Design and Implementation of a Smart Data Model for Geospatial Addressing Systems for Urban Areas in Ghana Using an Area Zone Identifier: A Case Study*

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Abstract

For effective processing of taxes and bills, recording of crime events, and dispatching of emergency services in Ghana, many organisations are maintaining large databases; unfortunately, within an organization, various units and sections of the same organization may be using varying address formats for streets and properties, whereby staff of the same organization often disagree on what address system to be adopted for a particular area. This often leads to stakeholders using different address systems for the same property. This brings about much confusion in the communities, especially with the city authorities, the utility companies and the Post Office and others. This usually poses significant challenges in sharing information, locating and extracting information that may be keyed to a situs address, or simply communicating about an address's location. Therefore, one of the principal needs for this standard is to make addresses more uniform and, thereby, facilitate the sharing of address information. With technological advancements, addresses can be directly associated with features like points, polylines or polygons. In order to combine all formats of address systems into a unique and uniform standard system, a smart data model for a geospatial addressing system has been designed and implemented, using sub-Metros of Accra Metropolitan Assembly as case study, for efficient courier system and communication in urban areas in Ghana. The results provide a system for naming existing and new roads, thereby directly associating addresses with graphic features such as points, polygons and line through GIS. The system can aid in the proper delivery of parcels without delays or lost parcels, efficient and timely responses by ambulance, fire services, and law enforcement agents, and effective revenue collection for the Metropolitan authorities.

Keywords: Geospatial address system, Data model, Area zone, Identifier

1 Introduction

Referencing information and features to geographic locations is essential to daily life. Postal addresses, a specific way of locational description, are the essential means by which people express their location in the real world. One particular dataset for a spatial information infrastructure is address data, which is the base for many administrative, statistical, and economic processes in every country (Lind, 2010). There are a variety of applications relying on address information (Beal, 2024; Christen and Churches, 2005; Veregen, 1999) like marketing, planning, emergency services, route planning, crime mapping, and environmental health studies, among others (Gaffney *et al*, 2005). In order to know one's exact location, it is necessary to know the longitude and latitude (Tobler, 1972; Dueker, 1974; Beal, 2003; Lee, 2004). The process of determining these coordinates and linking this intelligence to a physical street address is known as geocoding (O'Reagan and Sallfeld, 1987). Therefore, an essential feature in many applications, especially in Geographic Information Systems (GIS), is the capability to locate addresses, i.e., geocode to address level. Geocoding, to some, is only in the context of generating maps, and this is merely one application. Geocoding is the enabling technology for spatial analysis, determining where one location is relative to other locations or for determining the territory or zone it is located in (e.g., health (Vine *at al*., 1998; Boulos, 2004; Rushton *et al*., 2006); crime analysis (Olligschlaeger, 1998; Ratcliffe, 2001); political science (Haspel and Knotts, 2005); computer science (Hutchinson and Veenendall, 2005b; Bakshi *et al*., 2004).

By knowing the latitude and longitude of two locations, it is possible to compute the distance between them, for example, and to perform spatial analysis, analyzing one location in relation to the other (Cayo and Talbot, 2003; Bakshi *et al*., 2004; Hutchinson and Veenendall, 2005). Knowing a location's geocode can also provide a key to accessing data files that contain additional location-dependent attributes and characteristics. Unfortunately, most databases containing address information (e.g., customer, prospect or vendor files, business directories, etc.) do not include geocodes as part of the associated address data. Currently, in Ghana, no standard database exists that includes specific and exact geocodes for cities in terms of our postal addresses. Proper street naming and property addressing are essential components of any urban setup. These are useful in locating any place for critical delivery systems or emergency services, and most properties are easily located when they have proper standing signage with names. Street names

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are also essential, for they give an individual the direction to their destinations (Chen *et al*., 2003).

