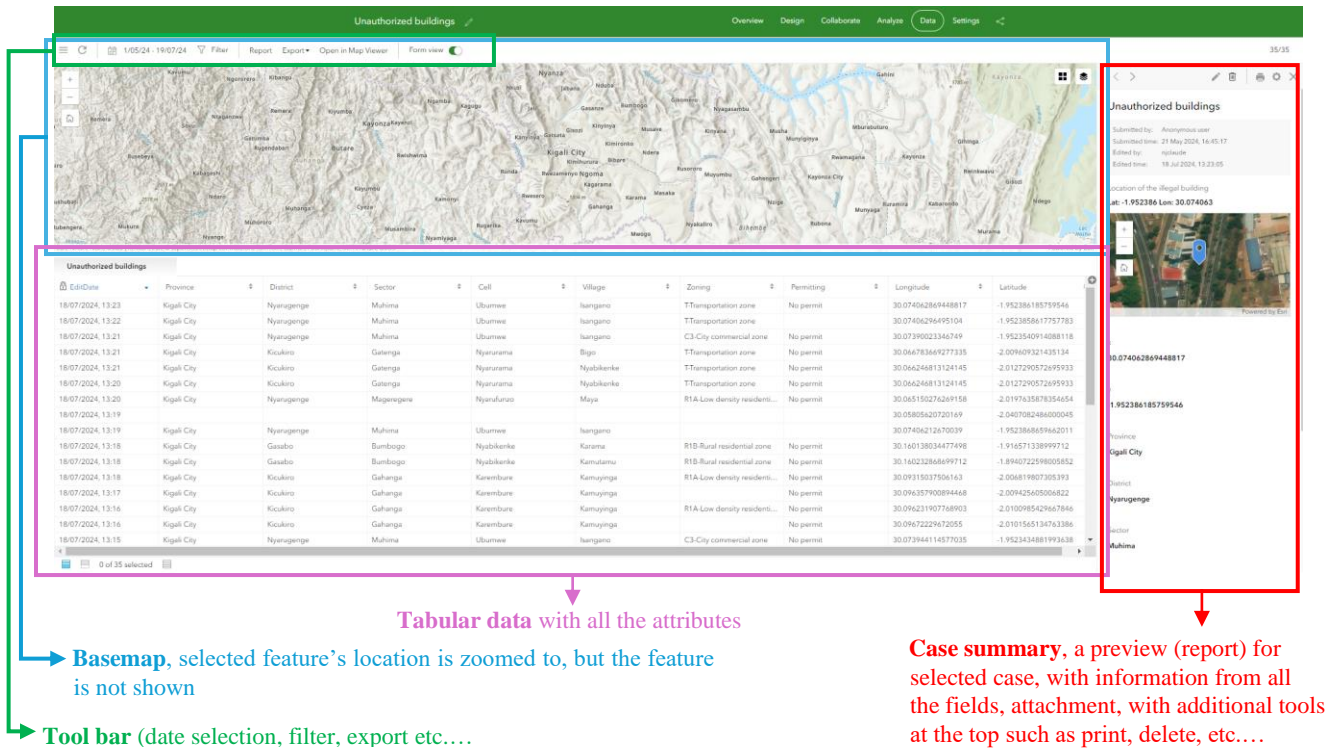


Figure 4-7: Test data

The reported cases can be viewed on map viewer in AGOL as indicated on figure 4-8 below.

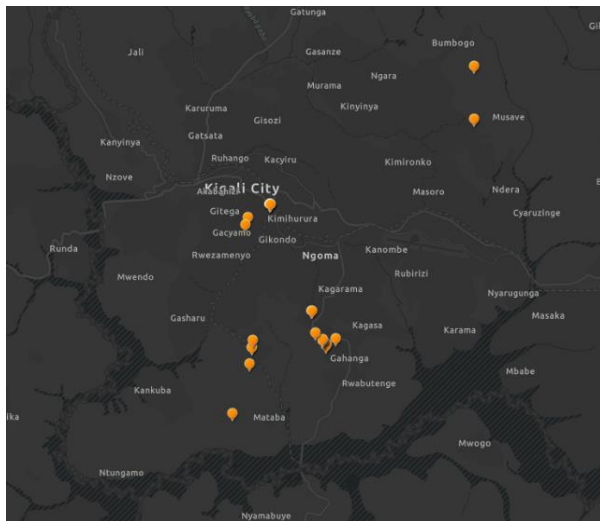


Figure 4-8: Screenshot of the reported cases

Below is a sample report for one reported case that was printed to PDF from Survey123 Website.

Unauthorized buildings
Submitted by: Anonymous user
Submitted time: 19 May 2024, 12:11:40

Location of the illegal building
Lat: -2.019764 Lon: 30.06615



x
30.066150276269158

y
-2.0197635878354654

Province
Kigali City

District
Nyarugenge

Sector
Magerogere

Cell
Nyarufunzo

Village
Maya

Zoning
R1A-Low density residential densification zone

Permitting
No permit

Figure 4-9: Report for one case

The evaluation process included iterative feedback from testers, ensuring the application's effectiveness, accuracy, and reliability in real-world scenarios. Approximately 30 tests have been conducted so far. It was observed that following the user guide (Appendix 1) ensures data capture within the relevant parcel, aiding analysts in identifying affected parcels. Instances where reports were mistakenly logged on roads were corrected (figure 4-10) using the Edit widget within the Case Analyst application. The filter widget facilitated easy identification of cases reported on the road.

