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Development of Spatial Inspection Methods to Support Building Inspections and Compliance

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

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ABSTRACT

The process and efficiency of monitoring building and construction violations is a concern of the construction industry. In Riyadh, the capital city of Saudi Arabia, building inspections result in construction violations when approved building plans are changed and building regulations are disregarded. The detection of violations requires appropriate and sufficiently accurate geospatial information to manage and support a comprehensive inspection process and monitor compliance. A building inspection workflow must extract appropriate spatial and measurement information from a variety of sources, identify potential violations across a range of compliance criteria and determine the quality of the resulting inspection reports. This research presents the spatial methods and spatial information used to support building inspections and to detect construction violations or compliance failures.

Current inspection processes involve issues concerning the identification of building violations, access to building regulations and existing spatial information, integration of a range of spatial and non-spatial information, and the quality of decisions within the inspection workflows. A survey of building inspectors was conducted and used together with these previously identified issues to establish the requirements for a spatial inspection framework. The results demonstrate how such geospatial information can support improved decision-making and reduce fieldwork effort in detecting and measuring the accuracy of building violations involving building placements, street offsets and footprint areas.

Geographic information system tools were used to develop a spatial inspection framework for the building inspection process. This framework was designed to support building inspection in order to manage compliance and facilitate communication between the public and the planning department. The framework includes five main modules: data input, quality assessment, data preparation, violation detection and violation reporting.

This research will enable building inspectors to improve their knowledge of the building inspection task and to become familiar with the spatial inspection methods that can be used to support and enforce building plan compliance with local government regulations. The implementation of the prototype has shown that this building inspection framework is feasible to implement, and that the implementation of geospatial methods remedies a considerable weakness in the current inspection process. The results from this research model demonstrate the capacity of the proposed framework to detect violations and to assess data accuracy from different input sources.

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RELATED PUBLICATIONS

Aboshiqah, S, Veenendaal, B&Corner R. (2013). Towards a spatial framework for supporting building construction inspection. In: Proceedings of The 5th International Conference on Construction Engineering and Project Management, Anaheim, California, pp. 572–580.

Where required, copyright statements for selected publications are included in Appendix G.

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LIST OF ABBREVIATIONS

AB	As Built
ALS	Airborne Laser Scanning
CAD	Computer-Aided Design
CoR	City of Riyadh
CoJ	City of Jeddah
CPIS	Construction Project Information System
DBM	Data Building Model
DEM	Digital Elevation Models
DMI	Digital Measurable Images
DSM	Digital Surface Models
DTM	Data Terrain Model
DWG	Drawing (CAD programs filename extension)
GIS	Geographical Information System
GPS	Global Position System
IS	Informal Settlements
IT	Information Technology
LiDAR	Laser Imaging Detection and Ranging
MIA	Mobile Inspection Assistant
ORR	Object Recognition and Reconstruction
PPE	Project Performance Evaluation
PPMS	Project Performance Monitoring System
QIDMS	Quality Inspection and Defect Management System
SBC	Saudi Building Code
SEBI	Spatially Enabled Building Inspection
SPSS	Statistical Program for Social Sciences
WFoI	Workflow of Inspection
SR	Saudi Riyal

1 INTRODUCTION

Building inspections are important to manage and control during the construction process. The aim of inspection is to achieve the minimum requirements for built environment aspects such as human health and safety. Building inspections requires certain techniques to support the process of inspection and construction monitoring. Spatial information supports building inspection by providing, implementing, analysing and managing the inspection data. This thesis investigates how a Geographic Information System (GIS) supports the inspection process that audits compliance in the Riyadh municipality of Saudi Arabia. The King Fahd district is the study area for this project. This district is located in the north of Riyadh City, within the Al-Olaya sub-municipality, one of the 16 municipalities in the City of Riyadh (CoR). Inspectors in the King Fahd district aim to achieve inspection efficiency on a daily basis, as do all inspectors in the CoR. However, inspectors in Riyadh lack the knowledge to understand the key issues of geospatial inspection methods and are still challenged by the inspection process and the technology required to implement building regulations on construction sites.

1.1 Background

Building control systems are one of the concerns in urban areas and building codes have been implemented in numerous countries around the world, including Australia, New Zealand, Britain, Sweden and the Netherlands. For example, the Australian Federal Government and the State and Territory governments recognise the Building Code created by the Australian Building Code Board. The goals of the Australian Building Code are to achieve a minimum and acceptable standard of structural sufficiency, safety and health (Australian Building Codes Board 2013). As another example, in Germany local building control is self-monitored, and imposes limits of a maximum floor area of 200m^2 and a maximum height of one storey on residential buildings (Viscera and Meijer 2005b).

The construction industry needs to achieve minimum standards for the design and implementation of local government regulations (Tricker, Alford, and Algar 2012). This research will therefore develop a geospatial inspection-enabled method that will consider the different local government regulations pertaining to building inspections (Heijden 2007). It will also enable finding the links and facilitating the integration of the multiple stages of the inspection process, in order to extend the use of GIS techniques to municipalities (Hockey 2007). Building inspection is one of the important sectors within urban environments in various municipalities around the world (Masser and Ottens 1999). Geospatial-enabled methods improve the inspection environment and provide the required data for inspection (Huxhold, Fowler, and Parr 2004).

There are many challenges facing the inspection process. One of these is to handle the massive amounts of inspection data (Cox, Perdomo, and Thabet 2002a). The biggest challenge facing advocates of GIS is promoting its use in public and private sector organisations and within local governments (Krouk, Pitkin, and Richman 2000). The benefits of GIS include efficiency, economy and accuracy through automation, sharing of information and reduction of redundant datasets by creating an information base (Goodchild 1992). However, in the Riyadh municipality, obstacles that face the implementation of geospatial methods include the lack of technological development and the lack of understanding of the potential contributions of GIS.

Saudi Arabia has witnessed rapid and large-scale growth in the construction of various types of buildings. Riyadh's population has increased from 300,000 inhabitants in 1968 to 1.4 million in 1987, a growth rate of about 19% annually (Mubarak 2004). After 1987 this rate dropped to 12.4% annually, with a population of about 3.1 million in 1997. The population of Riyadh was 5.5 million in 2005, and this figure is expected to reach 7.7 million inhabitants in 2014 and 10.5 million inhabitants by 2022, an annual growth rate of up to 8 % (Al-Abasi 2005). Thus, building inspection in Saudi Arabia should be maintaining the regulations by enforcing the minimum requirements of the Saudi community.

Since the CoR's spatial information infrastructure is still deficient, there is no firmly established planning institution and hence these is a lack of laws to guide construction in this growing city. The phenomenal growth of urban construction in the CoR contributes to the problems facing the Riyadh municipality. In some developing countries control process for the changing of an urban area has been proposed, such as in Kuala Lumpur in Malaysia (Johar et al. 2007). The CoR deals with different inspection cases daily, but it is suffering from the consequences of poor quality inspection. For example, the quality of violation detection results.

Despite the benefits of enormous oil-generated funds being available to support the Riyadh municipality, the city's infrastructure remains fairly modest and the planning institutions and laws that guide growth are still developing. New initiatives are being trialled to bring urban development under the control of the relevant authorities. However, as yet there is no system available to integrate an inspector's technical requirements during a building inspection task with the implementation of the numerous building instructions and regulations present in Saudi society. Hence, this research aims to develop geospatial inspection methods to support the building inspection process in the Riyadh municipality of Saudi Arabia by using GIS to bring about the required integration of technical requirements with building instructions and regulations.

In Riyadh the Building Permit Department is the authority responsible for issuing building permits while the Building Inspection Department takes responsibility for the monitoring and inspection of all construction work. However, the manual system used in the past was slow, with some applications taking weeks to process or even being lost. To improve the current system, GIS should be applied in order to integrate the various inspection data and enable effective and efficient monitoring of the building inspection process (Alterkawi 2005).

1.2 Research Objectives

The aim of this research is to develop a geospatial-enabled method to support the process of building inspections and compliance. To realise these aims, this research is guided by the following objectives:

1. Identify the inspection issues surrounding the process, building regulations and geospatial information that are used and implemented by building inspectors. The sub-objectives include:
   - Identify the stages in the building inspection process that require the use of geospatial information,
   - Determine the scope of current building inspection issues that can be addressed through geospatial information,
   - Identify geospatial information that addresses the building inspection issues, and
   - Identify the building regulations implemented during the inspection job in the field.
2. Design and develop a geospatially-enabled framework to support building inspections and compliance.

   The sub-objectives include:
   - Use the building construction techniques and regulations to determine the framework requirements, and
   - Identify the design requirements of the framework.
3. Test and evaluate the building inspection framework.’

   The sub-objectives include:
   - Evaluate and validate processes and inspection decision outcomes with the use of a prototype, and
   - Evaluate the framework based on building inspection issues, violations and implementation of building regulations.

1.3 Significance of the Research

Key activities of construction projects are presented through building inspections (Ochoa et al. 2011). This research investigates how geospatial information supports the building inspection process and compliance with local government regulations in building inspections, and which geospatial techniques can be used to ensure that these aspects are protected. Furthermore, this research develops spatial inspection methods that use local government regulations to support Saudi Arabian citizens to construct traditional housing within the guidelines of the law.

This research presents empirical evidence to explain the importance of the integration between building inspections and geospatial information. Eben Saleh (2001) has indicated that building regulations should give more consideration to the national culture and be developed according to environmental and socioeconomic aspects. Other studies discuss building regulations but not the integration between the geospatial components of the building inspection task and the different building regulations in Saudi society (Abu-Gazzeh 1997). The implementation of spatial information used for building inspection will be reviewed in this study, particularly when examining the main issues concerned with enforcing local government regulations in the building inspection process. Furthermore, this research will contribute to resolving the lack enforcement of building plan compliance within local government regulations in Saudi Arabia.

In the Riyadh municipality, one of the problems in the construction inspection process is how to detect violations, how best to communicate them to the user, and how to represent them in an appropriate format. This research presents the spatial method and designs an inspection framework to enable the use of spatial information to detect construction violations and support the building inspection process. Therefore, this research will contribute to a better understanding and a wider application of building inspection concepts and the effective and efficient use of geospatial information in building inspection tasks. This research project extends the knowledge in this field by investigating and developing geospatial methods to improve building inspection quality rather than only enhancing the accuracy of violation detections.

1.4 Methods Overview

This part of the chapter presents the research methodology processes that will be used to achieve the research objectives. Figure 1.1 shows an overview of the methods. This research determined the geospatial inspection methods that were used to support the inspection process and building regulations compliance. In general, the method contains six main components: a) identify the building inspection process and workflow; b) identify the geospatial information involved in the inspection process; c) identify the building regulation thresholds; d) identify the requirements of the proposed framework; e) design a framework for building inspection; and f) test and evaluate the framework. The results test and evaluate the Spatially Enabled Building Inspection to be used to improve the design of the SEBI framework.

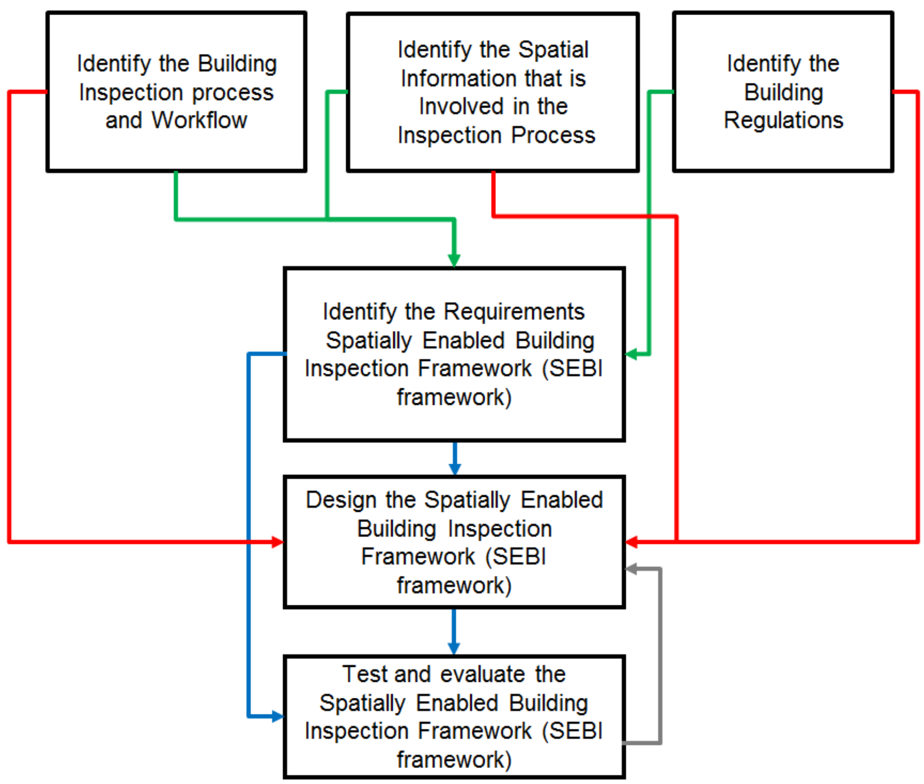

Figure 1.1 Overview of the research methodology

1.5 Overview of the Thesis

This thesis is divided into seven chapters. Chapter 1 presents an introduction to the study, the background to the research, the research problem statement, and the significance of the research, along with an overview of the methods, scope and limitations of the study. Chapter 2 reviews and summarises the various opinions of researchers in determining how geospatial information affects building inspection processes and compliance. Chapter 3 presents the research methods and design used in this study. Chapter 4 presents the building inspection issues and the framework requirements. Chapter 5 develops and designs the building inspection framework. In addition, this chapter demonstrates the prototype implementation and outcomes of violation detection within a GIS environment by using the ModelBuilder technique contained in the ArcGIS software. Chapter 6 tests and evaluates the framework and validates the framework design. Finally, the conclusions of this study, the recommendations and proposed future directions for research are presented in Chapter 7.

2 LITERATURE REVIEW

This chapter describes the background to building construction inspection, including the processes and issues, how they apply to the current implementation of a building inspection. It highlights some of the GIS technique implementations used to support building inspections and regulation compliance, and reviews various spatially enabled methods that have been investigated in connection with construction and building inspection processes.

2.1 Building Construction Inspection

The inspection process and building regulations are of great concern for the construction industry to improve building monitoring, penalties and human conflicts. Therefore, the need to increase the effectiveness of site and building inspection is paramount (Mpambane 2008). The inspection process involves all construction stages (Ochoa et al. 2011). ‘Building inspection services help to protect public health and safety by ensuring that buildings are designed and constructed in accordance with current building codes and regulations’ (Municipality of Cumberland 2013). Building inspections and defect management are important processes for ensuring construction quality (Dong, Maher and Daruwala 2009).

The concept of inspection is an aspect of total quality management aimed at improving the performance of a firm’s processes in either a business or industry (Chin-Keng and Abdul-Rahman 2011). Inspection in field surveys and on-site investigations are necessary to ensure that project managers make quality decisions regarding sites (Harris, McCaffer and Edum-Fotwe 2006). Building monitoring is used to ensure that the minimum requirements of building regulations are achieved (Hess, Bales and Folk 2007). Construction assessment is a professional process that finds faults and violations of building regulations (MacCollum and Hughes 2005). Building inspections help local governments to protect the development of building laws and regulations as their main objective is to enforce the implementation of different building regulations (Listokin and Hattis 2005).

2.1.1 Inspection aim

The aim of an inspection is to follow up on the building construction stage based on the building licence and approval plan to implement the building regulations and thresholds. It is also important to execute some tasks during the inspection process, such as issuing the construction completion certificate or completing the inspection job within the department schedule. The aim of the building inspection is to ensure that the building complies with regulations. Inspectors often make an initial inspection at the first phase of construction and make further follow-up inspections throughout the construction period (Ledbetter and Lemer 1991). Both building design and as-built construction on site are inspected to ensure the health and safety of the people who are inside or around the building (Pheng and Wee 2001). Inspection is the responsibility of government departments as well as the building owners, designers and constructors. The inspector should ensure that no activity is overlooked, since an error in a single activity could result in a substandard project (Hutchings 2003). However, there are different inspection methods and they depend on organisational policy (Schnotz and Bannert 2003).

2.1.2 Inspection process

The inspection process can be defined from the view of both the design information and the actual construction information from the site (Gordon, Akinci, and Garrett 2007). Sunkpho (2002) subdivided the inspection process into four stages: inspection planning, inspection preparation, inspection performance and preparation of the inspection report. Inspection management entails planning, controlling, organising, staffing and directing all the activities of the construction process (Zhi 1995). The building inspection process should cover all stages in the life cycle of a construction process to ensure that the building complies with building codes, municipal plans and quality controls. Further, as-built (AB) documentation should be produced by the constructor to ensure that the actual construction will be accepted. Figure 2.1 shows the process of inspection at the different stages in the life cycle of a building (Pardasani et al. 2008). However, during the construction inspection process, building regulations and approval permits are implemented at all stages of construction.

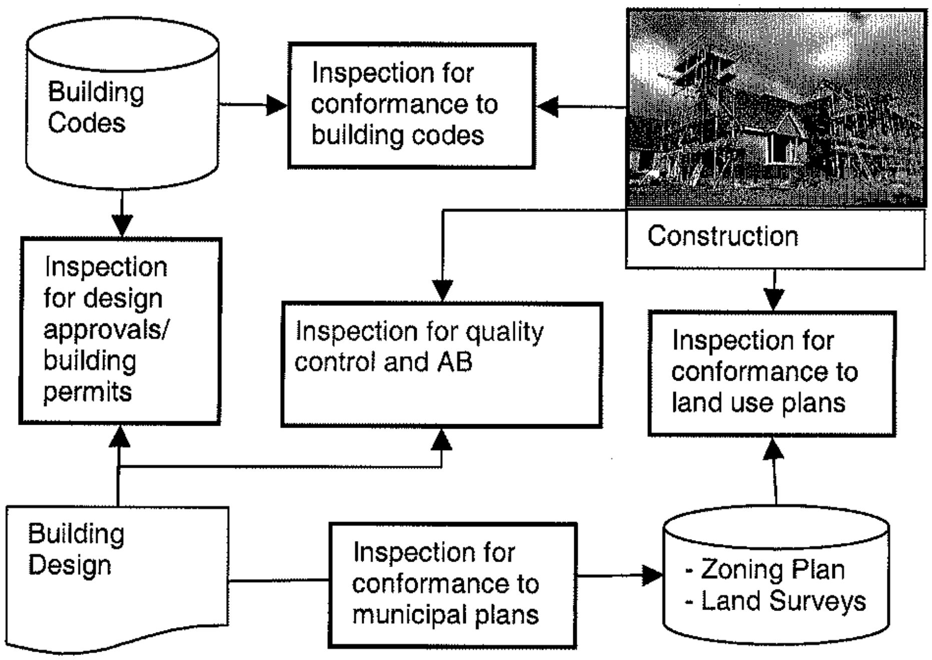

Figure 2.1 The process of inspection at the different stages in the life cycle of the construction process (Pardasani et al. 2008)

A review of the inspection process in different countries around the world indicates that there are common inspection processes, the main aim of which is to apply building regulations and codes. For example, in the City of Troy, Michigan, in the United States, building inspections cover all stages of construction to ensure compliance with the city building code (Stimac 2006). In Canada, in building inspections in the Town of Halton Hills, Ontario, compulsory inspection requirements are written on the building permit document and include the following steps: (a) the foundation,(b) structure and framing, and (c) final inspection (Town of Halton Hills 2008). The main four stages of inspection are (a) planning, (b) preparing, (c) performing and (d) reporting (Garrett and Smailagic 1998). For example, building inspections in the city of Toronto, Canada, include inspections for small buildings and large buildings. Both of these follow the same process, namely, footings, foundations, structural framing, fire separations and closures, insulation and vapour/air barriers, fireplaces, gas appliances, chimneys, life safety systems, final interior inspections and final exterior inspections. However, large building inspections include two or more additional steps: site meeting and occupancy (City of Toronto 2008).

2.1.3 Inspection requirements

Identifying key requirements of the building inspection process is important for realising the aim of the inspection (Alterkawi 2006). The inspection process comprises a wide range of tasks, namely, job planning, task design, data access and preparation, on-site inspection and measurement, data integration and processing, quality assessment and compliance decision making. A range of geospatial data regarding location, proximity to other features (e.g. roads), distances, areas and other measures provides valuable and necessary information to support appropriate and reliable decisions on building regulation compliance (Aboshiqah, Veenendaal and Corner 2013).

Wang (2008) has suggested that the framework for building inspections should consist of (a) a model to represent different data types required to assess the inspection process and violation detection, (b) inspection knowledge, (c) instruments and techniques to collect and display inspection data, and (d) support for all inspection tasks and processes. Inspection requirements are important for understanding the workflow of inspection (WFoI) and to ensure the building regulations were implemented. For example, Hacibaloglu (2003) has addressed some requirements of inspection in Turkey, explaining that the inspection process should contain the following: (a)inspection of stakeholders' information needs, (b) office information, (c) site information, (d) inspection equipment, (e) data accuracy, (f) data integration, (g) communication environment, (h) test and data evaluation capability, (i) data analysis, (j) data documentation, (k) data representation and (l) data sharing and distribution. In designing Boukamp and Akinci (2007) identified that it is important for construction teams to know what should be inspected on a construction site and to understand the difference between the design and AB on site, in designing a new automated process of construction, specifications to support inspection and quality control.

The Riyadh Municipality is not able to process building inspection because of the shortage of human resources and due to the lack of experience of current inspectors. However, those two reasons add to the cost of the inspection project. The cost of inspection in Saudi Arabia is high; this is because the budget of the inspection cost of the municipal sector in CoR more than 20 million SR per year. For example, building inspection in 2007 cost the Riyadh Municipality 21.5 million SR (City of Riyadh 2009).

The other example of the process of inspection in Saudi Arabia is the process of inspection in City of Jeddah (CoJ). The process of inspection requires essential data, such as, the building regulations based on the local subdivision plan, building design (approval plan), building licence and the ownership documents (City of Jeddah 2000).

2.1.4 Building regulations

Essentially, building regulations are the guidelines for the building inspection process. Regulations are written clearly in the building licence and stated on the approval plan design. Moreover, regulations are displayed on the construction site to confirm compliance based on the approval plan and to consider the detection of building inspection violations. Inspectors check building regulations based on the approval documents and other related information to ensure that building structures follow building regulations, both during and after construction (Pedro, Meijer and Visscher 2009). Compliance with the building regulations of local authorities is essential in most Western countries (Visscher and Meijer 2005a). The inspector's task is to assess the compliance, adequacy and eligibility of proposed projects with regard to the laws and regulations in force (Van der Heijden and De Jong 2009). Building monitoring is used to ensure that the minimum requirements of building regulations are implemented (Van der Heijden 2009). Building regulations are used to ensure a quality design was implemented within the planning and objectives of the government (Imrie 2004). Therefore, building regulations are in place to ensure that structures aresafe and habitable, and that they meet all the environmental requirements envisaged by a specific regulatory authority (Visscher and Meijer 2005a). Building regulations are one of the main factors that affect the inspection (Love et al. 2002). When the building regulation and inspection criteria are not defined clearly, different inspectors can produce contradicting reports because they sometimes overlook critical issues. Meacham et al. (2003) have elucidated performance-based building regulations that need to be implemented during the designing and constructing of a building. Further, building regulations take care of all aspects of the construction project (Meijer, Visscher and Sheridan 2003). According to Pheng and Wee (2001), building regulations are standards that are set for both the design and construction of buildings fundamentally, to ensure the health and safety of the people inside or around the building. The quality of housing design is affected by the building regulations (Imrie 2003).

Building plans are usually examined to determine whether the design of the building structure conforms to building codes and ensure that it is suited to the environmental as well as the engineering demands of the site (Fryer et al. 2004). The number of site visits made by building inspectors is determined by the size of the structure and the rate at which it is being constructed. Once the project is completed, the inspectors must make a final and comprehensive inspection before the building can be occupied (Newton and Christian 2006). Discussing the inspection environment in South Africa, Mpambane (2008) comments that the building inspector needs to know how to determine the site-specific requirements that apply to a given situation; in other words, how regulations must be applied to the structure under inspection, whether in direct application of the laws and regulations, licences or in permits. Thus, the inspector must know how to carry out an inspection to obtain complete information that is credible, verifiable and objective.

The implementation of building regulations has spread widely throughout the world. In Europe, there are different systems in each country for building inspections. As Hacibaloglu (2003, p.79) comments, ‘Every system of different countries has its own characteristics depending on its culture, history, geography, politics and other subjects, likewise EU regulation and FIDIC rules which are the combination of many countries’. In Germany, building inspection officers have significant responsibility and operate building monitoring promptly (Visscher and Meijer 2002). In Beverly, Massachusetts, in the United States, the inspection department is responsible for inspecting and issuing certificates of inspection for residential and commercial buildings in the city (City of Beverly 2013).

This research focuses specifically on building regulations that involve geospatial information related to either cadastres or buildings. Figure 2.2 shows basic geospatial information relating to a cadastre, including dimensions, area, road frontages and adjacency to other parcels. Hoogwout and Velde (2004) have suggested that providing complete digital building licences is a challenge for many governments. Therefore, if the approval plan is unavailable on site, this causes inspection tasks to be omitted and some inspection errors. Examples of geospatial building information are the area of buildings, street setback distances, side and rear setbacks of buildings and geospatial dimensions as identified in the approval plans (see Figure 2.3).

Figure 2.2 Basic cadastre geospatial information including dimensions, area, road frontages and adjacency to other parcels

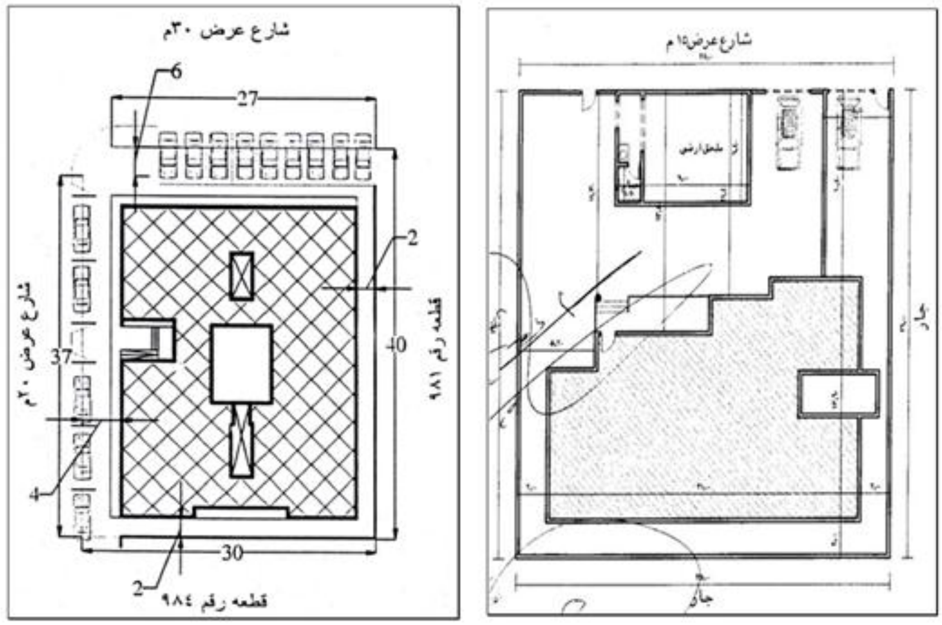

Figure 2.3 Geospatial building information identified in the plans including building footprint areas and setback distances to parcel boundaries and road centreline

2.1.5 Violation of building regulations

Building regulation violations on construction sites cause the expenditure of time and effort on the part of the designers and engineers to detect the regulation violations (Imrie 2003). Building and construction violation is an important concern in the construction industry (Abdullah and Thai 2006). Specifically, violations and defects in the construction process can be grouped as follows: 32%of the defects happen in the early phases, approximately 45%of the defects originate on the site and in the design, and approximately 20%of the causes of the defects originate in the materials or machines (Josephson and Hammarlund 1999). Defects, and their causes in building and construction, have received considerable attention over the last two decades (Kagioglou, Cooper and Aouad 2001). Poor performance in construction projects occurs not through ignorance of what should be done, but rather through doing what is known should not be done (Atkinson 1999). The common defects detected and recorded during inspection can be classed as technical, aesthetic or functional (Li et al. 2013).

Violation detection is a major challenge in the building inspection process. Identification of building violations is an important factor in the design and development of the framework. Figure 2.4 shows examples of two building violation types in CoR: side setback and upper annex building violations.

Figure 2.4 Example of violation types: (a) side setback, (b) upper annex building

Construction defects accrue during construction phases. Such defects result from noncompliance with building regulations and not applying the building permit. Most of construction defects can be recorded on the construction site (Patterson and Ledbetter 1989). The effects of violations of the regulatory framework for buildings in the architectural environment include the built environmental effect on adequate housing conditions, the coverage area of the main building and ground annex building, the upper annex building, the street setback dimensions, and the sides or rear setback dimensions and their effects on the constructional and architectural character (Alkahlout 2006). Figure 2.5 illustrates the building application procedure in force in the municipalities investigated: grey boxes highlight the inspection steps, dotted lines indicate steps that vary from case to case, and continuous lines are those common to all cases.

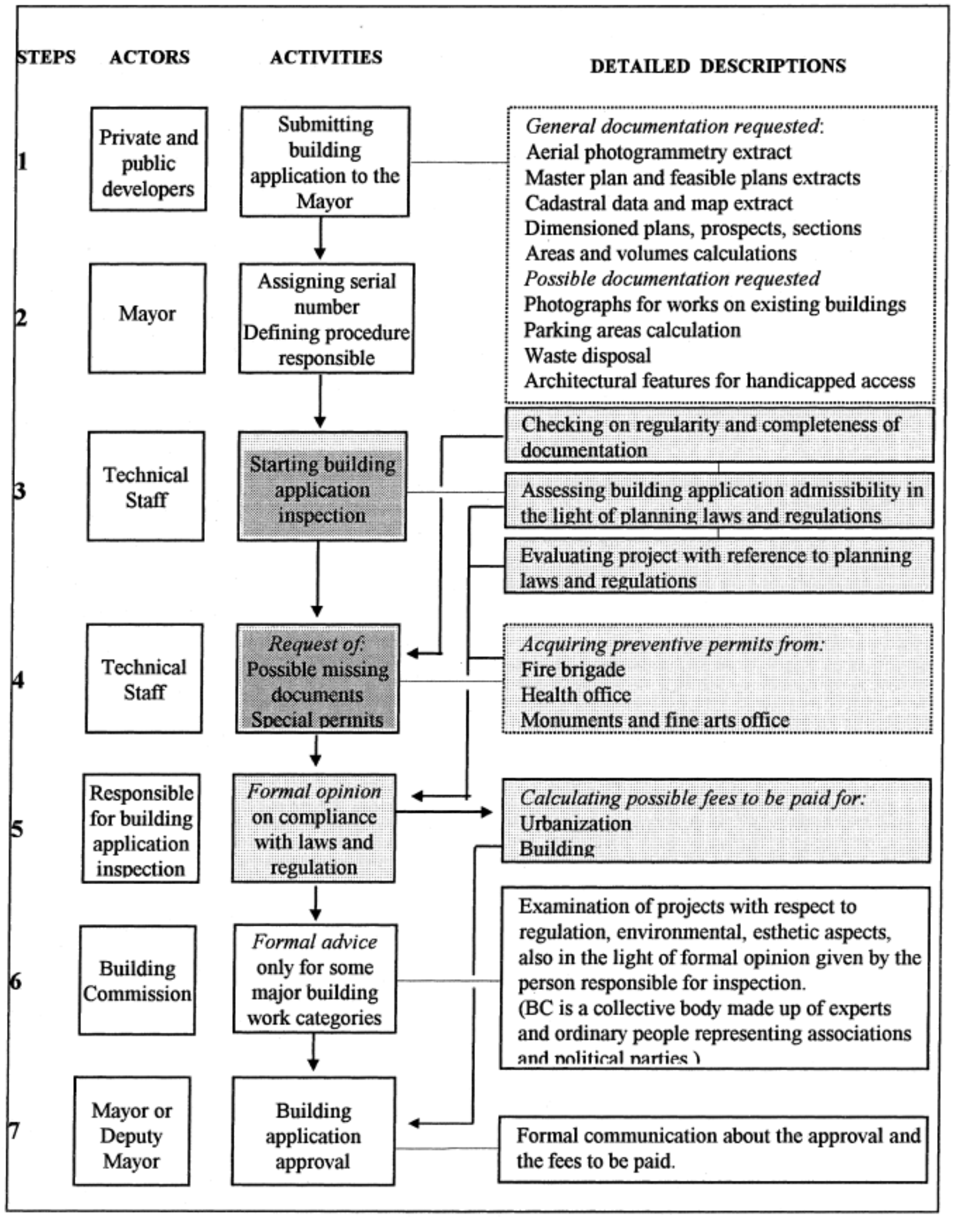

Figure 2.5 Building application procedure in force in the municipalities investigated (Barbanente and Maiellaro 1998)

2.2 Inspection Quality

Quality of the inspection is one of the important aspects that affect the outcomes of violation detection. To check the implantation projects requirements such as legal, aesthetic and function will be achieved by good quality of inspection. This section will present the quality of the inspection process and quality of inspection data.

2.2.1 Quality of the inspection process

One of the major factors affecting the performance and efficiency of a construction project is the site supervision quality (Alwi, Hampson and Mohamed 1999). In Korea,Chin, Kim and Kim (2004) have proposed a process-based quality management information framework to improve inspection quality, inspection testing and non-conformance in reporting corrective action. In addition, a group information model was built and developed based on ISO 9000. The proposed framework and model support inspection quality by conducting three main stages: work prepared before the activity starts, inspection of the work in process and inspection of the final product. The Quality Inspection and Defect Management System (QIDMS) can detect the defect data from a construction site in real time and improve and effectively manage the status and results of construction supervision (Kim et al. 2008).

Inspection quality in architectural work is visually limited. The inspector is not able to provide an accurate decision about the possibility of defects without sufficient technical support. However, techniques such as digital imagery can help to visualise the architectural work and increase the reliability and quality of the inspection outcome, Figure 2.6 demonstrates an example of quality evaluation in the inspection process (Laofor and Peansupap 2012). The overall aim of the evaluation is to use the measurable attributes and subjective attributes to assess the inspection. From the measurable attribute defect quantification, the acceptable defect level evaluation will be obtained. If the evaluation passes, the inspection continues to the next process. If it does not pass, the current process will be corrected and the inspection will occur again.

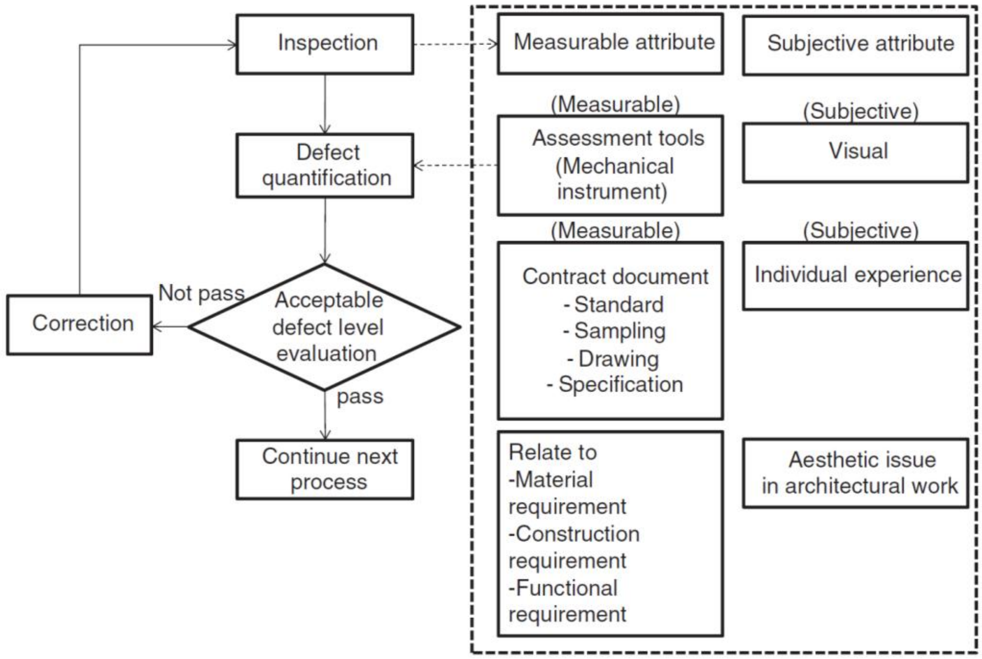

Figure 2.6 Quality evaluation in inspection process (Laofor and Peansupap 2012)

2.2.2 Quality of inspection data

Knowing the quality of data during the cycle of a building inspection facilitates the categorisation of map quality (high, moderate or low) and identifies the accuracy ranges for map sources. This requirement supports the inspection data quality at different stages of the inspection. The quality aspect includes data accuracy and offers an inclusive solution to achieve highly accurate data.

A building inspector needs certain data to conduct the inspection activities. The data required for an inspection is separated into two parts: data created before construction and data produced during 'actual construction'. Therefore, construction projects involve a large amount of data, and these data need to be collected and processed with a good standard of accuracy (Alwi, Hampson and Mohamed 1999; Cox, Perdomo and Thabet 2002b). Understanding the quality aspects of inspection data is important in knowing the performance and efficiency of inspection outputs. Shahi (2012) has illustrated the use of different technologies for organising an enormous amount of construction data that has been collected automatically or semi-automatically. Poor management of the construction documents is a significant risk factor during project performance (Shehab, Moselhi and Nasr 2009).

Building construction defects negatively affect the built environment. The presentation of accurate data of inspection activities is important for knowing the history of construction to prevent defects in the early stage. However, organising the construction data and improving the quality of inspection data supports the progress monitoring system’s assistance with construction management. For example, checklists and references such as drawings help the inspector to assess the inspection with some guidelines. The inspection structure system in Japan contains four main subsystems: (a) the inspection system for architects and construction managers, (b) the checklist and reference system, (c) the position check system, and (d) the progress monitoring system. The main system supports the inspection action to check and record the actual construction on site and show the condition of the construction graphically (Kimoto et al. 2005).

2.3 Inspection data accessibility and integration

Construction inspection data include spatial and non-spatial data related to construction resources; the accessibility of these data is important in monitoring construction activities. Providing the inspection data and making it accessible is essential to support the inspection workflow. Bansal and Pal (2006) have designed a construction project information system (CPIS) in ArcView 3.2 to generate various tables for storing construction data and updating a resources database. This technique helps the inspector and decision maker to obtain the appropriate and required inspection data and extract the information from the available database for construction. Further, inspection data accessibility offers the opportunity to be aware of construction activities and all related data on real time. Better usage and integration of inspection and related data allow for a more efficient inspection process and improved accuracy of violation detection (Wang 2008). Providing the inspection department office with inspection data, such as tests, images of the construction and the accuracy of defect locations, is an inspection issue that needs accurate system control (Dong, Maher and Daruwala 2006). Geospatial information related to an inspection should also be easy to access and available to those who need it at any time (Brédif et al. 2013). A survey for the United Kingdom's Department of Trade and Industry was conducted by Bowden et al. (2004) to understand the relation between construction processes and information and communication technologies. Integration of geospatial data in the inspection process is essential to ensure feasible control through the inspection steps. Inspection processes are improved by geospatial information techniques. Some weaknesses of geospatial technique performance are the consequence of documentation methods, such as site inspection and data storage.

Knowledge sharing is of great importance to the performance of any organisation because it enhances performance and productivity. Data sharing saves time as well as costs by removing the need for organisations or individual inspectors to re-conduct an inspection. They only need to borrow from what has already been established and use it to carry out further inspections (Moses, El-Hamalawi and Hassan 2008). In the case of inspections, this technology allows information on codes, regulations, building materials and procedures based on the geographic nature of the place to be managed and used effectively. In addition, inspectors use this information to advise those who are building and, when conducting an inspection, to ensure that the buildings comply with the requirements (Yaakup et al. 2003).

2.4 Information Technology in Building Inspection

Technological changes have had a major influence on the construction industry in the last few decades (Griffith and Watson 2004). The transfer of inspection methods from traditional methods to technical methods has developed recently in inspection sectors. The influence of information technology (IT) on the construction industry has developed rapidly. IT has generated an improvement and an increase in efficiency in construction monitoring. Exercising construction project control based on suitable techniques for monitoring the construction and conducting inspections on site is essential for the detection of building regulation violations. Thus, inspection techniques help construction project to achieve high productivity. Figure 2.7 shows the development framework of the proposed Project Performance Monitoring System (PPMS) in Hong Kongfor assessing and controlling building construction projects. The figure shows the interface on the PPMS home page at http://www.PPMS.org for helping stockholders of a construction, such as the constructor, client, owner and consultants, to enter the data, access the databases of construction such as surveys and other activity, report the activity and, finally, take corrective action to improve the performance. The project performance evaluation (PPE) framework proposed for the New South Wales Public Works Department in Australia covers a wide range of performance parameters (Cheung, Suen and Cheung 2004). Using technology features and intelligent systems for the inspection process helps the inspectors in local government planning departments of small-sized towns in Apulia, Italy. Barbanente and Maiellaro (1998) provide useful examples of the inspection process, actors, activity and detailed descriptions.

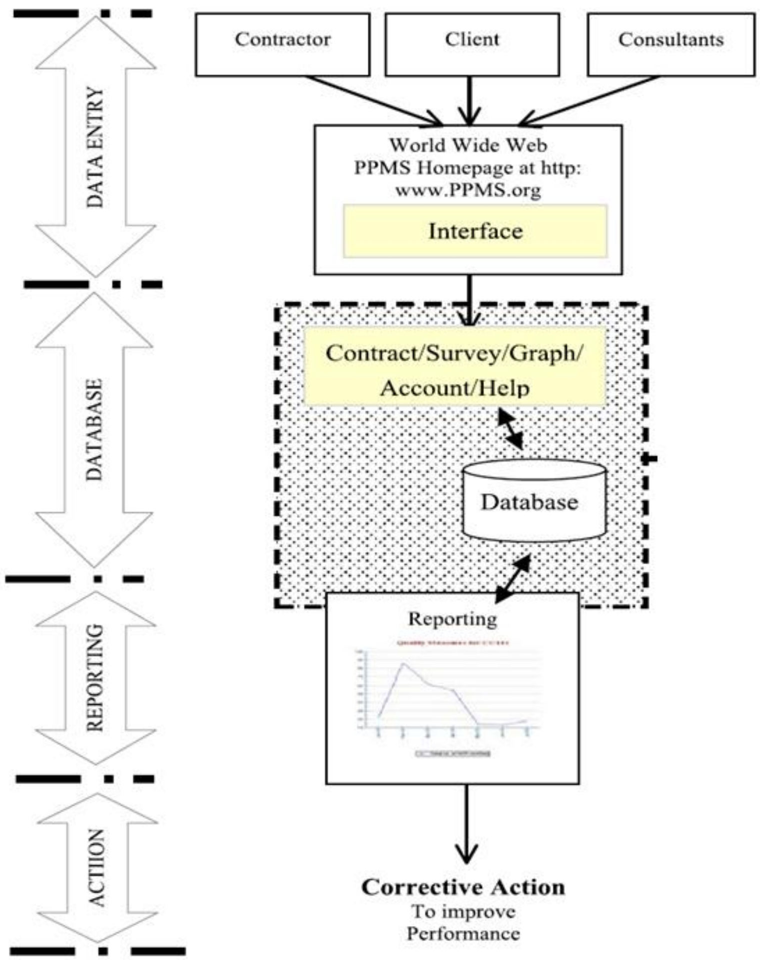

Figure 2.7 Framework of the proposed PPMS (Cheung, Suen and Cheung 2004)

2.4.1 Onsite inspection techniques

Anitha et al. (1998) have suggested a computer system called the Mobile Inspection Assistant (MIA), a system that supports the inspector in the collection of information from the field and the production of the inspection report. This software contains the following components: (a) a graphic user interface (GUI), (b) a speech recognition tool, (c) an information database, (d) a sketching tool and (e) a photo editing/viewing tool. Jung (2004) has provided an algorithm with a very low false positive rate for the detection of building changes and any new features; the algorithm uses multi-temporal aerial stereo-pairs by comparing digital elevation models (DEM).