Residents usually bear the cost of poorly designed addressing system; deliveries are not sent to the right locations most of the time, and there is a need to update and upgrade street names to ensure better service delivery (Boscoe *et al.,* 2002; Chen *et al.,* 2004; Churches *et a*l., 2002; Dearwent *et al*., 2001). Business owners often lose out on potential customers when their businesses are not located due to missing street names and signage. Most urban areas' Metropolitan Municipal District Assemblies (MMDAs) often face a dilemma in revenue collection due to missing signage and misplaced street names. The government also loses huge revenue in urban areas since no uniform systems exist for property taxation. This could be done with good street naming and property numbering (Boulos, 2004; Croner, 2002; Gatrosek and Cressie, 2002). These street naming and property addresses need to be well addressed in a GIS environment to aid in navigation even when road signage is destroyed so that deliveries and the residents are not affected. Some of the associated problems are:

i. The public will have difficulties in finding their way around the city;
ii. Timely response by ambulances, firemen and law enforcement personnel will be affected;
iii. Sending mail to private mailboxes or houses will be difficult;
iv. Delivery of rates statement will be affected;
v. Utilities services delivery will also be affected; and
vi. Garbage collection service providers etc.

Many different socio-economic applications of address-based data in a Geographical Information System (GIS) exist. With improvements in the capabilities of GIS and databases, uses and applications of address-based data have increased significantly. Such applications include a wide range of records such as insurance policyholders, medical records or vehicle ownership, and application areas also include the provision of public utilities and the work of emergency services (Ratcliffe, 2001; Nuckos *et al*., 2004; Haspel *et al*., 2005; Oliver *et al*., 2005). Due to the complex nature the roads, address systems and property coding, there is no tailored model or system that is able to address the afore-mentioned problems. This study presents a newly designed smart data model of a geospatial addressing system designnated for use in urban areas in Ghana, tested with case studies in selected areas.

2 Resources and Methods Used

2.1 Study Area

The study area is Ayawaso Central, located in the Greater Accra Region of Ghana, under the jurisdiction of the Accra Metropolitan Assembly (AMA), which carries out the legislative, deliberative and executive functions for the area. The AMA is run as a corporate body with 90 members, 60 of whom are elected and 30 appointed by the government (Anon, 2008).
The functions of the AMA are outlined in a legislative instrument (L.I. 1500) and are summarized as follows:

i. Provision of a sound, sanitary, and healthy environment;
ii. Provision of educational infrastructure for first and second-cycle schools;
iii. Provision of markets and lorry parks within the metropolis;
iv. Planning, development and control of all infrastructure within the Accra metropolis;
v. Activities bordering on the maintenance of peace and security within the metropolis;
vi. Provision of public safety and comfort.

The study area, Ayawaso Central, is a sub-metro that is an administrative entity approximately 5 miles north of Accra Central, Ghana (Fig. 1). Its boundaries are ring road in the south, a popular slum area called Nima to the East, Kwame Nkrumah Circle, the Odaw drain and industrial area to the west, and Olusegun Obasanjo Highway to the North. The sub-metro comprises four communities: Alajo, Kokomlemle, Kpehe and Kotobabi. The area was chosen out of the lot as the pilot area, and the criteria were (Anon, 2008):

i. It is an urban area;
ii. It has a well-defined area boundary;
iii. It is made up of a mixture of planned and informal settlements;
iv. It is also made up of a mixture of public and customary land tenure;
v. It comprises a mixture of different land use, i.e. residential areas, government use, commercial use and industrial use; and
vi. A mixture of different street names and types.

For Administrative purposes, the city is subdivided into 11 administrative entities called Sub-Metropolitan District Councils, commonly referred to as "sub-metros" (Adeleye *et al*., 2014) . The sub-metros are Ablekuma North, Ablekuma Central, Ablekuma South, Ashiedu Keteku, Ayawaso Central, Ayawaso East, Ayawaso West, La, Okaikoi

North, Okaikoi South and Osu Klottey as shown in Fig. 1.

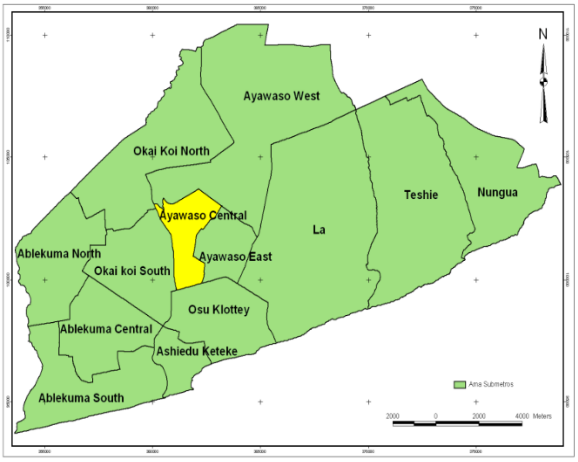

Fig. 1 The Sub-Metros of Accra Metropolitan Assembly

Each sub-metro has an administrative building with staffing. The sub-metros are responsible for decentralized functions, which include some combinations depending upon the requirements of the particular sub-metros.