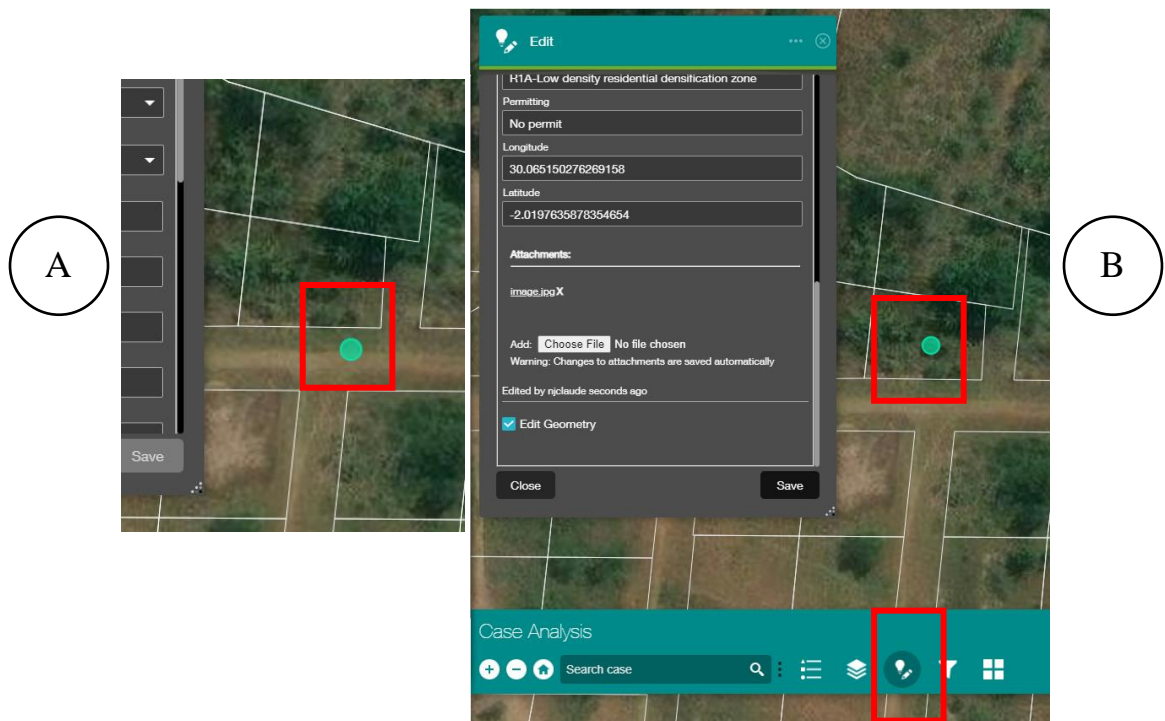


Figure 4-10: Editing the location of the reported case using Edit widget

We have used the edit widget to move the reported case from location A to location B, but for the attributes, we use Survey123 form that was used by the reporter. This helps to reduce any potential typing error. The form must be added to the dashboard as embedded element and connected to the cases list through filter action using GlobalID as common field.

Important observations:

- Taking photos at construction sites with people present can lead to inquiries from supervisors, compromising anonymity. Solutions include taking distant shots or omitting photos and focusing on location.
- Report submission failures often stem from large photo sizes. If an issue occurs, delete and retake the photo. Long-distance photos are larger than close-ups.
- Photos can be captured either before or after location data is recorded.
- To minimize location errors at fenced construction sites, get as close as possible. Zoning may initially show as "transportation," requiring correction by office analysts.

4.7 Proposed users

As shown in figure 4-11 below, Reporters (1) use mobile devices with internet access to submit cases, which are stored on Kigali City's AGOL (2) and routed to specific districts via the Case Analyst application (3). GIS personnel (4) log in to review these reports against existing layers like the Kigali Master Plan, Parcels, BPMIS, and administrative boundaries, and make necessary updates. Inspectors (5), after logging in, access cases within their jurisdiction for analysis and field verification, then report back to the Case Analyst Application. All edits are automatically compiled into a single layer used by the public dashboard (6).