Handheld computers can be usefully employed to support construction monitoring activity such as data collection, scheduling and estimating (Williams 2003). IT systems provide the integration for data collected from construction sites and offer access to the required inspection data in an accurate format (Reinhardt, Garrett and Akinci 2005). To improve the performance of an inspection, the assistance of a system such as an object-oriented prototype is needed (Gordon, Akinci and Garrett 2008). Fifteen years ago, Paterson, Dowling and Chamberlain (1997) reported on experiments in which a robot enabled with computer vision carried out building inspections to record defects, especially for large buildings. More recently, hang et al. (2009) examined the interface between computer vision and three-dimensional computer-aided design (CAD), for example, to capture the features for the site and check the measurements from digital images.

Cheng and Chen (2002) developed the ArcSched system to help site engineers to monitor an actual construction in real time. The system incorporated an automated schedule for building construction; the concept involved distributing and collecting the construction data AB on site. Cheng and O’Connor (1996) developed the ArcSite system, which includes GIS, tools to solve construction layout problems and manage spatial information for designing and planning a construction. Figure 2.8 shows the procedures of knowledge acquisition and ArcSite knowledge representation.

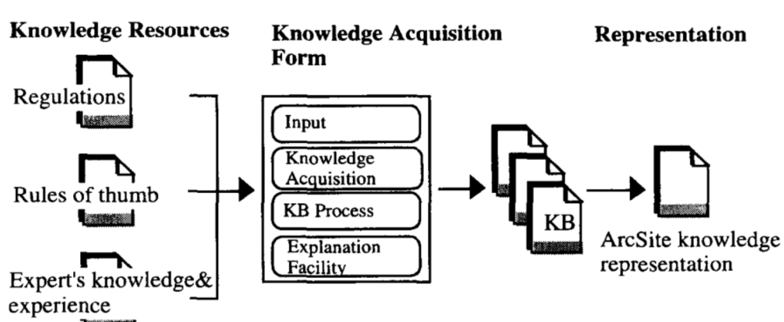

Figure 2.8 Procedures of knowledge acquisition and representation(Cheng and O’Connor 1996)

2.4.2 GIS for building inspections

To develop monitoring during construction and improve violation detection, it is necessary to have effective tools such as geospatial information to support the visualisation of the construction defects. GIS tools are helpful in tracking the construction process and providing comprehensive geospatial information to help inspectors make decisions and analyse construction defects. The implementation of a GIS in the municipal sector allows the management of data and functionality of built-up urban areas. GISs also provide accessibility to essential information from different departments in organisations (Vanier 2004).

GIS techniques can be used to conduct advanced analysis of urban planning and monitoring of data and to update databases as well as site maps. This ensures that inspectors produce organised and accurate data that can be used in decision making for those intending to build. Urban area management in Kuala Lumpur, Malaysia, involves certain techniques to control the development process; for example, a GIS application is used for building control by implementation of a geospatial database (Yaakup et al. 2003). In Japan geospatial information allows users to obtain computer-generated construction maps free of charge. These maps can be used to study the site and make recommendations regarding the safety of any buildings to be constructed (Kohsaka 2001).

GISs ensure data accuracy integrity, for example, for inspection of the number of properties recorded (Lake et al. 2000). GISs have greatly influenced inspection processes in the public works sector. Figure 2.9 shows how to implement quality control on construction sites using the Advanced Sensor-based Defect Management on Construction Sites (ASDMCon) model (Akinci et al. 2006). Geospatial information should also be easy to access and available to those who need it at any time (Brédif et al. 2013). To achieve this, GIS technology should be integrated into site inspection to make decision making more efficient (ESRI 2013).

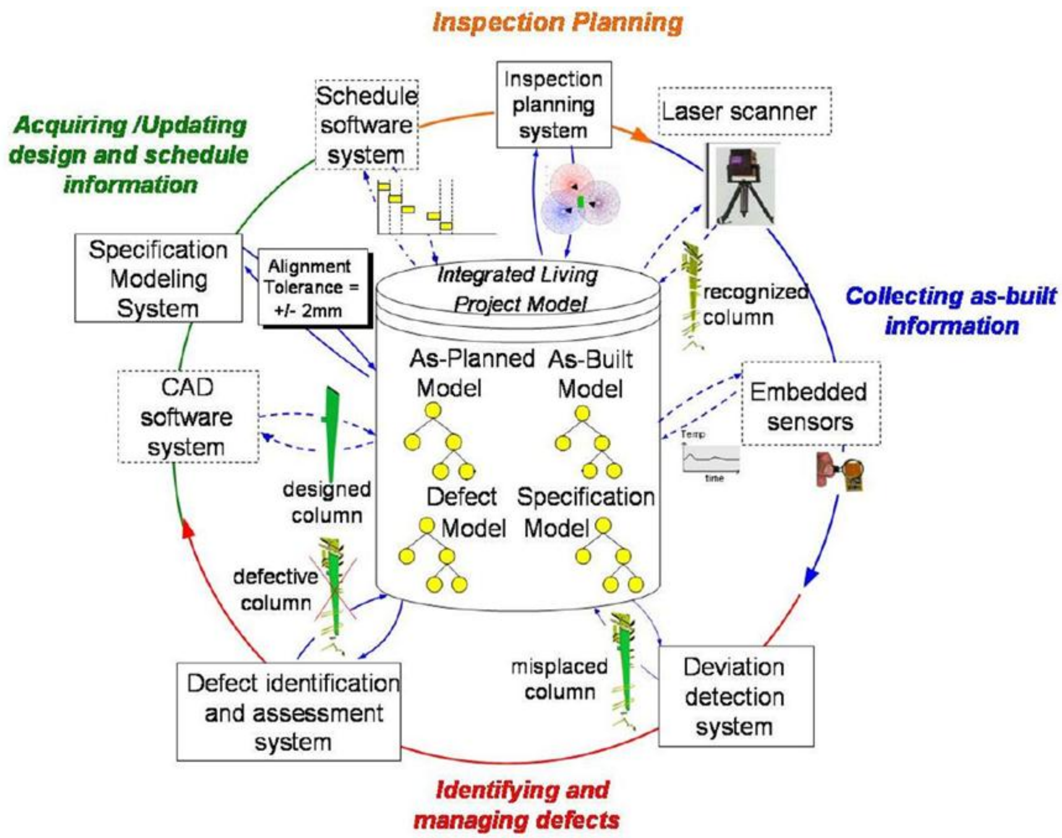

Figure 2.9 Schematic overall approach for sensor-based quality control(Akinci et al. 2006)

The visualisation of construction activity and provision of required data for inspection are important for presenting the activities of construction AB. The monitoring of the building construction and the comparison of the actual construction on site with the as-planned construction, need sequences of conceptual visualisation techniques (e.g. charts, graphs and photos) (Golparvar and Peña-Mora 2007). For example, Meacham et al. (2003) have offered a progress monitoring and visualisation technique to present differences between as-planned and AB progress (e.g., frequent errors and changes). Figure 2.10 shows augmented reality-based progress monitoring for presenting a construction (as-planned and AB) and a visual comparison.

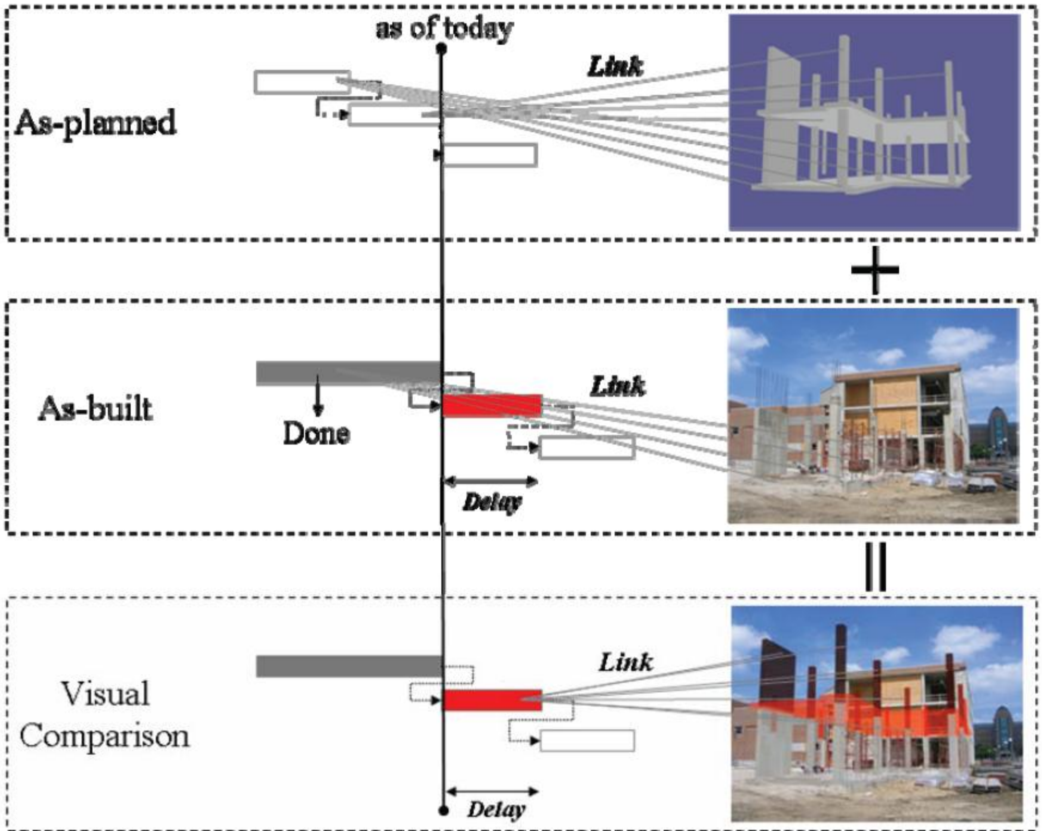

Figure 2.10 Augmented reality-based progress monitoring (Golparvar and Peña-Mora 2007)

Poku and Arditi (2006) have developed a progress monitoring system with GIS to support graphic presentations for construction. This also involves a GIS package for presenting complete information on the construction and visualising the construction activity at any stage of the construction process. Figure 2.11 shows the design and information flow chart of Progress Monitoring System with Geographical Information Systems (PMS-GIS) implementation. The figure also shows the steps of the inspection data operation, for example, drawing creation and database creation.

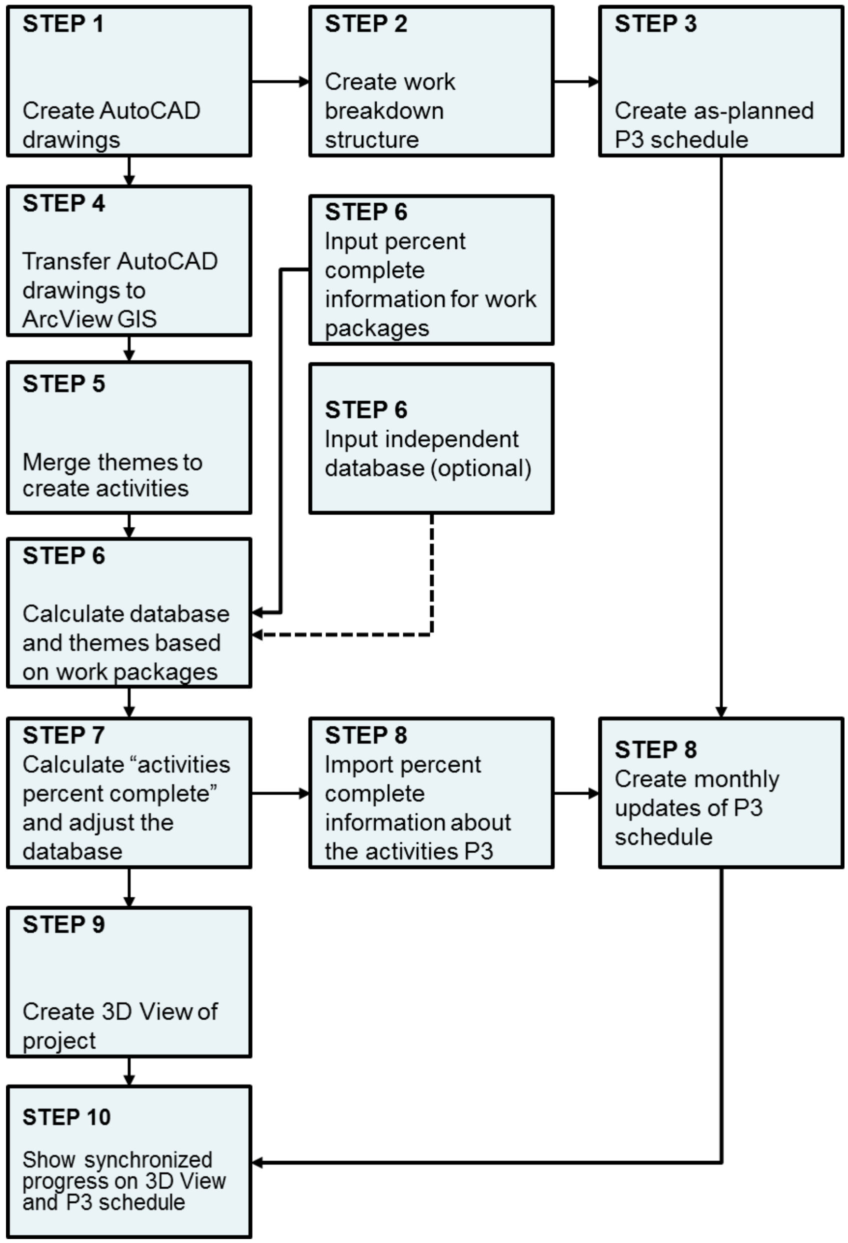

Figure 2.11 Design and information flow chart (Poku and Arditi 2006)

Geospatial information enables statistical analysis, cartography and database technology to be merged (Mingxin, Keli and Jianhua 2011). This allows for labelling of features such as parcels, buildings or parts of buildings on site, as well as effective communication. Moreover, it reduces the time required to understand the location of these features in relation to the site (LaGro 2001). Geospatial information can be used effectively to build a database of construction measures, features and quality control for potential building and construction activities (Bansal and Pal 2006). Data managers can deduce geographical analyses, statistical analyses and mathematical models of the site under inspection through the use of GIS (Durieux, Lagabrielle and Nelson 2008). A building inspection process can be made easier with a GIS that provides readily accessible, integrated and quality geospatial data. This can be used to represent and locate features, thus providing a platform for meaningful analysis, monitoring and decision making (Ghose 2001). Using the spatial information for identification of the construction features takes less time than when manual methods are used.

Land cadastre data is essential for construction inspection, for example, the parcel boundary and area. Waters (2002) has suggested that GIS can be successfully used in the integration of land records management systems. However, several organisations lack key components in their computer systems that would otherwise enhance the daily business operations, and this includes the lack of GIS integration. Integrating geospatial information enhances accuracy for the analysis and monitoring of a construction project (Bevir 2001).

Geospatial information that is integrated into site inspections in data collection, analysis, manipulation and storage, saves on costs and time while improving efficiency and accuracy. This allows information to be entered once by the site inspector and enables instant authorised sharing among departments such as the planning, mapping and registry departments (Abdulaal 2009). Communication between inspectors on the site and their headquarters can be made in real time using distributed GIS (Niu et al. 2004). Developing site inspection within geospatial IT implies using this technology in all the related activities, including data collection, analysis, storage, access, retrieval and communication. It is worth noting here that the role of building inspectors is to inquire, inspect and make recommendations (Kim et al. 2008). According to Kohsaka (2001), GISs lead to a reduction of working hours and improve local government productivity in managing built-up areas.

There are requirements for assessing a building inspection from a spatial perspective. Aerial and satellite imagery can be used in the extraction of construction features and measurements. Building outlines and street centrelines can be extracted as vector data (Baltsavias 2004). Digital surface models (DSMs) from airborne laser scanning (ALS) are beneficial for detecting changes in buildings and extraction of urban area data without omission errors (Murakami et al. 1999).

2.4.3 Building and construction feature extraction

To visualise construction components, geospatial representation is appropriate for presenting urban features such as buildings and cadastres. Digital image analysis for construction helps the inspector to extract construction features. In addition, aerial images enable provision of the position and value of construction defects and the quality of building inspection. Satellite imagery helps to detect building change (Champion et al. 2010). ALS provides valuable information for urban areas such as building footprints and can be used for change detection. Figure 2.12 shows the overall workflow of change detection methods based on stereo imagery (Rutzinger et al. 2010; Tian, Chaabouni-Chouayakh and Reinartz 2011; Tian et al. 2010).

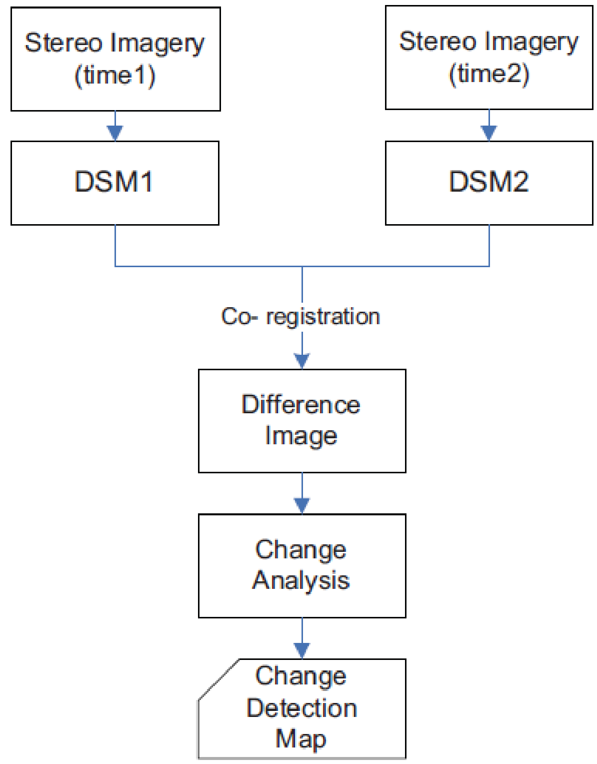

Figure 2.12 Change detection process methods(Tian, Chaabouni-Chouayakh and Reinartz 2011)

Identifying construction features in detail is a significant factor in assessing and monitoring on-site construction. Examples of such features include buildings, parcels, fences and other attached features such as ground annex buildings. Developing countries face the complex problem of improving living standards in informal settlements (ISs). This problem is all too clear within built-up areas. Mason and Baltsavias (1997) have presented a strategy that uses a geospatial database for ISs to extract and detect man-made features within urban area structures. Figure 2.13 shows an example of a filter-enhanced section of an orthoimage and corresponding ground truth data showing above-surface man-made structures.

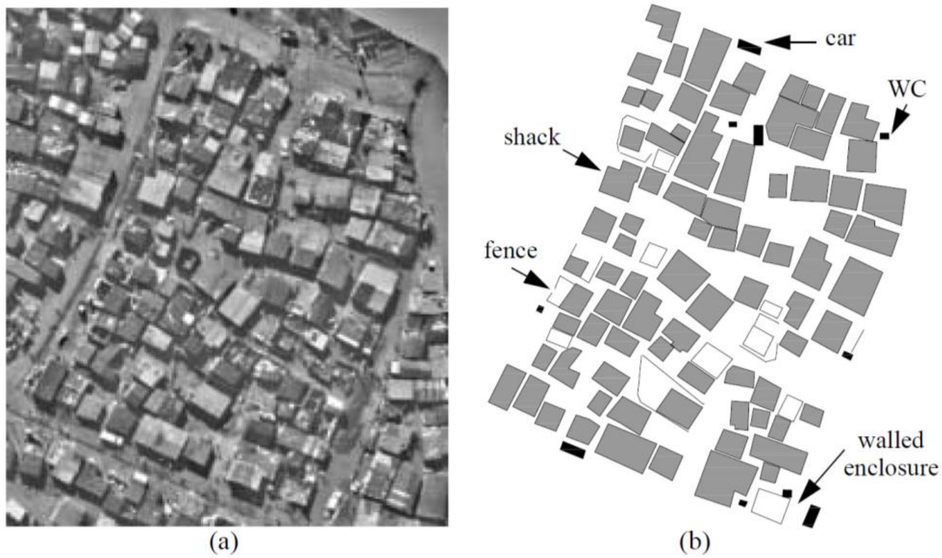

Figure 2.13 Test data and ground truth: (a) filter enhanced section of orthoimage; (b) corresponding ground truth data showing above-surface man-made structures (Mason and Baltsavias 1997)

Built-up area monitoring and change detection can be obtained from the automatic detection of buildings based on aerial images using invariant colour features (see Figure 2.14). Information that is essential for multi-temporal monitoring of the change of an object or phenomenon includes (a) area and rate of change, (b) spatial distribution of changed types, (c) change routes of land-cover types and (d) accuracy results assessment of detection (Shehab, Moselhiand Nasr 2009).

Figure 2.14 Example of detection of building footprint, after Sirmacek and Unsalan (2008)

Obtaining construction features and measures from digital maps such as DSMs is helpful for representing on-site construction object attributes, for instance, the building footprint, cadastre boundary and street centreline. DSMs from Light Detection and Ranging or Laser Imaging Detection and Ranging (LiDAR)are used to extract buildings in the following steps: (a) image process algorithms, (b) image processing and human integration operation, (c) setting up of a DBM and (d) generation of a data terrain model (DTM). The outcome of these steps is the creation of a features database (Brédif et al. 2013; Li et al. 2013; Zhou et al. 2004). Digital measurable images (DMIs) provide building facade measurements based on digital image processing (Cong et al. 2013). Automatic building extraction can be obtained from one-metre resolution IKONOS imagery with multispectral bands, and LiDAR data with horizontal point spacing of about three metres, to provide building detection and building description. Lin and Nevatia (1998) have demonstrated a method of building detection and description from a single intensity image (see Figure 2.15).

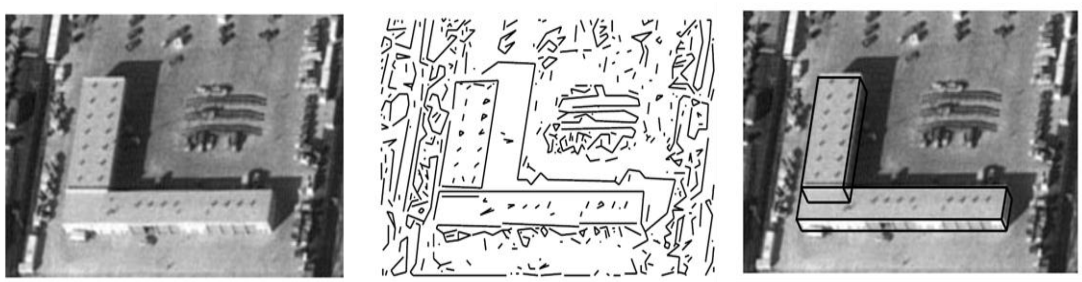

Figure 2.15 Building extractions from intensity image (Lin and Nevatia 1998)

According to Ioannidis, Psaltis and Potsiou (2009), high-resolution imagery allows the monitoring and detection of new buildings by the extraction of features. Figure 2.16 shows the extraction process for a building footprint based on aerial images (Woo et al. 2008).

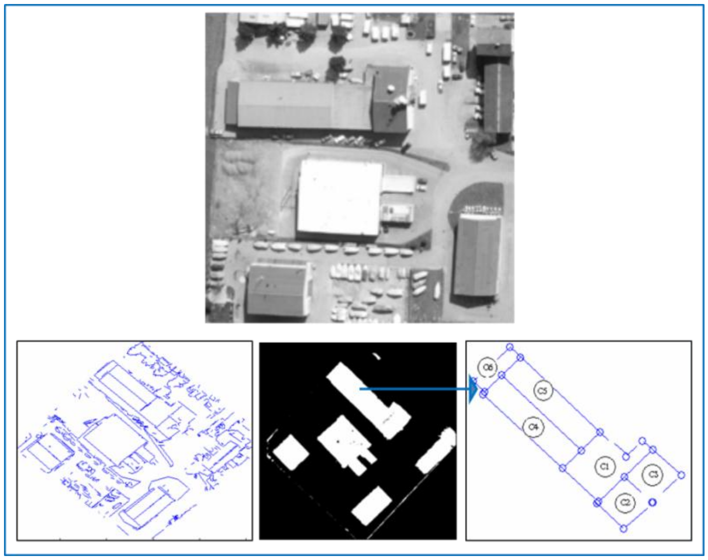

Figure 2.16 Extraction of building features from imagery (Woo et al. 2008)

Object-based classification methods support the rapid monitoring of construction building through the production of an updated urban reference map. Ahmadi et al. (2010) have proposed a method of extraction and detection of building boundaries and the detection of building boundary shapes by radiometric matches between the building roof and background of the image (see Figure 2.17).

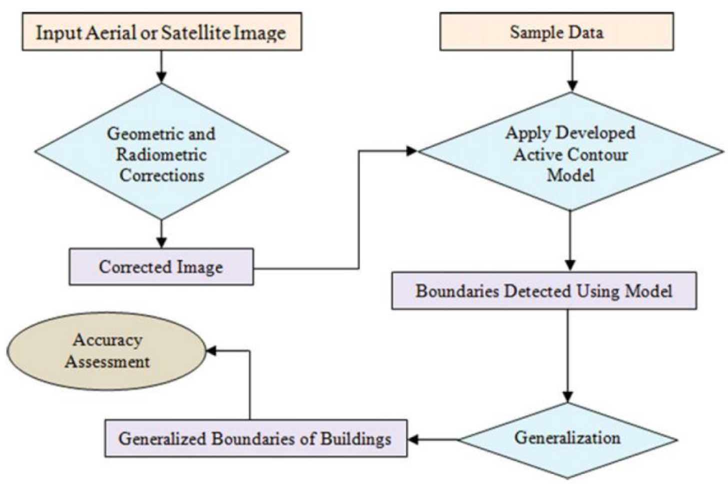

Figure 2.17 Flowchart of building extraction algorithm (Ahmadi et al. 2010)

Similarly, Samadzadegan et al. (2005) have proposed a method called object recognition and reconstruction (ORR) to represent and extract some features of built-up areas such as buildings and trees (see Figure 2.18).

Figure 2.18 The ORR method of extraction of features of built-up area (Samadzadegan et al. 2005)

2.5 Building Inspection in the CoR

The workflow of inspection (WFoI) gives a broad overview of the total images of building inspection and violation detection. Atkinson (1999) explains that quality-related issues in projects are mostly a result of unclear and inadequate project process, which in itself is a result of managerial inadequacies. Thus, the WFoI is the basic approach to understanding the integration of building inspection and violation detection. The aim is to guide the evaluation of the inspection process from different aspects such as geospatial, technical and administrative performance. Figure 2.19 shows examples of real construction stages in the CoR, including site preparation, construction foundation, ground floor construction, first floor and upper annex building construction, and final construction and material for residential and commercial land use.

Figure 2.19 Example of construction stages: (1) site preparation;(2)foundations;(3) ground floor;(4) first floor and upper annex;(5) and(6) final construction and material for residential and commercial land use

In Saudi Arabia construction defects fall in to six main groups of building violations. These relate to construction design, construction inspection, civil construction, constructor's administration, construction materials and construction equipment. Building defects may be undetected due to a lack of inspections, hiring unqualified inspectors, neglecting the importance of inspections and not implementing corrective action during the job execution (Assaf, Al-Hammad and Al-Shihah 1995).

Despite several departments in the Riyadh municipality contributing to and sharing inspection responsibility, the frequency of building violations has increased in the last few years in Riyadh (Alterkawi 2006). Building owners still want to practise according to the old system that has been in use for the last 50 years. The owners want to control the construction task before, during and after the construction processes. The same situation exists in Canada, where building owners should comply completely with all the building instructions presented as part of the approval plan process (Al-Hussein et al. 2006). Alterkawi (2006) has proposed an engineering supervision and inspection module for the Riyadh Municipality to present building permit data and update construction information (see Figure 2.20).

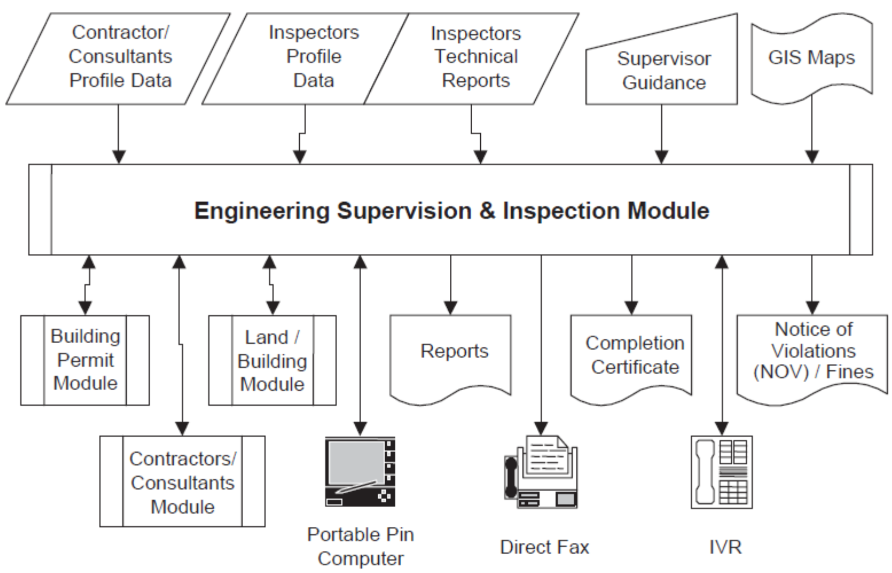

Figure 2.20 Engineering supervision and inspection module (Alterkawi 2006)

Figure 2.21 shows the current building inspection process in the Riyadh Municipality. The process consists of the following: (a) plan and design review, (b) site plan application, (c) civil construction inspection, (d) engineering and architectural inspection, (e) construction materials and (f) final and comprehensive inspection. Building permits must be issued accordance with minimum building inspection requirements, for instance, the Saudi Building Code (SBC) and Municipal Building Regulations. However, Satti and Krawczyk (2004) are of the opinion that rules and regulations should be implemented and written on the approval plan.

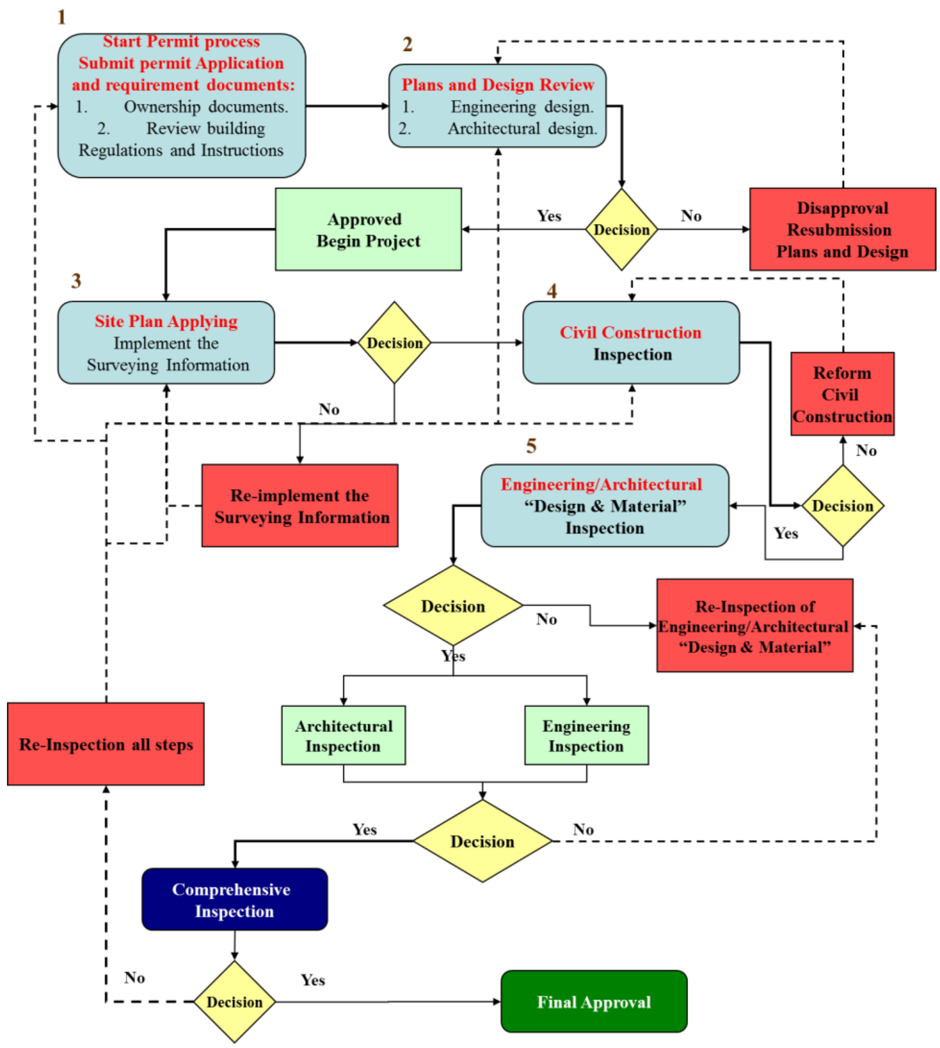

Figure 2.21 Building inspection process in the Riyadh Municipality

2.6 Chapter Summary

This chapter has described the diverse opinions of researchers on issues such asbuilding and construction inspections, the inspection process, inspection criteria, building regulations implementation, geospatial information effects and the development of building inspection processes and compliance. It has also demonstrated various aspects of geospatial information implementation within the building inspection process and monitoring. These include building inspection techniques and other aspects that improve the building inspection process. The integration and quality aspects of inspection data have been discussed to show how geospatial information in the site inspection process helps to reduce the challenge of information inadequacy. Recent developments in building inspections and related geospatial technologies have also been discussed, such as building construction extraction from different image sources. Companies that are involved in geospatial information need to participate in collaborative studies to test the effectiveness of spatial data. For building inspections to achieve the potential described in the literature, they should be based on the geospatial information incorporating solutions described in this chapter.

3 RESEARCH METHODOLOGY DESIGN AND IMPLEMENTATION

The aim of this research is to develop efficient spatial methods to support the process of building inspections and compliance. This chapter presents the research design of the study and the activities that were deemed essential to complete the research successfully. A discussion of the research methodology includes the methodology of enabled spatial data, implementation of the research methodology and data management and analysis.

3.1 Methodology of Enabled Spatial Data for the Inspection Process

An outline of the main building inspection issues and the related spatial aspects was provided in Sections 2.2 and 2.3. These issues are building regulation implementation, the inspection workflow process, inspection data access and integration, inspection data quality, spatial characteristics of inspection and implementation of geospatial techniques for inspection violation detection. These issues included the spatial aspects of inspection and the various processes of the workflow of inspection (WFoI). Further, each building inspection issue was related to one or more processes and included data implementation during inspection activities. The following sections describe the methodology that was used to address the research objectives in this study.

3.1.1 Methodology overview

Figure 3.1 shows an overview of the methodology adopted in this research. The literature review identified building regulation and inspection issues, and then, based on the issues, the geospatial information used for inspection. The first field trip was implemented to conduct the inspection survey and review building inspection department records. The second field trip was implemented to obtain the field inspection report for evaluation. Four main steps were implemented to achieve the research objectives listed in Section 1.2:

(a) Identify the inspection issues: the process and building regulations and geospatial information that are used and implemented by building inspectors.

(b) Identify the building inspection framework requirements.

(c) Design the building inspection framework.

(d) Test and evaluate the building inspection framework.

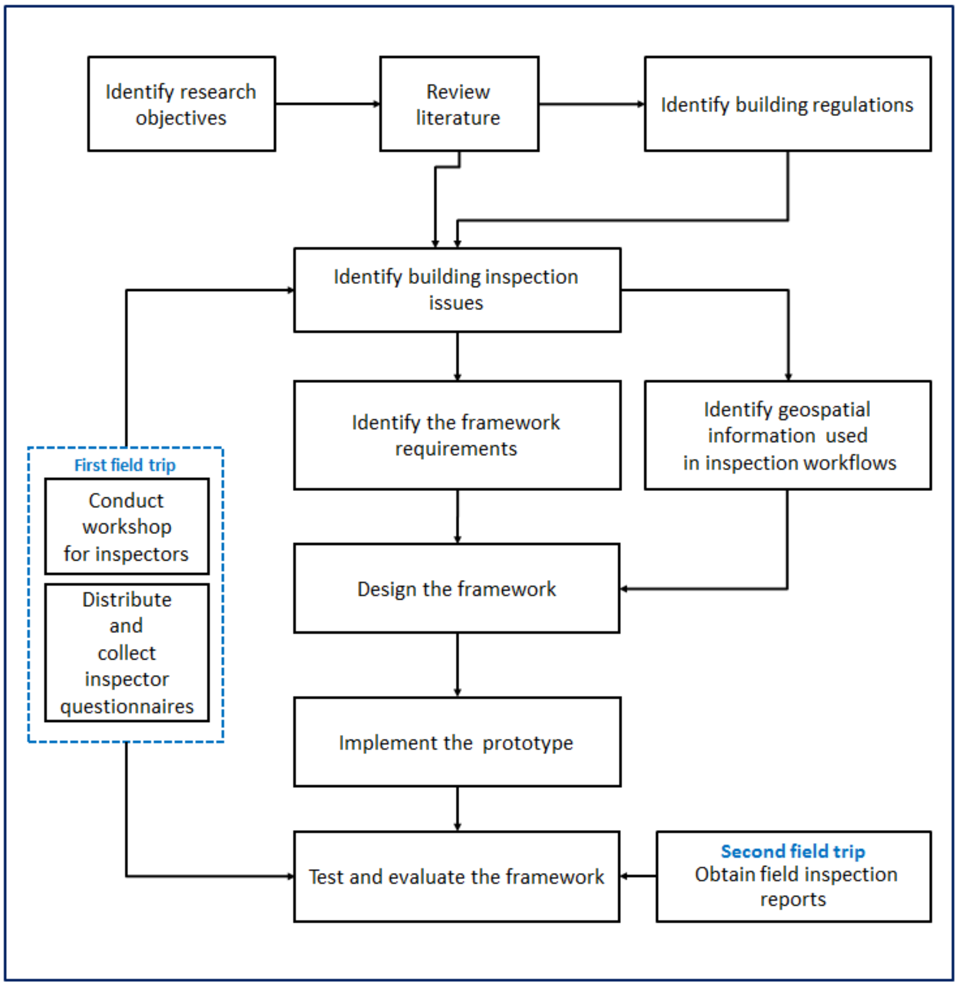

Figure 3.1 Research methodology for the development of geospatial inspection methods to support building inspections and compliance

All the steps of the research methodology are discussed in detail based on the arrangement in Figure 3.1. The description of the research methodology includes all the methods and activities such as field trips that were conducted during the research period.

3.1.2 Identifying the inspection issues, processes, building regulations and geospatial information

The review of the literature provided perspectives on the inspection issues, processes, building regulations and related geospatial information used for inspections. The aim of this process within the methodology is to understand and identify the issues of inspection in more detail. Thus, further investigation in to the inspection issues expands on the explanation in the literature review, especially as it relates to the City of Riyadh (CoR). Geospatial information within the inspection process is compared and contrasted to understand which criteria enhance the building inspection process and how the integration of different information and criteria improves that process. Building and construction inspections are assessed through a review of the documents and records of different departments in the Riyadh Municipality such as the building inspection and building licence departments. The aim of reviewing these documents is to extract the inspection processes data which include spatial aspects in the CoR. Stakeholders of inspections provided insights on building inspections in the CoR, for example, the current workflow of the inspection process, the implementation of geospatial information and violation detection.

Figure 3.2 shows the methodology used to define the inspection issues and processes, especially those involving spatial aspects, building regulations and geospatial information, based on the review of three main sources:

(a) the literature,
(b) municipality inspection reports and studies,
(c) Municipality inspector surveys.

The municipality present survey provides essential information from the inspector who carries out construction inspections on a daily basis. The information obtained from the inspector includes violation types and detection performance, inspection techniques, workflow process and the implementation of spatial information. The goal in obtaining this information is to understand the actual inspection situation in the CoR with regard to common violations, difficulties of implementing spatial information and the required data for inspection.

Accordingly, these sources were reviewed to understand what spatial information is used, how it is used and how it can be useful in the inspection process.

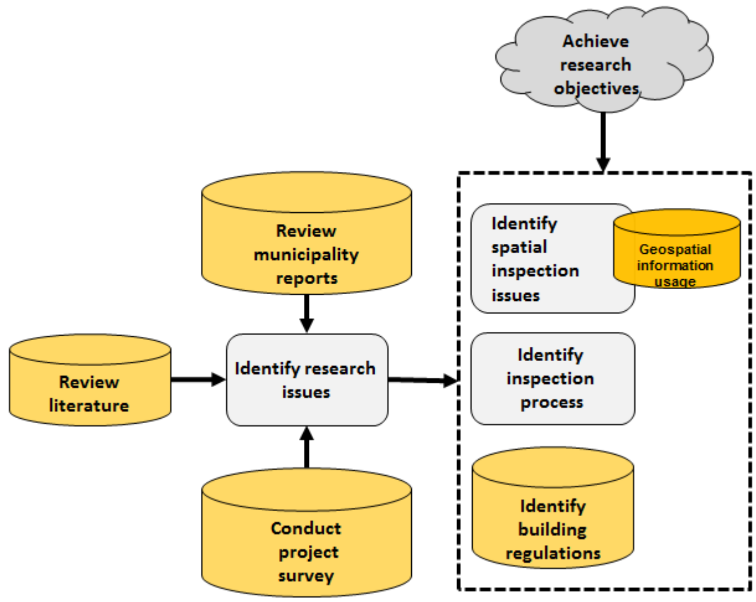

Figure 3.2 Methodology for identification of inspection issues, processes and regulations

Thus, this part of the methodology is discussed in detail to achieve the first research objective, which is to identify the inspection issues, processes, regulations and spatial data.

Inspection issues: The aim in identifying the inspection issues is to understand the lack of current processes and implementation of geospatial inspection information. For example, the integration of construction data such as graphic data and attributes data is affected by the use of the traditional manual method. Further, the quality of the inspection data is affected by data sources such as imagery and attributes that provide construction features and measurements (see Section 2.1).

Inspection process: The process of inspection was identified to understand the mechanism of inspection and workflow. The process was identified for different sources including the current processes of inspection in the Riyadh Municipality (see Section 2.1.2).

Building regulations: The spatial aspects in the current building regulations and thresholds that are implemented during inspection were defined, for example, the %age of coverage area of building footprints and the dimensions of main buildings, ground annex buildings, upper annex buildings and setbacks.

Geospatial information: Geospatial information includes the features and measurements that are used in building inspections and violation detection, for example, the building footprint, cadastre boundary, buildings and cadastre area, and setbacks dimensions (see Section 2.4.2).

3.1.3 Identifying the framework requirements

The framework requirements were determined based on the needs of such factors as the inspection process, workflow and inspection data. The main source used to identify the requirements was the literature related to building inspections and inspector surveys. Further, the requirements were extracted from related examples by analysing the current conditions of inspection workflow around the world, including basic data of inspection, the standard process of inspection, the level of quality and integration, data accessibility and adherence to building regulations. In addition, the inspector survey provided information that could not be obtained from the literature such as violation classes and types, and other issues related to violation detection (see Section 3.1.2). The aim was to recognise in the implementation examples perfect structure and framework design based on defined requirements. In addition, the aim was to use surveys to identify and add specific requirements or sub requirements related to the inspection process in the CoR.