As the city grows, large settlements develop around the city boundaries. These settlements have become separate municipalities in the last several years with their own administrations. Some of these surrounding municipalities are home to high-income households, while others are predominantly comprised of low-income households. Because of the city's centrality as an administrative and commercial centre, it draws many worker commuters from these radial municipalities

2.1.1 Location

The study area is a second-class residential community in the Ayawaso central sub-metro. It lies around the latitude 5°34'13.50" N and longitude 0°12'17.45" W in the Greater Accra region of Ghana (see Fig. 2). It has an area coverage of about 4 km^2 with a total population of 35 519 (Census 2010 estimate). This is a result of ongoing migration from the neighbouring cities, especially, Nima and Alajo, characterized by rapid, mostly unregulated growth, coupled with the challenges of its fragmented geography that often results in chronically congested traffic conditions on the city roads, and this is shown in Fig. 2 (Adeleye *et al*., 2014).

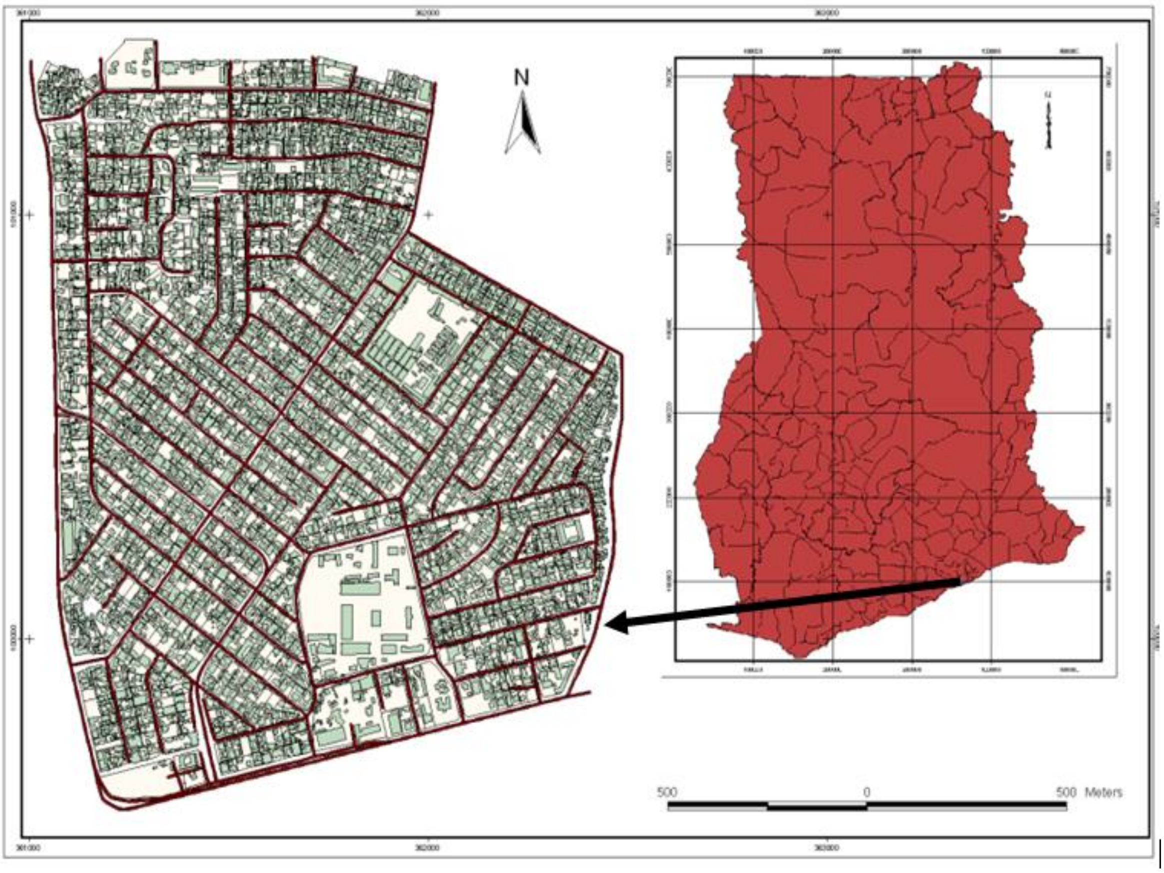

Fig. 2 Location of Study Area on the Ghana Map

2.1.2 Climatic Conditions and Topography

Kokomlemle lies in the savannah zone. There are two rainy seasons. The annual rainfall is about 730 mm, primarily during the two rainy seasons. The first begins in May and ends in mid-July. The second season begins in mid-August and ends in October. There is minimal variation in temperature throughout the year. The mean monthly temperature ranges from 24.7 ºC in August (the coolest) to 28 ºC in March (the hottest), with an annual average of 26.8 ºC. The study area is close to the equator, so the daylight hours are uniform during the year. Relative humidity is generally high, varying from 65% in the mid- afternoon to 95% at night. The predominant wind direction in the area is from the WSW to NNE sectors. Wind usually speeds range between 8 to 16 km/h (Anon, 2010).

2.2 Zones in Study Area

The study area is classified into zones consisting of all the housing units within the city. Under the concept of zoning, the study area's land use was grouped into categories of densities (Fig. 3): single-family residential, multi-family residential, neighbourhood, commercial, light industrial, among others (Annan *et al*., 2024). These are used systems and specifications for parcel identifiers. Proper identification of properties in the sub-metro is essential to accurate valuation. A parcel identification system put in place by the Survey and Mapping Division (SMD) of the Land Commission for Land Title Registration (LTR) provides a method for referencing land parcels or data associated with parcels using several codes instead of a complete legal description.