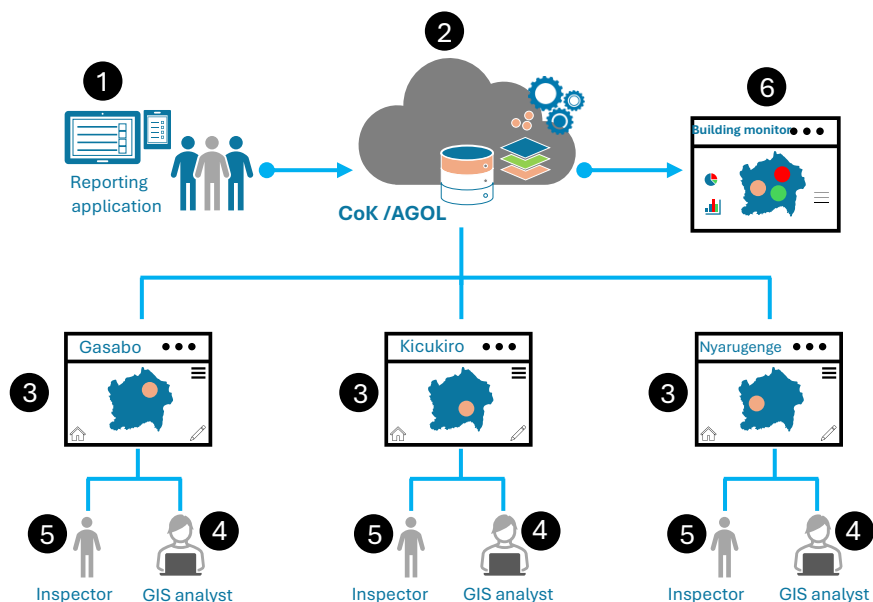


Figure 4-11: Suggested users of the applications

4.8 Implementability analysis

The proposed application designed to support compliance with zoning regulations in Kigali City is technically feasible, leveraging the existing capabilities of ArcGIS Online and the presence of GIS personnel across both the City of Kigali and its districts. This foundation ensures compatibility with current infrastructure and technical resources, minimizing the requirement for substantial new investments in personnel, software, or hardware.

Operational considerations and training needs:

Resource requirements primarily focus on ensuring adequate bandwidth and connectivity for seamless data submission and real-time monitoring. While both the City of Kigali and districts already possess GIS staff and inspectors, additional operational considerations include continuous training to enhance proficiency with the application's features.

Integration and framework alignment:

Operationally, the application aligns well with existing administrative frameworks and institutional structures within Kigali City. Integration with critical datasets like the Kigali Master Plan and BPMIS through APIs enhances data accuracy, despite potential challenges related to data availability and technological constraints that may require continuous support and troubleshooting.

Deployment timeline, cost implications and sustainability:

Given the use of established technology platforms and existing operational frameworks, the application can be deployed promptly. Continuous support and maintenance will be essential to address any unforeseen technical issues and to adapt the application to evolving regulatory requirements or technological advancements. This framework should accommodate regular updates, user feedback, and enhancements based on field testing outcomes and operational experience. Cost implications are expected to be moderate, primarily involving operational expenses such as API integration maintenance and periodic training sessions for new users or on new updates. The presence of existing infrastructure and skilled GIS personnel within Kigali City and its districts mitigates the need for significant investments in new hardware or software licenses, ensuring sustainability over the application's lifecycle.

4.9 Comparison with Global Geospatial Solutions

Our geospatial tool is a set of three applications, and report on a single category (land use), while the Haysville model which inspired our choice put together all needed interfaces, and accommodate for many categories namely Animal Problems, Code Enforcement Violations, Park/Tree Problems, Zoning Violations, Street Problems, and Sewer/Stormwater/Water Problems. As indicated in table 4-4 below, our Reporter’s interface simplifies reporting with only two straightforward entries, eliminating the need for manual typing. The integration with important layers is done in the background (figure 4-13) without the need for displaying any of them to users.

Table 4-4: Comparison between Kigali City’s tool and Haysville model

Characteristics	Citizens-centric	Web browser	Geospatial technology	Total anonymity	Number of questions	Mandatory entries
Haysville Citizen Problem Reporter	Yes	Yes	Low-Code/No-Code	Yes	7	1
Kigali City Model	Yes	Yes	Low-Code/No-Code	Yes	2	1

Source: (City of Haysville, 2024)

4.10 Integration with Existing data systems

Integration of the reported cases with other data is done in two places as indicated in figure 4-12:

- ✓ Within the data collection application through “pulldata”, “getRecordAt” & “getValueAt” syntaxes, where the form is prefilled with information from Kigali City Administrative boundaries, Kigali City Master Plan and Kigali BPMIS data (Permitted Parcels) depending on the location of the reporter [steps (1), (2), (3), (4), (5), (6) & (7)].
- ✓ Within the layered environment (web map) where the popups show information from Kigali City Administrative boundaries, Kigali Parcels, Kigali City Master Plan and Kigali BPMIS data (Permitted Parcels) depending on the clicked feature [steps (1), (2), (3), (4), (5), & (7)].

Note that in both places, the layers are not hosted on the same AGOL as the application since the data are consumed through the links (services). These layers come from systems like the Kigali City Zoning Plan from Kigali City ArcGIS Enterprise, Kigali Parcels from LAIS through NSDI portal, and the Kigali BPMIS layer (Permitted Parcels) from BPMIS API through the NSDI portal.