The requirements explain what the framework should include and provide support for the enabling of geospatial information to support building inspections and compliance. The purpose of identifying the framework requirements was to determine the main guidelines for the framework. The requirements for the framework include presenting the inspection data, integrating geospatial and non-geospatial support data between site and office, improving inspection knowledge, applying inspection data accuracy, presenting digital inspection report and providing a geodatabase of building regulations (Ekholm and Fridqvist 1996). Once the requirements are implemented, the inspection process will be improved to support the process of violation detection and building regulations compliance.

Framework requirements maintain and perform the inspection to demonstrate the required workflow of the inspection process. Inspection requirements are determined to ensure and achieve building inspection aims. Moreover, implementation of the process within a geospatial environment ensures that a high quality of violation detection is achieved. Requirements contribute to implementing building regulations and violation detection within the workflow of the inspection process and activities. The framework solution can be identified from the relative requirements and framework quality protocols to achieve high inspection accuracy. The proposed framework presents the actual construction situation and detects building violations in different processes. However, multiple stages of the inspection framework should be used to apply specific geospatial and non-geospatial data at each inspection process.

The aim of implementing the requirements is to ensure that the framework components enable geospatial information to support and improve the building inspection and violation detection process. Further requirements are to support the transfer from current traditional processes to developed geospatial inspection methods with higher performance. Requirements support the components of the framework in solving problems of the current inspection process, for examples, data collection, recording and reporting. This kind of support will achieve the aims of building regulation compliance and violation detection.

A requirement has been used to perform the framework component functions and interpret the building regulations based on a building licence and approval plan. When the requirements are met, the quality and other components are achieved, benefiting the formulation of components concerned with the inspection process at decision points and the WFoI within the geospatial environment, both in the early stage and at all steps of the inspection. The framework requirements will guide the inspector and decision maker in maintaining the inspection process and give them accurate data for the inspection and violation detection process.

3.1.4 Designing and developing the framework for using spatial information in building inspections

A framework is a vision rather than a system. A framework can be tailored by adding further details to improve it and create a complete vision of enabling geospatial information to support building inspections. A framework was designed and developed to present the integration between different components and issues of building inspections such as building regulations, building violation detection, geospatial information and inspection workflow. A framework is an approach to develop a high level of violation detection for municipal building violation to track an incompliance based on the approval plan. In addition, all requirements of inspection processes are inclusive within the framework such as data, quality of data, detection process and reporting all the violation types and classes. Further, the framework produces the vision and strategy to implement building construction monitoring (Kagioglou, Cooper, and Aouad 2001). The integration between inspection components is important for compatibility between issues. The framework defines simple steps to enable the inspector to make use of high-quality geospatial and non-geospatial information to support the accuracy of the inspection process when detecting violations and building regulation compliance. Figure 3.3 shows the overall integration and architecture of the framework and inspection workflow. The proposed framework encompasses the WFoI process even after the completion certificate has been issued and the building is occupied. The proposed framework provides a comprehensive view to enable geospatial information to support building inspections, solve inspection issues and improve the inspection process and workflow based on the framework requirements.

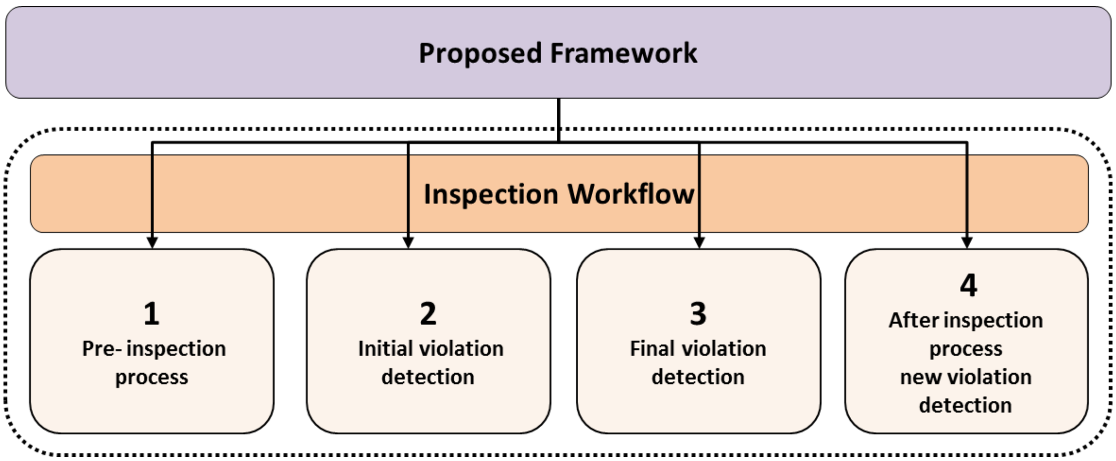

Figure 3.3 Overall integration and architecture of the framework and inspection workflow

3.1.5 Prototype implementation

The prototype implementation aims to test and evaluate the framework from the technical perspective. The outcomes of the prototype model were then used for an evaluation. Identification of the process, issues and implementation of building regulations, and application of the geospatial information for inspection were tested through the prototype to evaluate the framework. A prototype was developed for a case study and used to evaluate the framework. The prototype utilised a range of data and imagery of various levels of quality to identify and compare instances of violations with calculated certainties. A prototype implementation was applied to the technical aspects of the framework. A highly accurate data source was implemented within the prototype to obtain reliable violation detection results. In addition, the violation detection workflow process is presented within the framework by inspection stakeholders, including the inspection data, building regulations, quality assessment, and violation arrangement and presentation.

3.1.6 Testing and evaluating the framework

The framework testing and evaluation method applied was based on three main aspects: prototype outcomes, inspector survey outputs and ground truth field survey reports. The aim of testing and evaluating the method was to determine the capabilities of the framework design to enable the geospatial information to support building inspections, violation detection and regulations compliance, and to identify the strengths and weaknesses of the design. The aim of the second field trip was to obtain the ground truth regarding field inspection reports to evaluate the project prototype and achieve the third research objective. Further, the aim is to provide empirical evidence such as the actual measurements of construction to prove the framework design. Thus, some locations within the study area will be examined to obtain the actual measurements such as building ratio, cadastre area and setback dimensions.

The basis for the evaluation of the framework can be summed up by the following themes: (a) using prototype outcomes to evaluate the framework components by classifying these outcomes to demonstrate the efficiency of the framework design; (b) discussing the prototype implementation from a geospatial enabled perspective; and (c) explaining the differences in inspection ability between the proposed framework and the current inspection process and the weaknesses that the framework uncovered and solved. The evaluation needed to assess the involvement of the inspection feedback from the survey and the prototype outcomes. Understanding these aspects delivered significant indicators about the implementation of the geospatial methods required to support the inspection workflow in the CoR and added valuable ideas for assessment in terms of developing the inspection of buildings and construction.

The evaluation of the framework needed to assess the implications of enabling geospatial information in the framework components. Evaluation of the concepts supported the tracking of requirements implementation through the framework components. The framework and project prototype model were assessed by testing and evaluating its ability to achieve the framework requirements.

Figure 3.4 shows the steps in testing and evaluating the framework undertaken to achieve integration between the requirements, inspection issues, framework components, prototype implementation and findings of the ground truth field inspection reports. Overall, the integration between the design of the framework and the outcomes of the prototype to achieve the framework was evaluated. The requirements, components, inspector survey and prototype outcomes were used to evaluate the framework. However, the model results, inspector survey and field inspection reports tested the prototype results. Further, the framework requirements were implemented to assess the model results and achieve the framework design aim.

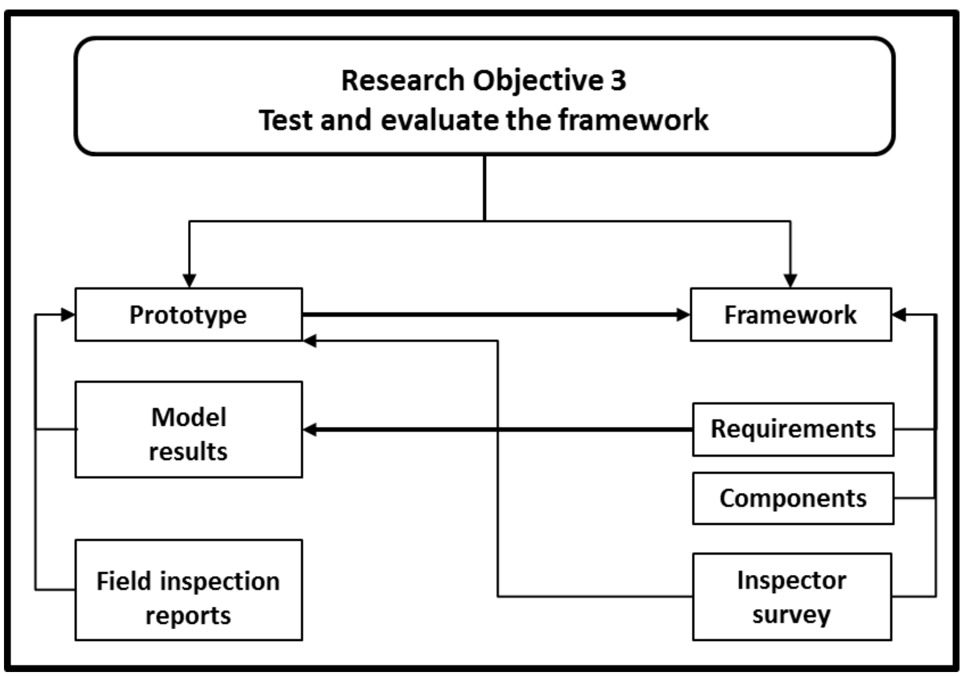

Figure 3.4 Framework evaluation aspects

An evaluation of the developed framework was carried out to determine whether or not it would provide the required support to ensure efficient and effective inspection. The framework should be able to integrate geospatial information in order to improve the building inspection process.

3.2 Implementation of Research Methodology

This section shows how the research method was implemented. In addition, the study area is defined, the data collection methods are explained and the field trips, study sample size, inspector workshop and inspector survey questionnaire are described. Finally, the implementation of the framework design through the prototype is presented.

3.2.1 Study area

This study examines the various geospatial inspection issues within the urban area of the CoR, the capital of the Kingdom of Saudi Arabia, which has a municipality responsibility in built-up areas. King Fahad District contains various building land uses: residential, commercial and mixed land use and services such as education, religion, health and government land use (see Figure 3.5).

The study area selected for this research is the CoR in Saudi Arabia, which was chosen because of the high level of observed building violations. King Fahad District was selected as the specific study area. This area is approximately one square kilometre within the CoR and comprises approximately 776 land parcels, 937 buildings and 99 streets. Moreover, it contains varying street widths and functions: residential streets of 8, 10, 12, 15 and 20 metre widths and commercial streets of 30, 36, 40 and 60 metre widths. The current building inspection process is lacking with regard to access and integration of suitable geospatial information, and hence, is not as effective as it should be. Riyadh is a rapidly growing city and the current inspection process cannot manage the monitoring of compliance that is necessary (Al-Hathloul and Mughal 2004). The building inspection department of the CoR still uses manual methods to assess building sites and detect violations. ModelBuilder is an application used by researchers to edit and mange some ArcGIS tools to assess, process, and automate the prototype process to achieve the framework design (ESRI 2013).

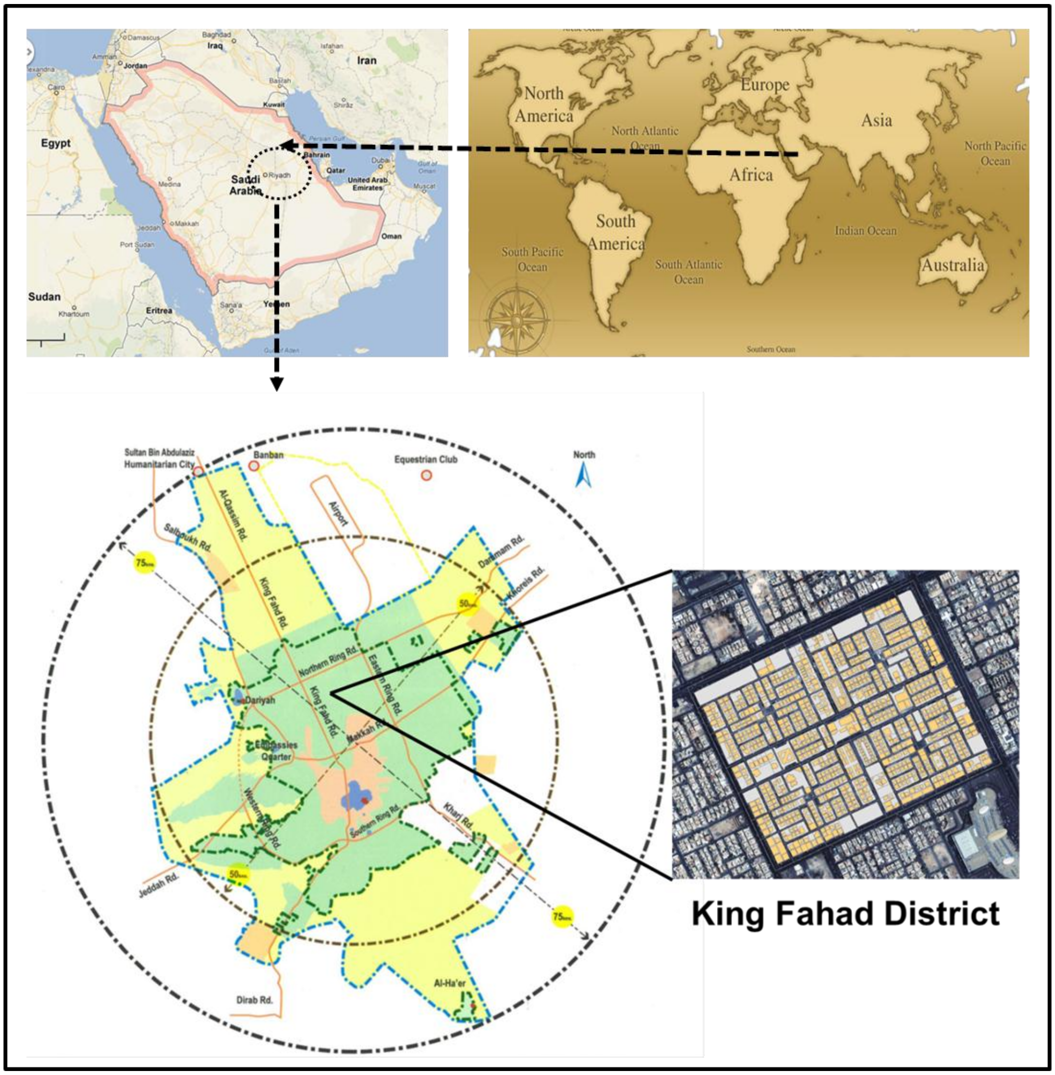

Figure 3.5 Study area: King Fahad District

3.2.2 Study design

The data collection plan involved three main steps. The first and second steps, i.e., obtaining the inspector feedback and collecting secondary data from the Riyadh Municipality, were carried out in the first field trip. The third step i.e., to validate the outcomes of the project prototype, occurred during the second trip to get the actual measurements of property (areas and dimensions), review the old inspection reports for the study area and capture the knowledge of the inspectors for particular inspection results from study area. Figure 3.6 shows these steps in detail.

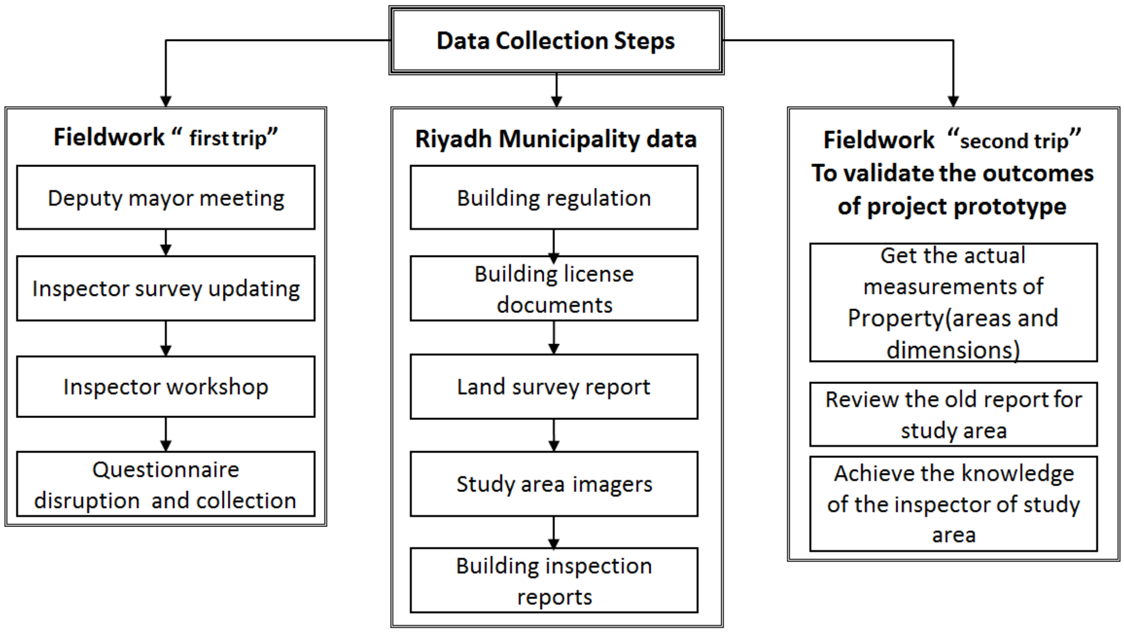

Figure 3.6 Data collection plan

This research study employed a descriptive analysis method (Garett and Sunkpho 2000) to examine the research objectives and the existing geospatial methods used for building inspections in the Riyadh Municipality. To achieve the research objectives, the research design used an experimental methodology to ensure that evidence was collected from varied sources of inspection studies. From the literature review the research identified the main issues involved in building inspections, the geospatial information that can be used in the inspection process and common building violations. This identification led to a definition of the framework requirements, the design of the framework, and testing and evaluation of the framework. The research used an inspection survey to observe the current inspection situation. In addition, this research presents recommendations and geospatial guidelines for the inspection process and building regulations compliance.

3.2.3 First field trip

Preparation before the field trips was important to ensure that all required data would be collected. This step shows the data and processes that needed to be collected and assessed during the first field trip. Preparation involved designing a draft of the inspector survey and reviewing it with supervisors, choosing the study area, identifying the data types that needed to be collected from the Riyadh Municipality such as inspection reports and images. The draft of the questionnaire was presented to the supervisors and the GIS group in the Spatial Sciences Department to obtain feedback for improving and updating the inspector survey. This stage of data collection was aimed at collecting the primary and secondary data. The data that needed to be collected in the first trip were the inspector survey and a review the field inspection report (see Section 3.2.2).

3.2.3.1 Procedure for data collection

During the first field trip, the researcher met with the deputy mayor of Riyadh and the general manager of the building inspection department to describe the purpose and aims of the research. A memorandum was sent from the deputy mayor to inspectors in the different departments that deal with building inspection explaining the purpose of this study and confirming management approval to conduct this study. A packet containing a description of the research and instructions were attached to each survey. At the beginning, a workshop was organised to explain the purpose of the research and the objective for all participants (inspectors). After the workshop and presentation, the researcher distributed the questionnaires.

The project survey was undertaken by the inspectors and consultants of the building inspection department. An effort was made to understand the requirements of everyone involved in building inspections in the Riyadh municipality. In this research, multiple sources of data were used (Schwandt 2007), including documents from national and international organisations. The data obtained on the first field trip were mainly collected from the inspectors and managers who deal with the inspection tasks. Additionally, building inspection recorders represent a key resource in this study; they were used to understand the geospatial information and how it involves different regulations in the building inspection process.

3.2.4 Riyadh Municipality inspector survey

The inspector survey used to confirm one of the experimental methods was implemented (Ezemenari, Rudqvist and Subbarao 1999; Kitchenham, Pickard and Pfleeger 1995). Thus, a comprehensive inspection survey was conducted as an important part of this research. The project survey was used to achieve the research objectives and to identify the inspection issues, including (a) process, (b) geospatial information, (c) regulations and threshold, (d) inspection data integration and (e) data quality that are used in building inspection processes.

Through the inspector survey, this research investigated the specifics of building layouts that violate building regulations, specifically, the design and implementation. Building inspections operate in a multilayered system that includes the building inspection process, geospatial information, municipal performance, building inspection department inspectors' behaviour, different users' behaviours, administrative strategies and the wider international context (Alexander et al. 2009). This study also included various aspects of teamwork, plans, events, processes and policy. In Saudi Arabia, the various stakeholders involved in design and implementation are the owners, designers, various decision makers, inspectors, constructors and suppliers.

3.2.4.1 Questionnaire design

This section explains the design of the question sections and directions that were obtained from diverse sources including the literature, Riyadh Municipality reports, a review of inspections carried out in global municipal sectors and other related sources. The aim of the inspection questionnaire was to obtain information about the inspection process, inspection workflow, implementation of geospatial information, violation detection and building regulations compliance. In addition, to design the questionnaire, the following processes were carried out and implemented: (a) creating the questionnaire draft, (b) reviewing the questionnaire with the inspection decision makers and inspection mangers, (c) updating the questionnaire, e) realising the feedback of the inspectors and (f) producing the final inspector questionnaire.

The questionnaire section solicited updated and full data that were important for developing geospatial information to support building inspections and compliance, including(a) demographic characteristics of inspectors, (b) inspection aims, (c) basic information required for the inspection job, (d) data types inspectors require before going to the site, (e) data types inspectors collect from the site, (d)building violation types, (f) current inspection performance, (g) inspection errors, (h) inspection error causes, (i) current geospatial building violation documentation methods and (j) inspection data sharing and access. See Appendix B for a sample of the questionnaire.

3.2.4.2 Population and sampling plan

The study population of this research comprised the building inspectors and building inspectors' directors who are currently working in the Riyadh Municipality. A comprehensive sample was used to recruit all building inspectors and building inspectors' directors working in the Riyadh Municipality. In this quantitative study, equal opportunities were given to all responders to the survey questionnaire (Shahi 2012). Attempts to overcome the limitations of the sampling method and to increase appropriate representation were made to ensure that a wide range of inspectors across the Riyadh Municipality were recruited. For example, the survey was distributed to the entire inspection department within the municipality and sub municipalities, and the inspection project consultancy staff. An effort was made to recruit 173 building inspectors and building inspectors' directors. However, the sampling plan was a crucial step in obtaining inspectors' opinions about geospatial inspections, because it is impossible to investigate all inspection issues and geospatial aspects. In particular, the three-dimensional aspect of geospatial inspection was excluded as being outside the scope of this project. The three-dimensional aspect was not investigated due to lack of data.

3.2.4.3 Inspector workshop and survey refinement

Generally, meetings, preliminary training sessions, pilot mapping and social surveys, user needs and requirements workshops were the main aspects that were used to introduce the project. Further, explanations were carried out on a continuing basis as the project was implemented, for example, through the interview guides when the questionnaire surveys were conducted. The workshop was intended to introduce the inspector questionnaire, the research aim and the implementation of geospatial information in building inspections. During the inspector workshop, all of the inspectors' questions were answered to clarify the concept and aim of the questionnaire and to present all of the questionnaire sections. After the workshop, the inspectors were familiar with the importance of geospatial information to support the inspection process and building regulations compliance. The questionnaire could be distributed at the activity workshop (see Appendix A).

Providing clarification on the project survey was an important part of the planning and design stage of the inspector workshop. Another important part was the development of the plan of the workshop with the decision makers in the Riyadh Municipality such as the deputy mayor, the building inspection manager and the inspection project consultant manager. The workshop took10 working days; each session was held for two hours in the morning and each group included 15–20 inspectors.

3.2.4.4 Questionnaire distribution and collection

The inspector survey was distributed after the workshop presentation. The questionnaire was handed to each inspector who then read and answered all sections. Before collecting the questionnaire, the researcher reviewed it with the inspector, explained any confusion and ensured that the inspector answered all questions. In addition, the inspectors signed the questionnaire consent form for ethical purposes.

3.2.5 Prototype implementation method

The framework was partially implemented through the prototype. The prototype was developed and implemented based on the framework design. The prototype described the steps that should be followed to implement the framework components. A data model for building inspection and violation detection was developed in the prototype. The geographic area for the prototype implementation was one square kilometre, which contained the whole study area (see Section 3.2.1). The aim of this stage was to build the geospatial rules for building inspections. Then apply an algorithm using those rules within the GIS environment to enable geospatial information support for building inspections and violation detection. Moreover, an algorithm encapsulating the geospatial rules for building inspections within the GIS environment was developed and tested during this stage.

3.2.5.1 ModelBuilder

ModelBuilder is a tool within ArcGIS that facilitates the creation, editing and management of a project model (Johnson, Maidment and Katz 2005). The ModelBuilder was used to automate the work. Using the model, the original and existing set of tasks or workflow could be maintained. The ModelBuilder was used to link some tools together to operate a violation detection building inspection based on the framework. The tools created within ModelBuilder could be added to the Arc Toolbox as a model tool to present dialog and command line windows. The benefit of using ModelBuilder tools is that they enable identification of the workflow of violation detection, implementation of the building regulations and processing of violation detection.

Figure 3.7 shows a model consisting of the elements, connectors and text labels. The ModelBuilder application provided a swift model improvement setting for the building inspection process and field equipment, inspection results, regulations implementation and the inspection geodatabase. It supported integration of all the different geospatial aspects of the building inspection process. The use of such a modelling process will help in the development of new techniques for violation detection. Moreover, the model is flexible and comprehensive based on inspection requirements.

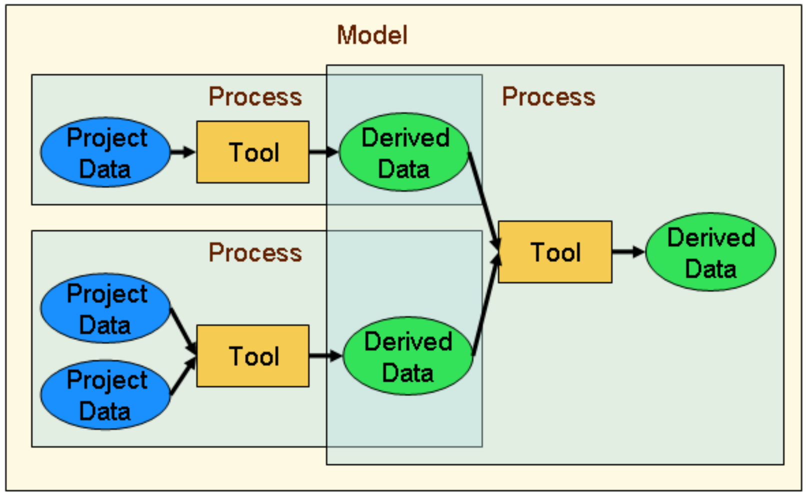

Figure 3.7 A model consisting of elements, connectors and text labels (ESRI 2006)

The activities undertaken in developing the model comprised of; (a) understanding the process, (b) testing the representation of the process, (c) development of data needed to achieve the comprehensive representation for violation types and inspection criteria, (d) validation of the result of the violation detection, (e) investigation of methods for the implementation of regulations and (f) investigation of ways in which the model can support future changes in the regulations. It contains numerous tools including some standard ArcGIS tools, script tools and model tools. Figure 3.8 shows the basic model structure and mechanism in the inspection ModelBuilder within three main steps: pre-processing the data, processing the data, and visualising and analysing the data.

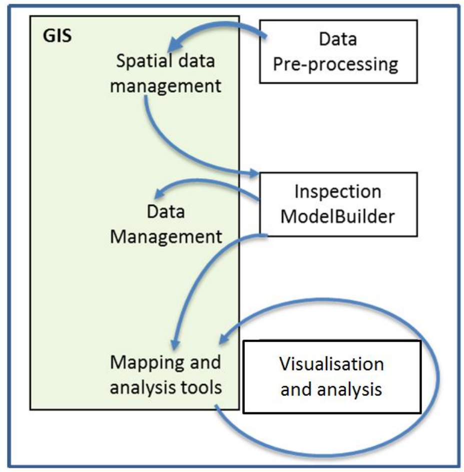

Figure 3.8 Two views of ModelBuilder project integration, after Argent (2004)

3.2.5.2 ModelBuilder geodatabase

Within ModelBuilder, a geodatabase was built to support the research solution and geospatial inspection framework. All the required data to demonstrate the violation detection process were integrated into the model geodatabase. The geodatabase stored and managed the framework components data. It created a data repository and combined the building inspection geospatial data with the database. Geospatial datasets use various digital maps and high-resolution satellite imagery. These data reflected the real data that affected the building inspection process in the Riyadh Municipality. Attributes associated with each feature were stored in the same table. The geodatabase held building and cadastre measurements, geometric networks, models, feature classes and tables. More details of the geodatabase structure can be found in Appendix E.

3.2.6 Data quality assessment

The prototype shows the framework data quality assessment. The images used in this research were obtained from the Riyadh Municipality; the imagery was produced in 2002 from aerial photography and the simulation data from imagery captured by the cadastre data from land subdivision plans. The first image source has a high accuracy image source scale of 1:2500 with (± 2.85m^2) metre square (m^2) area error ranges and (± 7.45cm) centimetre distance error ranges. The second image source has allowed an accuracy image source scale of1:5000 with (± 5.7m^2) area error ranges and (±17.60cm) distance error ranges. For more details about the source of aerial photograph, image pre-processing procedures and results, and the procedures for calculating error source described in this section can be found in (Section 5.2.32). Table 3.1 shows summary error of the imagery (City of Riyadh 2002).

Table 3.1 Summary error of the imagery

Elements Checked	:	6512
Total Warning/Errors	:	252
Improper Nodes	:	10
Duplicate Segments	:	12
XY Slivers	:	15
Z Spikes	:	5
XY Spikes	:	21
Z Residuals	:	6
Level Features	:	21
Duplicate Points	:	13
Short (Isolated) Elements	:	5
Different Features at Joins	:	7
Directionality	:	18
Uphill Drainage	:	3
Hanging End Point	:	48
Unmatched Construction Lines	:	50
Closed Features	:	18

3.2.7 Second field trip

Figure 3.6 presented the third step of data collection, which was to collect the actual measurements of construction features such as areas and dimensions from the field to test and evaluate the framework (see Section 3.1.1.4). The field inspection report is one of the framework evaluation aspects. The field inspection report in this stage checked the site construction details, for example, the features and measurements such as the building footprint, cadastre boundary, areas and dimensions. These geospatial data were used to prove the prototype outcomes and to test and evaluate the violation detection results of the module based on the actual measurements in the field inspection reports.

3.3 Data Management and Analysis

Microsoft Excel was utilised for the inspector survey data entry. Error-checking routines were created as part of the database application. Data were entered twice and cross-checked. The Statistical Program for Social Sciences (SPSS) Version 17 was used for data analysis. Data analysis began with preparatory activities such as the treatment of missing data, identification of outliers, and other such data-cleaning tasks (Aitchison 1982).

3.4 Chapter Summary

This chapter has presented in detail the research methodology used to achieve the research objectives. It included (1) an overview of the methodology used to identify the inspection issues of processes, building regulations and geospatial information; (2) design and develop the inspection framework; implement the prototype; and (3) develop a logical method to test and evaluate the building inspection framework. The chapter included an introduction to the study area, study design, a description of the data collection methods, fieldwork, inspection survey, and questionnaire design, distribution and collection. Finally, data management and analysis were defined in this chapter.

4 INSPECTION ISSUES AND FRAMEWORK REQUIREMENTS

This chapter describes in detail the inspector survey that was conducted during the first field trip (see Section 3.2.4). It presents the building inspection issues extracted from the inspector survey, municipality reports and literature. Further, this chapter presents the framework requirements that were used as guidelines to design the framework.

4.1 Inspector Survey Results and Issues

The inspector survey revealed a range of issues related to the building inspection process. These issues assisted with the design of the inspection framework components. They include the various features of the inspection framework and were used as a guide to design the building inspection, further understand and identify the requirements, and design and evaluate the framework.

4.1.1 Description of the questionnaire sample and demographic data

The survey target was a sample of building inspectors in the Riyadh Municipality, Saudi Arabia. Copies of the survey document were distributed to 173 building inspectors. A total of 143 questionnaires were returned. Among these returned questionnaires, 15 were excluded because they had missing responses in more than one section of the questionnaire. The total response rate for this research was about 83%.

Table 4.1 shows the demographic data characteristics and experience with different software such as AutoCAD, MicroStation, ArcGIS and Excel obtained from 128 subjects. Regarding the education level of participants, the majority (n=106 or 82.8%) had obtained a diploma after high school, Less than one % (n=1) of the inspectors had an intermediate degree and 12.5% (n=16) had a bachelor’s degree. Five respondents (3.91%) had graduated from high school, With regard to the length of time the inspectors had worked in the inspection profession, 71.9% (n=92) had worked between one and 10 years, 11.7% (n=15) had worked 11–20 years 9.38% (n=12) had worked for more than 21 years, and seven %(n=9) had worked for less than one year. The participants' positions included field inspectors 75.8% (n=97), inspection managers 14.8% (n= 19), heads of inspection department 8.6%, (n=11), and building plan approval officer, 0.8% (n=1). Responses based on which department they were currently working in were as follows: building inspection department in the sub-municipality, 52.3% (n=67), building inspection consultant 21.2% (n=27), building permit department 11.7% (n=15), central department of building inspection, 7.8% (n=10), and main municipality office 7% (n=9). Therefore, from the survey sample, an appropriate response was obtained from a range of inspectors; the sample covers all education levels, most of the departments in which the inspectors' work, and the actual work and experience of the inspectors.

Table 4.1 is important and relevant to the SEBI framework for several reasons: it helps to ensure proper understanding of the use of the SEBI framework, to give an idea about the inspector's knowledge such as the spatial data experience and to recognize the background and experience of the inspector about the GIS software. In addition, demographic data is necessary to understand the main concept of the SEBI framework and help to design the inspection model.

The inspectors' experience with GIS software and databases indicates that about 50% of inspectors do not use AutoCAD software; 88% of inspectors do not use MicroStation software and about 80% do not use ArcGIS software. Experience with Excel is either moderate or extensive for 49% of the inspectors, 65% of inspectors do not use Access databases while experience with Oracle databases is either moderate or extensive for 14%. Usage of GIS software and databases to support building inspection is inadequate; AutoCAD software is used more than other software because building licences, building design and land subdivisions are produced by AutoCAD software. However, experience and usage of databases are limited as well, except for Excel software, which is used to a slight degree because most of the inspectors had have training in its use and they used it in a few cases to interpret some of the inspection reports. Hence, these results showed the limitation in the use of both software and databases for inspections. This limitation affects the final product of violation detection, such as the violation type and measurements. The limitation also affects the outcomes representation of the actual construction AB, such as the quality and final product of inspection.

Table 4.1 Frequencies and percentages of demographic variable

Demographic variables			**Frequency**	**Percentage**
Level of education	Intermediate school		1	0.78
	High school		5	3.91
	Diploma after high school		106	82.81
	Bachelor’s degree		16	12.5
		Total	**128**	**100**
Experience	< 1 yr		9	7.03
	1–10yrs		92	71.87
	11–20 yrs		15	11.72
	21+ yrs.		12	9.38
		Total	**128**	**100**
Nature of work	Head of inspection dept.		11	8.59
	Inspection management		19	14.84
	Field inspector		97	75.78
	Building plans approval officer		1	0.79
		Total	**128**	**100**
Current department	Main municipality office		9	7.03
	Sub-municipality		67	52.34
	Building permit dept.		15	11.72
	Central dept. of building inspection		10	7.81
	Building inspection consultant		27	21.1
		Total	**128**	**100**
Experience with AutoCAD	Do not use it		61	47.65
	Limited		29	22.66
	Moderate		21	16.41
	Extensive		17	13.28

		Total	**128**	**100**
Experience with MicroStation	Do not use it		113	88.28
	Limited		4	3.13
	Moderate		8	6.25
	Extensive		3	2.34
		Total	**128**	**100**
Experience with ArcGIS	Do not use it		100	78.13
	Limited		5	3.91
	Moderate		15	11.72
	Extensive		8	6.24
		Total	**128**	**100**
Experience with Excel	Do not use it		45	35.16
	Limited		20	15.62
	Moderate		41	32.03
	Extensive		22	17.19
		Total	**128**	**100**
Experience with Access	Do not use it		83	64.84
	Limited		8	6.25
	Moderate		14	10.94
	Extensive		23	17.97
		Total	**128**	**100**
Experience with Oracle	Do not use it		101	78.91
	Limited		9	7.02
	Moderate		4	3.13
	Extensive		14	10.94
		Total	**128**	**100**

4.1.2. Common building violations

Josephson (1999) has indicated that violation detection on construction sites can be categorised as follows: violation in the early phases, violation on site and in design, and violation in materials or machines. About 75 % of the inspectors reported violations have happened on site and during the redesigning of building plans after the original has been approved (see Section 2.1.5). According to May (2004), detection of building violations is one of the most important potential motivations for compliance. The annual inspection report confirms noncompliance of land use and approval plans at about 92.3%. Previous municipality inspection reports reveal the types of violations commonly found in the CoR (City of Riyadh 2008). Figure 4.1 shows the results of a review of about 80 reports on common building violations found in Riyadh. Construction sites without building approval plans were identified as the highest violation type at 59% of all violations. Other relatively common violations, occurring in 5 to 11 % of all violations, included noncompliance with allowable land uses, building footprint areas greater than the allowable coverage area of the land parcel, building setback distances less than the minimum required measures, not adhering to approval plans and noncompliance with regulations regarding inappropriate views from building windows.

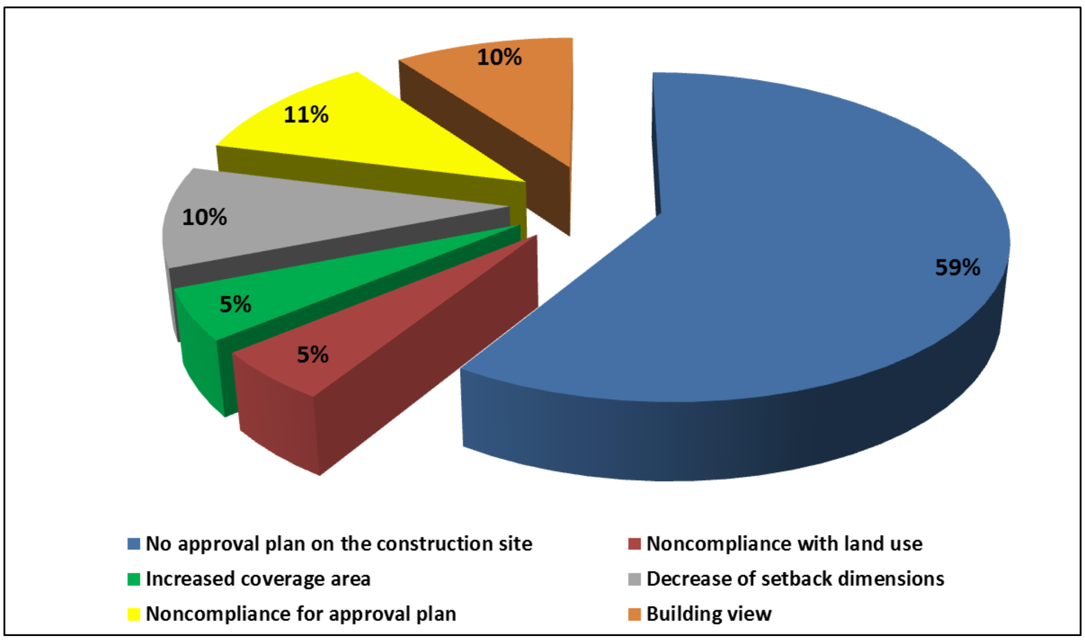

Figure 4.1 Building violations types (City of Riyadh 2008)

The inspector survey revealed the proportion of inspectors that identified particular violations occurring often or very often (see Figure 4.2). Overall, the number of violations is high, and the types of violations are varied. Only a few types, such as buildings without licences or inappropriate elevations, occurred relatively few times. Violations that were high in frequency included not adhering to approval plans (77.3 %);

violations occurring after construction completion, over large areas for upper annex (90.6 %) and over large areas for the main building footprint (56.3 %); and building side and rear setback distances less than the minimum regulation requirements.

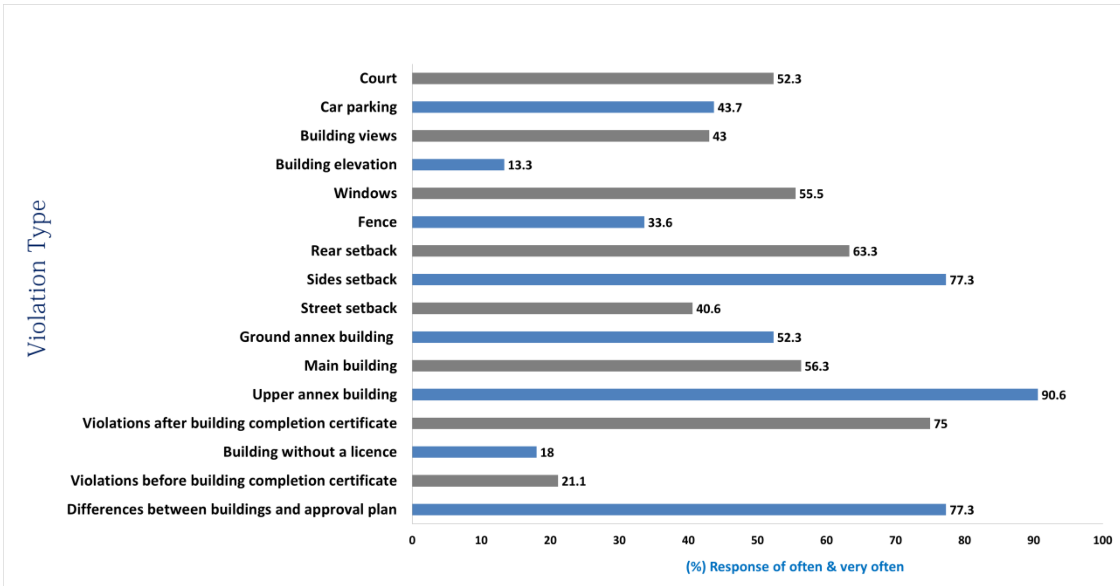

Figure 4.2 Percentage of inspectors that identified particular violations occurring often or very often

The percentage of building violations that occurred before a completion certificate was granted was 21.1%; this is low because there are regular site inspections. Violation after a completion certificate was issued was 75%; this is higher because there is no scheduled site inspection after a completion certificate except if there is a complaint from the neighbours. Main building, ground annex building and street setback violations occur less frequently because these are easy to detect and are watched by the inspector. The average invisible violations were upper annex building, side setback and rear setback violations; these occur frequently because they need more time and concentration to detect. According to Alterkawi (2005), the frequency of building violations in Riyadh has increased in the last few years. This proliferation constitutes a serious breach of the regulations and legislation concerning organisations and city buildings.

Therefore, the greatest number of building violations are those that occur after a completion certificate is granted. Low violation frequencies were those occurring before the completion certificate and were visible, such as the street setback. Building violations have increased in various quantitative and qualitative directions. The purpose of the survey on violation types was to confirm which violation types are most commonly encountered, to refine and confirm the violation types found in the literature and to decide which violations were to be addressed in this research and implemented within the project prototype. For example, the buildings coverage area and various types of building setbacks. Further, the violation types and detection were used to support the evaluation of the framework.