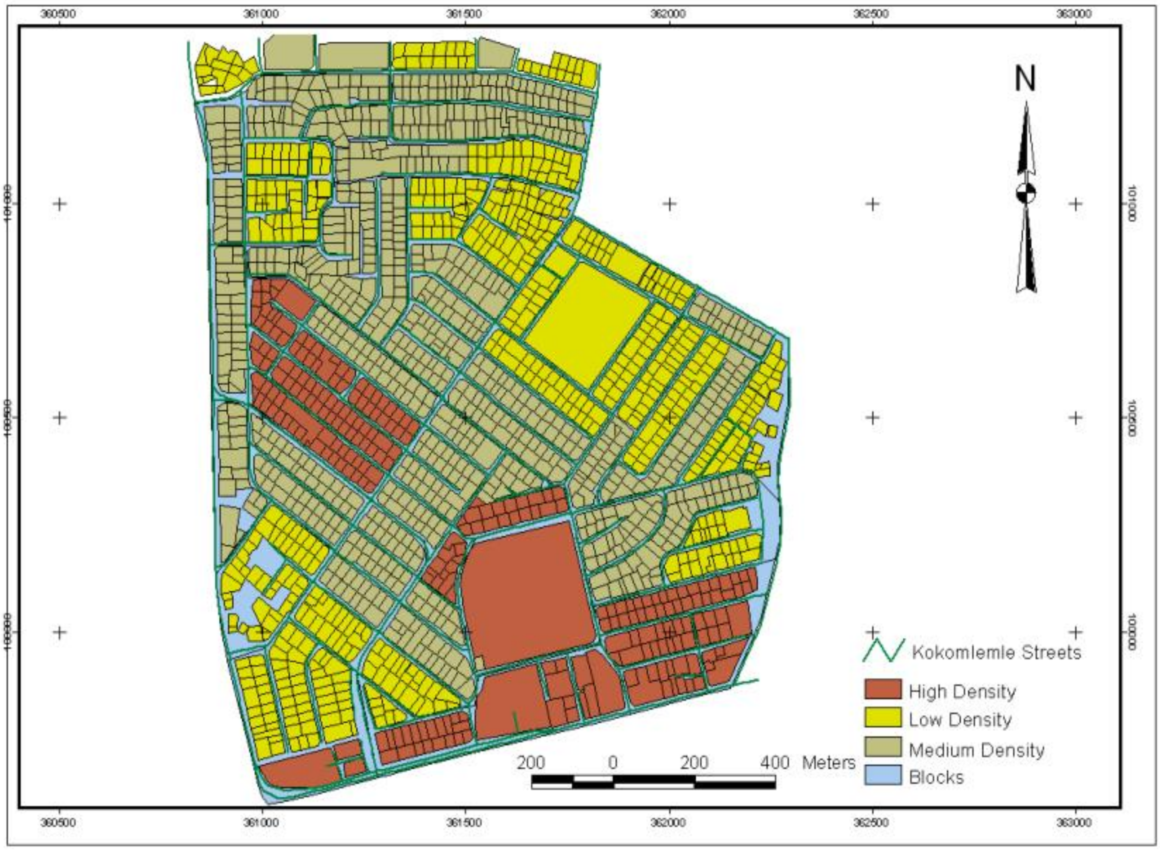

Fig. 3 Categories of Densities in the Study Area

2.3 Data Sources

Aerial photographs for this study were obtained for the base map cartography from the Urban Management Land Information System (UMLIS) project, which is used for revenue generation through property rate, business operating permit, and building permit. It was flown at an altitude of 850 metres along the flight lines, with the image resolution (Ground Sample Distance, GSD) being 0.1 metres (Swede survey, 2005). Within the flight lines, as shown in Fig. 4, each successive photo overlaps the previous image frame between 60% and 80%.

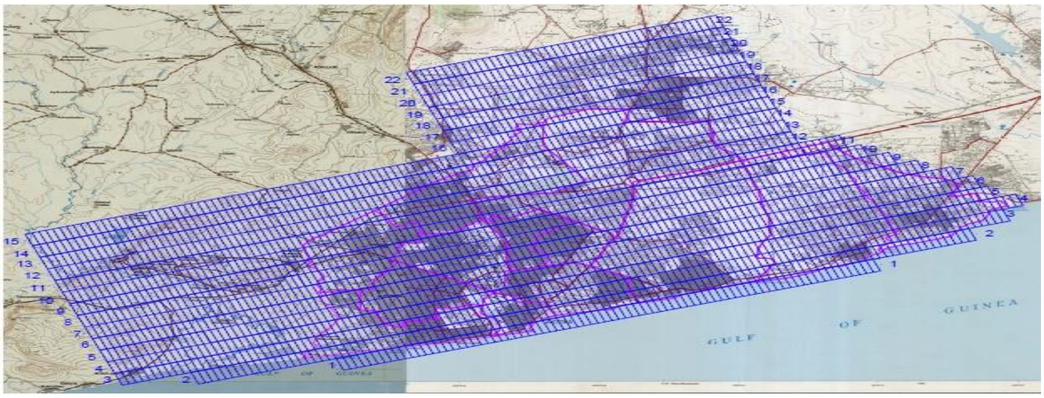

Fig. 4 The Flight Plan Lines Diagrams

The overlap area between the two successive frames allows for stereo (3D) viewing of the area in common and the subsequent collection of the digital elevation model (DEM).

2.3.1 Digital Orthophoto Generation

The creation of the digital ortho-photography started with careful planning for the final image product. In preparation for the aerial flight, ground controls were established and identified to be seen and recorded in the film, where the values X, Y, and Z of