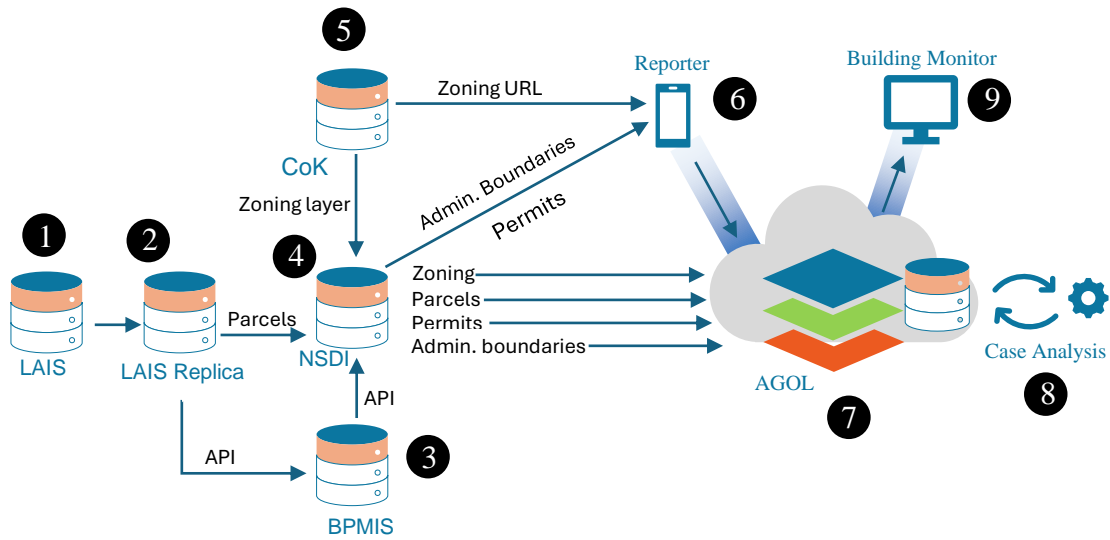


Figure 4-12: Integration of the reported cases with other data

4.11 Challenges and Limitations

The development of the application encountered various challenges particularly concerning BPMIS data availability. The absence of a current publicly available API for BPMIS (which is currently being revamped), necessitated the use of an older version of the BPMIS data available from NSDI Hub. Another limitation is on the used syntaxes (see section 4.4.1) which consider only the point corresponding to the reporter location. In the case indicated in figure 4-13 below, the syntaxes will record that the house is being built within residential zone, while it is also being built within commercial zone. This is complemented by the integration within layered environment (section 4.3).

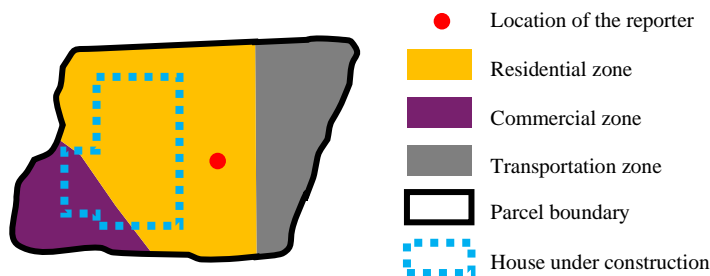


Figure 4-13: Illustration of a house being constructed within multiple zones

Other foreseeable challenges include potential data quality limitations due to weather during reporting. Addressing these requires leveraging solutions like Continuously Operating Reference Stations (CORS) to enhance accuracy.

5 CONCLUSION AND RECOMMENDATIONS

The application developed to support compliance with zoning regulations in Kigali City addresses critical urban challenges exacerbated by rapid urbanization and outdated planning frameworks. Urbanization pressures, including housing deficits, sprawl, and informal settlements, hinder sustainable development goals such as affordable housing and infrastructure access. In Kigali, these challenges are compounded by historical planning inefficiencies and inadequate monitoring systems, allowing unchecked urban growth and illegal developments.

The application integrates advanced geospatial technologies to enhance zoning regulation monitoring and enforcement, focusing on GIS and near-real-time monitoring capabilities rather than relying on remote sensing or expensive and untimely high-resolution satellite imagery. By leveraging GIS technologies, we aim to improve upon current manual inspection methods, ensuring more accurate compliance assessments and timely interventions.

This initiative aligns with Rwanda's broader goals of efficient land use and sustainable urban growth, establishing a robust framework for spatial data integration and analysis crucial for informed decision-making and effective urban management. The literature review underscores the pivotal role of geospatial tools in zoning compliance, particularly through citizen participation facilitated by GIS-based applications like ArcGIS Citizen Problem Reporter in municipalities such as Haysville and DuPage County. These tools empower residents, streamline identification and resolution of non-compliance, and enhance transparency and accountability in urban governance.

Unlike applications reliant on satellite imagery, the approach envisioned here offers scalable solutions adaptable to various urban contexts. By integrating these technologies, cities like Kigali can overcome limitations of traditional enforcement methods, effectively managing urban growth while ensuring zoning compliance. Methodologically, focusing on Kigali City as a critical study area due to its economic significance and rapid urbanization, the research adopts a structured approach divided into four phases. Leveraging ArcGIS WebGIS technology—specifically ArcGIS Online robust handling of user submissions within existing institutional frameworks like the City of Kigali and the National Land Authority.

The development aligns with the low-code/no-code approach, centered on leveraging ArcGIS Online's capabilities to build tailored applications for data collection, analysis, and visualization. This approach ensures usability and accessibility across devices, supported by open datasets and interactive maps that enable stakeholders to monitor and analyze urban development patterns effectively. The developed application comprises three components, namely the user-friendly Reporting Application ("Reporter"), Case Analyst, and Building Monitor, and together they facilitate efficient reporting, assessment, editing, and real-time insights into zoning violations.

Testing and validation involved field works and user feedback to enhance application accuracy, revealing challenges like photo capture for fenced private properties, and sometimes issues with data submission failures due to weak network in some areas. Integration with Kigali City Master Plan and BPMIS through APIs enhances data accuracy and applicability, despite ongoing challenges in data availability and technological constraints. Overall, while this application can help in addressing specific urban challenges in Kigali, continuous improvement and collaborative efforts are necessary.