4.1.3 Inspection data accessibility and integration

This section discusses the second type of inspection issue: inspection data accessibility and integration (see Section 3.1.1). The inspector survey revealed a number of additional issues related to the availability of data to support inspections and the processes that underpin the inspection workflows. For example, only 22.7% of inspectors indicated that they had access to digital map data to identify the current stage of construction, 37.5% could access building background information prior to performing an on-site inspection and 55.5% reviewed the history of violations prior to conducting an inspection. These results indicated that poor accessibility by inspectors to appropriate data, insufficient access to tools to integrate information and assess compliance, and insufficient information to ascertain the quality of a decision, reduce the amount of fieldwork required and assist in making decisions. The net effect is that either the inspections are incomplete or they do not actually eventuate, generating a greater level of noncompliance and risk due to violations not being attended to.

With regard to the inspection process, the surveys revealed that 52.3% of inspectors felt that the current process clearly defined the inspection criteria. The percentage of inspectors who felt that the processes adequately supported the inspection job between clients and the builder was 26.6%. These figures indicate that not only are the inspection processes not well supported by necessary geospatial data, but the processes themselves are either not clearly defined or not clearly understood by the inspectors who use them. Figure 4.3 shows weaknesses of inspection data integration such as the construction attribute based on the building licence and actual construction, for example the measurements of setback dimension, cadastre dimensions, the areas of buildings and street width. Therefore, this kind of missing integration firstly, affects the WFoI and, secondly, affects the inspection detection results.

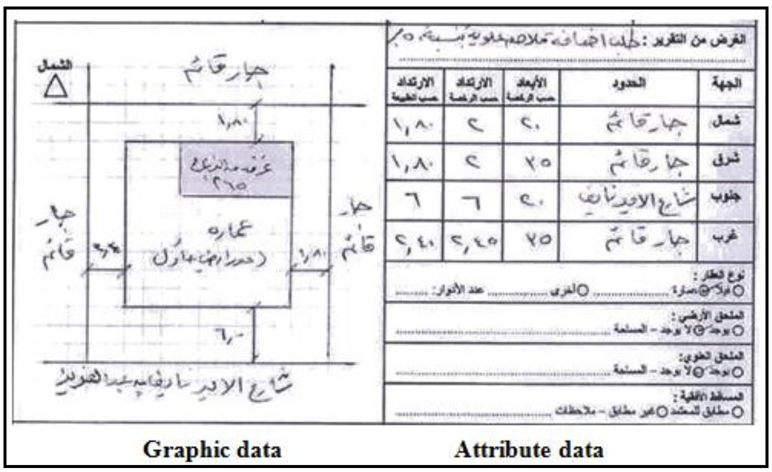

Figure 4.3 Example of weaknesses of inspection data integration

4.1.4 Geospatial data integration and usage

Despite the availability of some digital format production techniques in different departments, such as the building licence and land survey departments, none of these techniques were available for Riyadh inspectors to improve the inspection process and quality of violation detection. From the survey conducted, only 4.7% of the inspectors thought that the support for GIS applications and techniques in their department was adequate, less than 27.9% received support for the GIS applications and techniques in the inspection department and 62% of the inspectors confirmed that they had no access to GIS applications and techniques as part of their job. Instead of being able to integrate data within a common system such as a GIS, current practices rely on traditional methods to prepare for inspections. For example, the usage of traditional methods for reporting a violation includes 95.5% in the current process and 72.2% allow freehand drawing to store inspection data. However, current methods support usage of aerial photography (17.2%) and satellite imagery (18.8%) in the inspection workflow. In addition, more than 80% of inspectors suggested that the efficiency of the current process of inspection using the geospatial information for inspections was low.

For example, 95.5% of inspectors use paper-based site photography and 72.2% use freehand drawings to obtain information and record inspection outcomes, whereas only 17.2% use digital aerial photography and 18.8%use satellite imagery to inform their inspections. The result is that most inspectors are unable to access and integrate data easily for a particular inspection target, and further, they are unable to communicate inspection outcomes in a form easily accessed by others and integrated with existing data.

The survey revealed that 80% of inspectors feel that the availability of required geospatial information is poor, less than 5% of inspectors thought that geospatial information support is sufficient, and 73% indicated that the current processes using geospatial information are inadequate. According to Akinci et al. (2006), to perform appropriate monitoring during construction, and to improve violation detection, it is necessary to have effective tools such as geospatial information to support the visualisation of construction defects. However, the findings of this study overlapped with those reported by Liao, Liu and Zhao (2009), which showed that some inspectors tend to use their experience and knowledge of the building codes and regulations rather than new techniques such as digital maps and databases.

Therefore, building inspections in the Riyadh Municipality do not improve because there is no integration between inspection data and management techniques in the construction site and the interactions among inspection data differ across the three main stages: before, during and after the inspection job. All these stages are extremely important, but current inspection performance does not support interaction between them. Deficient GIS support in the inspection department causes weaknesses in inspection performance. The existing geospatial information in the inspection process does not provide sufficient support for the inspection job. Further, limited support for geospatial information during the inspection affects the accuracy of results and the output of the inspection report. The lack of integration of geospatial data affects the accuracy and measurement of the actual construction and violation detection due to limited access to geospatial information in both the building licence department and the surveying department in the Riyadh Municipality.

4.1.5 Inspection data quality

The findings of the survey indicate that 73.4% of the inspectors believe that the current geospatial data are not capable of providing adequate quality of inspection data and that there is a lack of quality in the inspection and defect management system (see Section 2.2.2). For example, Figure 4.4 shows an example of the lack of quality in the data currently used for inspections. This is an example of the basic form of geospatial information that is provided to the inspector in hard copy during the inspection process. The minimum quality level required for an inspection, such as measurements of building construction and cadastre, is lacking. According to Kamat et al. (2010), to develop monitoring during construction and improve violation detection, it is necessary to have more effective tools such as geospatial information to support visualisation of construction defects. Thus, high-quality inspection data will support final decisions on violations by detecting the violation, determining the violation class and reducing uncertainty about detection outcomes.

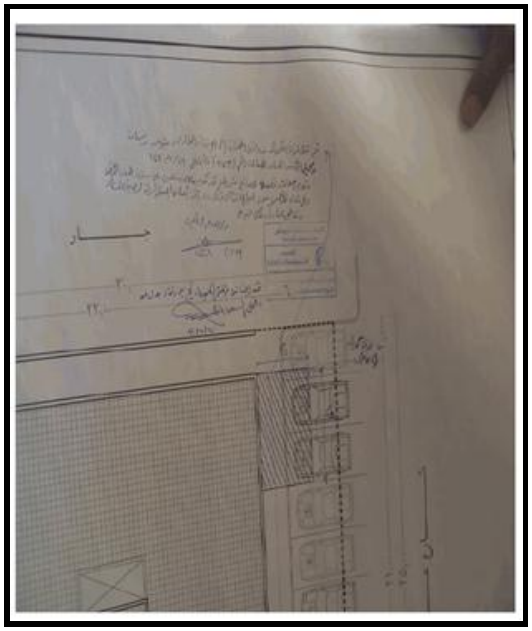

Figure 4.4 Sample of an approval plan used during inspection

According to Zhi (1995), weak geospatial support in construction inspections and monitoring of building regulations and construction standards affects the quality of the inspections. Geospatial information supports the efficiency and effectiveness of the inspection process (Abdullah and Thai 2006). However, the current processes do not implement good quality data sources for inspection. For example, the production of a digital map in the current detection process was used by 34.3% and Excel spread sheet 15.4% of inspectors. The survey results indicate that appropriate quality standards of input data for inspections are not available.

Figure 4.5 shows an example of inspection data in a current inspection report in the Riyadh Municipality failing to present the real conditions of violation. Further, this example shows the poor quality of current inspection data, such as the poor presentation of the inspection outcomes and the absence of essential measurements of violation, which causes essential data that are required to detect and report the violation to be missed.

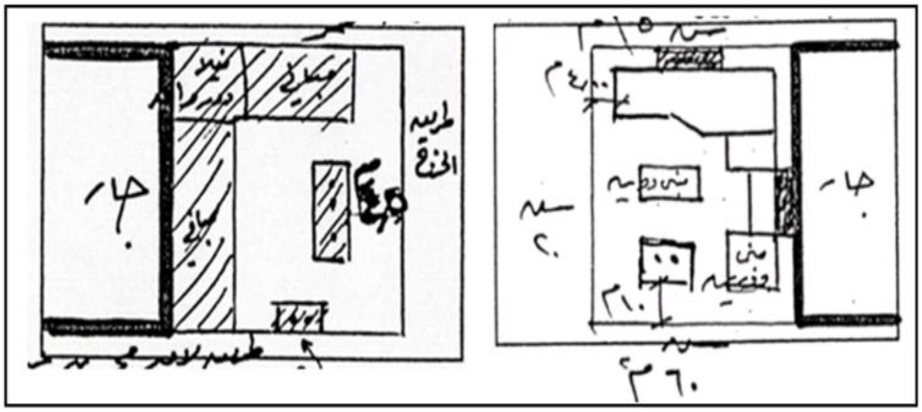

Figure 4.5 Sample of inspection data quality in the Riyadh Municipality

Thus, the inspection data quality in the CoR is not capable of providing basic information such as measurements and features to support decisions about violation detection results. The efficiency of geospatial information in the current process is not adequate and not capable of supporting quality aspects during the WFoI process. The current system does not give the inspector sufficient quality data to be used as input data of inspection. The quality of the current inspection information is not satisfactory; this is because of the limitation of geospatial inspection. Finally, the quality of violation detection outcomes is poor and does not provide clear information for decision makers.

4.1.6 Inspection workflow

Figure 4.6shows triggers or reasons for initiating an inspection: inspections based on an order from the department manager (78.9%) inspections based on complaints from neighbours (75%) issuing certificates on completion of construction at 71.9% and, finally, inspection based on order of the building owner at 36.7%. The results of the questionnaire indicate that the current inspection process is not organised and some locations are not inspected until the order comes from outside of the inspection department. In some cases, the inspection process does not apply, or no building inspection occurs unless the building owner orders the building completion certificate or it is based on the order of the department manager. Hence, the current inspection process lacks flow through the building construction process in all stages.

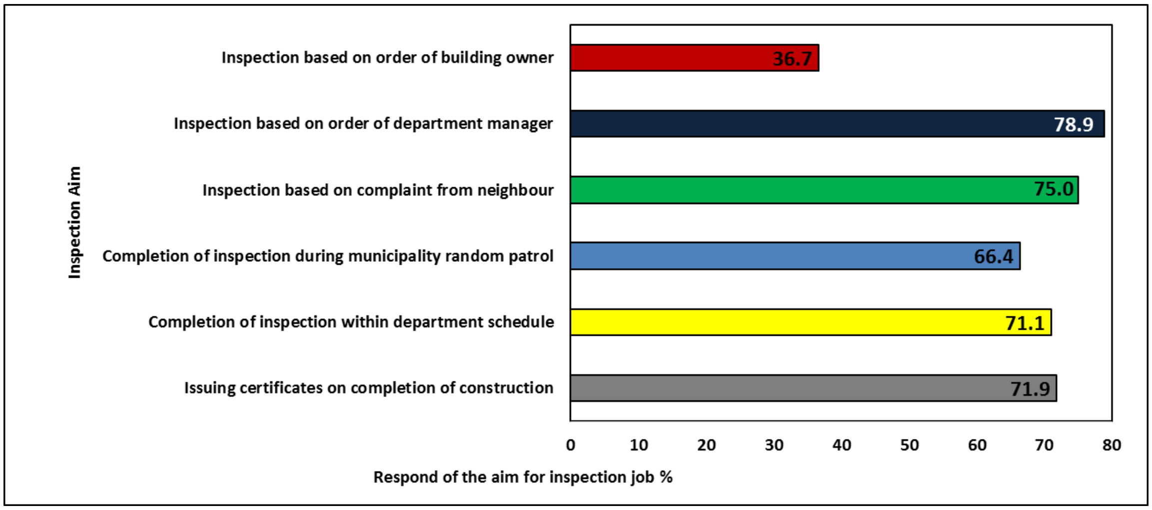

Figure 4.6 Triggers or reasons for initiating an inspection

Some of the inspection errors were issues related to lack of skill, lack of knowledge and lack of care of the operation site, unclear or missing project information and low quality design. Figure 4.7 shows the percentage of times that the error arose among all inspections. The highest number of errors during inspection was 53.9% arose from the calculation of violation areas and dimensions of buildings and cadaster 43.8% of inspection errors arose from difficulty of documentation of site violations. Therefore, the current inspection process is unable to provide accurate measurements for construction features to determine building violations. Inspection errors indicate that there are some weaknesses and some missing stages in the workflow of the inspection process, or that these stages are not applied step by step in the inspection process. Error and the omissions of inspection are a result of the missing non-implementation of spatial information for WFoI.

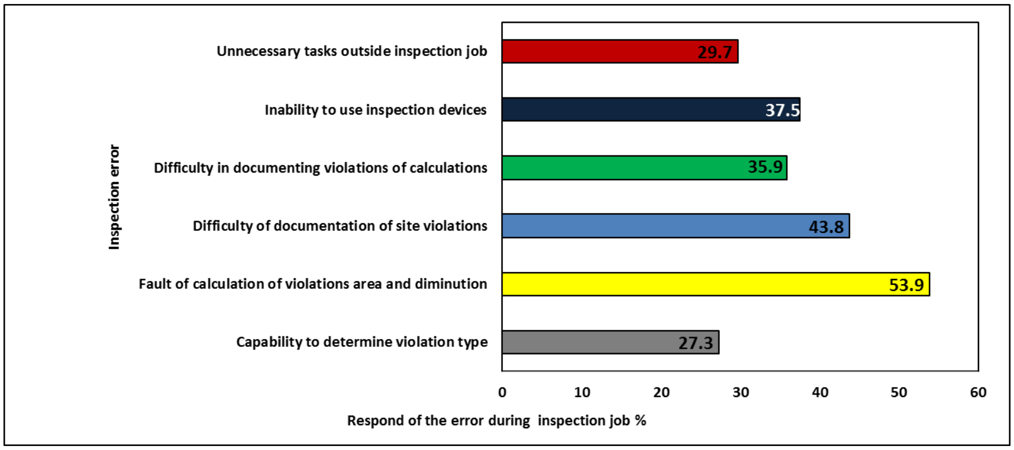

Figure 4.7 Percentages of times that error arise in among all inspections

The description and analysis of current inspection performance is important for outlining the workflow issues that need to be addressed and implemented in the framework components. Table 4.2 shows the frequency of the answer ‘agree’ in the inspection performance section of the survey. This section covers both the process and the technical aspects, for example, the required process and spatial information provided within the current process. The percentage of inspectors who confirmed that the current inspection process helps in their daily inspection work was 64.1%; therefore, some inspectors still consider the current process is working well. The percentage of inspectors who disagree about the ability of the current process to support the construction industry to detect building violations was 83.59%, while 73.44% of the inspectors disagreed about the capability of the current process to support communication between clients and the main contractor to improve violation detections. About 50% of the inspectors indicated that the inspection criteria are not clearly defined in current processes, and only 16.4% of the inspectors stated that the construction industry accepts the current processes. Only 39.8% of the inspectors indicated that the current processes are adequate. As a consequence, the current inspection process is not adequate, and therefore, some essential processes of inspection are omitted. This results in inspection errors, lack of violation detection and non-compliance of building regulations.

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Table 4.2 Inspection performance

Inspection characteristics	Percentages Frequency of agreement
Inspection helps in daily inspection work	64.1
Processes reflect inspection ability in real situation	63.3
Inspection criteria are clearly defined in current processes	52.3
Processes helpful in supporting inspection job between main office and sub municipality	47.7
Processes useful in managing defect documentation	46.1
Process helps to select and implement all inspection processes	45.3
Processes save time when returning to the office	43.4
Processes interact well with other programs	42.2
Geospatial inspection information is well provided for in system	41.8
Processes are increasing speed of the inspection job	40.61
Processes are well organised	39.8
Process of sorting out data with current inspection processes is useful	39.2
Processes are flexible when choosing most appropriate options	37.5
Processes useful in supporting job between clients and main contractor	26.6

The inspectION survey revealed some significant inspection issues that are affecting construction monitoring and building regulations implementation on construction sites. Some violation types are commonly encountered and faced daily by the inspectors, such as increasing the coverage area of a building and decreasing the setback dimensions. Implementation and access to geospatial data are insufficient, so the results of violation detection are inaccurate and do not present the actual violation attributes such as measurements. The satisfaction of inspection stakeholders about the quality of inspection data input and the detection outcomes is low and not helpful for decision makers. Finally, the omissions and unorganized inspection process affect the outcomes of the WFoI.

4.2 Framework Requirements

Addressing the second research objective involved designing a geospatially enabled framework to support building inspections and compliance to address the requirements identified in Section 2.1.3. Identifying the requirements is helpful for gathering, understanding, reviewing and articulating the needs of stakeholders at all stages of the framework. To implement the inspection process, it is necessary to cater for all basic requirements and represent them to achieve all inspection activities (Sunkpho 2002).

During the detection and identification of violations, the framework should allow for a higher level of detection, determination, identification, classification and categorisation of building violations. Also to include all the violations within the scope of the research. For inspection data accessibility and integration, the requirements support the integration of data and measurements preserve and realise the building regulations for inspection, as well as to insure implementation of building regulations in the inspection process, integration of features and measurements information. To endorse geospatial data integration and usage, the requirements aim to insure that all geospatial data from various data sources are integrated. The requirements support the assessment and implementation of data quality, the quality of the inspection data source, the quality of inspection data that are collected from the site, and the quality of testing and evaluation of the data for decision making. For the workflow inspection process, the requirements provide integration of all inspection processes and solve the weaknesses in the current inspection workflow. The following section describes the framework requirements in detail.

4.2.1 Ability to determine and classify building violations

One of the important issues facing the inspector on a construction site is determining and identifying building violations. The framework covers a range of violations related to geospatial aspects. One of the advantages of determining building violations is solving the issue of noncompliance with building regulations at an early stage (see Section 2.1.5). The other advantage in determining and classifying building violations is that it assists in making appropriate decisions about managing violations and deciding whether the violation type will affect the construction in the future, or may cause other violations. Certain questions should be answered by this sub requirement, such as how to determine a building violation, how to classify the violation and how to describe the violation type. In addition to the classification, the violation group to which it belongs needs to be determined, for example, coverage area or setback dimension violations.

4.2.2 Integration of features and measurements

Data integration renders the inspection information reliable and efficient (see Section 2.3). As a result of integration, the core data for inspection can be extracted from cadastral and building data. Integration in this requirement includes the integration of features, measurements and data that relate to the cadastre and buildings. The first part of the integration is the cadastre data integration, such as the cadastre surveying report and the land subdivision plan (see Section 2.1.2). The main data in the surveying report are measurement data such as the cadastre area, dimensions, road centreline, street width and land topology. Integration of cadastre measurements and information between different elements is one of the most important components to use as a base for building inspections and violation detection. This is because the measurements are applied from the early stage of construction and inspection.

The second part of integration is the building data integration. The building licence and approval plan are the core resources for the building inspection tasks. These documents should not be separated from the others because the core information is linked, particularly the geospatial information (see Section 2.1.4). The geospatial data are included in the building licence and approval plan documents to define accurate measurements for the building footprint area and dimensions. This document shows the formal agreement between the building owner and the municipality. The importance of these documents comes from the quantity of the data within them, which the inspector needs to complete the inspection; they contain vital data to assess and construct the inspection process and provide the required data for all processes of the WFoI.

Consequently, the integration of data from the cadastre and building data supports building inspections and violation detection. Further, integration of measurement requirements supports and facilitates the data captured from cadastre and building data, such as building licences, approval plans and cadastre surveying reports. Moreover, this requirement increases data control of the inspection process, applies building regulations and provides geospatial data solutions for building inspections and building violation detection.

4.2.3 Applying inspection data quality

The framework requirements' quality component ensures that processing, recording and distribution of the inspection data will follow the inspection requirements and principles. Since building inspection generates a large amount of data, the quality requirement component should be implemented at different inspection stages to ensure the data accuracy (see Section 2.2.2). The three components of quality are quality of data sources, quality of field data and quality of final data product. The data quality of building inspection and violation detection improves the ability of the framework components to enhance the geospatial method for building inspections and regulation compliance.

Therefore, data management deals with a huge amount of inspection data and accurate measurements of construction. However, recognition about the needs of inspection data quality in the current inspection process is still very low in the Riyadh Municipality (see Section 4.1.5). Accordingly, all inspection data in the individual processes should be managed in all tasks: preparing, collecting, assessing, presenting and reporting for all inspection stakeholders. Inspection data quality is important for the inspection to be able to support the decision maker about validation of violation detection results.

4.2.4 Adherence to building regulations performance and maintaining workflow of inspection in the required sequence

First, building regulations and thresholds are defined within the framework to support the detection of all violation types. Adherence to building regulations performance are implemented through the framework based on various processes: identifying the data source of regulations and threshold, providing measures for all of the building components such as area and dimensions, determining the threshold and choice of regulations, checking the actual construction based on building regulations (see Section

2.1.4). Hence, the adherence of building regulations in the framework is essential for the geospatial information to support the inspection process; this is because most building regulation information is geospatial. The core perception in the regulations enhancement is to achieve the geospatial aspects of the inspection process and support choosing and coding the threshold.

Secondly, one advantage of applying framework requirements is to ensure the implementation of all required inspection tasks and processes in the required order. Performance and maintenance of the WFoI requirement support the framework for the entire cycle of inspection during the life of the building. Further, protecting the sequence ensures that the inspection workflow is satisfactory. This is because every new step of the inspection requires that the previous step be finished, as such as the information can be used for new tasks and the existing violations can be managed at the previous stages (see Section 4.1.6). Therefore, this requirement provides a good tracking concept of the inspection process and WFoI, and automates the inspection data within the geospatial environment. Further, it improves the ability to automate the field and inspection data and track the progress of inspection data on the construction site. This requirement supports the sequence of the WFoI without missing any steps of the process, and maintains the missing data and/or ignoring any steps of WFoI.

4.3 Chapter Summary

This chapter has described the inspector survey demographic data characteristics. This chapter has identified building violations, including spatial aspects and other violations. It defined the issues that were identified from the literature, municipality reports and inspector survey. The building inspection issues identified in this chapter were (a) identification of building violations, (b) inspection data accessibility and integration, (c) geospatial data integration and usage, (d) inspection data quality, and (e) WFoI. In addition, this chapter defined the following framework requirements: (a) ability to determine and classify building violations, (b) integration of features and measurements, (c) application of inspection data quality, and (d) adherence to building regulations performance and maintenance of WFoI in the required sequence. The first research objective was partly defined in this chapter, and the issues and requirements were used as guides to design, develop and evaluate the framework, as discussed in the next chapter.

5 A SPATIALLY ENABLED INSPECTION FRAMEWORK

The specification-modelling framework and the developed reasoning mechanisms are believed to be an important piece for the future automation of inspection planning and defect detection in the construction industry (Boukamp 2006, 147).

This chapter discusses the design of the framework used to enhance the use of geospatial data in building inspections and the partial implementation of the framework as a prototype. The presentation of the prototype design and implementation covers the function of the different framework sections based on the collective inspection issues essential for the development and design of the framework. These issues were discussed in Chapter 4, as were the requirements for a generic inspection framework.

5.1 Framework Design

In order to design a building inspection framework it is necessary to understand the current building inspection process, the importance of improving the process to achieve the aims of inspection (see Section 2.1.1) and to cover the relevant issues in the current inspection process (see Section 4.1). This improvement can be obtained through the use of spatially enabled building inspection methods. The framework designed in this study enhances the effectiveness and efficiency of the building inspection WFoI (see Section 4.3.5). It employs spatial methods to improve the traditional inspection processes (see Section 5.2 below).

The Spatially Enabled Building Inspection (SEBI) framework designed in this study allows the determination and classification of building violations, the integration of features and measurements, the maintenance of inspection data quality and adherence to building regulation performance, while maintaining the WFoI in the required sequence. To address the issues regarding the lack of support within the current inspection process, a framework was developed to provide the spatial information and integration tasks necessary to support decisions regarding building violations. In addition, the framework contains modules for capturing and extracting the required data, preparing the data by identifying thresholds and violation class types, violation detection determination, quality assessment and inspection reporting.

The modules of the SEBI framework are supported by the integration of geospatial and non-geospatial data. The SEBI framework presents and contains input data, processes, techniques, data quality and integration, building regulations and inspection criteria and data output. Further, the SEBI framework supports and provides data for all stages of the inspection task(see Sections 2.1.2 and 2.5): inspection planning, job design, task data preparation, job implementation on-site, and inspection job data processing and quality assessment. The workflow process of inspection and information within the SEBI framework should be clear as it is based on the inspection criteria and designed to assist the inspector implement building regulations and perform building violation detection. The framework structure was designed with respect to the main steps of the workflow (see Section 3.1.4) and different national and international examples of inspection frameworks.

The SEBI framework allows interaction between the different modules to achieve the final inspection through various inspection stages. It maintains inspection issues within the geospatial environment by using GIS tools to execute building inspection, violation detection and regulation compliance. Figure 5.1 illustrates the high-level architecture of a SEBI framework containing five modules: (a) inspection of input data, (b) data preparation, (c) quality assessment, (d) violation detection and (g) reporting.

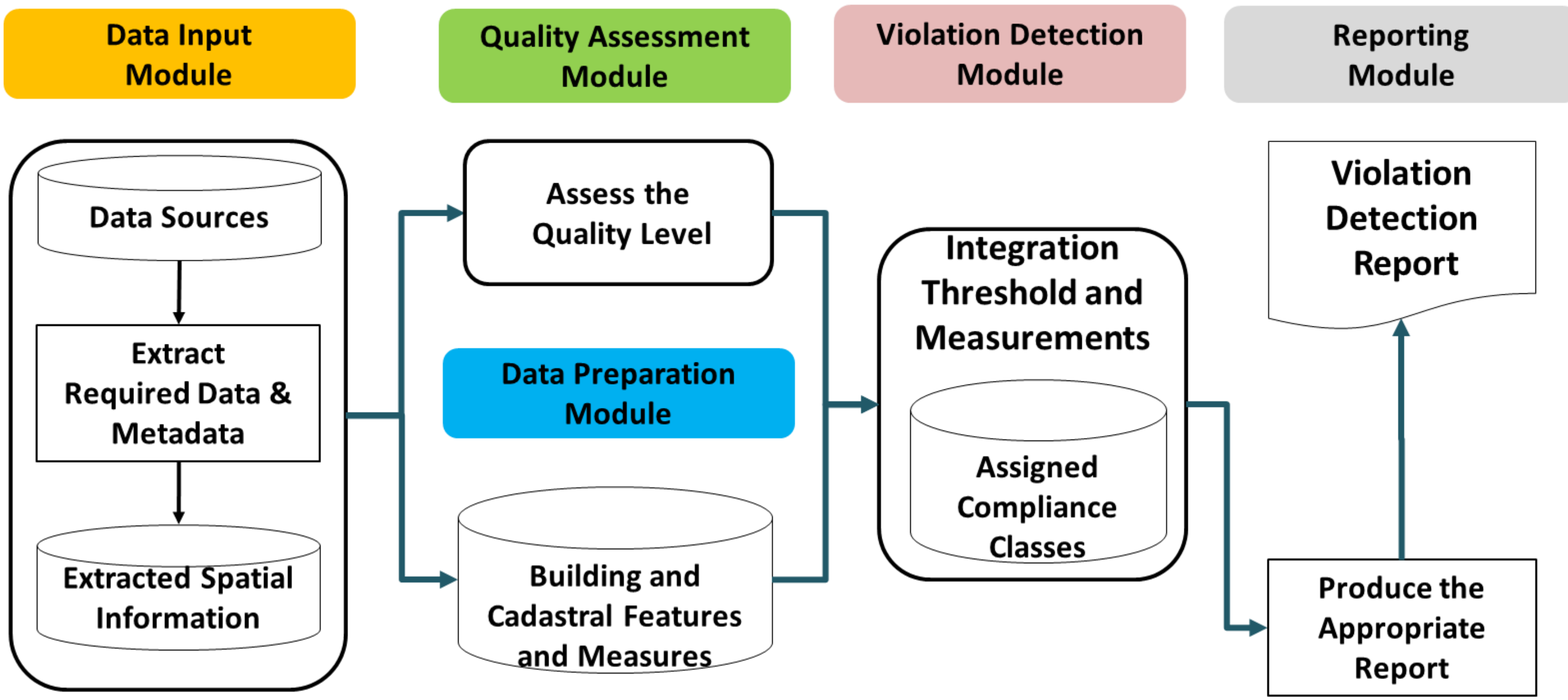


Figure 5.1 SEBI framework architecture

5.1.1 The inspection data input module

The inspection data input module recognises data from multiple sources that are required or able to support the inspection process. For each dataset entered, the appropriate information and measures must be extracted and fed into the other components within the framework as necessary. Data sources include building approval and land subdivision plans, building licenses, technical survey reports, and a range of remotely sensed imagery, which is potentially at different spatial scales and with different geographic coverage. Measures and values need to be extracted from these data sources, together with quality information regarding the data sources. For example, the dimensions and area of land parcels can be extracted from subdivision plans, approved dimensions of buildings can be extracted from approval plans, actual dimensions of buildings can be extracted from digital imagery, quality of imagery in relation to scale and resolution can be extracted from digital imagery, and the threshold values for minimum setback distances and the proportion of the land parcel covered by building footprints can be obtained from building regulations.

Data in the prototype such as the actual dimensions of buildings can be extracted from digital imagery; this extraction is obtained by manually digitising from building boundaries and cadastre boundaries in the traditional method. In addition in an operational system it can extracted automatically.

The inspection data input module contains data sources and the geospatial information extracted from these sources. The action linking different data is the extraction of the required data and metadata. Figure 5.2 shows the details of the data input module. The data input module offers the required data that is needed before, during and after the inspection job. However, some inspection data is required prior to carrying out inspection tasks, while other data must be collected from the site to support decisions made about any violations detected.

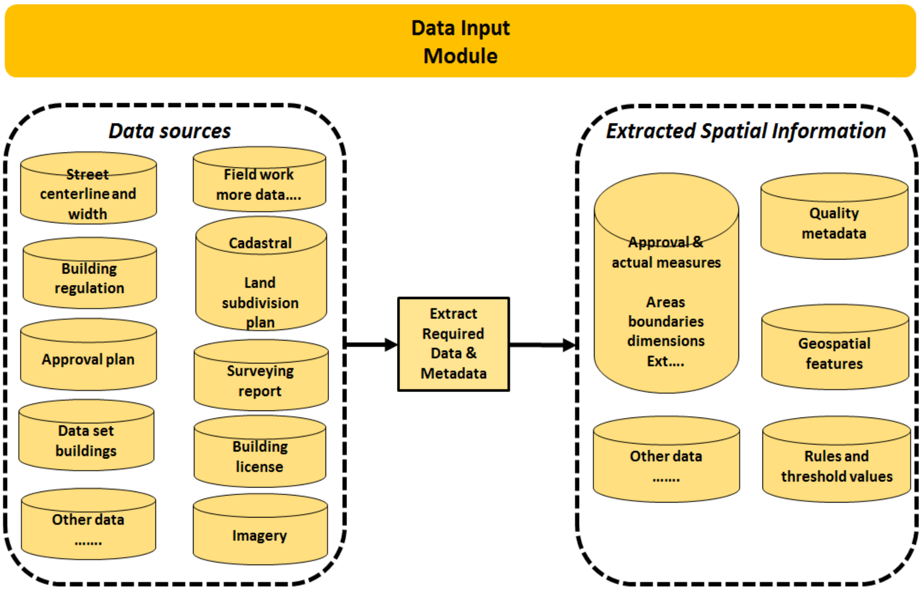


Figure 5.2 Structure of the data input module

5.1.1.1 Data sources

Data sources are the inspection data repositories that include all the data required to assess the inspection job at any stage of the WFoI. Data sources include the following: (a) approval plan, (b) dataset of buildings based on actual measurements, (d) building regulations, (e) building licence, (f) cadastral land subdivision plan, (g) survey report, (h) street centreline and width, (i) imagery (aerial photography and satellite images) and (j) fieldwork and other required data. The following section explains the sub-module of data sources. All data sources, e.g. data source, resolution, error are described in details in (Section 5.2.3.2)

- *The approval plan*

  The approval plan for the building is the document produced by the Building Licence Department in the CoR. Providing an approval plan is an essential component of the data input module (see Section 4.3.4). The inspector's survey is one of the important data sources in the approval plan. In addition, the accuracy of the approval plan is high, since the building design is produced by AutoCAD software in DWG format, and full implementation of building regulations is guaranteed in the approval plan. The necessary guidance for the construction is explained in the details of the plan. The SEBI framework emphasises the need to provide the approval plan as a core aspect of the data input module. For example, the approval plan contains measurements of the construction, such as areas and dimensions. Finally, the framework provides the approval plan in a digital format, allowing the inspector full access to all data needed for the inspection process.

- *Building the data set*

  Dataset building provides a footprint of buildings, such as the main building, the ground floor annex, the upper annex and other features on the construction site. This type of data solves the existing problem of the lack of data on building attributes, dimensions and areas, which would otherwise require more fieldwork. In addition, this type of data offers building source metadata and regulations.

- *The building regulations*

  Providing the building regulations within the framework is a core sub-module of the data input module. Including building regulations satisfies part of Research Objective 1 by providing some of the building criteria that must be addressed during inspection to support violation detection. All the building regulations and thresholds that are needed for inspection are provided in the framework, such as those that relate to: (a) the main and ground annex building coverage area, (b) the upper annex building coverage area, (c) street setback distances and (d) side/rear setback distances. All of these regulations will be included in the prototype model described in Section 5.3.

- *The building licence*

  The building licence is one of the essential documents used in inspections. The building licence is issued by the Building Licence Department and includes the official attributes of the building and cadastre parcel, such as the ownership details. It also includes geospatial attribute data such as cadastre and building features and measurements. These include the parcel number, area, dimensions, topology, street name and width, area of different levels of the building and all the building setbacks dimensions (street, rear and sides). The framework implements all these construction characteristics to improve the data quality for the inspection. An example of a building licence document is provided in Appendix C.

- *The survey report*

  The land survey report is a description of cadastral conditions and details. In fact, this kind of report is produced in the field before the start of construction; however, it is a requirement for the issue of a building licence. The survey report is produced individually for every parcel, and includes almost all the data that are reported in the land subdivision plans. An example of a survey report is provided in Appendix D.

- *The cadastral land subdivision plan*

  The land subdivision plan is digital format. These types of data are important because it provides accurate standards and includes all the data required for inspection purposes. The most accurate cadastre data can be extracted from the land subdivision plan. This includes all cadastre data such as areas, dimensions, georeferencing and topology. Project prototypes use the data source in the data input module to obtain high quality cadastral data; at this stage the expectation of cadastre data error is almost zero. However, the cadastre data in the framework is obtained from different sources (imagery and the land subdivision plan) and these sources produce data of different quality.

- *The street centreline and width*

  The street dataset contains the attribute data for the street, such as street width and centreline. These are used to make the street buffer rule '1/5 street width' and implement the street setback. These data should illustrate all street types and widths. More details relative to the chosen case study are given in the discussion of the project prototype implementation in Section 5.3.3.

- *Imagery*

  The data sources for the SEBI framework include different high resolution images to improve input data quality. These images include aerial photography and satellite images, which add further details of the actual construction. Further, the images cover a geographic region of the inspection area, and can be used to identify and measure features of cadastre and buildings.

- *Fieldwork and other required data*

  More accurate data may be available from the data sources specified within the SEBI framework and highest quality data in the input module, such as imagery with highest quality for a particular feature and fieldwork. The SEBI framework allows building inspectors to obtain high quality data when it is required; for example, in instances when the inspector must make a decision on potential violation detection. To obtain more accurate information, the data are processed via the quality assessment module after the decision point is reached in the violation detection module (see Section 5.1.2). This type of dataset may include fieldwork from the construction site and more accurate data such as high resolution and updated images. Examples of necessary data include measures of area, dimensions and construction features.

5.1.1.2 Extracted geospatial information

Measures and values are extracted from the data sources, together with quality information regarding the data sources. For example, the dimensions and area of land parcels can be extracted from subdivision plans, the approved dimensions of buildings can be extracted from approval plans, the actual dimensions of buildings can be extracted from digital imagery, while the threshold values for minimum setback distances and the ratio of building footprints compared to the land parcel area can be obtained from the building regulations data.

Inspection information related to geospatial aspects can be extracted from the data source within the data input module. This action will extract the data required for the assessment of each violation type by providing the relevant building and cadastre data from the data source. The data that can be extracted include the approval and actual measures, areas, boundaries, dimensions, quality metadata, geospatial features, rules and threshold values. This information will produce the data error classes of area and dimensions and determine the violation classes, boundaries, and ranges that have been tested within the quality assessment module.

5.1.2 The quality assessment module

This module is necessary to ensure the quality of the inspection outcome and the detection efficiency at all stages of the inspection process, as well as to verify the required level of accuracy of the data (see Section 2.2.1). It provides a solution to the current issues of poor inspection quality and poor inspection process outcomes by providing a clear vision for the inspector of what *high* and *good* quality data sources are (see to Section 4.5.2.5). In this module, the framework seeks to apply quality assessment to ensure that the inspection process works within the framework concepts as designed. Figure 5.3 shows the concept of the quality module and how it assesses the quality level. The violation classes, boundaries and ranges are firstly, determined. Then the error ranges dataset based on the quality metadata from extracted spatial information within data input module are produced. Secondly, error classes based on extracted data from the geospatial features dataset within data input module and the error ranges dataset are created. Finally, higher quality data from the data source based on the analyses cases of possible violation are obtained.

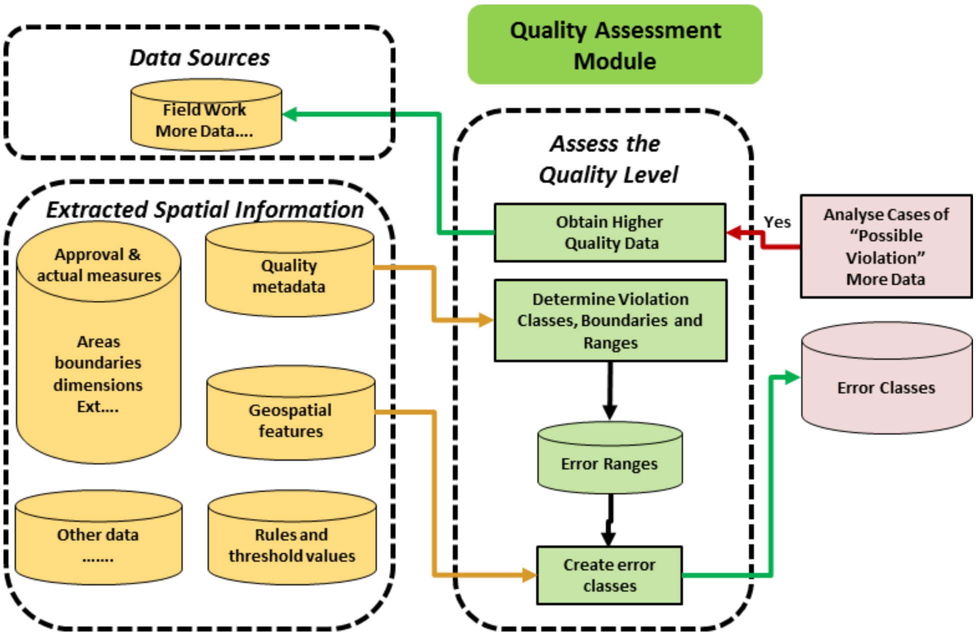


Figure 5.3 The concept of the quality assessment module

5.1.2.1 Determination of violation classes, boundaries and ranges

Violation classes, boundaries of error, and the ranges of errors of the data are determined by this module. The first step is to identify the data source quality and type; for example, the quality of the imagery, approval plan, and land subdivision plan from the input data module are classified as high, moderate or low. The second step is to identify the map accuracy ranges for each level. The third step is to ascertain the error boundaries. The final step in this module is to obtain a higher quality data source from the input data module, depending on whether a need for this has been identified by the validation detection module (see Section 3.3.3) for the method used to determine the violation classes, boundaries and ranges.

The quality assessment module uses the quality information for each of the data sources to categorise the various inspection measures according to the errors they contain. This has been explained in Sections 3.6.1 and Section 3.6.2 and implemented within the prototype as discussed in Section 5.3. Quality values are assigned to the boundaries of these categories, which are then used in other modules to enable the association of measures of quality to the violation detection outcomes. For example, multiple aerial images at different geospatial resolutions will have varying degrees of error associated with measurements obtained from buildings and parcels extracted from the image. The classes produced will assist in determining the reliability of a violation being detected or the confirmation that no violation has occurred.

5.1.3 The data preparation module

The data preparation module takes the measures and a quality value obtained and prepares them for the next stage of violation determination. Further, this component takes the quality categories defined in the quality assessment module and generates the rules for the violation classes and boundaries to be used to represent the violation detection outcomes. Figure 5.4 shows the data preparation module, which prepares the actual features and measures the construction data from the data source. Data extraction from the data input module includes the building and cadastre data. Assigning compliance or not depends on this data; for example, in order to calculate the ratios of the building footprints and assign these to error classes for the main and ground annex buildings, first the parcel area is extracted from the land subdivision and/or imagery data, and second, the building footprint boundaries are extracted from geospatial features and/or imagery. Hence, the importance of this module within the framework is to provide the core and actual inspection data, as built on the construction site, from the appropriate sources.

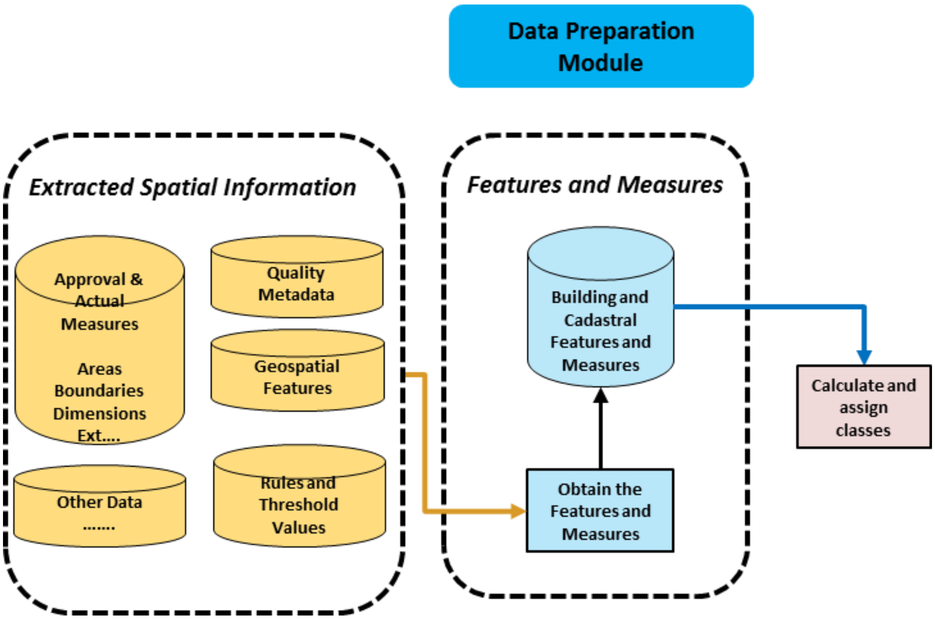


Figure 5.4 Data preparation module

5.1.4 The violation detection module

The violation detection component analyses the actual building construction measurement and derived data in relation to the thresholds of allowable values obtained from the building regulations. For each violation type, a determination is made for each building to determine whether a violation is possible, or does not occur (i.e., the building is compliant). Positive and negative assessments regarding the occurrence of a violation can only be made when the input information clearly supports this beyond the limitations of its error. If such a determination cannot be made, then the outcome is a possible violation. The value of this process is that quality information is associated with all violation assessment outcomes and hence building inspectors have an indication of the reliability and quality of each inspection result which informs the decision of violation determination. Figure 5.5 shows violation detection accomplishment and the processes that are implemented in the violation detection module.

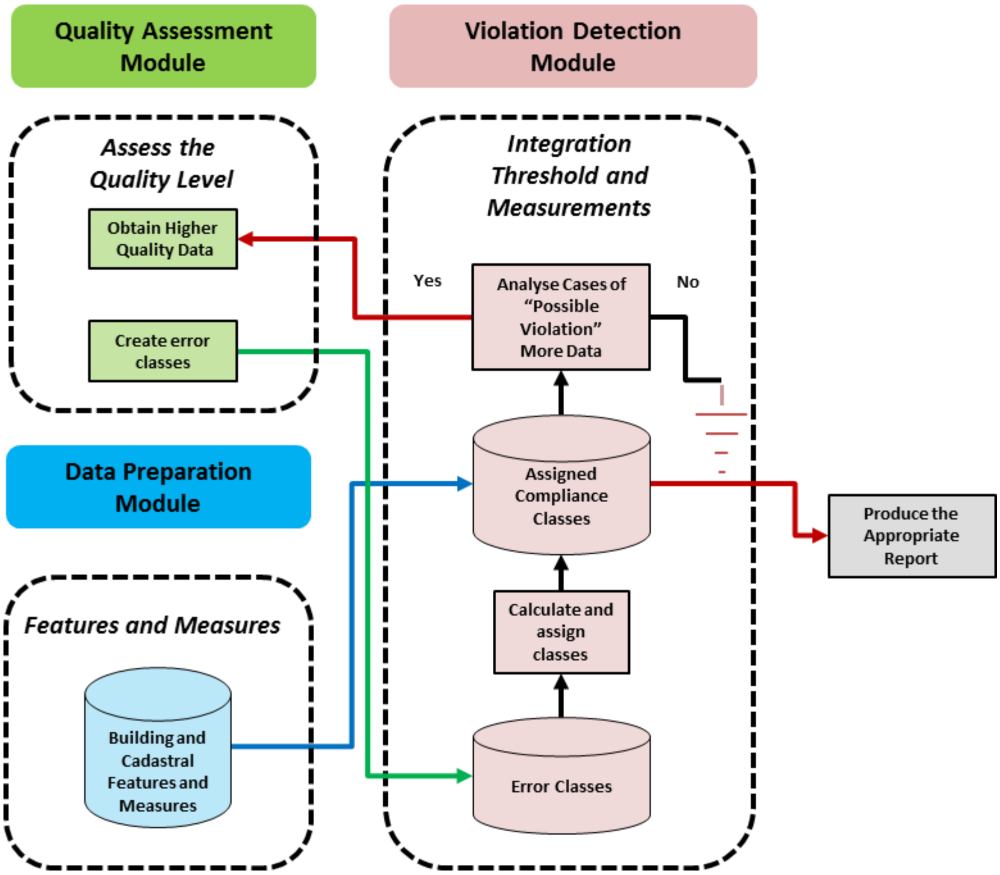


Figure 5.5 Violation detection module

The violation detection module includes two datasets and two processes before an appropriate report within reporting module can be produced.

- *Producing the error classes*

  Error classes are produced from the error ranges in the quality assessment module and from the geospatial features that were extracted from the data input module (Section 5.1.1 and Section 5.1.2).

- *Calculating and assigning classes*

  The different actual measures calculated based on the error classes that were created from quality metadata are used to assign the compliance classes (Section 5.1.2.1).

- *Assigning compliance classes*

  This data is the output of the calculation of the measures of the different violation types. Decisions need to be made about which violation classes will be highlighted at this point; therefore, an inspection report can be produced at this stage, signalling a definite violation, possible violation or no violation.

- *Analysing cases of possible violation*
  This action assesses the result of the third violation class: possible violation to determine the need for more data. This type of result appears within the medial range of error. Based on the error ranges the proportion of this violation class becomes high when the quality of data is low. Therefore, the framework solves issue of poor quality of violation detection by obtaining more required data (Section 5.1.1.1).

Consequently, the integration between the thresholds and measurements in this module is achieved by assessing the actual on-site construction, based on the implementation of the values of the thresholds of different single violations. This can be done by calculating and comparing the differences between the actual construction and the thresholds. Finally, an important action in this module is to determine the need for additional accurate data when analysing cases of possible violation.

5.1.5 The reporting module

Reporting is the final stage of the SEBI framework. The aim of the reporting module is to generate various inspection outcomes and reports to inform the various steps of the WFoI. Maps for a geographic region and reports for individual buildings are able to be generated for a range of violation types. Inspectors can use this information to make informed decisions and determine the quality of the information being used in those decisions. For example, an inspector may decide that a certain property is noncompliant and be sufficiently confident of the decision to issue a compliance order without any further work being required. Alternatively, if the outcome is at best a possible violation, they can use the inspection report data to prioritise where further fieldwork needs to be done to confirm this or to provide on-site measures.

This module visualises the violation detection result as a property compliance report, violation map, inspection report, violation description and possible violation map. The outcomes of the reporting module provide the results of some violation types in each process of the WFoI to present and visualise the detection outcomes with deferent reports. This module presents the formal and complete inspection result as an outcome of integration and incorporation between previous prototype modules. Figure 5.6 illustrates the design of the reporting module.

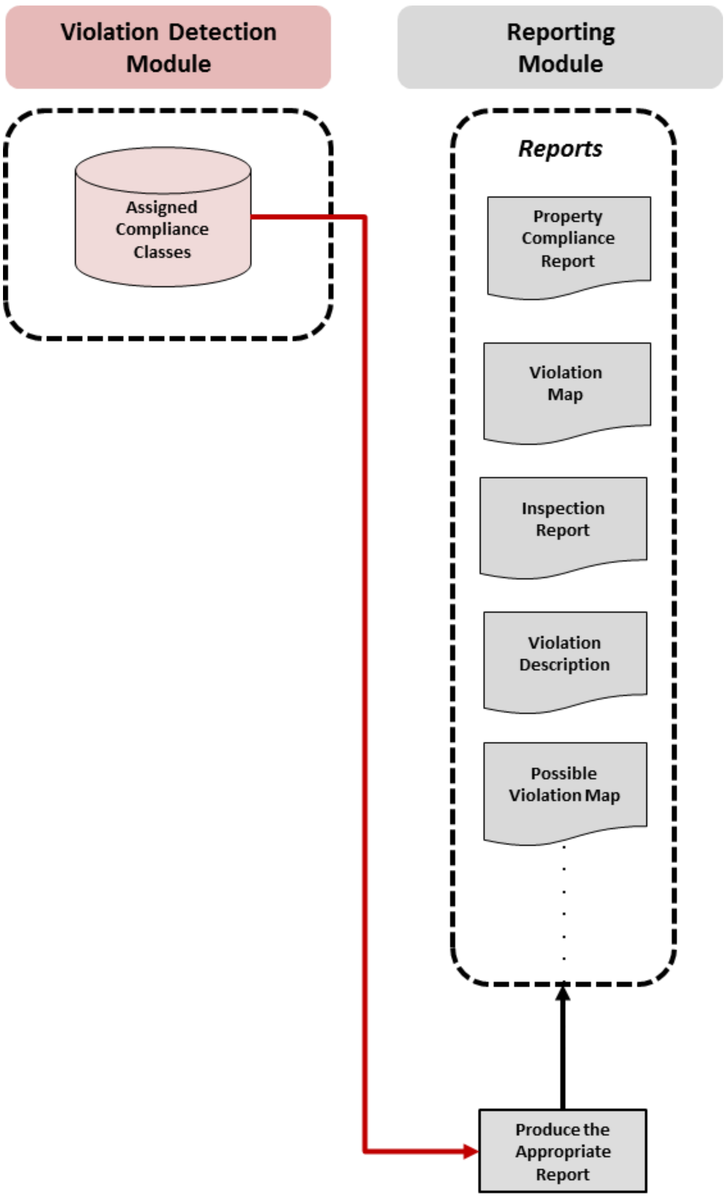


Figure 5.6 Reporting module design

This module is the product of all the inspection activity and data processing, and supports the WFoI for the situation that arises when a violation has been detected. Reporting outcomes present the detection results such as the measures of area and dimension for different violations in accurate scale. Finally, in this module, all inspection data will be presented to explain the inspection outcome, with examples of geospatial data such as the approval plan, cadastral information, building regulations, and non-geospatial data such as owner and ownership details.

5.2 Prototype Development

This section describes the development of a prototype design based on the SEBI framework, and illustrates the geospatial methods used and the technical characteristics of the modules. In addition, this section discusses the process used by the geospatial information to support building inspection and violation detection.

5.2.1 Prototype design

The prototype structure implements aspects of the SEBI framework architecture described in Section 5.1. Figure 5.7 shows the modular architecture of the SEBI prototype, illustrating the interactions of the various modules with one another through the synchronisation module. The prototype includes aspect of all the main modules of the SEBI framework. Spatial data related to inspections can be extracted from data sources, for example, building source metadata and regulations. The data preparation module provides features and measurements for cadastre boundary, building footprint boundaries and street centrelines. The inspection data quality is assessed based on two sources: from quality metadata, thresholds and the ± resolution of aerial photo sources from quality metadata. The integration of the thresholds and measurements is achieved within the violation detection module; however, the assigning of compliance classes is obtained after calculating the errors of the areas and distances. Further, this module includes an option to provide more data for possible violation classes. Finally, an appropriate inspection report is produced based on the results produced by the violation detection module.

The model prototype was implemented in three main steps, as defined in the framework modules:

(a) Provide data input or sources

(b) Generate the Process ‘ACTION’

(c) Obtain Output

The ModelBuilder developed was able to process and demonstrate the technical aspects of the SEBI prototype. The ModelBuilder includes the data necessary to present the results of the detection of violation types within the scope of the model: for example, building, cadastre and regulation data as input data; the process and action, for example, calculation of the coverage area of the building; and the output after the processing of the input data, for example, the compliance result. Figure 5.8 shows an example of the SEBI prototype model schema. For example, creating local variables (data input) such as parcels, ground annex building, upper annex building and street. The second step involved data processing, such as calculating field, spatial join and creating the error classes. The third step shows the output of the data processing, such as: main building area ratio. Appendix E provides the complete geodatabase for all building violation types in the project.

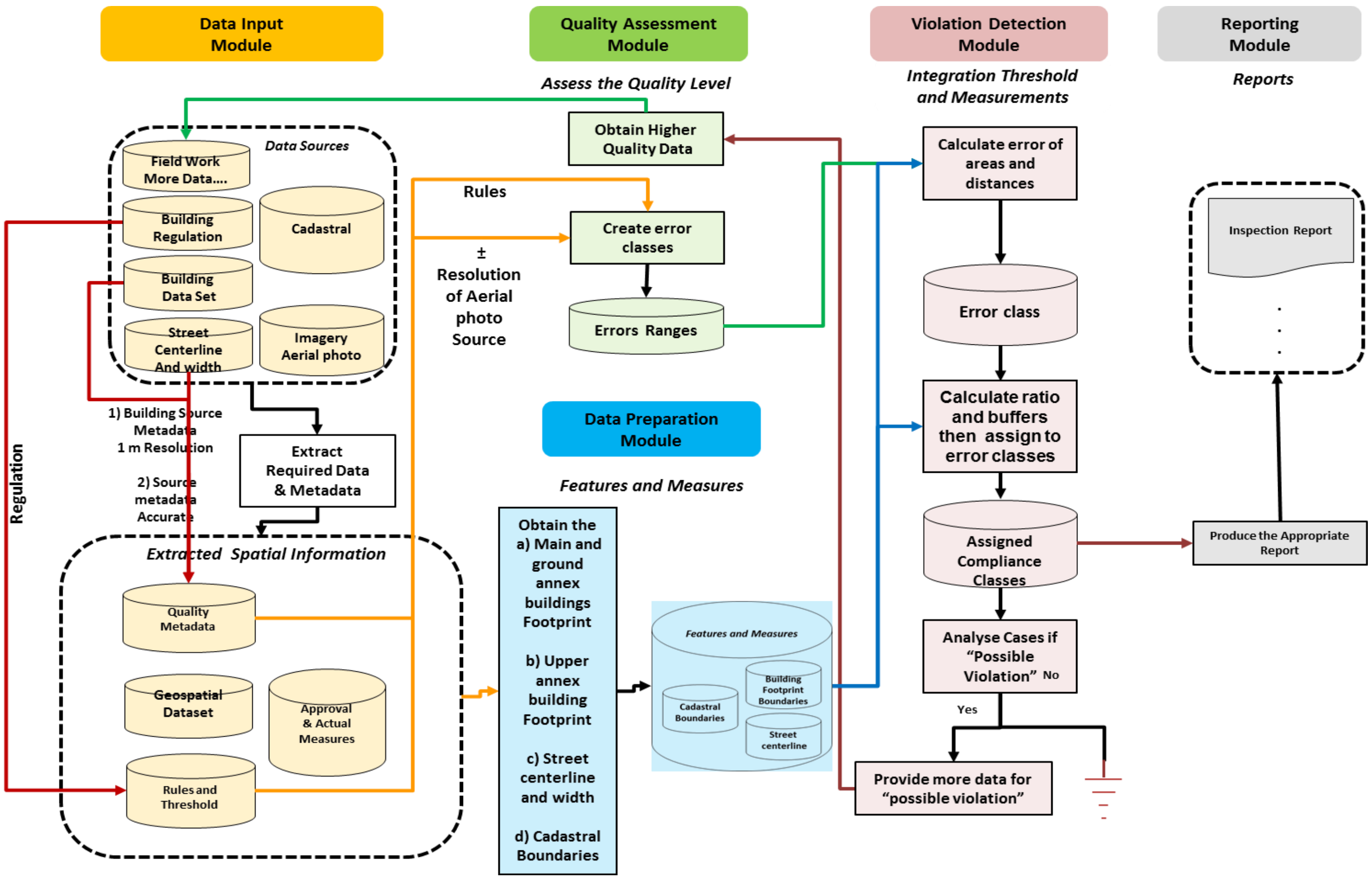


Figure 5.7 Modular architecture of the SEBI prototype

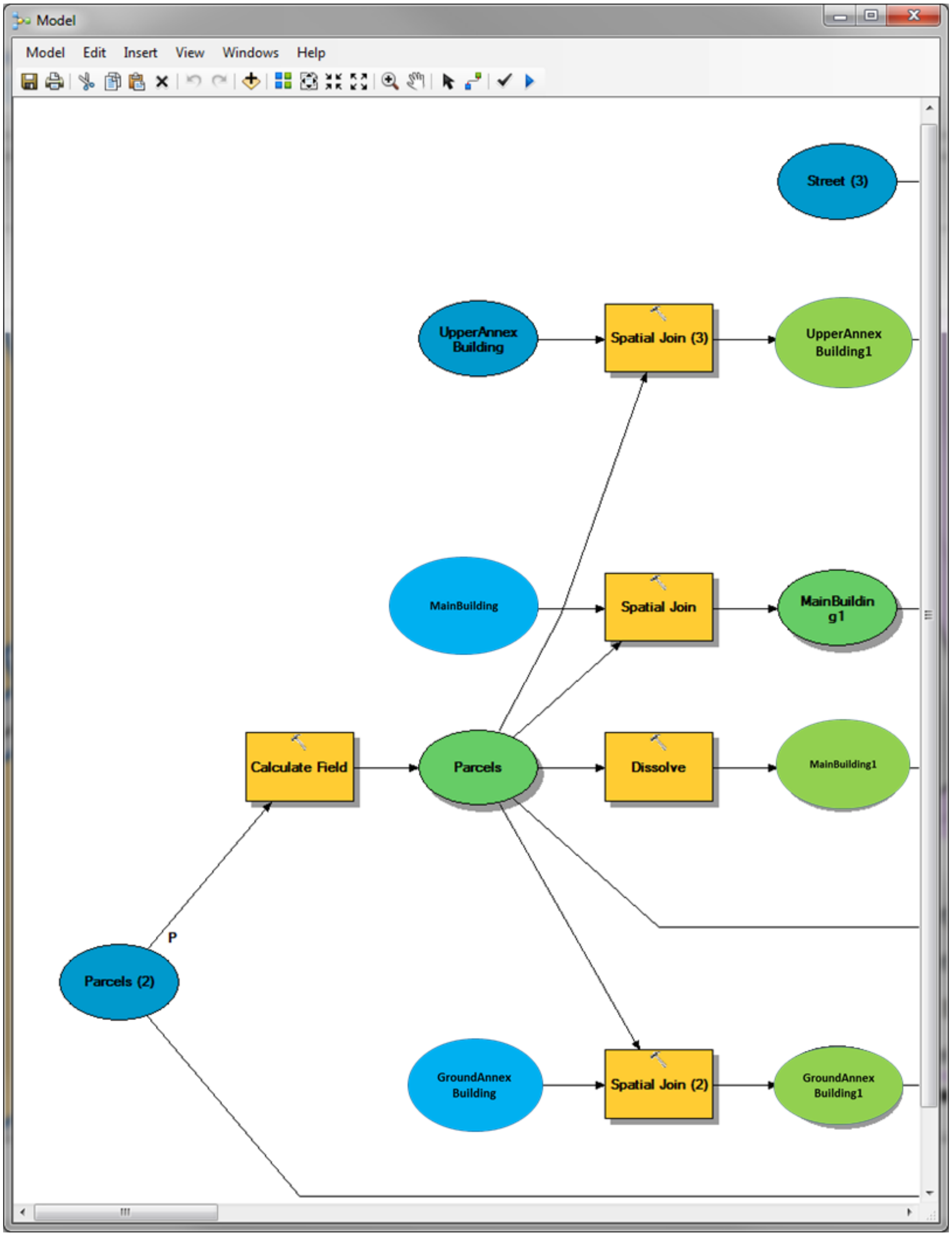


Figure 5.8 Schematic representation of the SEBI prototype model

5.2.2 The data input module

The SEBI prototype creates the initial container for the inspection data and provides the required data for prototype activities and modules such as building and cadastre data. Since the inspection data are important to support and maintain the prototype workflow, the data input structures should be able to provide and hold all the vital data required by the inspection prototype model. The prototype model user can then find all the necessary data to test and assess violations within the scope of the project.

5.2.2.1 Data sources

The framework data input module is partly developed in the prototype. The input data can be used to detect all four violations for which data is available within the scope of this study and the limitations of the model data. Table 5.1 shows the violation types and the data that are used to assess each violation. For example, the data source is the aerial photo 'Year2002'at 1m resolution and the land subdivision plan (see Section 3.2.6). Figure 5.9 shows input layers of the prototype, taking advantage of the available data from Riyadh Aerial Photography (2002), for example geospatial data of cadastre, buildings and streets.

Table 5.1 Data input for each violation type

Violation Types	**Features and Measures**	**Data Sources**
Main and ground floor annex buildings coverage area	Cadastral boundary Building footprint boundaries	Digital subdivision plan Imagery
Upper annex building coverage area	Building footprint boundaries	Geospatial features: • Main and ground annex buildings • Upper annex building • Street setback • Side/rear setback Imagery: • Aerial photo
Street setback	Street centreline Cadastral boundary	Geospatial features Imagery
Side/rear setback	Cadastral boundary Building footprint boundaries	Digital subdivision plan Geospatial features Imagery

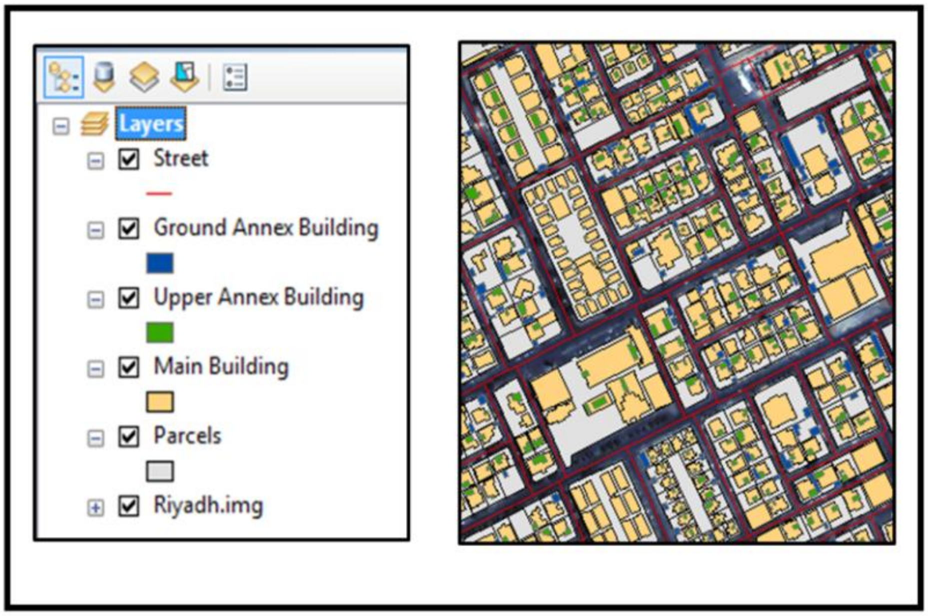


Figure 5.9 Input layers of the prototype

5.2.2.2 Extraction of data and metadata

The prototype extracts and applies the required inspection data and geospatial information from a range of sources. First, quality metadata are extracted from the building dataset, street centreline and street width; these data include building data source metadata, for example, 1m resolution imagery of the actual building and the metadata accuracy of buildings. Second, the geospatial dataset is extracted from the data source module and produces data for the main and ground annex buildings, upper annex building, street setback and the side/rear setbacks. Third, the approval and actual measures are extracted to obtain areas, boundaries and dimensions from two sources: imagery at the 1:2500 scale and the ‘accurate’ subdivision plan. Finally, the regulation data contains two main features: coverage area regulations and setback dimension regulations; these include street setback and side and rear setbacks.

At this stage of the process of development of the model, the basic building regulation modules are developed, allowing model users to match the violation type with the appropriate regulations. The rules and thresholds to be used are extracted from the building regulation data source (see Section 5.2.2.1) and include the regulations concerning the main and ground annex buildings coverage areas, upper annex building coverage area, street setback distance and side/rear setback distances. More details of pre-processing of aerial photograph are described in data input module (Section 5.1.1).

5.2.3 The quality assessment module

An essential part of the SEBI framework involves testing the quality of the violation detection products against the accuracy levels of various sources. Section 3.2.6 provides greater detail on the quality of the imagery required. This study has proposed an additional classification: possible violation. The main benefit of identifying the possible violation class is to prove the advantage of the use of high quality data sources to reduce the error range of violation determinations. This new violation class will be determined based on the source map accuracy and the value of this class compared to the definite violation value and the no violation value. The reason for identifying the possible violation class is to determine the error ranges of the violation detection and determine the necessity for obtaining more accurate data, in an effort to reduce the need for further on-site inspection and fieldwork. Two boundaries, a minimum and a maximum, are determined based on the (±) ranges of the error.

5.2.3.1 Creating error classes

During the assessment of the quality of inspection data the error classes created are based on building regulations and the error ranges of the imagery resolution (see Section 5.1.2.1). Error classes are calculated for measures of both area and distance. The implementation of quality assessment in the prototype model sets out to demonstrate the feasibility of using imagery sources for building violation detection.

The first detection assessment implemented in the quality module is the assessment of the basic data source. The data source for the cadastral parcel, buildings, street centreline and street width is aerial photography at a 1:5000 scale. The second quality detection assessment simulated in the quality level is based on the accuracy range calculations of cadastral area, buildings area and dimensions from aerial photography at scales of 1:2,500 and 1:5,000 and land the subdivision plans. The implementation of quality assessment demonstrates how the data quality affects the need to obtain more data, for example, from more fieldwork, as discussed in Section 5.1.1.

5.2.3.2 Error ranges

Error ranges are the outcome of the error classes. These error ranges can be categorised as follows, based on the highest quality data input source:

(a) Error area ranges
(b) Error boundary ranges from the cadastre
(c) Error boundary ranges based on street width

Map source accuracy ranges have been developed, based on the ranges of the (±) map errors. Table 5.2 shows the error ranges for building footprints and cadastral boundaries in all map sources. The accuracy of area ranges affects the violation detection results for the coverage area of buildings (main and ground annex building, and upper annex building). Table 5.3 shows the error ranges of buffer rules for buildings and cadaster in all map sources; the accuracy ranges of the buffer affect the violation detection results of setback distances from the street. Table 5.4 shows the accuracy of the map sources and error results for the main building and ground annex building, for example buildings with error range in high accuracy source from aerial photography 'Scale 1:2500' is (± 2.85) m^2 and cadastre error range from land subdivision plan is (0), the total error range. The other example is error range for both buildings and land subdivision plan in low accuracy source from Aerial photography 'Scale 1:5000' (± 6.65) m^2, the total error range (± 13.3) m^2.

Table 5.5 shows the accuracy of the map sources and error results for the main building and ground annex building. For example main building error range in high accuracy source from aerial photography 'Scale 1:2500' is (± 2.85) m^2 and upper annex building error range in high accuracy source from the same imagery is (± 2.85)

m^2, the total error range is (± 8.7) m^2. The other example is error range for both main building and upper annex building in low accuracy source from aerial photography 'Scale 1:5000' (± 6.65) m^2, the total error range (± 13.3) m^2.

Table 5.6 Violation classes, boundaries and ranges of sides and rear setback buffer (mm). For example, the error ranges is (1.925 <Length>2.075) in high accuracy source and (1.648 <Length> 2.352) in low accuracy source. Table 5.7 shows the error ranges boundary of the streets setbacks in detail and Table 5.8 shows Input error range boundaries of street setbacks in high accuracy source only. In addition, Figure 5.10 shows the input error range boundaries of street setbacks and threshold implementation in the prototype. More details of error of the imagery are described in (Section 3.2.5.2).

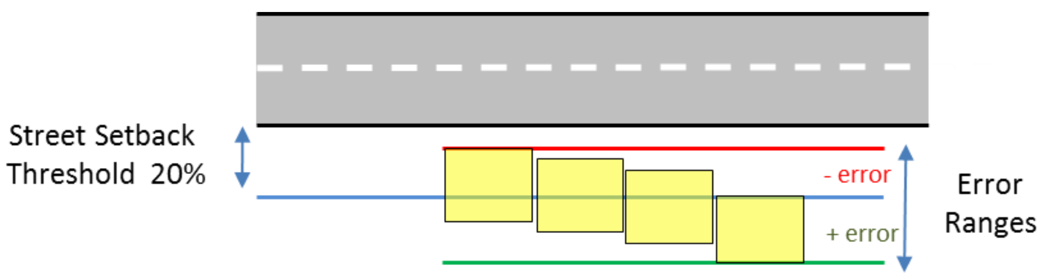


Figure 5.10 Example of the implementation of a range of street setback buffers

Table 5.2 Error ranges of building footprint and cadastre boundaries

	High Accuracy Source	High Average Accuracy Source	Low Average Accuracy Source	Low Accuracy Source
Source of buildings	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’
Source of cadastre	Land subdivision plan	Land subdivision plan	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’
Buildings error	(± 2.85) m^2	(± 2.85) m^2	(± 6.65) m^2	(± 6.65) m^2
Cadastre error	0	(± 2.85) m^2	0	(± 6.65) m^2
Total of the errors	(± 2.85) m^2	(± 5.7) m^2	(± 6.65) m^2	(± 13.3) m^2

Table 5.3 Error ranges of buffer rule building and cadastre

	High Accuracy Source	High Average Accuracy Source	Low Average Accuracy Source	Low Accuracy Source
Source of buildings	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’
Source of cadastre	Land subdivisions plan	Land subdivisions plan	Aerial photography ‘Scale 1:2500’	Aerial photography ‘Scale 1:5000’
Buildings error	(±7.45)cm	(±7.45)cm	(±17.9)cm	(±17.9)cm
Cadastre error	0	(±7.45)cm	0	(±17.9)cm
Total of the errors	(±7.45)cm	(±14.9)cm	(±17.9)cm	(±32.2)cm

Table 5.4 Violation classes, boundaries and ranges of main and ground annex buildings area

	High Accuracy Source	High Average Accuracy Source	Low Average Accuracy Source	Low Accuracy Source
Source of buildings	Aerial photography 'Scale 1:2500'	Aerial photography 'Scale 1:5000'	Aerial photography 'Scale 1:2500'	Aerial photography 'Scale 1:5000'
Source of cadastre	Land subdivision plan	Land subdivision plan	Aerial photography 'Scale 1:2500'	Aerial photography 'Scale 1:5000'
Buildings error	(± 2.85) m^2	(± 2.85) m^2	(± 6.65) m^2	(± 6.65) m^2
Cadastre error	0	(± 2.85) m^2	0	(± 6.65) m^2
Total of the errors	(± 2.85) m^2	(± 5.7) m^2	(± 6.65) m^2	(± 13.3) m^2

High Accuracy Source

Building	Cadastre	%
(–)	0	58.26
58.26	100	
(+)	0	61.74
61.74	100	

Result	Violation Classes
Area ≥58.26	No
58.26 <Area> 61.71	Possible
Area ≤61.71	Definite

High Average Accuracy Source

Building	Cadastre	%
(–)	(+)	56.67
58.29	102.85	
(–)	(–)	59.97
58.29	97.15	
(+)	(–)	63.52
61.71	97.15	
(+)	(+)	60.03
61.71	102.85	

Result	Violation Classes
Area ≥ 56.67	No
56.67 <Area> 63.52	Possible
Area ≤63.52	Definite

Low Average Accuracy Source

Building	Cadastre	%
(–)	0	56.01
56.01	100	
(+)	0	63.99
63.99	100	

Result	Violation Classes
Area ≥56.01	No
56.01<Area> 63.99	Possible
Area ≤63.99	Definite

Low Accuracy Source

Building	Cadastre	%
(–)	(+)	52.51
56.01	106.65	
(–)	(-)	60.00
56.01	93.35	
(+)	(-)	68.54
63.99	93.35	
(+)	(+)	60.00
63.99	106.65	

Result	Violation Classes
Area ≥52.51	No
52.51<Area> 68.54	Possible
Area ≤ 68.54	Definite

Table 5.5 Violation classes, boundaries and ranges of upper annex building area (m^2)

	High Average Accuracy Source			Low Accuracy Source	
Source of upper annex building	Aerial photography 'Scale 1:2500'		Aerial photography "Scale 1:5000"		
Source of cadastre	Aerial photography 'Scale 1:2500'		Aerial photography "Scale 1:5000"		
Buildings error	(± 2.85) m^2		(± 6.65) m^2		
Cadastre error	(± 2.85) m^2		(± 6.65) m^2		
Total of the errors	(± 5.7) m^2		(± 13.3) m^2		
Building	**Cadastre**	**%**	**Building**	**Cadastre**	**%**
(−)	(+)	18.89	(−)	(+)	17.51
19.43	102.85		18.67	106.65	
(−)	(−)	20.00	(−)	(−)	20.00
19.43	97.15		18.67	93.35	
(+)	(−)	21.17	(+)	(−)	21.96
20.57	97.15		21.33	97.15	
(+)	(+)	20.00	(+)	(+)	20.74
20.57	102.85		21.33	102.85	
Result	**Violation Classes**		Result	Violation Classes	
Area ≥ 18.89	No		Area ≥ 17.51	No	
18.89 <Area> 21.17	Possible		17.51 <Area> 21.96	Possible	
Area ≤ 21.17	Definite		Area ≤ 21.96	Definite	

Table 5.6 Violation classes, boundaries and ranges of sides and rear setback buffer (mm)

High Accuracy Source	
Result	**Violation Classes**
Length≥ 1.925	Definite
1.925<Length> 2.075	Possible
Length≤2.075	No
High Average Accuracy Source	
Result	**Violation Classes**
Length≥ 1.851	Definite
1.851 <Length> 2.149	Possible
Length≤2.149	No
Low Average Accuracy Source	
Result	**Violation Classes**
Length≥ 1.824	Definite
1.824 <Length> 2.176	Possible
Length≤2.176	No
Low Accuracy Source	
Result	**Violation Classes**
Length≥ 1.648	Definite
1.648 <Length> 2.352	Possible
Length≤2.352	No

Table 5.7 Violation classes, boundaries and ranges of street setback buffer (mm)

Street Width	**High Accuracy Source**		**High Average Accuracy Source**		**Low Average Accuracy Source**		**Low Accuracy Source**	
	Range of rule buffer	**Violation classes**	**Range of rule buffer**	**Violation classes**	**Range of rule buffer**	**Violation classes**	**Range of rule buffer**	**Violation classes**
60 m	Length≥ 11.925	Definite	Length≥ 11.851	Definite	Length≥ 11.824	Definite	Length≥ 11.648	Definite
	11.925 <Length> 12.075	Possible	11.851 <Length> 12.149	Possible	11.824 <Length> 12.176	Possible	11.648 <Length> 12.352	Possible
	Length≤12.075	No	Length≤12.149	No	Length≤ 12.176	No	Length≤12.352	No
40 m	Length≥ 7.925	Definite	Length≥ 7.851	Definite	Length≥ 7.824	Definite	Length≥ 7.648	Definite
	7.925 <Length> 8.075	Possible	7.851 <Length> 8.149	Possible	7.824 <Length> 8.176	Possible	7.648 <Length> 8.352	Possible
	Length≤ 8.075	No	Length≤ 8.149	No	Length≤8.176	No	Length≤8.352	No
36 m	Length≥ 7.125	Definite	Length≥ 7.051	Definite	Length≥ 7.024	Definite	Length≥ 6.848	Definite
	7.125 <Length> 7.275	Possible	7.051 <Length> 7.349	Possible	7.024 <Length> 7.376	Possible	6.848<Length> 7.552	Possible
	Length≤ 7.275	No	Length≤7.349	No	Length≤7.376	No	Length≤7.552	No
20 m	Length≥ 3.925	Definite	Length≥ 3.851	Definite	Length≥ 3.824	Definite	Length≥ 3.648	Definite
	3.925 <Length> 4.075	Possible	3.851 <Length> 4.149	Possible	3.824 <Length> 4.176	Possible	3.648<Length> 4.352	Possible
	Length≤ 4.075	No	Length≤4.149	No	Length≤4.176	No	Length≤4.352	No
12m	Length≥ 2.325	Definite	Length≥ 2.251	Definite	Length≥ 2.224	Definite	Length≥ 2.048	Definite
	2.325 <Length> 2.475	Possible	2.251 <Length> 2.549	Possible	2.224 <Length> 2.576	Possible	2.048 <Length> 2.752	Possible
	Length≤ 2.475	No	Length≤ 2.549	No	Length≤2.576	No	Length≤2.752	No
10 m	Length≥ 1.925	Definite	Length≥ 1.851	Definite	Length≥ 1.824	Definite	Length≥ 1.648	Definite
	1.925 <Length> 2.075	Possible	1.851 <Length> 2.149	Possible	1.824 <Length> 2.176	Possible	1.648<Length> 1.648	Possible
	Length≤ 2.075	No	Length≤ 2.149	No	Length≤ 2.176	No	Length≤1.648	No
8 m	Length≥ 1.525	Definite	Length≥ 1.451	Definite	Length≥ 1.424	Definite	Length≥ 1.248	Definite
	1.525 <Length> 1.675	Possible	1.451 <Length> 1.749	Possible	1.424 <Length> 1.776	Possible	1.248<Length> 1.952	Possible
	Length≤ 1.675	No	Length≤ 1.749	No	Length≤1.776	No	Length≤ 1.952	No

Table 5.8 Input error range boundaries of street setbacks in high accuracy source

Street width	**Error range boundaries**		
	Min-boundary	Ranges	Max-boundary
60 m	< 11.925m	11.925–12.075 m	> 12.075 m
40 m	< 7.925 m	7.925–8.075 m	> 8.075m
36 m	< 7.125 m	7.125–7.275 m	> 7.275m
20 m	<3.925 m	3.925–4.075m	> 4.075 m
12m	< 2.325 m	2.325–2.475m	> 2.475 m
10 m	< 1.925 m	1.925–2.075 m	> 2.075 m
8 m	< 1.525 m	1.525–1.675 m	> 1.675 m

5.2.4 The data preparation module

The data preparation module is an important component of the prototype, and provides the geospatial capacity of the model. This is required to provide the data for buildings, cadastre, regulations, street widths and rules within a geospatial format. This geospatial capacity allows the integration of all the prototype modules. This module offers all the requirements necessary to run ModelBuilder and obtain the violation detection results. Table 5.9 shows the geospatial contents of the prototype. It contains features and measures, such as buildings area, buildings dimensions, building coverage area regulations, street width and setback rules, sides and rear setback rules.

Table 5.9 Prototype geospatial contents

	Geospatial contents						
	Area	Dimensions	Street width	Regulation			
				Coverage area	Street setback	Sides setback	Rear setback
Cadastre	✓	✓			✓	✓	✓
Main building		✓		✓	✓	✓	✓
Ground annex building	✓	✓		✓			
Upper annex building	✓	✓		✓			
Streets			✓		✓	✓	✓

Figure 5.11 shows the street setback regulations in the prototype geospatial data from the street centreline. Street Buffer = (0.2 street width + 0.5 street width). The prototype geospatial component contains: (a) the main building and ground annex buildings footprints, (b) the upper annex building footprint, (c) the street centreline and width and (d) cadastral boundaries obtained from the geospatial information extracted by the data

input module. Figure 5.12 shows an example of the prototype for the side and rear setbacks line intersect buffer at 2m, based on the cadastral boundaries.

OBJECTID *	SHAPE *	SHAPE_L	STREETWIDTH	Buffer
380	Polyline	1115.5397	60	42
379	Polyline	907.89609	60	42
381	Polyline	1116.9889	40	28
378	Polyline	908.46975	36	25.2
342	Polyline	62.492709	20	14
335	Polyline	383.88180	20	14
367	Polyline	396.40196	20	14
364	Polyline	80.669761	20	14
316	Polyline	1118.1492	20	14
293	Polyline	1118.4553	20	14
341	Polyline	383.60465	12	8.4
318	Polyline	397.90573	12	8.4
327	Polyline	483.53142	12	8.4
350	Polyline	806.97072	12	8.4
295	Polyline	295.96594	12	8.4
313	Polyline	294.78248	12	8.4
297	Polyline	464.82224	12	8.4
298	Polyline	823.38204	12	8.4
305	Polyline	134.21011	10	7
336	Polyline	130.10182	10	7
352	Polyline	95.683242	10	7
337	Polyline	101.74201	10	7
338	Polyline	119.55093	10	7

Figure 5.11 Prototype attributes data for street regulations

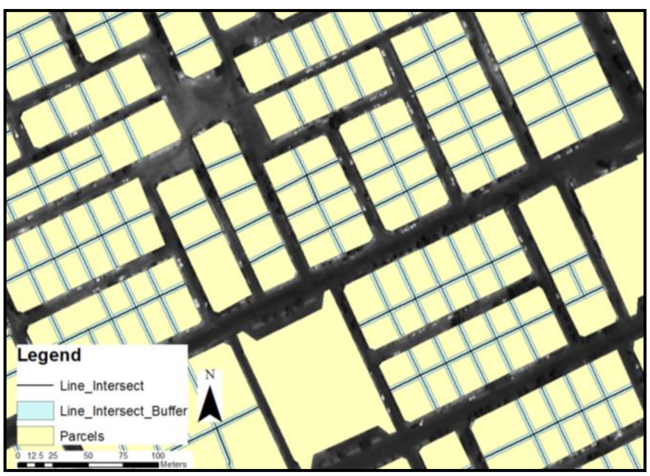


Figure 5.12 Side and rear setbacks lines intersect buffer ‘2m’

5.2.5 The violation detection module

The violation detection module functions by processing the inspection data. Violation detection is conducted and assessed based on a combination of the coverage area and the setback dimensions.

5.2.5.1 Calculating the error of areas, distances and buffers

Calculation of errors in building areas and dimensions, as well as the data sources used for these calculations is assessed by this module of prototype. First, the error range data for area and distance are extracted from the quality module (see Section 5.2.3.2). Second, features and measures data are extracted from the data preparation module (Section 5.2.4). Figure 5.13 shows the process used to merge the areas of the main and ground annex buildings in the prototype model; the figure demonstrates how to calculate the regulation threshold field for the main and ground annex buildings and places the area of those building in one field. The SEBI prototype includes a script to implement the relevant building regulations; for example, Figure 5.14 shows the implementation of the street setback buffer (1/5 street width) and Figure 5.15 shows that form the common boundary between parcel and building are used to assess side and rear setback thresholds.