While our thesis focused on zoning regulations, future scalability offers opportunities for broader impact and collaboration in land use planning initiatives, paving the way for sustainable development.

- The solution is scalable for nationwide implementation without requiring extensive modifications. It allows flexibility to expand data categories, such as reporting water leakages, road accidents, family violence, potholes, illegal dumping, and noise pollution.
- Educating the public through workshops, distribution of informational materials, and leveraging social media can boost adoption rates and enhance effectiveness.
- Establishing continuous monitoring and evaluation mechanisms will enable ongoing assessment and refinement of the application's performance.
- Opening the Building Monitor to the public for follow-ups on reported cases could enhance transparency and community engagement in urban development.
- Integration with the City of Kigali's planned satellite-based solution ensures timely tracking of illegal constructions.

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Appendix 1-User Guide

Geospatial Application for Zoning Compliance Monitoring in Kigali City

Reporter - User Guide

1. Introduction

Welcome to the Geospatial Application for Monitoring Compliance with Zoning Regulations in Kigali City! This user guide is designed to help you navigate and utilize the features of the Reporter application effectively. The Reporter application aims to empower citizens, inspectors, and city officials to report and address violations of zoning regulations in Kigali City.

2. Getting Started

System Requirements:

- Recommended devices: Smartphones, or tablets.
- Internet connectivity: Access to a stable internet connection is required.

Accessing the Application:

- Access the application through the following link:
<https://survey123.arcgis.com/share/2cc94d57fe934e0f90da342cc94d504e>
- Simply copy this link and paste it into the browser of your choice to get started.
- Alternatively, you can access the application by scanning the QR Code provided below:



- Simply open your device's camera, point it at the QR Code, and tap on the link that appears to launch the application

This application utilizes the GPS functionality of your device to accurately pinpoint locations. Upon the application launch, you will be prompted to grant permission for the application to access and utilize your device's location services. We kindly request that you accept this permission to ensure optimal functionality and accurate reporting.

3. Reporting Violations (Reporter Application)

Overview:

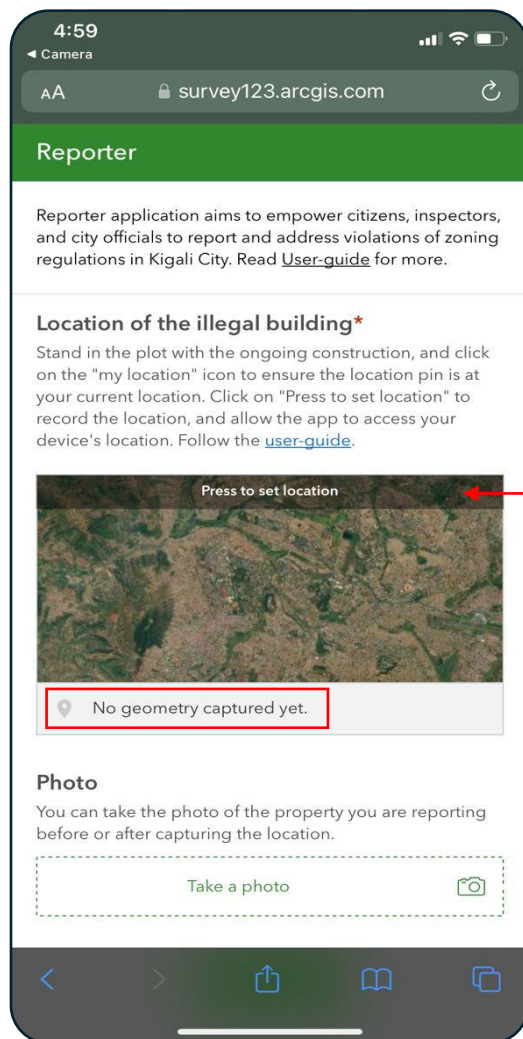
The Reporter application allows users to anonymously report violations of zoning regulations in Kigali City.

3.1 Location Tagging

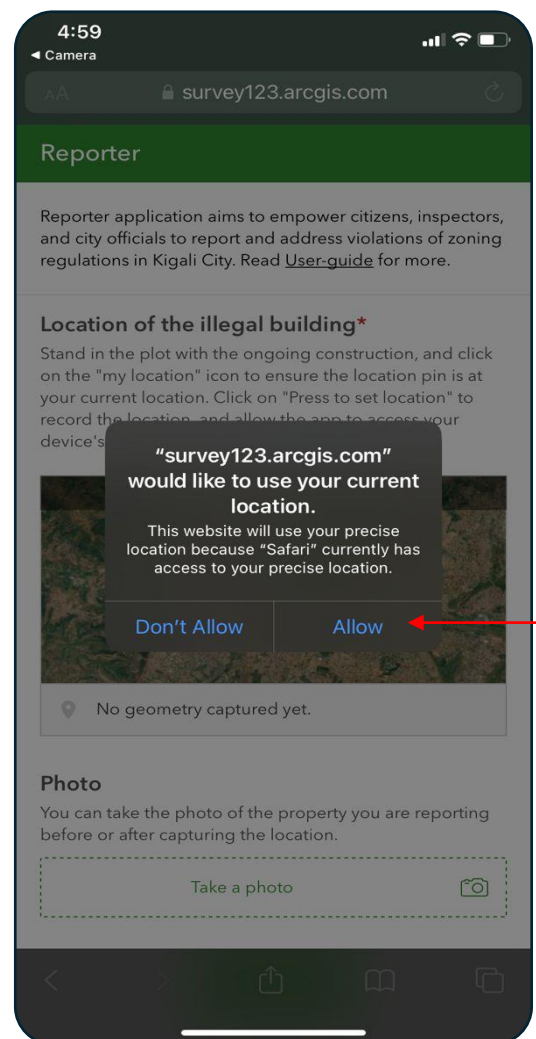
The first “question” comes with a map, and this is where the reporting person will record the location of a suspected illegal construction. When the application is opened, you can read at the bottom of the map near the pin, “No geometry captured yet”.

- a) Stand within the plot, near the building (or land depending on the construction progress) that you want to report and click on the map where it says “Press to set location” to record the location.
- b) Click on “Allow”

Note that (b) may appear before (a) depending on the device’s settings.




a



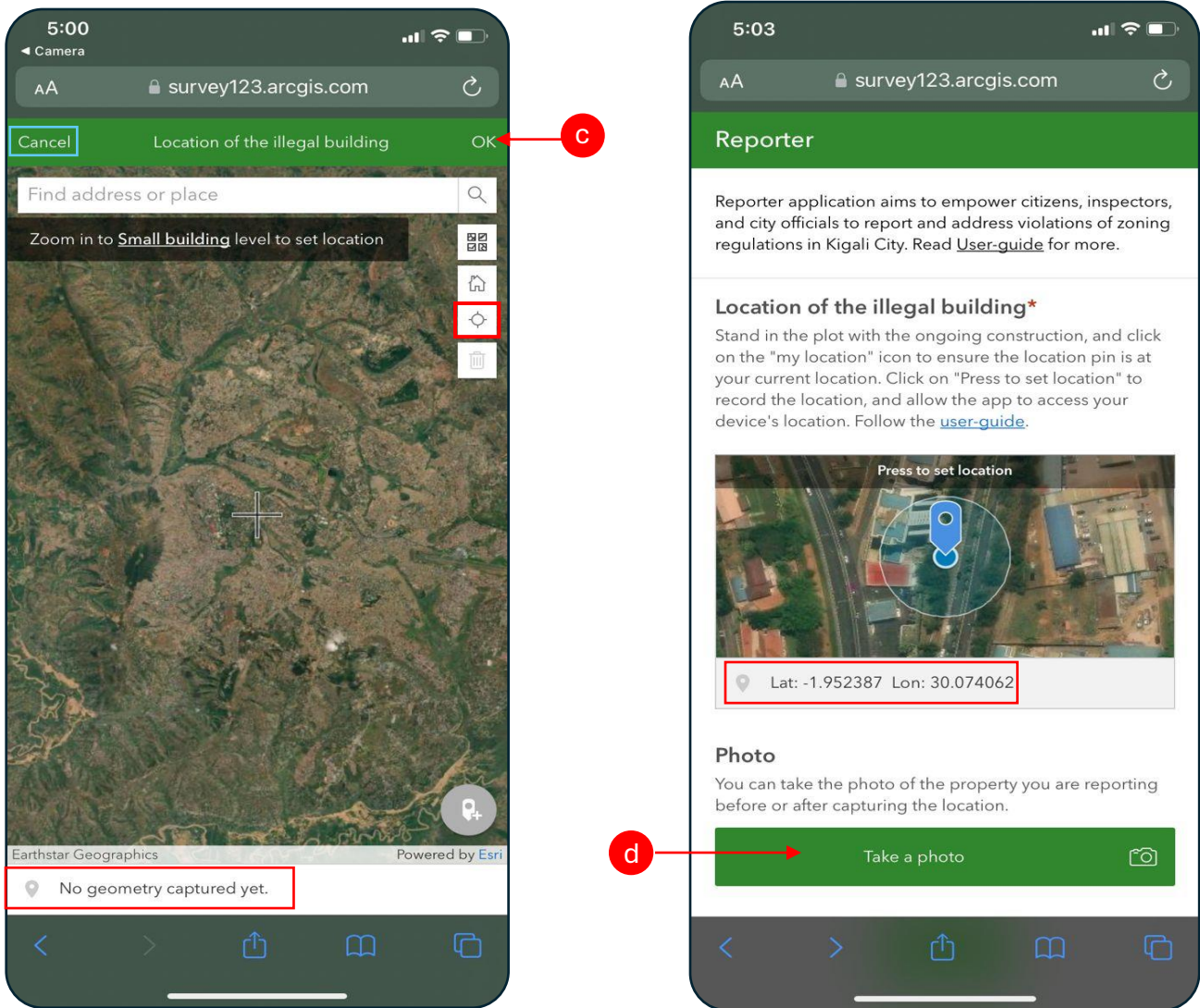
b

A blue pin and a blue dot will appear on the map. These two symbols represent your location, which must coincide to the location of the building (or land depending on the construction progress) that you are reporting.

Click on “my location” icon  to ensure the GPS pin is at your current location.

c) Click “Ok” to confirm the location.

NB: You can click “Cancel” and move to a different location if you want to.



You have now captured the location of the house (or land depending on the construction progress) that you want to report. You can click on “Submit” to report the case, but we recommend adding an image (step “d”) as explained below, if the device you are using has a camera.