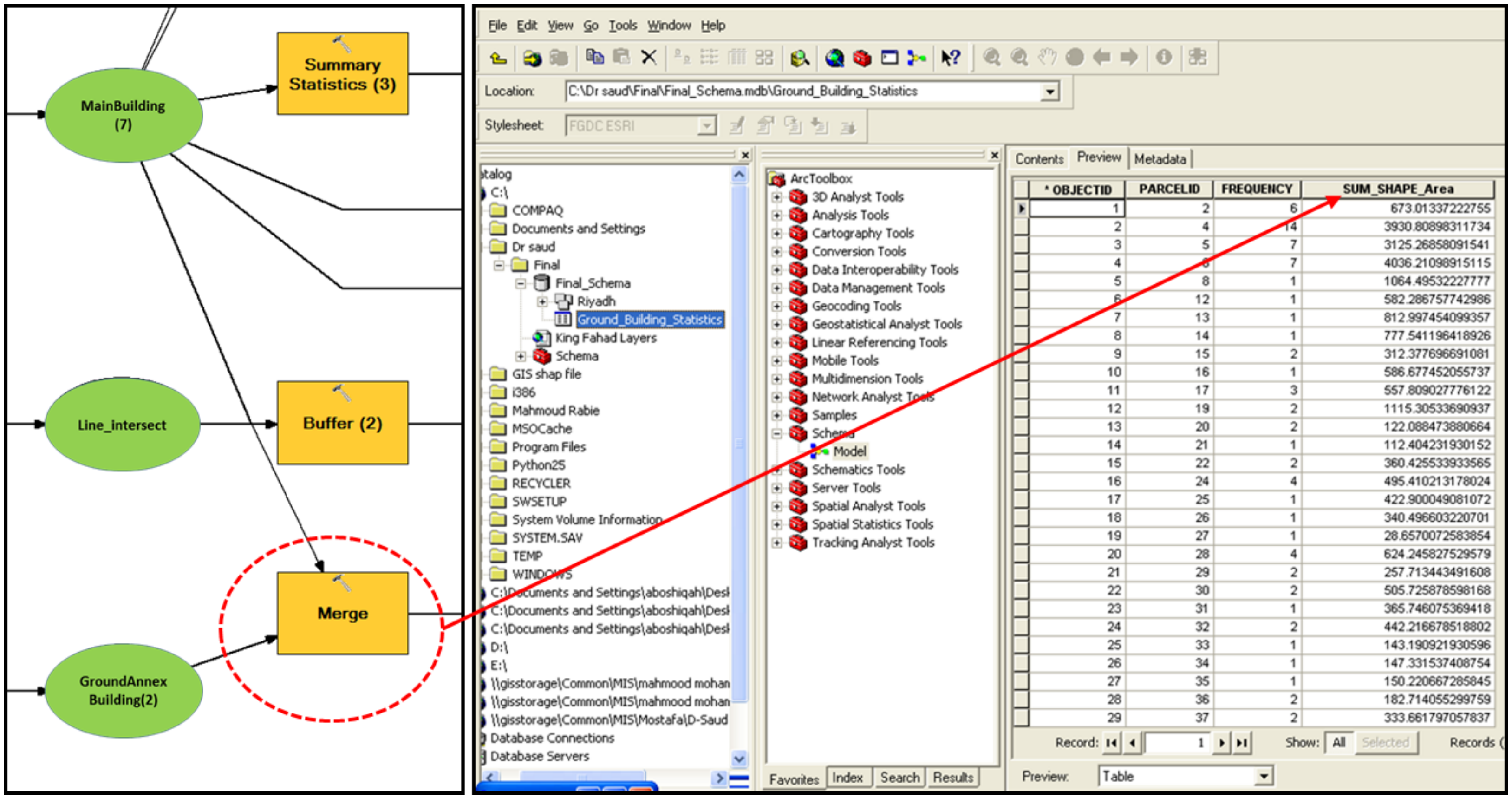


Figure 5.13 Calculation of the field for the main and ground annex buildings

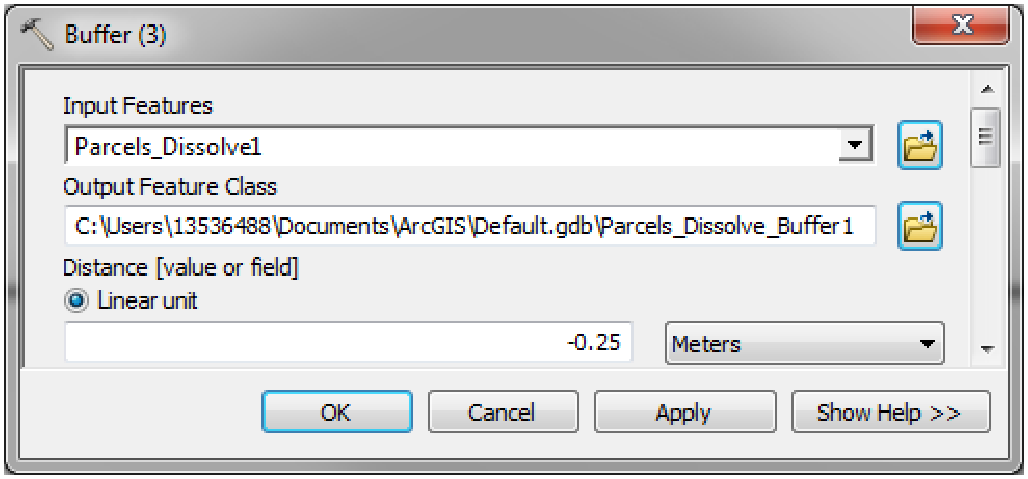


Figure 5.14 Implementation of the street setback buffer

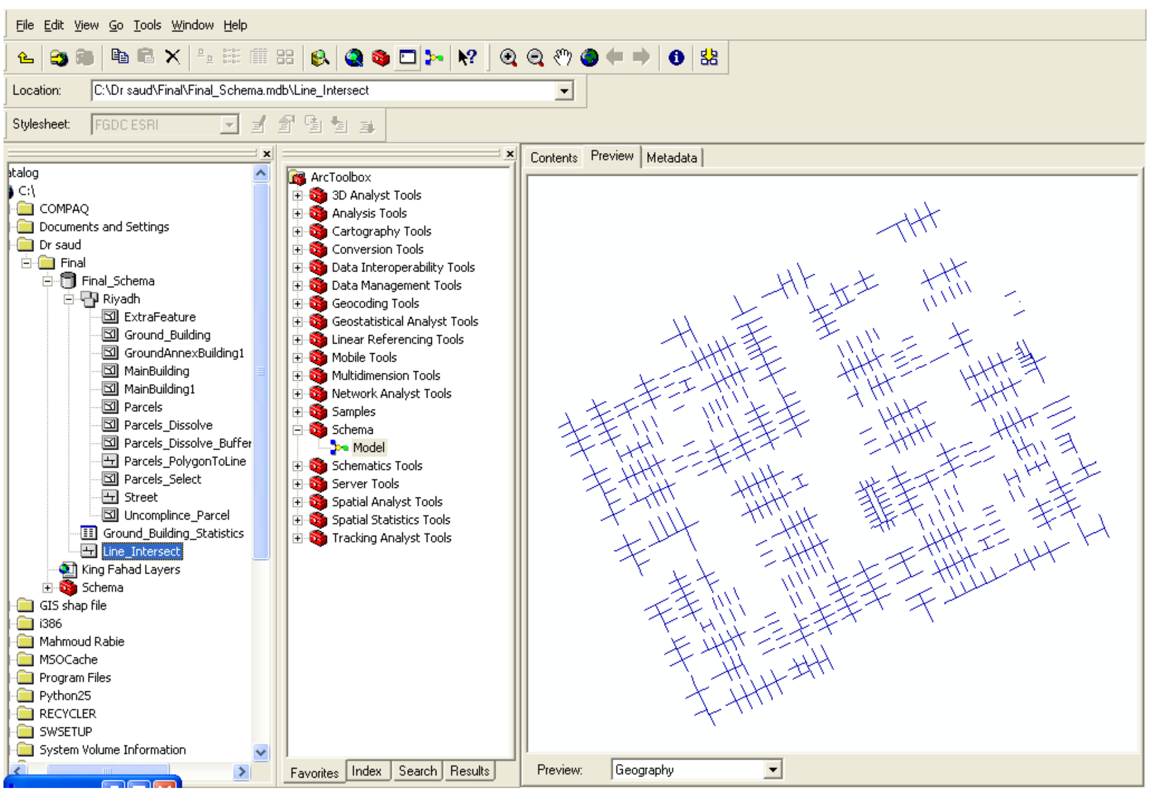


Figure 5.15 Common boundaries between parcels

5.2.5.3 Assigned compliance classes

The violation detection module was developed based on the integration of different data sources, requirements and quality aspects. This module implements the violation report and presents the results of the violation detection process. Two main scenarios can be generated from these data outputs: (a) production of the appropriate report if the violation detection result is definitely ‘violation’ or ‘no violation’, and (b) an analysis of cases where the result is ‘possible violation’ in order to provide more data. For all cases of possible violation, high quality data should be obtained from the data sources module.

5.2.6 The reporting module

The violation detection reporting module is the final stage of the prototype model. However, the outcomes produced from the implementation of all map sources are based on the accuracy ranges that have been detailed in Sections 3.6.1.1 and 3.6.1.2. The outcomes and reporting generated by the prototype provide the results of all possible violation types within the scope of the work in this study. The data output from this module produce the essential data from violation detection map data and attribute data. The violation detection reports are able to classify the inspection result as either no violation, possible violation or definite violation. However, the user of the prototype model can view the detection result for any cadastral parcel and building, or for the entire study area, by running the ModelBuilder schema. Finally, this module presents the complete formal and inspection result as an outcome of the incorporation and integration of the previous prototype modules.

5.3 Prototype Implementation

The implementation of the prototype was applied based on the SEBI framework design. The SEBI prototype only partly implemented the framework, but it covered all modules of the framework. The following sections cover the implementation of the SEBI prototype for each violation included in the scope of the prototype model: main and ground annex buildings coverage areas, upper building coverage area, street setback and side/rear setbacks. The prototype was tested using imagery at the 1:2500 scale and the cadastral area from the accurate subdivision plan.

5.3.1 First violation: Main and ground annex buildings coverage area

The required data and metadata extracted from the data sources included the building data at 1m resolution from aerial imagery, the coverage area regulations to obtain rules and the threshold building area (≤ 60) of the cadastral area, the approved and actual area of the building from imagery at the 1:2500 scale and the cadastral area from the accurate subdivision plan. Quality metadata and geospatial features of the main and ground annex buildings were extracted to produce the ± resolution error of the aerial source and the building footprint and cadastral area Then, assess the data quality of the building coverage area error classes, at this point of the process the error area ranges will accurate. Figure 5.16 shows the violation classes, boundaries and ranges of the main and ground floor annex buildings footprint coverage areas.

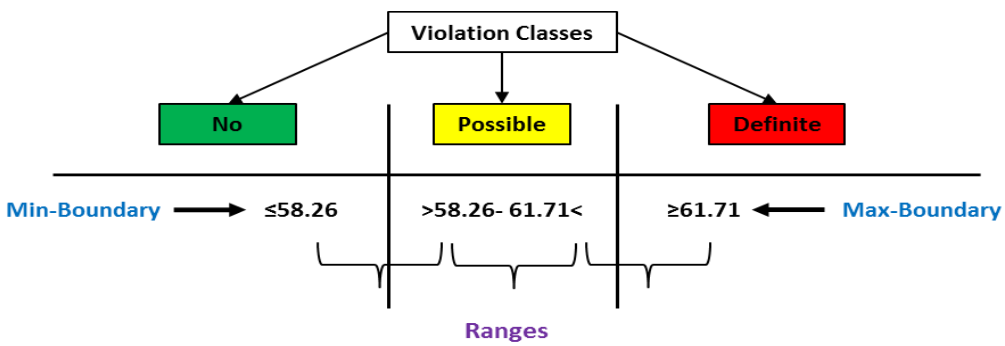


Figure 5.16 Violation classes, boundaries and ranges of the main and ground floor annex buildings footprint area

The SEBI prototype requires features and measurements to be prepared, such as the cadastre area and building footprint. The prototype is capable of examining all the buildings within the study area. For example, Figure 5.17 shows the processes involved in the main and ground floor annex buildings coverage area violation detection for three buildings namely: 64 Alsda Street, 19 Alfaris Street and 43 Salman Street. The cadastre areas and building footprints were obtained from extracted spatial information within the data input module. Integration thresholds and measurements were obtained from the area error ranges and the cadastre areas that were extracted from the features and measurements dataset. This action generated error class areas for the cadastre dataset;

the calculation of the building footprint ratio and assignment to error classes were made based on the error class areas of the cadastre dataset and the building areas. At this point of the SEBI prototype two decisions could be taken: the first was to produce the appropriate report classifying 64 Alsda Street as‘No Violation’, 9 AlFaris Street as ‘Possible Violation’ and 43 Salman Street as ‘Definite Violation’. The second decision was to provide more high quality data to the data input module in order to further assess the possible violation at 9 AlFaris Street. This might include fieldwork or more accurate imagery.

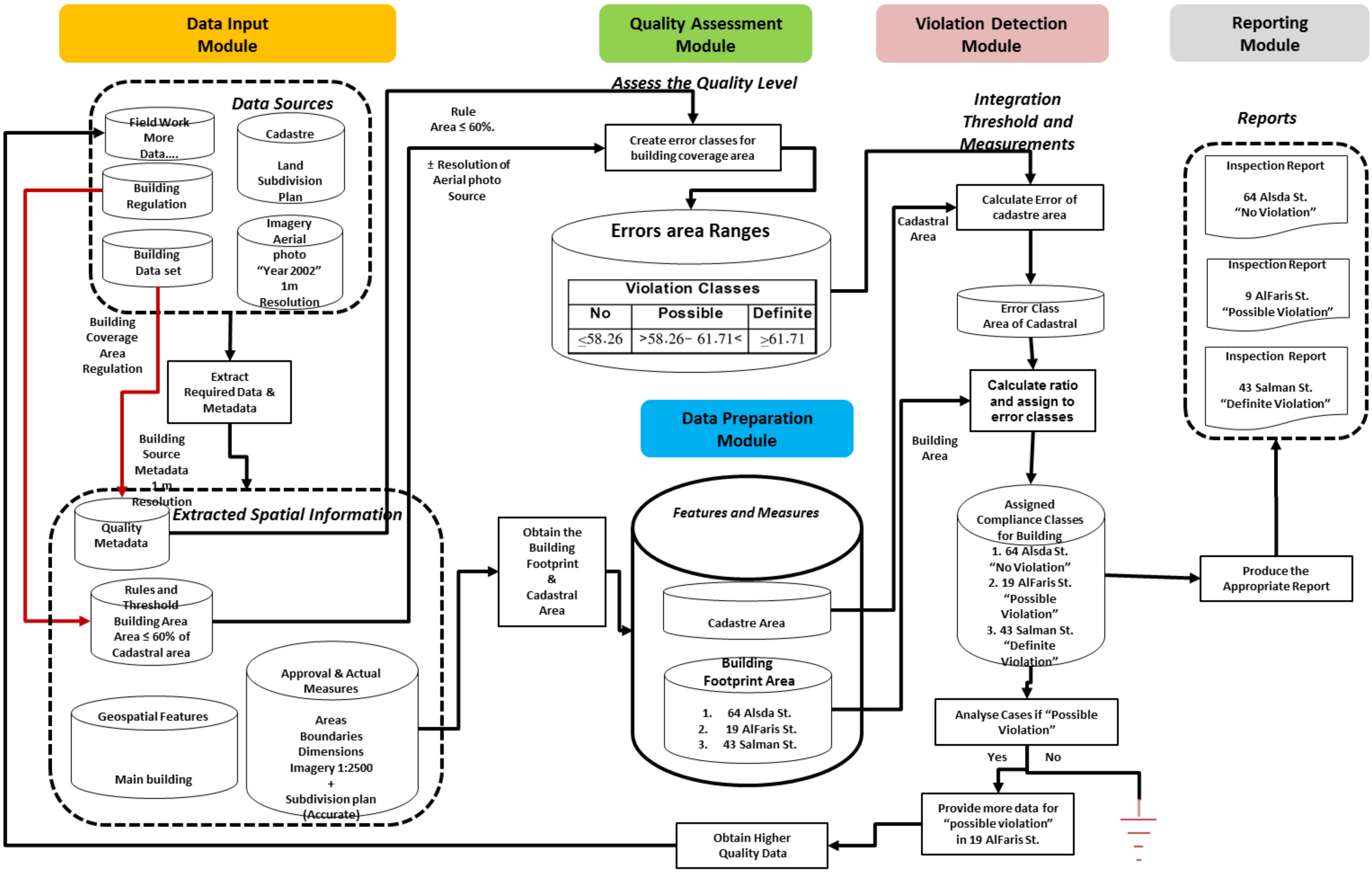


Figure 5.17 Main and ground annex buildings coverage area violation detection process

5.3.2 Second violation: Upper annex building coverage area

In this type of violation limited data sources were implemented because the only data input source was imagery at 1m resolution. The required data and metadata were extracted from the following data sources: the building area and coverage area regulations (to obtain the rules and threshold building area (≤ 20) concerning the upper annex building area) and the approved and actual measurements of the building area extracted from imagery at a 1:2500 scale. Quality metadata and the geospatial features of the upper annex building were used to produce the ± resolution error of the aerial photo and the rule area ≤ 20 of the building footprint to determine the data quality of the coverage area of the upper annex building error classes. Figure 5.18 shows the violation classes, boundaries and ranges of the upper annex building coverage footprint area.

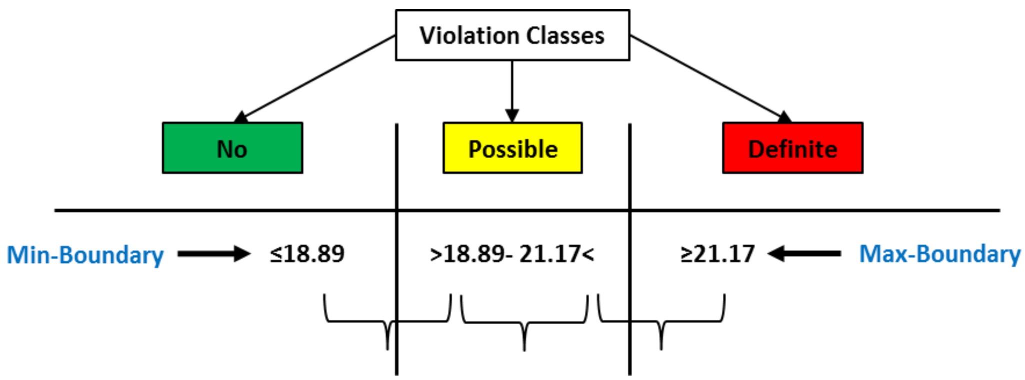


Figure 5.18 Violation classes, boundaries and ranges of the upper annex building

The required features and measurements of the upper annex building footprint were prepared after data extraction from the data input module. Figure 5.19 shows all processes involved in the implementation of the upper annex building coverage area violation detection for three buildings were examined in the prototype: 19 Fawaz Street, 27 Albatin Street and 8 Jamal Alail Street. Integration thresholds and measurements were obtained from the error area ranges of the buildings and the building footprint areas were extracted from the dataset of features and measurements to generate the error class area of the main building dataset. Calculation of the building footprint ratios and assignment to error classes was performed based on the error class area from the main building database and upper annex building area, extracted from the features and measurements dataset. The compliance results were: 19 Fawaz Street,‘No Violation’; 27 Albatin Street, ‘Possible Violation’; and 8 Jamal Alail Street,‘Definite Violation’. For the possible violation class at 27 Albatin Street more and better quality data are required from the data input module; for example, fieldwork or more accurate imagery. At the final stage of the SEBI prototype the inspector will be able to produce the appropriate report.

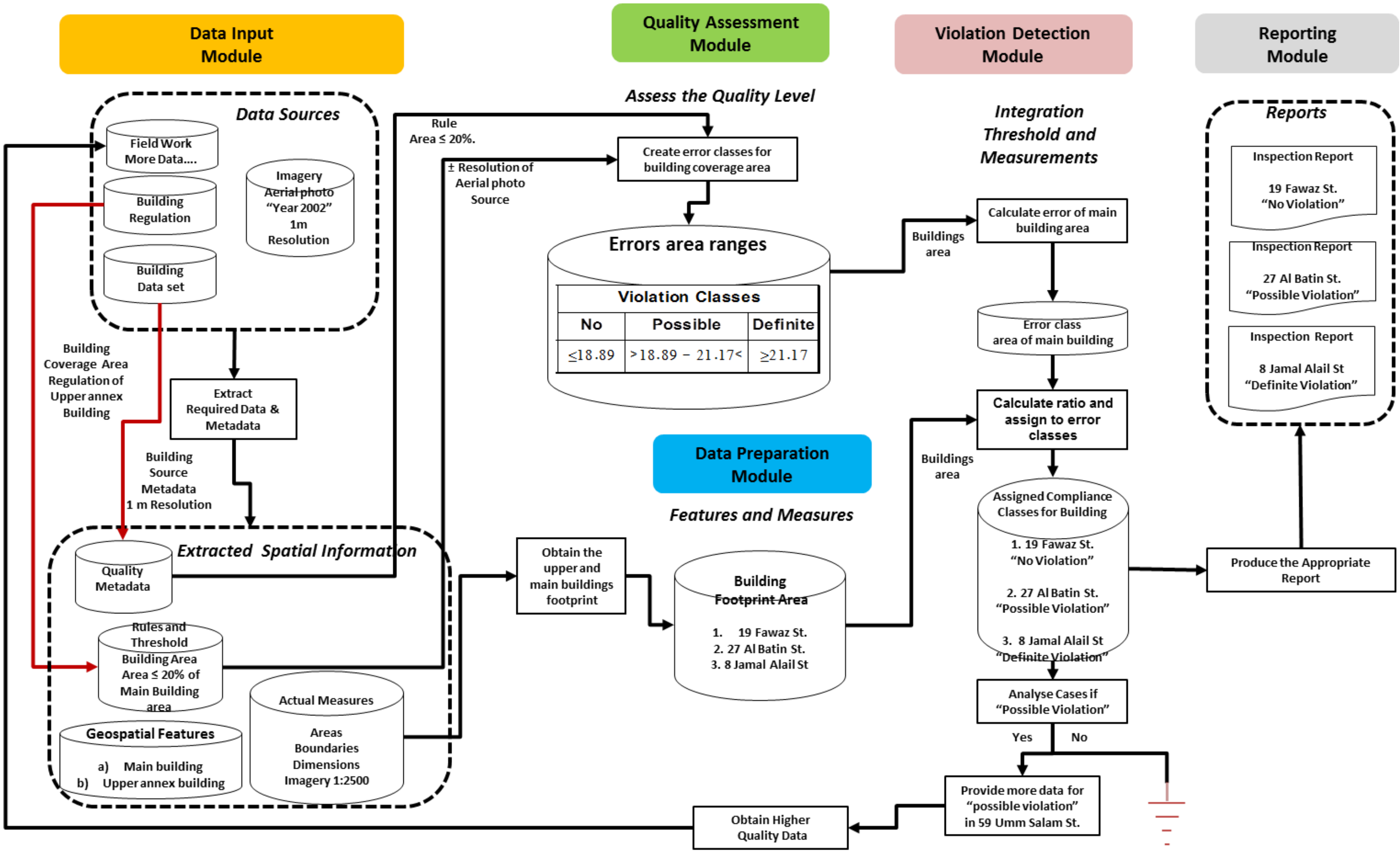


Figure 5.19 Upper building coverage area violation detection

5.3.3 Third violation: street setback distance

The data sources necessary for street setback distance violation detection are geospatial data and building regulations regarding the main building footprint, (1/5) street width, the building dataset, and the street centreline and width. Quality metadata for this type of violation were extracted from two sources: building source metadata at 1 m resolution and accurate street source metadata. The approved and actual measurements for the building footprint boundary were obtained from imagery at a scale of 1:2500, and the street centreline and width from the land subdivision report. The data quality was assessed based on the rule distance (≥ 1/ 5) street width and ± the resolution error of the aerial source for the footprint of the main building and the street centreline and width. The error classes were created for the street setback distance and the error boundary ranges produced (see Section 5.2.3.2).

The features and measurements of the street setback distance were prepared after the extraction of the data for the footprint of the main building and the street centreline and width from the data input module. Figure 5.20 shows all the processes involved in the implementation of street setback distance violation detection for three locations examined in the prototype were 36 Albatin Street, 59 Umm Salam Street and 43 Rumah Street. The integration threshold and measurements were obtained from the error boundary ranges of the street setback distances and the street centrelines extracted from the features and measurements dataset. The violation detection process began with the calculation of error buffers around the street centrelines to produce error class buffers for the street centrelines and assign compliance classes for the building based on their footprint boundaries.

The compliance assignment results were: 36 AlBatin Street,‘No Violation’; 59 Umm Salam Street, ‘Possible Violation’; and 43 Rumah Street, ‘Definite Violation’. For the possible violation class at 59 Umm Salam Street more and better quality data are required from data input module, for example, fieldwork or more accurate imagery. In the final stage of the SEBI prototype the inspector was able to produce an appropriate report.

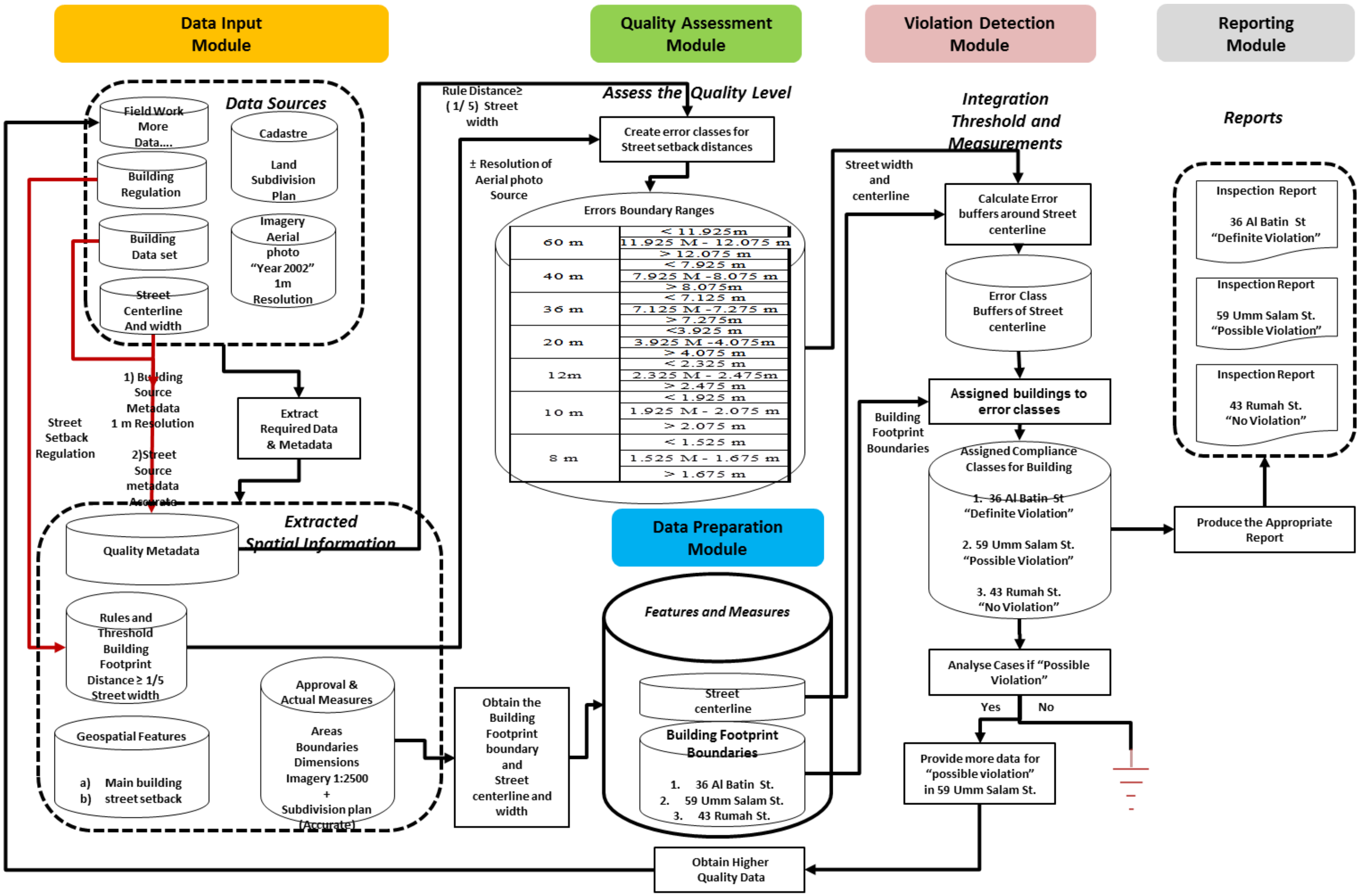


Figure 5.20 Street setback violation detection

5.3.4 Fourth violation: Side/rear setbacks distance

The side/rear setback violation detection data sources are slightly different to those for street setback violation detection. The sources used to extract the necessary geospatial information were the building regulations, building dataset, land subdivision plan for the cadastre data, and 1m resolution imagery. The extracted geospatial data were the rules and threshold building footprint distance (≥ 2m), the geospatial features of the main building and side/rear setbacks, the approved measures of cadastral and quality metadata of building from imagery at 1m resolution. A rule distance ≥ 2m and ± resolution error of the aerial source for the footprint of the main building were used to create error classes for side/rear setback distances and produce errors boundary ranges. Figure 5.21 shows the violation classes, boundaries and ranges of the side/rear setback distances.

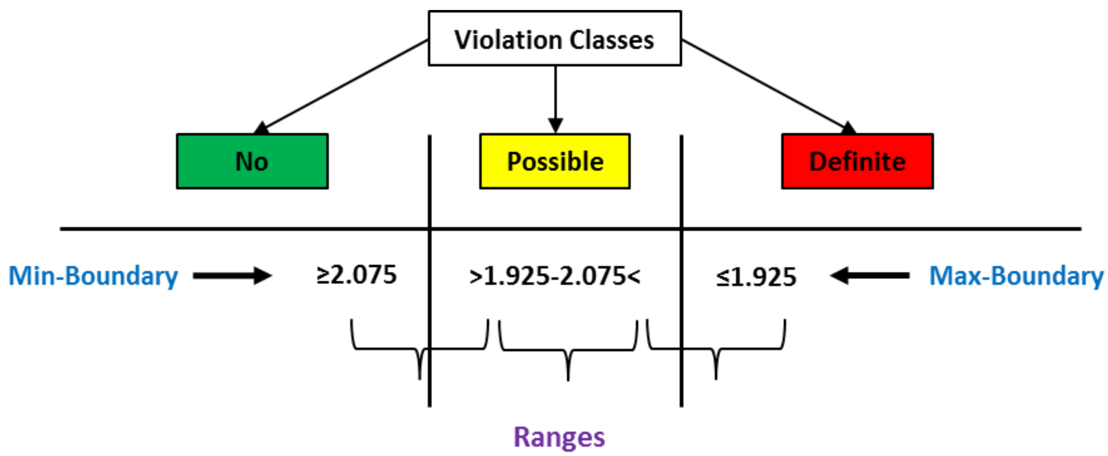


Figure 5.21 Violation classes, boundaries and ranges of side/rear setback distances

The features and measurements of the side/rear setback distances were prepared after extraction the footprint of main building and the cadastre boundaries from the data input module. Three locations were examined in the prototype: 21 Belad Street, 38 Hamam Street and 16 Al Murfa Street. Cadastre dimensions that were obtained from error ranges of the side/rear setback distances and the cadastre boundaries extracted from features and measurements dataset combined error buffers around cadastre to produce error class buffers of cadastre then overlay buffer and building to assign compliance classes for building based on building footprint boundaries.

The compliance assignment result is: 16 Al Murfa Street,'No Violation'; 38 Hamam Street, 'Possible Violation'; and 21 Belad Street,'Definite Violation'. For the possible violation class at 16 Al Murfa Street more and better quality is required from the data input module, for example, fieldwork or more accurate imagery. Figure 5.22 shows the final stage of the SEBI prototype used by the inspector to produce the appropriate report for the detection of side/rear setback violations. Figure 5.23 shows all processes involved in the implementation of street setback distance violation detection.

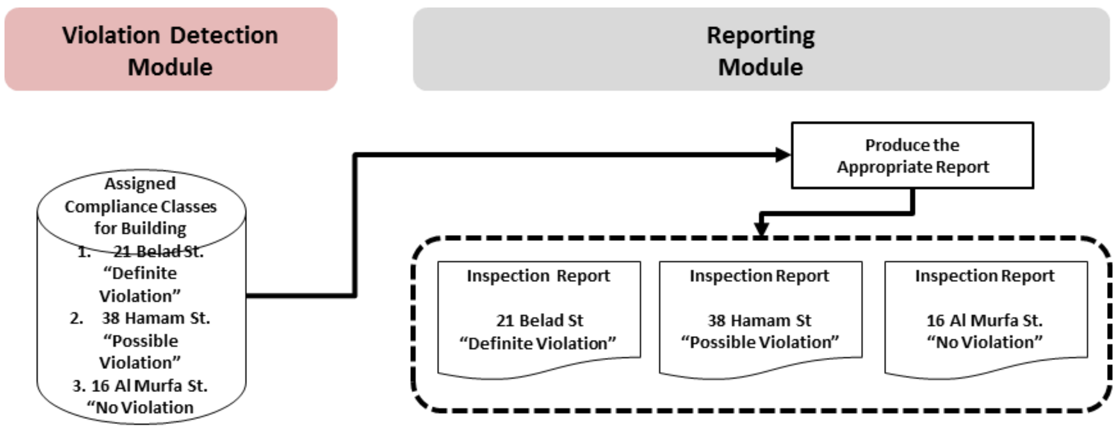


Figure 5.22 The final stage of the SEBI prototype and production of the inspection report

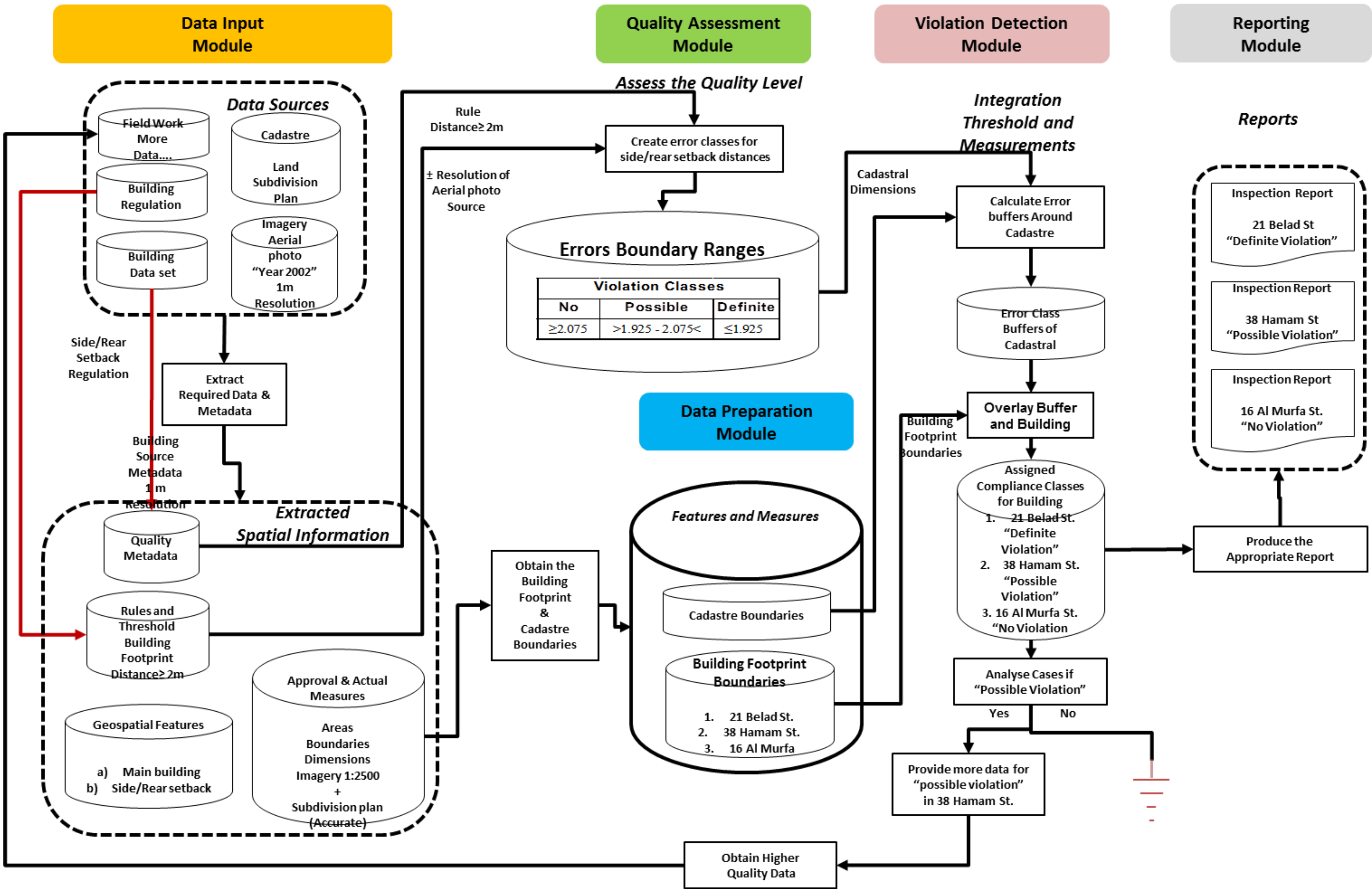


Figure 5.23 Side/rear setback violation detection

5.4 Chapter Summary

The first part of this chapter has outlined the inspection framework design; this design section will partially satisfy Research Objective 2. The inspection framework was developed based on the issues discussed in Chapter 4, as well as the issues that were identified in the literature review and the survey of inspectors. The design of the SEBI framework satisfies the requirements attribute discussed in Section 4.2. The framework has five modules: (a) inspection input data, (b) data preparation, (c) quality assessment, (d) violation detection and (e) reporting. The framework addresses the issues surrounding multiple datasets and formats, digital data of varying scales, resolution and geographic locations, the quality of measures and determinations, and decisions regarding violations to support the building inspection process. The second part of this chapter has discussed the design of the SEBI prototype to verify the technical capacity of the SEBI framework module design. The prototype was designed within a geospatial environment to support the implementation of geospatial methods and building regulation compliance. The prototype covers all four violation types considered within the scope of this project: the main and ground floor annex buildings, the upper annex building, the street setback, and the side/rear setbacks. The aim of the implementation of the prototype was to validate the SEBI framework design and to verify the benefits of the spatial method in improving building inspection quality.

6 SPATIALLY ENABLED BUILDING INSPECTION FRAMEWORK EVALUATION

This chapter presents the evaluation of the Spatial Enabled Building Inspection (SEBI) framework based on the outcomes of the inspector survey, prototype implementation outcomes and the field inspection report outcomes obtained during the second field trip. Evaluation aspects that will be covered in this chapter are violation detection, inspection data accessibility, inspection data quality and geospatial data usage and WFoI. The evaluation focuses on the framework requirement attributes listed in Section 4.3 in order to assess whether the SEBI framework has satisfied Research Objective 3, and will be performed from the perspectives of design and technical benefits. The chapter begins by describing the matrix of evaluation that was designed to understand the overlap and interaction between the framework modules and requirements.

6.1 Matrix of Evaluation of Content Overlap

The matrix of evaluation was designed to understand the overlap and interaction between framework requirements and modules. This matrix includes the five requirements addressed in (Section 4.3) the ability of the framework to detect a violation, to integrate the construction features and measurements, to apply the quality aspects, implement building regulations and maintain the WFoI. The evaluation matrix includes all the SEBI framework modules: data input, data preparation, quality assessment, violation detection and reporting. It shows the overlap and relationships between requirements and modules, for example, the overlap between the ability to determine and classify building violation requirements and the data preparation module functions to identify the violation type and determine its class. Another example, the overlap between applying inspection data quality requirements and the data input module functions to obtain highly accurate data from different sources.

Table 6.1 shows the evaluation matrix and the interactions between the framework modules, requirements and themes that create these interactions. Overall, basic and required data and the processes of inspection such as features and measurements, data quality, regulation performance and workflow implementation were tested and evaluated within different framework models. The matrix also shows that certain modules and requirements do not overlap, for example, there is no overlap or relationship between the ability to determine and classify building violation requirements and the data input module. This is because the detection actions are processed after the assessment of the inspection data quality and the preparation of the features and measures of the construction. Overlap and relationships are determined based on the possibility of a spatial relationship between requirements and modules.

6.2 Evaluation of Violation Detection

Identifying and detecting violations is one of the issues facing the building inspector during the inspection process. Based on the inspector survey 75% of inspectors identified particular violations as occurring often or very often (see Section 4.2.2). Figure 6.1 shows an example of the SEBI framework process to determine the violation classification for the main and ground floor annex buildings coverage area, based on the cadastre area and the building footprint area extracted from the features and measurements module. In this stage of the SEBI framework the actions of violation detection and the required data of inspections are integrated to calculate the ratio and assign compliance classes. For example, firstly, the data of building such as the area were extracted from imagery and building dataset. Secondly, the data of cadastre such as the area and dimensions were extracted from cadastre land subdivision plan. Finally, rules and threshold data were extracted from the building regulation data set. All of violation detection data were extracted from data input module. These data obtained to capture building footprint and cadastre area. This part of the SEBI framework achieves the requirement of ability to determine and classify building violation (see Section 4.2.1). Further, violation detection solves the lack of current process and the difficulties associated with violation detection on the construction site such as the fault of calculation of violation area and dimensions and capability to determine violation type (see Section 4.1.6). The module is able to detect some violations based on the features and measures as well as the actual construction.

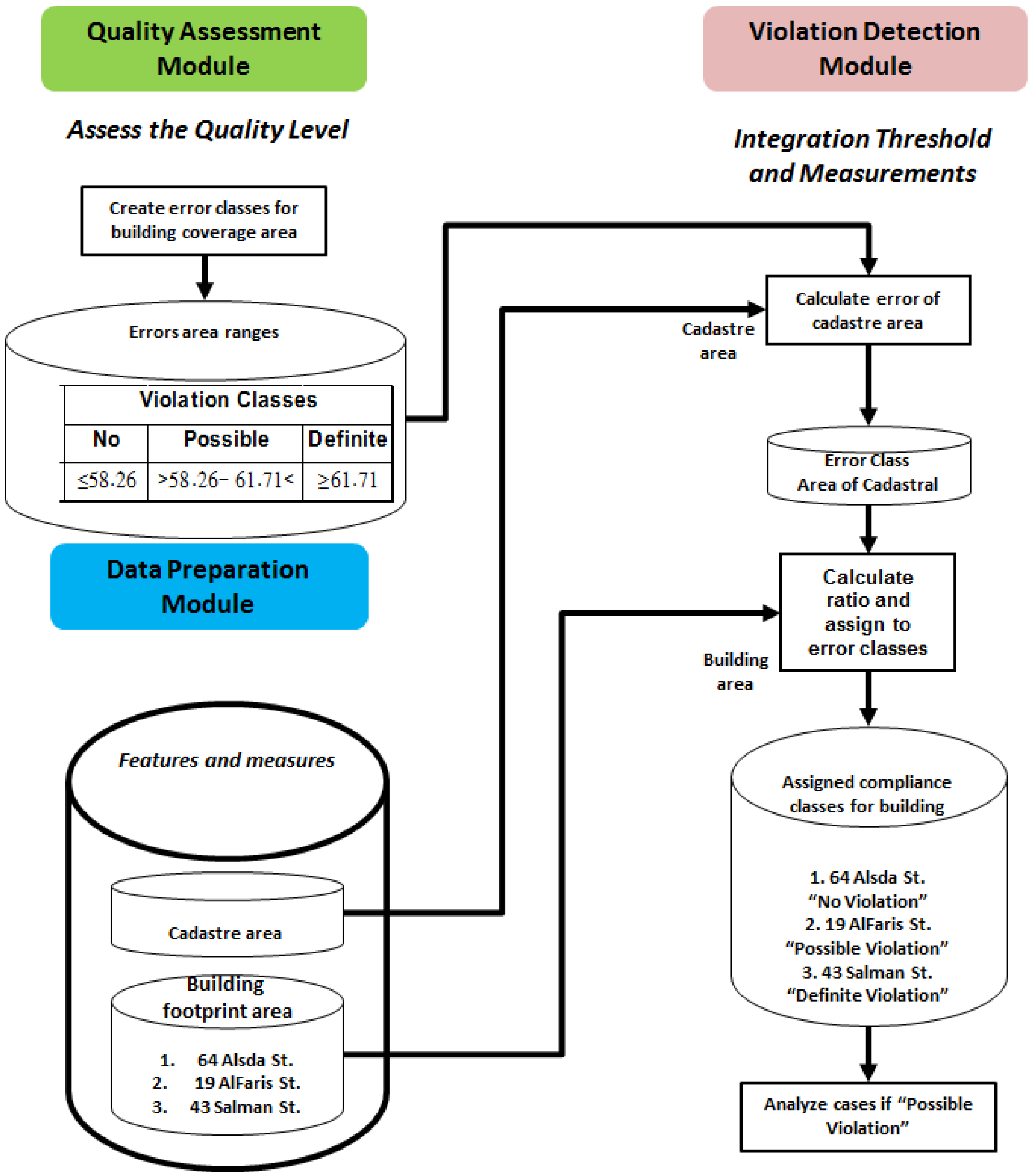


Figure 6.1 Main and ground floor annex buildings coverage area violation detection

Table 6.1 Matrix of evaluation contents overlap

Framework modules	Requirements				
	1	2	3	4	5
	Ability to determine and classify building violation	**Integration of features and measurements**	**Apply inspection data quality**	**Adherence to building regulations performance**	**Maintain workflow of inspection process in the required sequence**
Data input module	-	Provide core inspection data • Determine required data for all processes of WF sequence • Identify data source • provide measures of cadastre area and dimensions	Obtain high accuracy data: • Field work • Other.....	• Identify data source of regulations and threshold • Provide measures for all of building components such as area and dimensions	-
Data Preparation Module	• Identify violation types • Determine violation classes	-	-	• Determine threshold • Choice of regulations	-
Quality assessment module	-	**Categories of Map Source Quality** • High • Moderate • Low Identify accuracy ranges	Analyse Cases of “Possible Violation” and determine of more accurate data required	-	-
Violation detection module	-	Calculate the areas and dimensions for buildings and cadastre	• Calculate and assign Classes • Create error class’s database • Assigned Compliance Classes	Check the actual construction based on building regulations	• Carry out steps of detection in required WF sequence • Maintain the missing data and/or ignore some steps of violation detection within WF sequence
Reporting module	**Report violation classes and types** • Identify detected violation type • Classify detected violation group	-	-	-	-

As described in Section 4.2.4, the current violation detection method is limited and does not involve integration with the building regulations on the construction site. This means that the inspector may not perform the inspection correctly, and the detection results are not accurate and do not represent the reality of construction. Within the SEBI framework, the violation detection task implements all steps of detection and maintains the missing processes of WFoI, for example, it can detect new violations after the completion certificate is provided. The findings of the inspectors' surveys and the investigation of inspection issues reveals that the calculation of building, cadastre area, and dimension is a problem that inspectors face during the inspection process. This is due to no access to data to perform the calculations. Figure 6.2 shows the capacity of the SEBI framework to calculate the coverage area of a building footprint for the main and ground floor annex buildings from data input sources such as imagery, approval plan and land subdivision plan. It shows the ratio of the areas of the buildings to the area of the land parcel on which it is situated, in relation to the compliance criteria thresholds extracted from the building regulations. The SEBI framework has the ability to calculate the coverage area of main and ground annex buildings based on the area of the building and area of cadastre. Then the ratio of buildings by using the threshold of coverage area of the main and ground annex buildings (Area ≤60 %) is obtained.