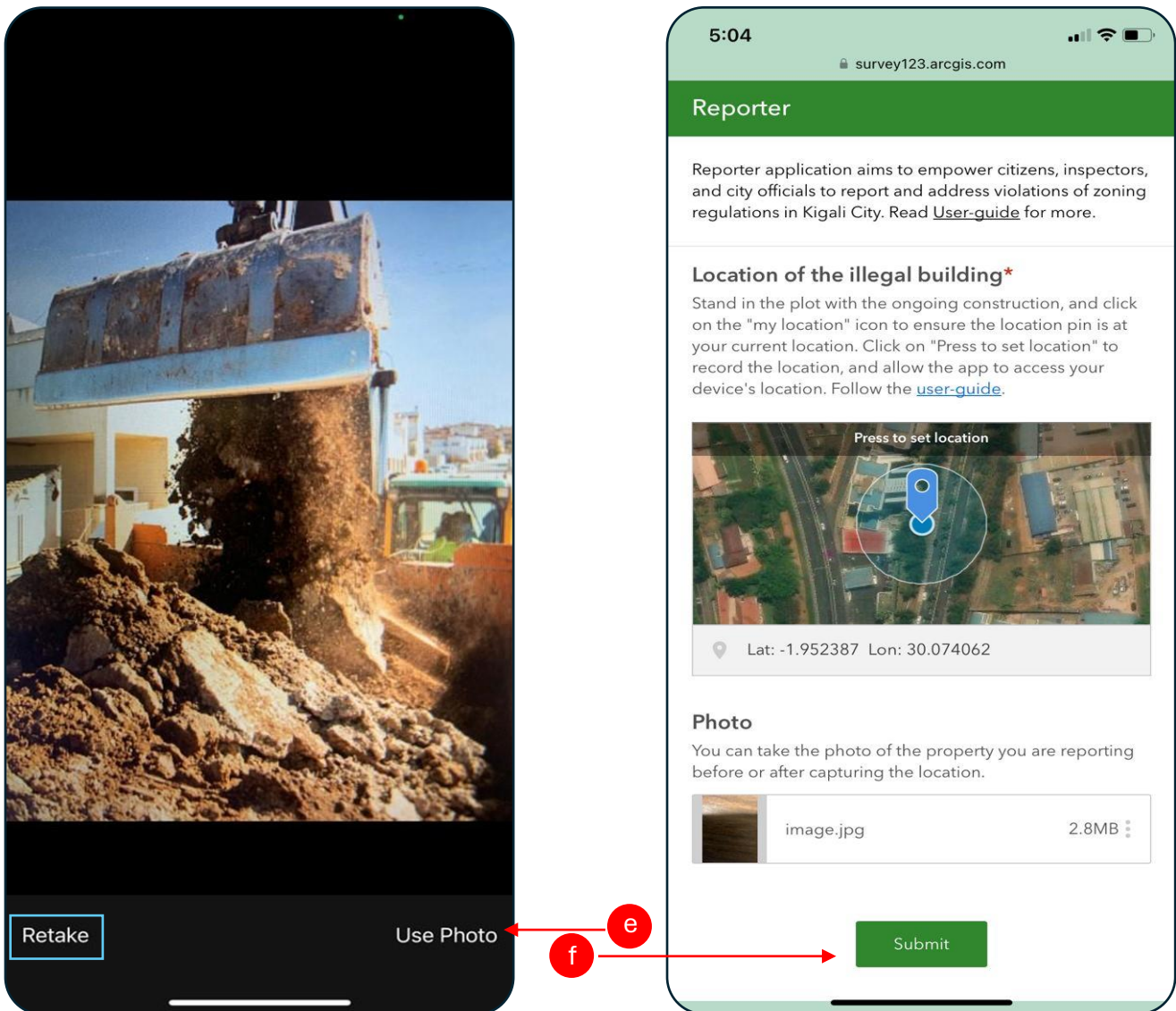
3.2 Capturing a Photo (Optional):

In the next step, you will add a photo of the house (or land depending on the construction progress) that you are about to report, to provide visual evidence of the violation.

d) Click on “*Take a photo*” button.

A camera app of your device will open. Point it to the targeted house (or land depending on the construction progress), and capture.

e) If you are happy with the photo that you have just taken, click on “*Use Photo*”. Otherwise, click on “*Retake*” to try a different view.



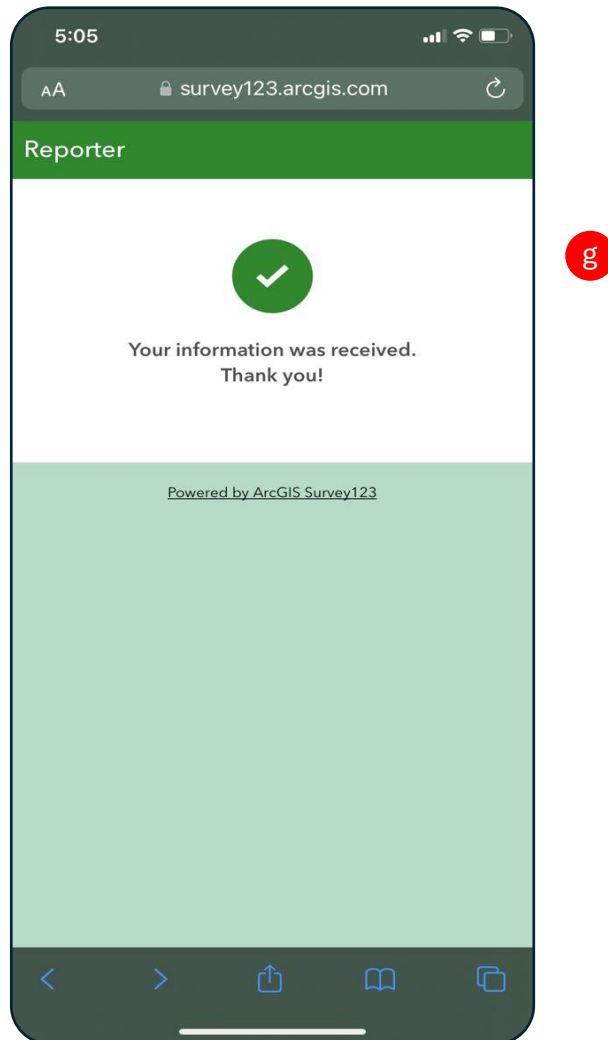
You have now captured all the information.

3.3 Submitting

f) Click on “*Submit*” to send your information.

The application will send the location of the case you are reporting and upload the corresponding photo.

g) When your information is successfully sent, you will receive a confirmation.



Anonymity and Privacy

Your privacy is paramount to us. You submit reports anonymously, without the need for signing in or providing any contact information. We guarantee that no identity will be stored or utilized, ensuring complete confidentiality and security.

Appendix 2-Comparison between Survey123 with other ESRI's field applications

	Survey123	Field Maps	QuickCapture
Type of data collection	Form based	Map-focused	Rapid, one-button data collection.
Authoring			
Authoring experience	Simple drag and drop website to create forms, or using ArcGIS Survey123 Connect for more complex authoring	Simple	Simple
Data Collection			
Anonymous data collection	Yes	No	Limited
Requires app installation for collection	No, it can use browser or app	Yes	Yes
Capture user-entered information	Yes	Yes	Limited
Capture multiple features simultaneously	No	No	Yes
Capture a line as you walk or drive along it	Yes	Yes	Yes
Offline			
Offline support	Yes	Yes	Yes
Offline basemap	Yes	Yes	Yes
After collection			
Viewing the data	Has integrated analytics and reports. Can also use Map Viewer or other apps.	Use Map Viewer or other apps.	Use Map Viewer or other apps.

Source: Kylie Donia, <https://kyliedonia.github.io/esri-k12/FieldAppsCompareTable.html>

Appendix 3-Interview questions list

CURRENT LAND USE COMPLIANCE MONITORING PRACTICES IN KIGALI CITY

1. Organizational Structure

- Who oversees the inspection activities related to zoning regulations in Kigali City?
- Can you describe the organizational hierarchy and responsibilities within Kigali?

2. Field Inspections

- How are building inspections currently conducted to ensure compliance with zoning regulations?
- What specific areas or sectors within Kigali are prioritized for inspections, and why?
- What tools or methods are currently utilized during land use field inspections (e.g., checklists, digital tools, documentation)?

3. Reporting Illegal Constructions

- What procedures are in place for citizens and stakeholders to report illegal constructions or zoning violations?
- How are reports of illegal constructions processed and escalated within the city administration?
- Are there any existing challenges or limitations in the current reporting process that a GIS based application could potentially address?

4. Operations plan/Schedule

- How is the daily schedule for inspections planned and managed?
- What factors influence the scheduling of inspections?
- How does the current operational plan accommodate flexibility and adaptability in responding to emerging issues or urgent inspections?

5. Technological solutions

- What technologies or software are currently utilized for land use compliance monitoring in Kigali City?
- Are there any specific tools used by the public for filing complaints about illegal constructions?
- Are there any technologies in place that allow the public to access information about land use compliance and inspection results?

Appendix 4- Feedback form

(available at <https://survey123.arcgis.com/share/f7489b15730b4f158836f49da7ee5c33>)

1. Which component are you using? (Please select one) *

- Reporter
 - Case Analyst
 - Building Monitor
-

2. Based on your experience, what advice would you give to someone just starting with this application?

(Open-ended response)

3. Did you encounter any difficulties using the application? (Please select one)*

- Yes
 - No
-

4. What aspects of the application's usability impressed you the most?

(Open-ended response)

5. How easy was it to learn and use the application?

(Please select one)

- Difficult
 - Less difficult
 - Somehow easy
 - Easy
 - Very easy
-

6. Is the interface user-friendly and easy to learn? (Please select one)*

- Yes
 - No
-

7. Are there any essential features missing that you would like to see added? (Open-ended response)*

8. Does the application offer any unique or innovative features that differentiate it from similar applications?

(Open-ended response)

9. What aspects of the application's functionality do you find most valuable?

(Open-ended response)

10. Which institution should be the owner of this application?

(Open-ended response)

11. What factors would most influence your decision to continue using or upgrade the application?

(Open-ended response)

12. What are your main suggestions for improvement in future versions? (Open-ended response)*

13. Does the application produce accurate results? (Please select one)*

- Yes
 - No
-

14. Do you experience any lag or delays while using the application? (Please select one)*

- Yes
 - No
-

15. How often do you encounter crashes, errors, or unexpected behavior?

(Open-ended response)

16. How well does the application perform on your device?

(Open-ended response)