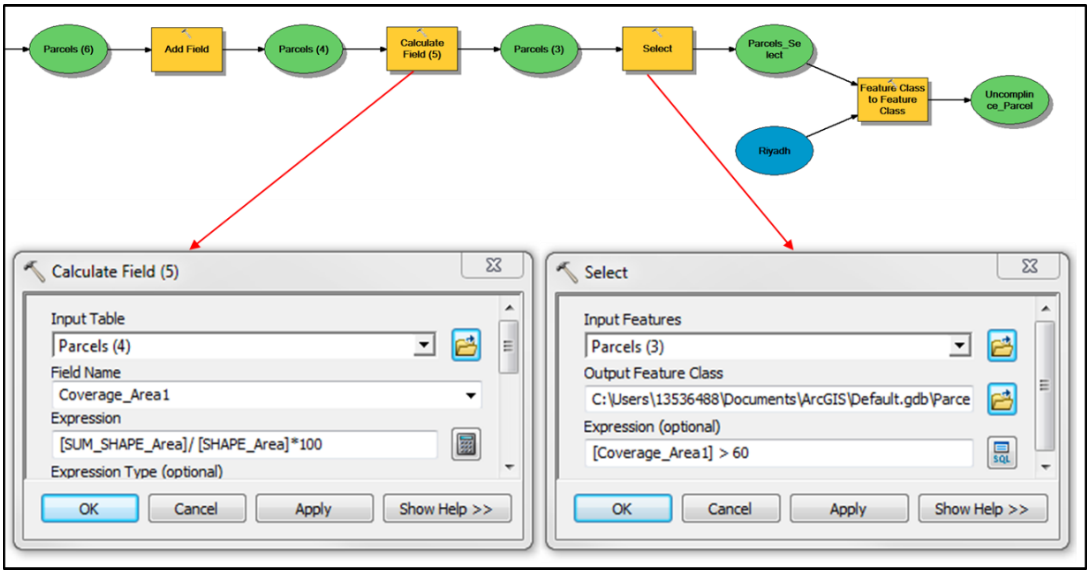


Figure 6.2 calculating the area and the ratio of main and ground annex buildings

Therefore, the SEBI framework improves the ability to determine and classify building violations through the violation detection component (see Section 4.3.1). The SEBI framework provides the ability to calculate the areas and dimensions of the actual construction from a geospatial dataset. The SEBI framework supports violation detection at the decision point of assigning the violation within WFoI. Finally, the capacity of the SEBI framework to detect violations is improved compared to current inspection process.

6.3 Evaluation of Inspection Data Accessibility

One of the framework requirements is to provide the access to measurements from cadastral and building data. Many difficulties of inspection were related to data accessibility, for example, the challenges of obtaining inspection data associated with obtaining the data needed to determine violations. The required inspection data such as cadastre, buildings and streets are accessible within data input module in the SEBI framework in different datasets. Figures 6.3 and 6.4 show the ability of the SEBI framework to provide data accessibility to the measurements and features required for inspection, such as cadastre area, building area and street width (see Section 2.2.3). For instance, (a) actual measures of buildings from the geospatial features data set, (b) cadastre area and boundary data from approval and actual data set and (c) streets width and centerline from geospatial features data set can be derived using geospatial tools. The current inspection process lacks access to such measurements that are required for decision making points (see Section 4.1.3)

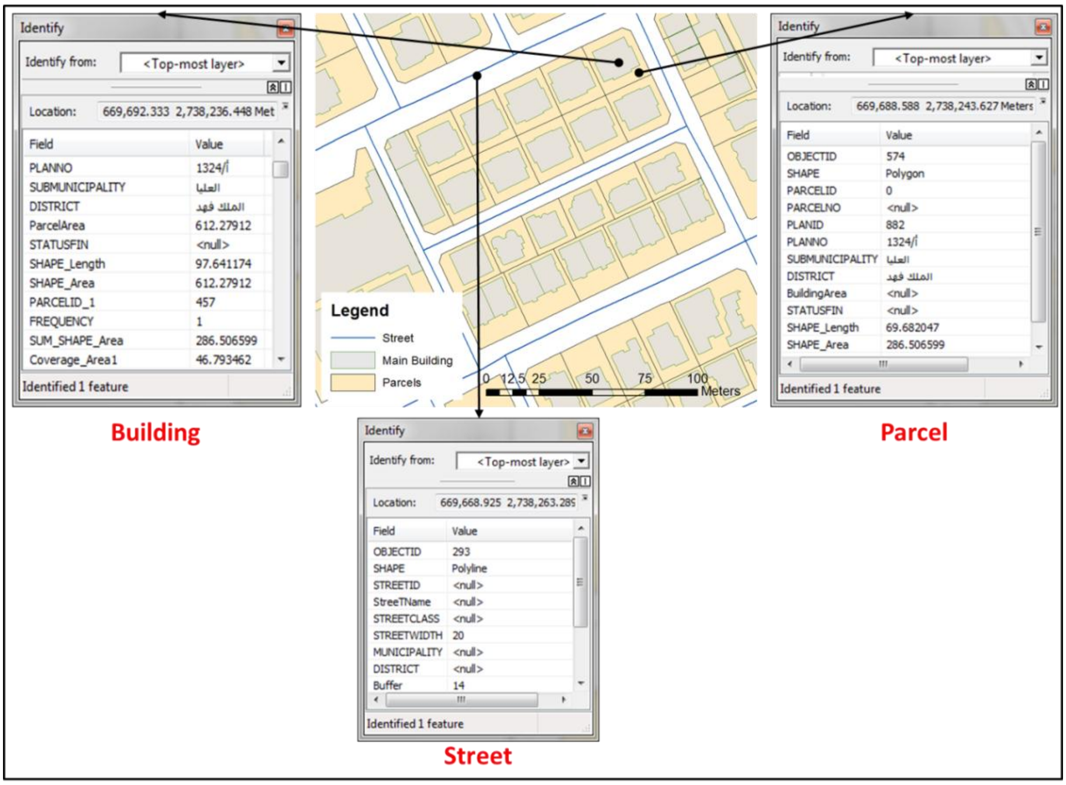


Figure 6.3 Access to measurements and features of cadastre, building and street

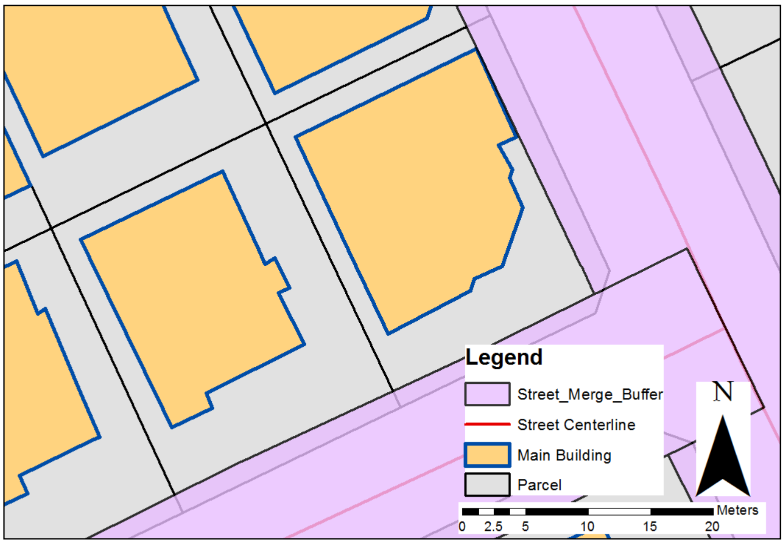


Figure 6.4 Data accessibility for the street centreline, main buildings and parcel

Figure 6.5 shows an example of the extracted spatial information of building such as footprint area from geospatial features and actual data sets within data input sources. These extractions provide geospatial features of different buildings and the actual measures such as areas, boundaries and dimensions of buildings and cadastre. These data were derived from aerial photographs and digital land approvals. The current inspection process in the Riyadh study area inadequate access to building data, in particular, inability to access the building footprint to perform the most recent on-site construction, in the other example, about 45% of inspector could not have access to review the history of the property (see Section 4.1.3). Thus, the required data sources of inspection such as the building footprint, cadastre boundaries, rules and threshold, and street width and centerline are accessible within framework through the data input module.

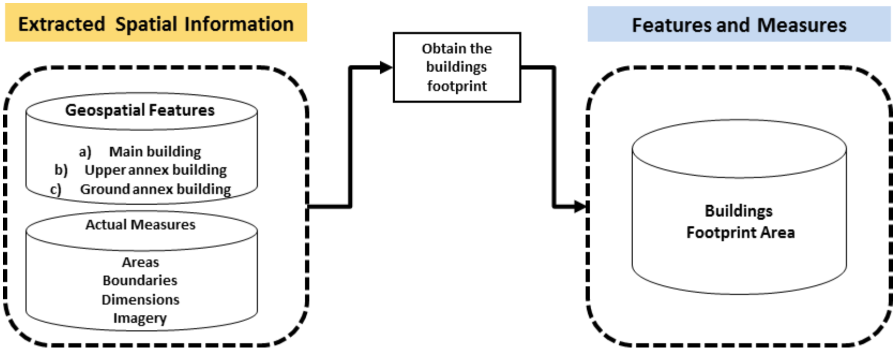


Figure 6.5 Obtaining the building footprint

Figure 6.6 shows a screenshot of geospatial information regarding the area of building footprints as calculated and obtained from the GIS for the SEBI prototype. These data were obtained from the building cadastral dataset which itself was derived from aerial photographs. This data were combined for main and ground annex building with a spatial join operation by parcel number. The current inspection process does not provide the necessary access to such current building area data (see Section 4.1.3).

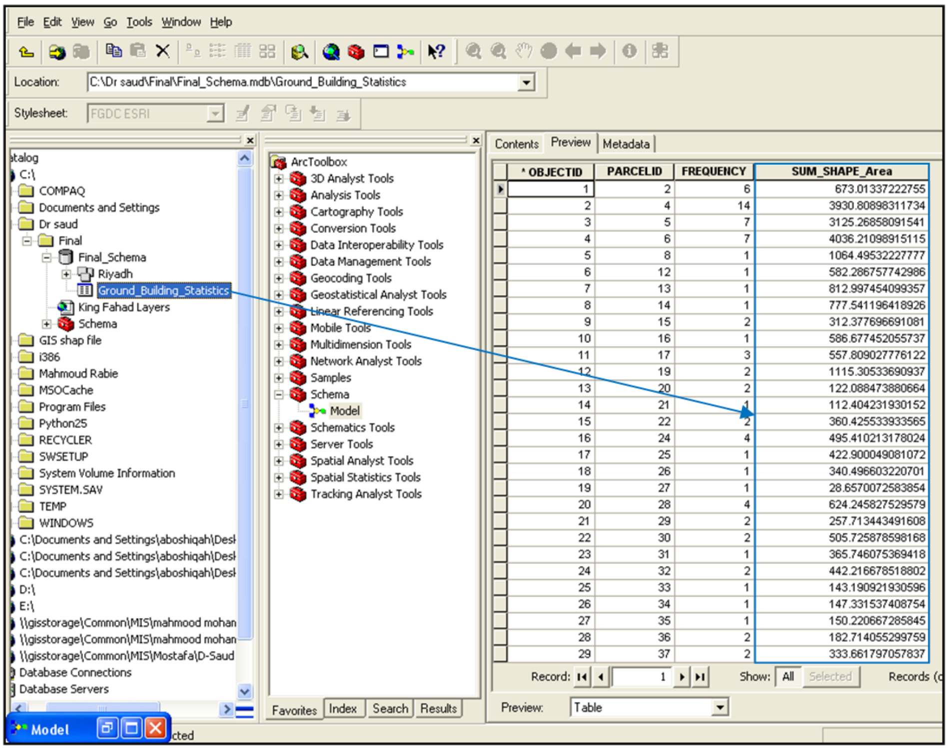


Figure 6.6 Crucial main and ground annex building area data accessed via the GIS used to implement the SEBI prototype

Hence, the SEBI framework provides access to required inspection data such as rules and threshold, buildings footprint, cadastre boundary, area and dimensions. These required data were accessible within the SEBI framework through data input module. In addition, extracted data sets from data sources were accessible, for example, geospatial features such as building, threshold and approval and actual measurements, for example areas, setbacks dimensions and boundaries.

6.4 Evaluation of the Quality of the Inspection Data

The evaluation of the quality of the inspection data includes two main parts: the first part is evaluation based on the prototype results and the second part is evaluation based on field inspection reports outcomes.

6.4.1 Evaluation of the quality of the inspection data based on the prototype results

In order to evaluate the implementation of the prototype, two images obtained from the Riyadh Municipality Aerial Imagery Project in 2002 were used for the King Fahd District study region, one with low resolution and the other with high resolution. As stated in Section 5.2.3.2, the low accuracy map source is aerial photography at a scale of 1:5000 with an error range ± 6.65 m^2 for the area and ±17.9cm distances for each feature. In essence, this means that the worst case combined error range for the area of cadastre and buildings is ± 13.3 m^2 and the worst case combined error range for the distances of cadastre and buildings is ±32.2 cm. The high accuracy map was obtained from aerial photography at a scale of 1:2500 with an error range ± 2.85 m^2 and ±7.45cm distances for each feature. Using the building measurements from this high resolution imagery together with cadastral data obtained from the land subdivision plans, which are highly accurate (i.e., assuming zero error), the combined worst case error range was assumed to be ± 2.85 m^2 for the area and ±7.45cm for the distances The following sections discuss the outcomes of the prototype model and field inspection reports that were used to test and evaluate the quality aspects of the SEBI framework (see Section 5.2.3.1). In addition, there is small error within land subdivision plan about ±35cm. For the practical inspection purpose this range is acceptable, because the tolerance range for inspection in CoR is (±50cm).

6.4.1.1 Coverage area of main and ground floor annex buildings violations

The SEBI prototype outcomes were performed and evaluated for the coverage area of the main and ground floor annex buildings. Figure 6.7 shows when the low accuracy source data were used, 18% of the buildings were identified as being noncompliant and 67% were assessed as being compliant. For the remaining 15%, compliance could not be determined because of inaccuracies and errors in the available data, and hence they were classified as 'possible violations'. When the high resolution image was used in the violation detection process, the number of occurrences of the possible violation category was reduced to 7%, the number of definite violations increased to 22% and the number of compliant buildings increased to 71%.

The results for assessing the coverage area of the main and ground floor annex buildings showed, for example, that when the high accuracy source imagery data was used, the 'possible violation' class could be reduced by more than 50 % compared to when the low accuracy source data were used in violation detection.

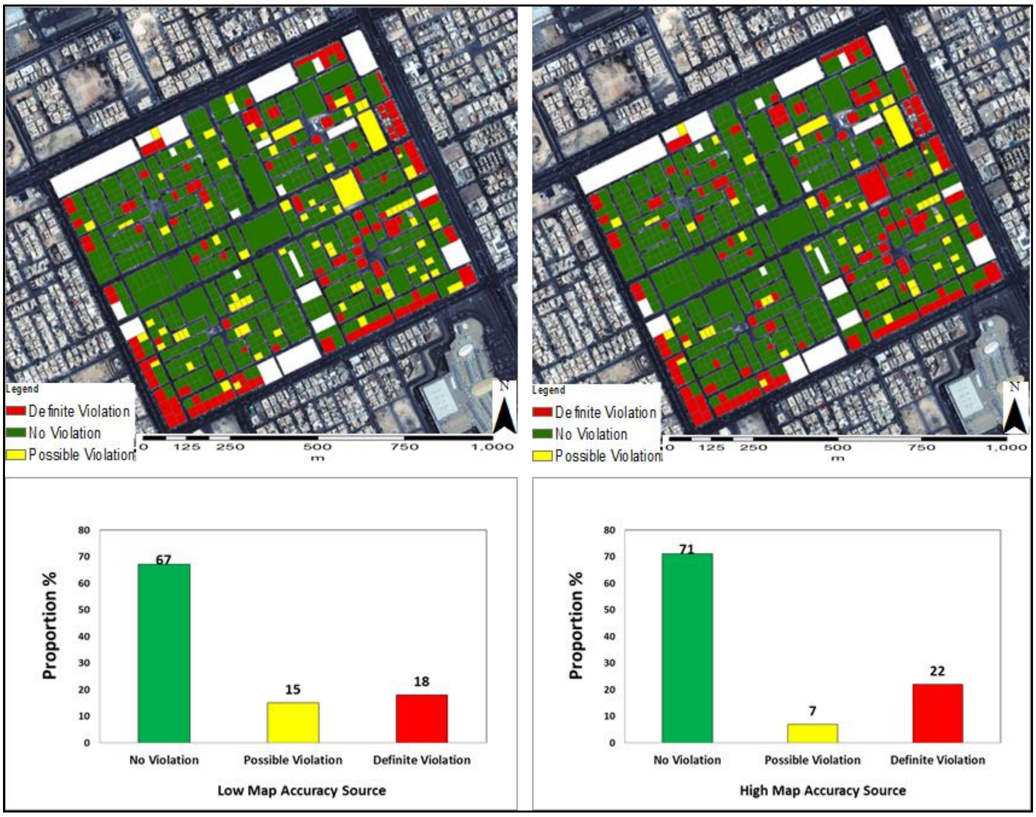


Figure 6.7 Detection results of coverage area for main and ground floor annex buildings violations

6.4.1.2 Upper annex building violations

When the low accuracy source data were used to detect the coverage area of upper annex buildings, 27% of buildings were identified as being noncompliant and 63%

were assessed as compliant (Figure 6.8). For the remaining 10% of buildings, compliance could not be determined because of inaccuracies and errors in the available data, and hence they were classified as ‘possible violations’. When the high resolution image was used in the violation detection process, the number of occurrences of the possible violation category was reduced to 6%, while the number of definite violations increased to 29% and the number of compliant buildings increased to 65%.

The outcomes of the prototype model show a high probability of coverage area of upper annex building violations compared to other coverage area violation types; nevertheless, this outcome overlaps with the survey result, 90.6% for the upper annex building (see Section 4.2.1). The quality of the upper annex building violation detection was improved, for example, the detection of violations using the high resolution image (either positive or negative) was 94%, and the possible violation class was reduced 40%. The current inspection process mixes the possible violation class with no violation / definite violation, consequently, the outcomes of violation detection in current inspection process contains some doubt and error especially for the upper annex building.

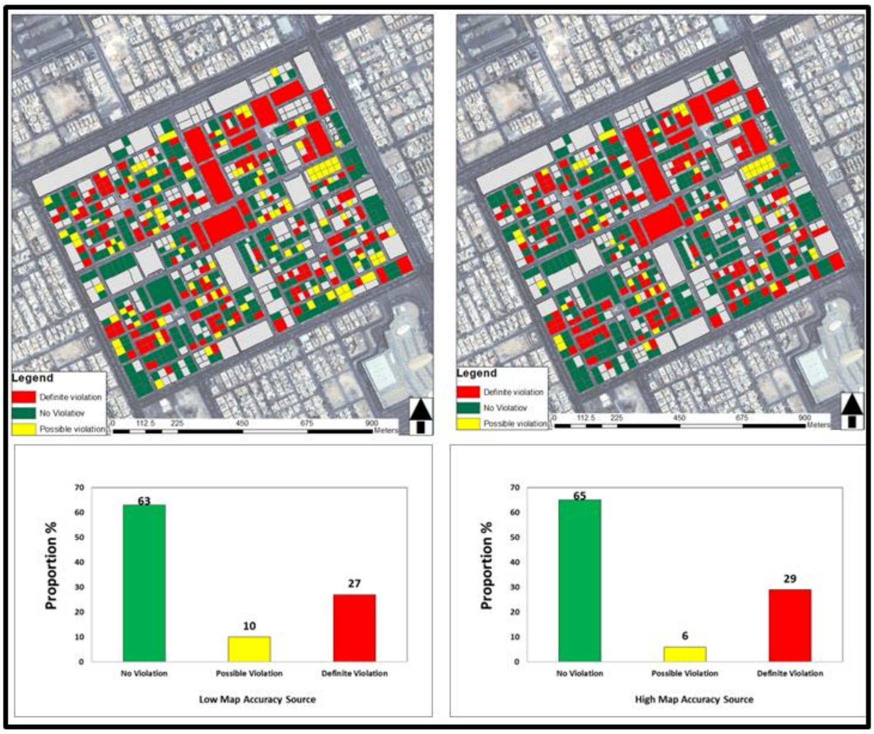


Figure 6.8 Detection results of coverage area for upper annex building violations

6.4.1.3 Street setback violation

When low accuracy image was used, 25% of the buildings compliance of regulations was identified as being noncompliant and 61% could be assessed as definitely compliant (Figure 6.9). For 14% of buildings compliance could not be determined because of inaccuracies and errors in the available data, and hence they were classified as ‘possible violations’. When the high resolution source image was used in the violation detection process, the number of occurrences of the possible violation category was reduced to 3%, while the number of definite violations increased to 30% and the number of compliant buildings increased to 67%. Thus, the quality of detection of street setback violations was improved, for example the possible violation classes reduced 80% when the high resolution source image was used.

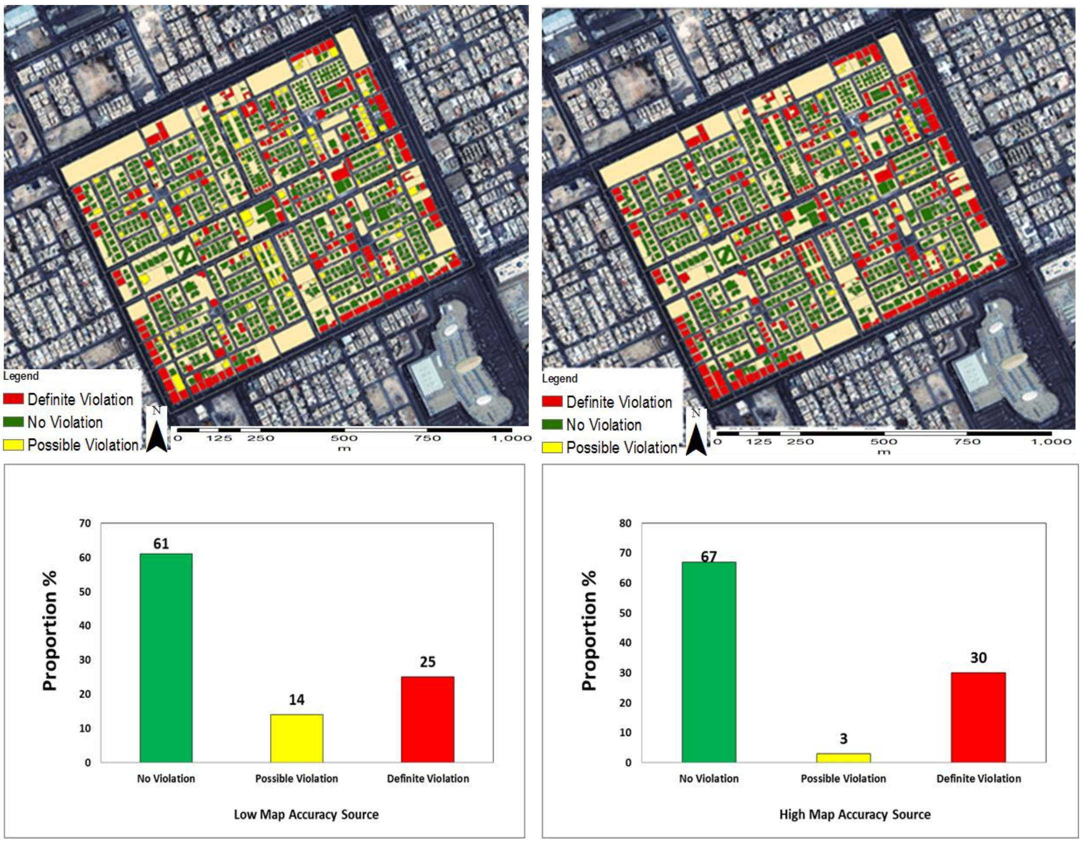


Figure 6.9 Detection results for street setback violations

6.4.1.4 Side/rear setback violations

Where the low accuracy source data were used, Figure 6.10 shows 56% of the buildings were identified as being noncompliant and only 28% could be assessed as compliant. For the remaining 16%, compliance could not be determined because of inaccuracies and errors in the available data, and hence they were classified as 'possible violations'. When the high resolution source image was used in the violation detection process, the number of occurrences of possible violation was reduced to 7%. The number of definite violations increased to 61% and the number of compliant buildings increased to 32%. Overall, the detection ability for the setback distance (both side and rear) was improved by the use of the high quality data source. The detection of setback distance violations (either positive or negative) with the low quality source was 86 %; however, this improved to 97% using the high quality data source. Based on the prototype outcomes the setback (rear/sides) violation detection improved from 84 % with the low source accuracy data to 93 % when using the high source accuracy data.

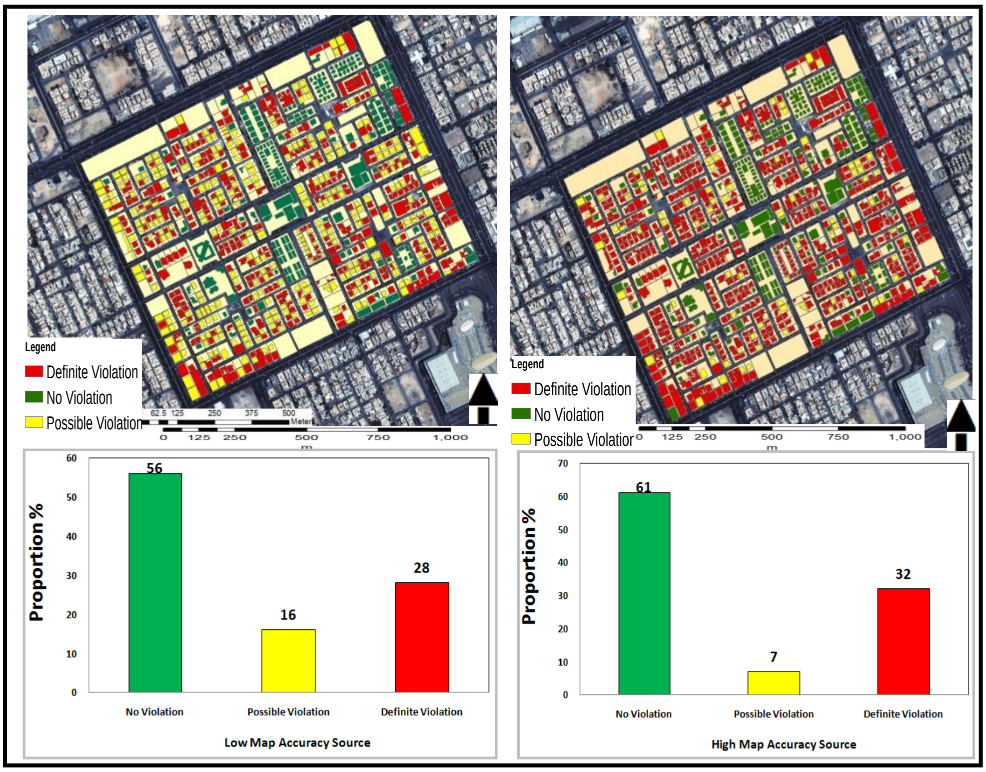


Figure 6.10 Detection results for side and rear setbacks violations

6.4.1.5 Discussion of quality of prototype results

Based on the current inspection process an inspector needs to go to a building site to obtain or confirm information used for violation detection, due to the lack of quality information regarding measurements of building footprints, cadastre boundaries, street widths and centrelines. However, the SEBI prototype utilises quality information for the data sources and provides information on the quality of a detection violation outcome.

The ability to detect violations and the quality of that outcome results in an improved detection determination process even with a low accuracy image source used in the SEBI process. For example, when applying the prototype to side and rear setback violations, 84% of properties could be identified as definitely having or not having a violation, with only 16% identified as possible violations, a result much better than the current process where more than 55pecent are not able to be determined (see Section 4.1.6). The additional benefit is that the number of possible violations can be further reduced with increasing accuracy of the source data (eg. down to 7% for this same example). This immediately reduces the need to perform field work or validate with additional data, relative to the current inspection process.

This same improvement in determining violations is apparent for each of the building violation types evaluated by the prototype. The quality information provided with the source data is utilised by the prototype to provide certainty when a decision is made regarding “definite violation” or “no violation”. For each of the four violation types, the number of properties remaining in the “possible violation” category was greatly reduced when applying the prototype, compared to the current manual inspection process. In each case, by improving the source data accuracies, this category of possible violations was still further reduced.

A further benefit of the prototype is that each of the building parcels has a quality indicator associated with the violation determination. Hence, for each of the properties identified as “possible violation”, an inspector knows the quality of the result, if it is tending towards a “definite violation” or towards a “no violation”. This can assist an inspector in prioritising which properties require further data or field work to be able to make a definitive decision regarding whether or not a violation as occurred.

6.4.2 Evaluation of the quality of the inspection data based on field inspection reports outcomes

This section provides an evaluation of the quality of the inspection data of the SEBI framework based on the outcome of the field inspection reports obtained during the second fieldtrip (see Sections 3.1.3 and 3.1.5). An inspector used a tape to obtain the measurements of areas and other dimensions. A sample of the report form is provided in Appendix F. A total of 26 reports were obtained during this fieldtrip (see section 3.1.6). The evaluation covers three types of violations: main and ground floor annex buildings coverage, side/rear setbacks, and street setback. The fourth violation type upper annex building coverage area was not included in this part of the evaluation. The reason was that the researcher and the inspectors from Riyadh Municipality faced problems in the second field trip, namely, that most of the building owners did not allow the inspectors to enter their house and/or to go up to the upper annex building. This refusal can be attributed to the culture and background of people in Saudi Arabia: access to private places in the home is prohibited to all but close relatives unless there is a good reason to allow it. Hence, the aim of the quality evaluation assessment is to demonstrate the ability of the framework to improve the quality of the results of inspection and violation detection. This part of the framework evaluation was based on the quality attributes described in Section 4.4.

Table 6.2 displays the outcomes of the fieldwork assessment of actual violation determinations relative to those produced by the prototype for the same study area. For each violation type, the fieldwork results of violation determination are compared to the prototype outcomes. For example, in case number one the prototype detection outcomes for main and ground annex buildings are 'possible violation' class (either low/high source accuracy). However, in the source accuracy the result is definite violation class. The other example, in case numbers 6,7,17 and 18 the prototype detection outcomes for main and ground annex buildings is no violation in low source accuracy and 'definite violation' in high source accuracy.

The field inspection reports from the CoR study area compare two map sources: the high accuracy map and the low accuracy map used by the prototype model implemented in Section 5.2.14. One of the important aims was to evaluate the result of the model for the ‘possible violation’ class. The other advantages of this evaluation method are that it allows the verification and testing of the framework design as well as the extraction and assessment of the quality of the geospatial inspection data used when implementing the model.

Table 6.2 Comparison of the SEBI prototype results with the field inspection reports

#	Vioaltion Detection Results (Low source accuracy, High source accuracy and field inspection reports)								
	Main and ground annex buildings			Sides/rear setbacks			Street setbcak		
	Low	High	Field Reports	Low	High	Field Reports	Low	High	Field Reports
1	P	P	D	D	D	D	N	N	N
2	P	N	N	D	D	D	D	D	D
3	P	P	N	D	D	D	N	N	N
4	P	P	N	P	P	D	P	P	N
5	P	P	D	D	D	D	N	N	N
6	P	D	D	D	D	D	N	N	N
7	P	D	D	N	N	N	N	N	N
8	P	N	N	D	D	D	N	N	N
9	P	N	N	P	D	D	N	N	N
10	P	P	N	D	D	D	N	N	N
11	P	P	D	P	D	D	N	N	N
12	N	P	D	D	D	D	N	N	N
13	P	N	N	D	D	D	N	N	N
14	P	P	D	D	D	D	N	N	N
15	P	N	N	D	D	D	N	N	N
16	P	P	N	D	D	D	N	N	N
17	P	D	D	D	D	D	N	N	N
18	P	D	D	D	D	D	N	N	N
19	N	N	N	P	P	N	P	N	N
20	P	P	D	P	D	D	P	D	D
21	P	P	N	P	D	D	N	D	D
22	N	N	N	D	D	D	P	D	D
23	P	P	D	D	D	D	P	P	D
24	N	N	N	N	P	D	P	D	D
25	P	D	D	N	N	N	P	N	N
26	P	N	N	D	D	D	N	N	N

N	No Violation	P	Possible Violation	D	Definite Violation

Figure 6.11 shows the confusion matrix which including overall accuracy, error of omission, and error of commission calculated for all the inspected buildings was created. The aim of this matrix is to assess the accuracy of the SEBI prototype imagery classification compared to field inspection reports.

Main and ground annex buildings

low source accuracy

Field report \ The SEBI prototype	N	P	D	
N	3	11	0	
P	0	0	0	
D	1	11	0	
	4	22	0	26
	15.4	84.6	0.0	100
Overall of accuracy		11.50%		

High source accuracy

Field report \ The SEBI prototype	N	P	D	
N	9	5	0	
P	0	0	0	
D	0	7	5	
	9	12	5	26
	34.6	46.2	19.2	100
Overall of accuracy		53.80%		

Sides /rear setbacks

low source accuracy

Field report \ The SEBI prototype	N	P	D	
N	2	1	0	
P	0	0	0	
D	1	5	17	
	3	6	17	26
	11.5	23.1	65.4	100
Overall of accuracy		73.10%		

High source accuracy

Field report \ The SEBI prototype	N	P	D	
N	2	0	0	
P	0	0	0	
D	1	2	21	
	3	2	21	26
	11.5	7.7	80.8	100
Overall of accuracy		88.50%		

Street setbacks

low source accuracy

Field report \ The SEBI prototype	N	P	D	
N	17	3	0	
P	0	0	0	
D	1	4	1	
	18	7	1	26
	69.2	26.9	3.8	100
Overall of accuracy		69.20%		

High source accuracy

Field report \ The SEBI prototype	N	P	D	
N	19	1	0	
P	0	0	0	
D	0	1	5	
	19	2	5	26
	73.1	7.7	19.2	100
Overall of accuracy		92.30%		

Figure 6.11 The confusion matrix of overall accuracy, error of omission and error of commission

Firstly, based on the confusion matrix overall of accuracy was increased from 11.5% to 53.8% for main and ground annex building, 73.1% to 88.5% for sides and rear setbacks and 69.2% to 92.3% for street setback when the high source accuracy was used. Secondly, the error of omission for all violation types within low source accuracy is **one**, in the other hand the error of omission for all violation types within high source accuracy is **zero**. Finally, calculating the error of the commission is impossible because the value of possible violation does not exist within field inspection report.

6.4.2.1 Coverage area of main and ground floor annex buildings violations

Figure 6.12 shows the outcomes of the samples of field inspection reports for 26 properties that were identified compared to the violation detection outcomes of low and high accuracy image sources. When using the low accuracy data source to determine the ‘violation’ and ‘no violation’ classes gave a total of 15% for the combined classes. Low source accuracy imagery shows that selected locations within the study area did not include the definite violation; because of the sample of field inspection report only 26 properties (see Section 3.1.6) and the quality of low source imagery is not able to detect the violation within small geographic area. This increased to 54% when the high accuracy data source was used. However, the current inspection process outcomes are poor as a consequence of low quality of data source and error ranges. The detection results with the high accuracy data source proved that 41% of buildings could be classified as ‘definite violations’ compared to the field inspection reports. According to the field inspection reports, 85% of buildings could be classified as ‘possible violations’, which was reduced to 46% when the high quality data source was used. The field inspections classified 15% of buildings as ‘no violation’, which increased to 35% when the high accuracy data source was used.

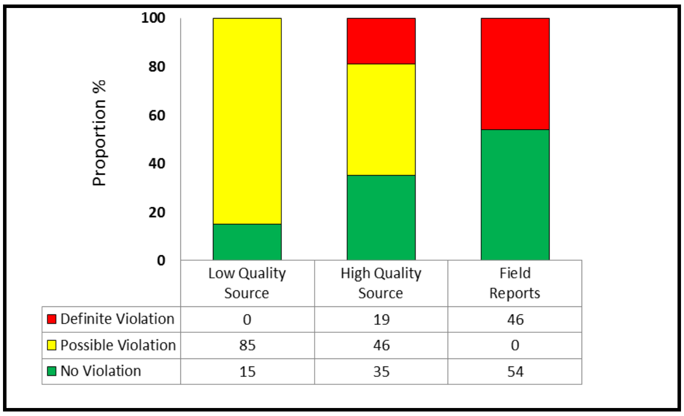
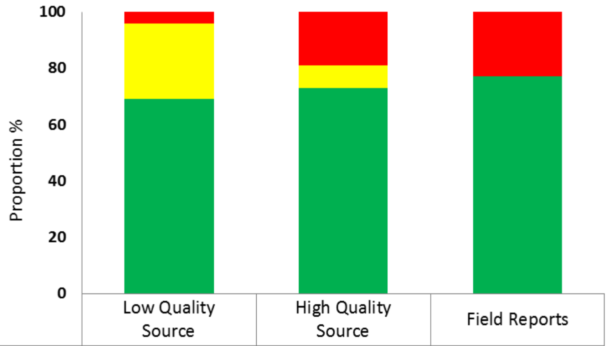


Figure 6.12 Main and ground annex buildings results

Hence, field inspection report shows that the quality of violation detection of main and ground annex buildings improved. For example, when the high source accuracy was used the detection result (either definite/no violation) raised from 15% to 54%.

6.4.2.2 Street setback violations

Here, the assessment of 83% of buildings as belonging to the ‘definite violations’ class using the high accuracy source data matched with the results of the field inspection reports. The ‘possible violation’ class was reduced from 27% to 8%when the high quality source data were used (Figure 6.13). Using the high accuracy data source, 95% of buildings could be classified as ‘no violation’, compared to 85% when the field inspection reports were used.



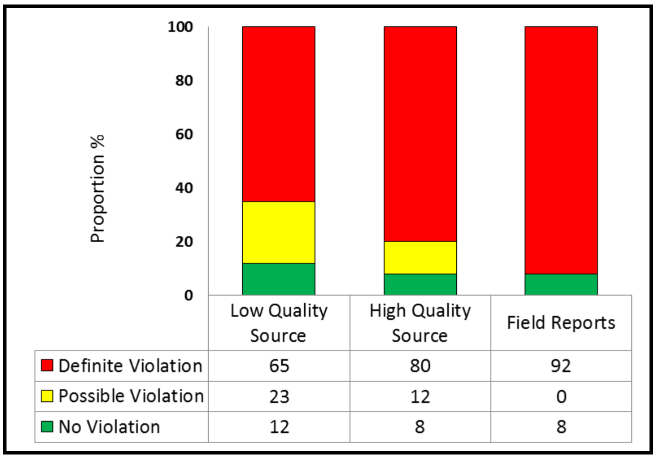
	Low Quality Source	High Quality Source	Field Reports
Definite Violation	4	19	23
Possible Violation	27	8	0
No Violation	69	73	77

Figure 6.13 Street setbacks result

The evaluation of street setback violations detection shows the ability of the SEBI framework to provide and implement high quality data sources, such as images and thresholds, from the data input. For example, the detection result increased from 73% to 92%. However, the field inspection reports prove the ‘possible violation’ class was reduced by approximately 70% when high quality inspection data were employed.

6.4.2.3Side/rear setback violations

Figure 6.14 shows that 87% of the ‘definite violation’ results were verified when the high accuracy data were used compared to the field inspection reports; however, the detection results from the high accuracy source data increased approximately 17% compared to the low accuracy source data for the same violation class. The 'possible violation' class were reduced from 23% to 12%when high accuracy source data were obtained. 'No violation' results were recorded for 8% of all buildings in the field inspection reports and when high accuracy data were used. However, when the low accuracy source data were used, 12% of buildings were classified as 'no violation'. The detection results from the field inspection reports prove that the quality of inspection was improved, with the detection result using low accuracy data being 77%, but when the high accuracy source data was used the accuracy rose to 88%. Both the prototype and the field inspection results show an improvement in the quality detection for the side/rear setbacks violations, with the detection results for the 'possible violation' class improving approximately 50%.



	Low Quality Source	High Quality Source	Field Reports
Definite Violation	65	80	92
Possible Violation	23	12	0
No Violation	12	8	8

Figure 6.14 Side/rear setbacks results

Doubts about the quality of violation detection were allayed based on the improvements observed when the quality of the violation detection was seen to improve with the use of highly accurate data sources. Current inspection and violation detection outcomes produce errors as a result of the low quality of the input data available. The SEBI framework provides an improvement of violation detection in the prototype model, with the field inspection reports providing the primary evidence confirming the ability of the SEBI framework to provide highly accurate data sources to detect side/rear setback violations. However, even with low accuracy imagery, the prototype provided an assessment for a larger proportion of buildings than did the current traditional process, which is of benefit in itself. In addition, high quality data was not derived from fieldwork alone; instead, it may be obtained from more accurate imagery. Further, the SEBI framework allows for the analysis of all inspection cases for which a detection result is possible and provides a decision as to whether or not more data is required, after which it produces a report.

6.5 Evaluation of geospatial data usage and the workflow of inspection

Geospatial information is used in the data input component, which is limited in the current inspection workflow in the CoR. This allows the production of accurate features and measures within the preparation component and offers the required information for inspection. The SEBI framework addresses limitations in existing inspection measurement support by providing the features and measures subcomponent, which enables satisfactory building inspection and violation detection. Figure 6.15 shows an example of geospatial data of building constructions used in the data input module such as parcels, street centrelines, main buildings, upper annex buildings, and ground floor annex buildings.

Figure 6.15 Geospatial datasets of building constructions, parcels, street centrelines, main buildings, upper annex buildings, and ground floor annex buildings

The framework manages the extraction of the geospatial data required for inspection by identifying the required features, measures and metadata from data sources. These include building, cadastre, street width, and street centreline data measures and areas, which are easily obtained in the SEBI framework (see Section 5.1.1.2). The geospatial data required assessing side and rear setbacks violation is provided within the framework and includes the buffer distance, cadastre boundary and main building boundary. This integration solves the inspection issues related to the lack of availability of appropriate geospatial information, measurement data and building regulations.

As stated in Section 4.2.6, the current inspection process does not cover all the necessary processes, or some of these processes do not apply. The SEBI framework provides an interpretation of the influence of framework design on the presentation of accurate violation detection results. One advantage of the SEBI framework is the change in the reporting of outcomes achieved by using accurate geospatial data. Providing geospatial data makes a significant change and improves the quality of violation detection and building inspection, as demonstrated by comparing the outcomes of the current inspection process and those generated by the prototype (see Figure 4.17). The data extracted from the geospatial information subcomponent within the framework supports the use of GIS techniques to provide quality metadata and the geospatial features needed for inspection (Section 4.3). The SEBI framework provides diverse inspection data by using GIS tools to extract the features and measures of a construction site from imagery, digital subdivision plans and approval plans (see Section 5.1.1). Inspection data are extracted from a range of sources and integrates a range of digital data and image sources. The prototype implementation shows the ability of the framework to extract and determine inspection data from different data sources for all processes involved in the WFoI to detect all violation types. The use of geospatial data allows an improvement in the quality of the outcomes for determining boundaries, ranges and violation classes. This improvement in the support of the inspection process is the result of the comprehensive data that is provided in the data input component.

The SEBI framework supports the use of geospatial data to improve the features and measurements of the required inspection data. It provides multiple datasets and formats, digital source imagery on varying scales, at different resolutions and geographic locations, and facilitates decisions regarding violations to support the building inspection process. A range of geospatial data can be used to support decision making within various steps in the building inspection workflow.

6.6 Conclusions

This chapter has provided an evaluation of the SEBI framework. To begin the evaluation, the interaction between the framework modules and requirements were examined within the evaluation matrix. This evaluation involved an analysis of three outcomes: the results of inspector survey; the outcomes of the implementation of the prototype and the analysis of the field inspection reports obtained during the second fieldtrip in Riyadh. This chapter has presented the four main guidelines used in this evaluation: the detection and identification of violations, the accessibility of the data required for the inspection, the quality of the inspection data and data usage and the WFoI.

The required data of inspection were accessible in the SEBI framework such as calculating the violation measurements and assigning compliance classes. Further, thresholds from regulations were accessible such as the building ratio and setbacks dimensions. In order to assess the equality of the SEBI framework two data sources were used: report outcomes prototype and field inspection reports. The SEBI framework works well in two respects. First, it provides highly accurate data from the data input component. Second, there is improved violation detection when inspectors are able to assess and implement high quality data. The average violation detection error decreases, namely, the average of the 'possible violation' classes is reduced when the quality of input data is improved. A valuable improvement in the quality assessment module was achieved with higher quality level inspection measurements such as building and cadastral areas and dimensions. Further, the detection results for each inspection data source are investigated and validated according to their quality. The high quality of the inspection data allows the user of the prototype model to verify the inspection results. It is particularly important to define the inspection data quality through available accurate sources without the need for a site visit for every inspection. Within the framework the usage of geospatial data were implemented such as digital cadastre and images. In addition the SEBI framework covers the WFoI with required sequence without missing of any step of inspection.

7 CONCLUSIONS AND FUTURE DIRECTIONS

This research study has investigated the implementation of geospatial methods to support building construction inspection and regulation compliance. In addition, it has presented a geospatially enabled building inspection framework to address the geospatial aspects of building inspection. The research conclusions presented here contain the outcomes, the contributions of this research, future directions and recommendations.

7.1 Research Outcomes

The outcomes of this research can be identified by the research objectives that have been achieved. Research Objective 1 has been addressed through the identification of current inspection issues in the study area surrounding the inspection process, the building regulations, and geospatial information. The building inspection stages and the required geospatial information used to process the inspection were identified. Finally, the building regulations that applied during field inspections were identified.

The following current inspection issues were identified: limited capacity to detect common building violations, poor accessibility to inspection data, and limited geospatial data integration and usage (see Sections 4.1.2. 4.1.3, 4.1.4 and 4.1.5). This research demonstrated how geospatial information can support and enhance the building inspection process as well as compliance. For example, the SEBI framework provides, prepares and presents the required data of inspection from imagery and digital plans such as footprint and ratio of buildings, area and boundary of cadastre, and street width, centerline and setback dimensions. The required aspects of geospatial data, such as cadastre and building attribute data used within a building inspection process were identified for a number of violation types. The quality of geospatial data used in an inspection process was determined as a significant factor influencing the outcome of violation detection.

The main processes that require the use of geospatial information were identified as initial violation detection, final violation detection and new violation detection, the latter being considered after a building certificate is issued (see Section 3.1.4). Some of building inspection issues were addressed through geospatial information, for example, inspection data integration and accessibility, geospatial usage and inspection data quality.

The building regulations associated with inspections were identified; in particular, those associated with violation detection processes that use geospatial information. Examples include coverage area of buildings (footprint ratio) and setback dimensions of street, sides and rear.

Additionally, the framework requirements were defined: the ability to identify violations, integrate inspection data, determine building regulation performance, implement the WFoI in the required sequence and apply inspection data quality. In addition, under this objective the inadequacies in the current inspection process in the CoR were analysed and identified. With respect to the inspection process, the surveys revealed that inspectors felt that the current process did not clearly define the inspection criteria. Inspectors reported that there was poor management of the recording of defects in the current inspection process. Furthermore, inspectors confirmed that they had inadequate access to GIS applications or techniques. Under the current process, traditional methods are used to report violations, for example, a freehand drawing is used to store inspection data. The current method has limited capacity of geospatial techniques to support the use of aerial photography and satellite imagery during inspections.

Research Objective 2 was to design and develop a SEBI framework for geospatial enabled support of the building workflow. This objective was addressed by the design and development of a framework with modules addressing the inspection requirements and issues. The framework has five modules: (a) inspection input data, (b) quality assessment, (c) data preparation, (d) violation detection, and (e) reporting. The modules of the framework were designed in response to the requirements identified for a spatially-enabled framework to support a building inspection workflow. In particular the data access and integration issues were supported by the input data and data preparation modules. The capture and manipulation of quality information is handled by the quality assessment module. The processes for using source and quality information to determine and assign violations are embedded in the violation detection module. Finally, the reporting module is able to extract and customise the necessary detection outcomes to support appropriate decision-making points within the WFoI.

The implementation and evaluation of the SEBI framework was conducted for the inspection workflow environment and case study area of the City of Riyadh. The implementation of the prototype proceeded to support four violation types: (a) main and ground floor annex building coverage area, (b) upper annex building coverage area, (c) street setback, and (d) rear and sides setbacks.

This research used the ModelBuilder technique in ArcGIS for violation tracking and implementation of the SEBI framework modules. The evaluation of the SEBI prototype confirmed the integration of several modules, for example, the robust flow of inspection data to provide, extract, prepare, validate, implement and report. Testing and evaluation of the framework demonstrated that it meets Research Objective 3 by achieving the framework requirements proposed prior to the framework design. The testing and evaluation proceeded in two stages:

(a) Describing the performance of framework modules by using an evaluation matrix to show the overlap between the framework modules and the framework requirements.
(b) Using the prototype outcomes of the violation detection results for the violations within the scope of the study. This research also allowed for a more in-depth investigation through the testing and evaluation of the framework after the inspection reports from the fieldwork were obtained.

The successful implementation of the SEBI prototype is evidence that this framework can be used to demonstrate the ability of geospatial methods to support the building inspection process and compliance with regulations. The prototype was tested and evaluated using a geographic region of approximately one square kilometre in the CoR. The evaluation assessed violation detection, data accessibility and integration, inspection data quality, data usage, and the WFoI, and demonstrated that the framework provides effective methods to detect and identify building violations.

The integration between the SEBI framework and requirement was obtained through the evaluation of the SEBI framework using an evaluation matrix to obtain overlap and interaction between framework requirements and modules. The detection of violation was achieved, for example, assigning compliance classes based on calculated violation measurements. Integration of the data input necessary for inspections was achieved by extracting the features and measurements of the building and cadastre. The quality of the inspection data and outcomes was verified by the violation classes, boundaries and ranges it determined. In addition, the framework is capable of utilising a range of high quality data as such high quality imagery and fieldwork.

The violation detection prototype improves the quality of results even with a low accuracy data source. This enables better determination of 'definite violation' or 'no violation' and reduction of 'possible violation' class. However, the quality of detection improved when the high accurate source was used, for example, 'possible violation' class of main and ground floor annex building violations reduced from 15% to 7% and side and rear setbacks violations reduced from 16% to 7%. However, even when low accuracy source imagery was employed for the analysis, the prototype provided an assessment for a greater proportion of buildings than the current manual system; this is an advantage in itself. In fact, the remaining occurrences classified as ‘possible violations’ had quality values associated with each building, making it easy to prioritise which required further analysis either by utilising higher accuracy data or by conducting further fieldwork to obtain more accurate data.

Moreover, the use of geospatial data to provide building and cadastre features and measures was implemented in the framework, which has resolved the issue of the lack of high quality data in the current inspection process. Finally, the WFoI implemented in the framework was designed to operate in the required sequence.

7.2 Contributions

This research will contribute to the development of geospatial inspection methods to support building inspections and compliance. Further, this research makes three main contributions with respect to the objectives identified in Section 1.2:

(a) The identification of the inspection process, issues and geospatial information required to assess an inspection job, as well as the requirements to support and implement the inspection workflow.

(b) The SEBI framework can be used by a foundation for future building inspection systems. The design concept of the framework develops the geospatial environment and proves the required inspection data, facilitates data extraction, provides measures and features, assesses the quality of data, detects violations with high quality levels, and produces the appropriate inspection reporting.

(c) A methodology to evaluate the SEBI framework by using prototype outcomes and simulating data accuracy ranges, then comparing these data with field inspection reports.

The framework provides the capacity to extract good quality measures to assess the inspection workflow. Additionally, the framework efficiently demonstrates the actual situation in relation to violation detection based on accurate data sources. The geospatial inspection framework overcomes the limitations and weaknesses of the existing inspection process. The framework solves the issues of missing data and/or ignored steps of violation detection within the WFoI. Moreover, the framework provides inclusive violation detection of the actual construction, and also defines sufficient inspection data in different inspection workflows. It offers different inspection reports and provides these reports for any WFoI stage to present the actual situation for a given stage of construction and violation detection results. The proposed technique can be transferred to any other city in Saudi Arabia or worldwide with some minor technical changes to accommodate the system in each city, for example, data preparation and production (see Section 2.1.3).

7.3 Future Directions and Recommendations

Problems with the existing building inspection process have been comprehensively examined in this study. Insufficient implementation of geospatial information for inspections results in many inspection weaknesses and incorrect violation detection results. Despite the use of geospatial method to support and enhance the inspection process, further examination of the practicality of this method is desirable, with a focus on implementation that includes all building violations types and three-dimensional violations related to building elevation, window locations and direction.

The outcomes of this research have demonstrated the benefits of the framework design and prototype model. Certain data input sources in the SEBI framework were included in the framework design due to their importance, but were not implemented in the prototype model. First, the data input module includes greater detail on the geospatial data inspection. Second, the data input module within SEBI framework has high accuracy sources, for example, the approval plan is in a digital format AutoCAD DWG file, while the survey report can be obtained from the field survey and used with a surveying application and georeferencing for cadastral maps by using a global positioning system.

In order to change the existing traditional building inspection process to the proposed new method following the geospatial inspection framework designed in this study, some essential technical preparation is necessary. The requirements for this are: (a) updated images, such as aerial photo and satellite images, (b) a geospatial model of construction violation detection, (c) experts to run and operate the systems, (d) improvements in the current inspectors' ability to use and manage the framework techniques and (e) hardware and software to implement the framework.

7.4 The Difficulties and Costs of the Proposed Framework

There are costs in implementing this building inspection framework. These framework implementation costs may be high at the beginning of a project, but the outputs of the framework design improve construction violation detection and tracking, one of the advantages of implementing the inspection framework as explained earlier. Some of the costs of implementation include: (a) the cost of obtaining updated images, (b) employing new experts, (c) training programs for current inspectors; (d) transforming inspection data to a new system, (e) IT tools such as software, hardware and networking techniques to run the system and (f) integration between all departments that deal with construction inspection data, such as the construction inspection department, the building licence department, and the surveying department.

This research has made an effort to add value and improve the inspection process and violation detection in Saudi Arabia. The development of geospatial inspection methods in this research study has provided an incentive to transform the current inspection process in the CoR in Saudi Arabia.

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APPENDIXA:INSPECTORS' WORKSHOP ACTIVITY

APPENDIX B: QUESTIONNAIRE FORM

Department of Spatial Sciences

Participant Information Sheet

My name is Saud Eissa Aboshiqah. I am currently completing part of the research for my Doctoral Degree of Philosophy at Curtin University of Technology. This research is performed under the supervision of Professor Bert Veenendaal, Head of Department of Spatial Sciences, and Dr. Rob Corner, Senior Lecturer in the Department of Spatial Sciences at the Curtin University of Technology.

Purpose of Research
My aim is to develop an efficient spatial framework and methodologies supporting the process of building inspections and inspection compliance within the Riyadh municipality.

My Role
I am interested in developing spatial methods for building inspections supporting local building regulations in the Riyadh Municipality; therefore, I am seeking your opinions regarding building inspection issues, inspection criteria, and spatial information in your department. The interview process will take approximately 20 minutes.

Consent to Participate
Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. By supplying your signature on the consent form, I will assume that you have agreed to participate and that you consent to the use of your data in this research.

Confidentiality
The information you provide will be kept separate from your personal details, and I will be the only person with access to this information. The interview transcript will not reveal your name or any other identifying information. In adherence to university policy, the interview tapes and transcribed information will be kept in a locked cabinet for five years, at which point they will be destroyed.

Further Information
This Study has been reviewed and given approval by the Curtin University of Technology Human Research Ethics Committee (Approval number HR 69/2009). The committee is comprised of members of the public, academia, lawyers, and doctors. The main role of the committee is to protect the rights of the participants. If needed, verification of approval can be obtained either by writing to Curtin University of Technology Research Ethics Committee, c/o office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth, 6845, Australia; by telephoning +618 9266 2784; or by emailing hrec@curtin.edu.au. Additionally, the researcher has obtained official approval from the Riyadh Municipality through the attached approval letter NO: 140413/1430 on 11/07/2009. If you would like further information about the study, please feel free to contact me at +966 500 444 410 or via email at saud.aboshiqah@postgrad.curtin.edu.au. Alternatively, you can contact my supervisors directly via email at B.Veenendaal@exchange.curtin.edu.au ***OR***R.Corner@curtin.edu.au

This survey asks for your opinions regarding building inspection issues, inspection criteria, and spatial information in your department. The survey will take approximately 15 to 20 minutes to complete.

<u>Demographics Characteristics</u>

This information will help in the analysis of the survey results. Mark ONE answer by filling in the appropriate circle.

1. How long have you worked in the building inspection profession?

- ○ 1. Less than 1 year
- ○ 2. 1 to 5 years
- ○ 3. 6 to 10 years
- ○ 4. 11 to 15 years
- ○ 5. 16 to 20 years
- ○ 6. 21 years or more

2. What is your highest level of education?

- ○ 1. Preprimary school
- ○ 2. Primary school
- ○ 3. Secondary school
- ○ 4. Diploma degree (please specify)
- ○ 5. Bachelor degree
- ○ 6. Master's degree
- ○ 7. Other, please specify below:

3. What is the nature of your work?

- ○ 1. Head of inspection department
- ○ 2. Inspection management
- ○ 3. Field inspector
- ○ 4. Building plans approving
- ○ 5. Other, please specify:

4. For which of the following departments do you work? (Choose one)

- ○ 1. Main Municipality office
- ○ 2. Building Inspection Department in submunicipality
- ○ 3. Building Permit Department
- ○ 4. Central department of Building inspection.
- ○ 5. Building Inspection Consultant
- ○ 6. Other, please specify:

5. Experience with use of mapping software	**Extensive** ▼	**Moderate** ▼	**Limited** ▼	**None** ▼	**I don't Use it** ▼
AutoCAD	⑤	④	③	②	①
Micro station	⑤	④	③	②	①
ArcGIS	⑤	④	③	②	①
Map Info	⑤	④	③	②	①
Other software, please specify: ………………………………..……………………………...……………………………					

6. **Experience with use of spatial and non-spatial databases**	**Extensive** ▼	**Moderate** ▼	**Limited** ▼	**None** ▼	**I don't Use it** ▼
Excel	⑤	④	③	②	①
Access	⑤	④	③	②	①
Oracle	⑤	④	③	②	①

Other Database, please specify:
…………………………………..…………………………..…………………………….

Other comments regarding your experience with mapping software and experience with use of spatial and non-spatial databases:
………
………
………
………
………………………………………………………………………………………

<u>The aim of your inspection operation:</u>
Mark ONE answer by filling in the appropriate circle

Inspection Aim	**Yes** ▼	**No** ▼	**Don't Know** ▼
1. Issuing certificates of completion of construction.	③	②	①
2. Completion of the inspection within the inspection department's schedule.	③	②	①
3. Completion of the inspection during a municipality random patrol.	③	②	①
4. Inspection based on a complaint from one of the building's neighbors.	③	②	①
5. Inspection based on the order of an inspection department manager.	③	②	①
6. Inspection based on the order of a building owner.	③	②	①

<u>Basic information required for the inspection job:</u>
Mark as many responses as necessary by filling in the appropriate circle(s).

1. **Parcel information:**
   - ○ 1. Parcel number
   - ○ 2. Block number
   - ○ 3. Plan number
   - ○ 4. Owner details
   - ○ 5. Land use
   - ○ 6. Other, please specify below:

2. **Inspection job drawing types**
   - ○ 1. Building plans
   - ○ 2. Building regulation plans
   - ○ 3. Building license document
   - ○ 4. Land subdivision plans
   - ○ 5. Aerial photography
   - ○ 6. Satellite imagery
   - ○ 7. Other, please specify below:

3. **Inspection job documents format:**
   - ○ 1. Hard copy pattern
   - ○ 2. Soft copy pattern
   - ○ 3. Other, please specify below:

4. Inspection job device types:

- ○ 1. PDAs
- ○ 2. Electronic scale of distance
- ○ 3. Laptop
- ○ 4. GPS device
- ○ 5. Other, please specify below:

<u>Data type's inspector requires before going to the site:</u>
Mark ONE answer by filling in the appropriate circle

Data types ▼	Yes ▼	No ▼	Don't Know ▼
1. Know the inspection job type (schedule, random, etc.).	③	②	①
2. Look at the digital map to know the building's construction stage.	③	②	①
3. Read the background of building to know (location, building regulation, building license…).	③	②	①
4. Review the building's history to determine if there have been previous violations.	③	②	①

<u>Data type's inspector collects from the site:</u>
Mark ONE answer by filling in the appropriate circle

Data types ▼	Yes ▼	No ▼	Don't Know ▼
1. Free hand drawing.	③	②	①
2. Photograph of the violations.	③	②	①
3. Tables (dimensions, lengths, areas).	③	②	①
4. Digital data (maps, spatial data, attribute data).	③	②	①

<u>SECTION A: Building Violation Types</u>
How often do the following violations occur within your area of responsibility? Mark your answer by filling in the appropriate circle.

Building violation types	Very often ▼	Often ▼	Not often ▼	Not at all ▼
1. Differences between existing buildings and approval plan.	④	③	②	①
2. Violations before building completion certificate.	④	③	②	①
3. Building without a license.	④	③	②	①
4. Violations after building completion certificate.	④	③	②	①
5. Upper annex building violations (area increasing, change of main building location).	④	③	②	①
6. Main building violations (area increasing, change of main building location, land use changing).	④	③	②	①
7. Grounds annex building violations (area increasing, change of main building location).	④	③	②	①
8. Street seatback diminutions violations.	④	③	②	①
9. Sides seatback diminutions violations.	④	③	②	①
10. Rear seatback diminutions violations	④	③	②	①

11.Fences violations.	④	③	②	①
12.Windows violations (size, direction, location, etc.)..	④	③	②	①
13.Building elevation violations.	④	③	②	①
14.Building views violations.	④	③	②	①
15.Car parking (size, numbers, etc.).	④	③	②	①
16.Court violations (size, diminutions, location, etc.).				

Other comments with respect to building violation types:
……
……
……
……
………………………………………………………………………………………

SECTION B: Current Inspection Performance

In this survey, think of your department as the work area where you spend *most* of your work time or complete *most* of your inspection jobs.

Please indicate your agreement or disagreement with the following statements about your work area/department. Mark ONE answer by filling in the appropriate circle

Think about your inspection work in your department:	**Strongly Agree** ▼	**Agree** ▼	**Disagree** ▼	**Strongly Disagree** ▼
1. The current inspection Process helps in daily inspection work.	④	③	②	①
2. The inspection criteria are clearly defined in the current inspection processes.	④	③	②	①
3. The current inspection processes will be helpful in supporting the inspection job between the main offices of municipality and submunicipality offices.	④	③	②	①
4. The current inspection processes will be useful in supporting the inspection job between the clients and the main contractor.	④	③	②	①
5. The current inspection processes reflect the inspection ability in a real situation.	④	③	②	①
6. The current inspection processes interact well with other programs such as Word with exporting data features.	④	③	②	①
7. The current inspection processes save time when you return to the office.	④	③	②	①
8. The process of sorting out the data within the current inspection processes is useful.	④	③	②	①
9. The current inspection processes will be useful to controlled the building violation size	④	③	②	①
10. The current inspection processes are useful in managing the defect documentation between the site and the office.	④	③	②	①
11. The current inspection processes are increasing the speed of the inspection process.	④	③	②	①
12. The current inspection processes are well organized (designed).	④	③	②	①
13. Construction industry professionals will accept (or use) the current inspection processes.	④	③	②	①

14. The current inspection processes are flexible with respect to the ability to choose the most appropriate inspection options.	④	③	②	①
15. The current inspection Process helps to select and implement all inspection process	④	③	②	①

Other comments regarding your inspection work in your department:
……
………………....………………………………………………………………………………
…………………………………….………………………………………………………………
…………………………………………………………..……………………………………
……………………………………………………………………………………….…

<u>Inspection Job Errors</u>
Mark ONE answers by filling in the appropriate circle:

Inspection Job Errors	**Yes** ▼	**No** ▼	**Don't Know** ▼
1. Capability to determine violation type.	③	②	①
2. Fault of accurate calculation of violations area and diminution	③	②	①
3. Difficulty of documentation of some or all site violations.	③	②	①
4. Difficulty in documenting violations of dimensions, lengths, and areas calculations.	③	②	①
5. Inability to use inspection devices.	③	②	①
6. Presence of unnecessary tasks outside the scope of the inspection job.	③	②	①

Perceived Causes of Inspection Errors	**Yes** ▼	**No** ▼	**Don't Know** ▼
1. Unclear inspection job aims.	③	②	①
2. Misunderstand of inspection process.	③	②	①
3. Lack of experience.	③	②	①
4. Interference of the building owner during the inspection process.	③	②	①
5. There are not enough specialized and sophisticated devices available capable of detecting violations.	③	②	①
6. Shortage or lack of equipment, technology, and software to document violations.	③	②	①
7. Non-use of traditional maps and plans during the inspection operation.	③	②	①
8. Non-use of digital maps and plans during the inspection operation.	③	②	①
9. Lack of sufficient time for the inspection process, the large number of sites to inspect, and increased requests from building owners.	③	②	①
10. No monitoring for inspectors	③	②	①

Other comments about inspection job errors and causes of inspection errors:
……
……

<u>SECTION C: Current Spatial Building Violation Documentation Methods.</u>

Please indicate your agreement or disagreement with the following statements regarding building violation documentation methods. Mark ONE answer by filling in the appropriate circle.

Building Violation Documentation Methods	Yes ▼	No ▼	Don't Know ▼
1. Does your inspection department use a Geographic Information System (GIS) to assist in building inspections?	③	②	①
If so, what GIS applications are used? Please specify: ……………………………………………………………………………………………………… ……………..……………………………………………………………………………………… ……………..……………………			
2. The System supports storage of a site photograph.	③	②	①
3. The System supports aerial photography.	③	②	①
4. The system supports satellite imagery.	③	②	①
5. The system incorporates an electronic database.	③	②	①
6. The system uses electronic tables.	③	②	①
7. The system allows production of digital maps.	③	②	①
8. The system allows freehand drawings to be stored.	③	②	①

Other comments regarding building violation documentation methods:
………………………………………………………………………………………………………
………………………………………………………………………………………………………
…………………………………………

SECTION D: Inspection Data Sharing and Access.

Mark ONE answer by filling in the appropriate circle.

1. How much of your inspection information is in digital form?

○1. More than 75%
○2. 51%-75%
○3. 25%-50%.
○4. Less than 25%
○5. None
○6. Don't know

2. How long has your inspection department had a GIS application for managing building inspection information?

○ 1. 1 year or less ○ 4. 11-15 yrs
○ 2. 2-4 yrs ○ 5. More than 15 yrs
○ 3.5-10 yrs ○ 6. Does not have a defined GIS unit

3. What %age of the time do you have access to the GIS on a regular basis?

○ 1. < 5% ○ 4. 51-75% ○ 7. No system.
○ 2. 5-25% ○ 5. 76-90%
○ 3. 26-50% ○ 6. > 90%

4. How would you classify the level of management support that the GIS unit receives within the inspectiondepartment?

○ 1. No support
○ 2. Limited support
○ 3. Satisfactory support
○4. Good support
○5. Very good support

5. Does your inspection department provide external users with access to spatial data via the internet; i.e. web Mapping/GIS?

○ Yes. Please provide web address: ……………………………………………………….

○ No

○ Under development

6. What are the most common ways of obtaining necessary mapping and spatial information?

	Building owners	Designers	Constructors
1. Direct connect (visiting the office)			
1. Direct connect (phone calls)			
3. Using the internet web map of our GIS			
4. Other, please specify: …………………….			

Your Comments:

Please feel free to share any comments regarding building inspection issues in your department.

Positive and strong point in the current system.

Negative and weakness in the current system.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY.

APPENDIX C:BUILDING LICENCE

بسم الله الرحمن الرحيم

المملكة العربية السعودية
وزارة الشئون البلدية والقروية
أمانة منطقة الرياض
إدارة رخص البناء

٢٣ / ١٤٢٩

٣٠٠٥٥٦٠

رخصة بناء عمارة سكنية

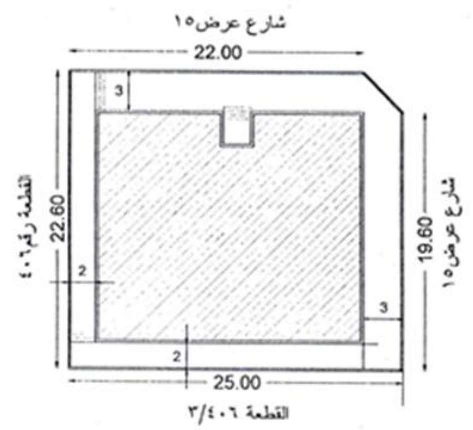
رقم الرخصة : ١٤٢٩/٥٦٧
تاريخ الرخصة : ١٤٢٩-٠١-١٩
تاريخ الإنتهاء : ١٤٣٢-٠١-١٩
نوع الرخصة : تعديل مخططات البناء

اسم المالك : [redacted]

رقم الإثبات : ١٠٠٣٥٥٦٣٨٦ تاريخه : ١٣٨٢-٠١-٢٨ مصدره :

رقم الصك :	٤١٠١٠٨٠٠٢٤٩٨	تاريخه :	١٤٢٧-١١-١٨
رقم القطعة :	٢/٤٠٦	رقم المخطط التنظيمي :	٦٨٩
الشارع :	شارع ثمامه بن اثال	رقم العقار :	
الحي :	حي السليمانيه	نوع البناء :	مسلح
مساحة الأرض :	٥٦٠،٥ م٢	محيط الأسوار : ٩٣،٤٥ م/ط — النطاق العمراني :	مرحلة ١

الجهة	الحدود	الأبعاد	الإرتداد
شمال	شارع عرض١٥	٢٢	٣
شرق	شارع عرض١٥	١٩،٦	٣
جنوب	القطعة ٣/٤٠٦	٢٥	٢
غرب	القطعة رقم٤٠٦	٢٢،٦	٢



مكونات البناء	عدد الوحدات	المساحة	الإستخدام
قبو	٠	٨١،٠٠	ترفيهي
أرضي سكني	٢	٣٤٠،٠٠	سكني
أول سكني	٢	٣٩٤،٠٠	سكني
ثاني سكني	٢	٣٩٤،٠٠	سكني
غرفة كهرباء	٠	٢٠،٠٠	غرفة كهرباء
ملاحق علوية	٠	٣٩،٤٠	خدمات
أسوار	١	٨٩،٠٠	خدمات

المكتب المصمم : [redacted]

رقم الترخيص : ٢٠٣٠ رقم المشروع : ٣١ رمز النظام : مناسيب الشوارع المحيطة : مستوي

سدد الرسوم مبلغ وقدره : ٤٧٧ ريال بموجب الإيصال رقم : ٢٩٠٠٠٤١٥٢٢ وتاريخ : ١٤٢٩-٠١-١٢ هـ

ملاحظات : مبلغ سداد:١٧ رقم الفاتورة:٢٩٠٠٢٨٢٢٩٠ تاريخ الفاتورة:١٤٢٩-٠١-١٢ ١- بموجب التقرير المساحي رقم (١٤٢٨/١٧٠٦) وتاريخ ١٩-
١٤٢٨هـ الصادر من بلدية العليا الفرعية.
٢- اعطي الموافقة على القبو ترفيهي بموجب خطاب الدفاع المدني رقم (١/٢/١١/٣٣/٦٣٤٩/دف) وتاريخ ٢٨-١٢-١٤٢٨هـ ويجب التنسيق مع
قبل صرف شهادات اتمام البناء.
٣- اعطي الموافقة على استخدام القبو ترفيهي بموجب توجيه سعادة وكيل الأمين للتعمير والمشاريع حيث أن الاستخدام عائلي خاص للعمارة.
٤- اعطي الموافقة على اقامة عمارة سكنية ارضي + دورين مساواة بالمجاورين بموجب توجيه سمو أمين منطقة الرياض بالمعاملة رقم (٥٦...
وتاريخ ١٤٢٨-٠٦-٠١هـ على ان يتم الحفاظ على خصوية المجاورين جهة الفيلا السكنية.
٥- اعطي الموافقة على اقامة الأسوار جهة الشوارع بموجب توجيه سعادة وكيل الأمين للتعمير والمشاريع على المعاملة رقم (٤٨٠٥) وتاريخ
١٤٢٩-٠٣-٠٨هـ - ********

رئيس قسم الرخص مدير إدارة الرخص مدير عام التخطيط العمراني

الختم الرسمي — أمانة مدينة الرياض — بلدية العليا الفرعية — ١٣٩٨

أي كشط أو شطب يلغي هذه الرخصة . يجب الإلتزام بالشروط الموضحة خلف الرخصة ت / ٣٠٥ / ٥٢٣

APPENDIX D: SURVEY REPORT

بسم الله الرحمن الرحيم

المملكة العربية السعودية
وزارة الشئون البلدية والقروية
أمانة منطقة الرياض
بلدية الروضه

رقم التقرير: ٤٥٣٣٦ /١٤٣٠
التاريخ: ١٤٣٠/١٢/٢٦
رقم الطلب: ٤٧١٣٣ /١٤٣٠
١٢٧١٥١

تقرير مساحي

الغرض من التقرير: رخصة بناء

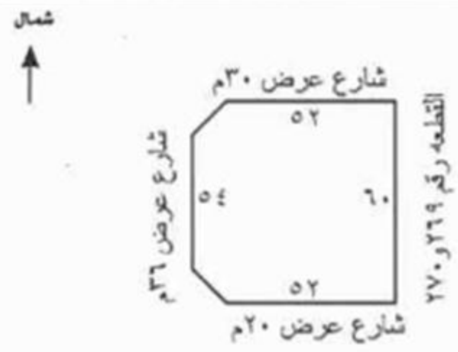
اسم المالك:

رقم الصك: ٩١٠١١٤٠٠٥٦٤٥ — تاريخه: ١٤٢٨٠٥١٦

رقم القطعة: ٢٧١ الى ٢٧٤ — رقم المخطط: ٢٧٥٧

حي: قرطبه — شارع: — عرض ٣٠م

رقم العقار: — نوع العقار:



مقياس الرسم: ١ / ....

الشوارع المحيطة		مناسيب الشوارع	
مسفلت	غير مسفلت	مستوي	مختلف المناسيب
نعم	لا	نعم	لا

حدود وأطوال ومساحة العقار

الإتجاه	الحدود حسب الطبيعة	الطول	الحدود حسب الصك	الطول	الحدود حسب المخطط	الطول
شمال	شارع عرض ٣٠م	٥٢,٠	شارع عرض ٣٠م	٥٢,٠	شارع عرض ٣٠م	٥٢,٠
شرق	القطعه رقم ٢٦٩و ٢٧٠	٦٠,٠	القطعه رقم ٢٦٩و ٢٧٠	٦٠,٠	القطعه رقم ٢٦٩و ٢٧٠	٦٠,٠
جنوب	شارع عرض ٢٠م	٥٢,٠	شارع عرض ٢٠م	٥٢,٠	شارع عرض ٢٠م	٥٢,٠
غرب	شارع عرض ٣٦م	٥٤,٠	شارع عرض ٣٦م	٥٤,٠	شارع عرض ٣٦م	٥٤,٠
المساحة(م٢)	٣٢٩١		٣٣٠٠		٣٢٩١	

المساحه بعد حذف الشطفات..

ملاحظات:

المساح المعد للتقرير — رئيس قسم المساحة — رئيس بلدية الروضه

APPENDIX E:GEODATABASE DESIGN

Geodatabase Design

Developed by The Applications Prototype Lab, ESRI® Redlands

Schema Creation	
Creation Date	2010-02-16 07:40:26
Creator	
Geodatabase	
Workspace Type	Personal
Flavor	Access
Version	2.3.0
Connection Properties	
DATABASE	C:\Users\mostfa\Desktop\Saud\Riyadh\Riyadh.mdb

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ObjectClasses

ObjectClass Name	Type	Geometry	Subtype
Riyadh			SR
ExtraFeature	FeatureClass	Polygon	-
GroundAnnexBuilding	FeatureClass	Polygon	-
MainBuilding	FeatureClass	Polygon	-
Parcels	FeatureClass	Polygon	-
Street	FeatureClass	Polyline	-
UpperAnnexBuilding	FeatureClass	Polygon	-
Stand Alone ObjectClass(s)			

ExtraFeature

Alias Extra Feature
Dataset Type FeatureClass
FeatureType Simple

Geometry: Polygon
Average Number of Points:0
Has M: No
Has Z: No
Grid Size:1000

Field Name	Alias	Type	Precn.	Scale	Length	Edit	Null	Req.	Domain Fixed
OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
Name	Name	String	0	0	50	Yes	Yes	No	No
Nots	Nots	String	0	0	50	Yes	Yes	No	No

Subtype Name	Default Value	Domain
ObjectClass		
Name		Extra feature

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

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GroundAnnexBuilding

Alias Ground Annex Building
Dataset Type FeatureClass
FeatureType Simple

Geometry: Polygon
Average Number of Points:0
Has M: No
Has Z: No
Grid Size:1000

Field Name	Alias	Type	Precn.	Scale	Length	Edit	Null	Req.	Domain Fixed

OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
PARCELID	PARCELID	Integer	0	0	4	Yes	No	No	No
PARCELNO	PARCELNO	String	0	0	20	Yes	Yes	No	No
PLANID	PLANID	Integer	0	0	4	Yes	Yes	No	No
PLANNO	PLANNO	String	0	0	11	Yes	Yes	No	No
SUBMUNICIPALITY	SUBMUNICIPALITY	String	0	0	255	Yes	Yes	No	No
DISTRICT	DISTRICT	String	0	0	255	Yes	Yes	No	No
BuildingArea	BuildingArea	Double	0	0	8	Yes	Yes	No	No
STATUSFIN	STATUSFIN	Integer	0	0	4	Yes	Yes	No	No

Subtype Name	**Default Value**	**Domain**
ObjectClass		
SUBMUNICIPALITY		RiyadhSubMunANameDomain
DISTRICT		RiyadhNeighborhANameDomain

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

MainBuilding

Alias	Main Building	**Geometry:**Polygon
Dataset Type	FeatureClass	**Average Number of Points:**0
		Has M: No
FeatureType	Simple	**Has Z:**No
		Grid Size:1000

Field Name	**Alias**	**Type**	**Precn.**	**Scale**	**Length**	**Edit**	**Null**	**Req.**	**Domain Fixed**
OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
PARCELID	PARCELID	Integer	0	0	4	Yes	No	No	No
PARCELNO	PARCELNO	String	0	0	20	Yes	Yes	No	No
PLANID	PLANID	Integer	0	0	4	Yes	Yes	No	No
PLANNO	PLANNO	String	0	0	11	Yes	Yes	No	No
SUBMUNICIPALITY	SUBMUNICIPALITY	String	0	0	255	Yes	Yes	No	No
DISTRICT	DISTRICT	String	0	0	255	Yes	Yes	No	No
BuildingArea	BuildingArea	Double	0	0	8	Yes	Yes	No	No
STATUSFIN	STATUSFIN	Integer	0	0	4	Yes	Yes	No	No

Subtype Name	**Default Value**	**Domain**
ObjectClass		
SUBMUNICIPALITY		RiyadhSubMunANameDomain
DISTRICT		RiyadhNeighborhANameDomain

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

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Parcels

Alias	Parcels	**Geometry:** Polygon
Dataset Type	FeatureClass	**Average Number of Points:**0
		Has M: No
FeatureType	Simple	**Has Z:**No
		Grid Size:1000

Field Name	**Alias**	**Type**	**Precn.**	**Scale**	**Length**	**Edit**	**Null**	**Req.**	**Domain Fixed**
OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
PARCELID	PARCELID	Integer	0	0	4	Yes	No	No	No
PARCELNO	PARCELNO	String	0	0	20	Yes	Yes	No	No
PARCELNAME	PARCELNAME	String	0	0	254	Yes	Yes	No	No
PARCELSUBTYPE	PARCELSUBTYPE	Integer	0	0	4	Yes	Yes	No	No
PLANBLOCKID	PLANBLOCKID	Integer	0	0	4	Yes	Yes	No	No
BUILDINGUSECODE	BUILDINGUSECODE	Integer	0	0	4	Yes	Yes	No	No
PLANID	PLANID	Integer	0	0	4	Yes	Yes	No	No
PLANNO	PLANNO	String	0	0	11	Yes	Yes	No	No
SUBMUNICIPALITY	SUBMUNICIPALITY	String	0	0	255	Yes	Yes	No	No
DISTRICT	DISTRICT	String	0	0	255	Yes	Yes	No	No
ParcelArea	ParcelArea	Double	0	0	8	Yes	Yes	No	No
STATUSFIN	STATUSFIN	Integer	0	0	4	Yes	Yes	No	No
East	East	String	0	0	50	Yes	Yes	No	No
West	West	String	0	0	50	Yes	Yes	No	No
North	North	String	0	0	50	Yes	Yes	No	No
South	South	String	0	0	50	Yes	Yes	No	No

Subtype Name	**Default Value**	**Domain**
ObjectClass		
PARCELSUBTYPE		ParcelGResidentAGLUDomain
PLANBLOCKID	0	-
SUBMUNICIPALITY		RiyadhSubMunANameDomain
DISTRICT		RiyadhNeighborhANameDomain

East	1	ParcelNeighbour
West	1	ParcelNeighbour
North	1	ParcelNeighbour
South	1	ParcelNeighbour

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

Street

Alias	Street	**Geometry:** Polyline
Dataset Type	FeatureClass	**Average Number of Points:**0
FeatureType	Simple	**Has M:**No **Has Z:**No **Grid Size:**1000

Field Name	Alias	Type	Precn.	Scale	Length	Edit	Null	Req.	Domain Fixed
OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
STREETID	STREETID	Integer	0	0	4	Yes	Yes	No	No
StreeTName	StreeTName	String	0	0	50	Yes	Yes	No	No
STREETCLASS	STREETCLASS	String	0	0	2	Yes	Yes	No	No
STREETWIDTH	STREETWIDTH	Double	0	0	8	Yes	Yes	No	No
MUNICIPALITY	MUNICIPALITY	String	0	0	50	Yes	Yes	No	No
DISTRICT	DISTRICT	String	0	0	4	Yes	Yes	No	No

Subtype Name	Default Value	Domain
ObjectClass		
STREETCLASS	2	Street type
MUNICIPALITY		RiyadhSubMunANameDomain
DISTRICT		RiyadhNeighborhANameDomain

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

UpperAnnexBuilding

Alias	Upper Annex Building	**Geometry:** Polygon
Dataset Type	FeatureClass	**Average Number of Points:**0
FeatureType	Simple	**Has M:**No **Has Z:**No **Grid Size:**1000

Field Name	Alias	Type	Precn.	Scale	Length	Edit	Null	Req.	Domain Fixed
OBJECTID	OBJECTID	OID	0	0	4	No	No	Yes	Yes
SHAPE	SHAPE	Geometry	0	0	0	Yes	Yes	Yes	Yes
PARCELID	PARCELID	Integer	0	0	4	Yes	No	No	No
PARCELNO	PARCELNO	String	0	0	20	Yes	Yes	No	No
PLANID	PLANID	Integer	0	0	4	Yes	Yes	No	No
PLANNO	PLANNO	String	0	0	11	Yes	Yes	No	No
SUBMUNICIPALITY	SUBMUNICIPALITY	String	0	0	255	Yes	Yes	No	No
DISTRICT	DISTRICT	String	0	0	255	Yes	Yes	No	No
BuildingArea	BuildingArea	Double	0	0	8	Yes	Yes	No	No
STATUSFIN	STATUSFIN	Integer	0	0	4	Yes	Yes	No	No

Subtype Name	Default Value	Domain
ObjectClass		
SUBMUNICIPALITY		RiyadhSubMunANameDomain
DISTRICT		RiyadhNeighborhANameDomain

Index Name	Ascending	Unique	Fields
FDO_OBJECTID	Yes	Yes	OBJECTID
SHAPE_INDEX	Yes	Yes	SHAPE

Spatial References

Dimension	Minimum	Precision
Riyadh		
X	-450359962737.05	10000
Y	-450359962737.05	
M	0	1
Z	0	100000

Coordinate System Description

PROJCS[“Ain_el_Abd_UTM_Zone_38N”,GEOGCS[“GCS_Ain_el_Abd_1970”,DATUM[“D_Ain_el_Abd_1970”,SPHEROID[“International_1924”,6378388.0,297.0]],PRIMEM[“Greenwich”,0.0],UNIT[“Degree”,0.0174532925199433]],PROJECTION[“Transverse_Mercator”],PARAMETER[“False_Easting”,500000.0],PARAMETER[“False_Northing”,0.0],PARAMETER[“Central_Meridian”,45.0],PARAMETER[“Scale_Factor”,0.9996],PARAMETER[“Latitude_Of_Origin”,0.0],UNIT[“Meter”,1.0]]

APPENDIX F: FIELD INSPECTION REPORT FORM

Field Inspection Report

Report number: Date:

Building number :	
Street name :	
Street width :	m

Cadastral area :	m2
Building area :	m2
street setback dimension :	cm
Side 1 setback dimension :	cm
Side 2 setback dimension :	cm
Rear setback dimension :	cm

Comments:

ReportSktech

Site Plan from Satellite Image

تقرير الرقابة الميداني

رقم التقرير التاريخ:

رقم المبنى:	
اسم الشارع:	
عرض الشارع:	م

مساحة الأرض:	م2
مساحة المبنى	م2
الارتداد الأمامي	سم
الارتداد الجانبي 1	سم
الارتداد الجانبي 2	سم
الارتداد الخلفي	سم

ملاحظات:

شكل توضيحي

الموقع العام حسب المصور الجوي

Note: An inspectors were used the tape to obtained the measurements of areas and dimensions.

APPENDIX G:COPYRIGHTSTATEMENTS

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