these points were known. These points form the basis for control coordinate assignment through aerotriangulation. The triangulation calculations were completed using the Ghana National Grid, Traverse Mercator projection of War Office Spheriod. The War Office Spheriod were in feet but converted to metres with the major axis a = 20,926,201, the minor axis b = 20,855,505 with flattening 1/f = 296 as in Fig. 5. After the aerotriangulation, the photography is then ready for the digital elevation model collection. This digital elevation model forms the basis for correcting scale differences across the aerial imagery due to elevation changes. It was also used to remove the relief displacement in the terrain. The elevation data were collected using an analytical stereo plotter to view the photography in 3-D and a representative sample of elevation points describing the area's relief.

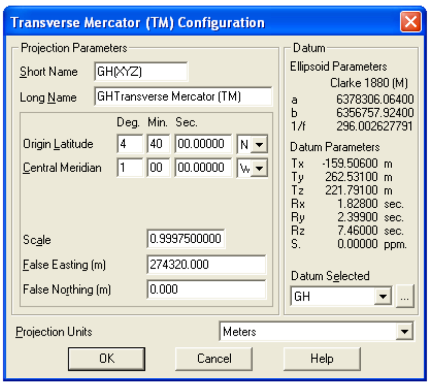

Fig. 5 Transformation Parameters Used in Orthophoto Generation

With the DEM collection completed, the photographs were scanned and converted into digital images. The photographs were scanned at a high resolution to ensure high image quality for the final product. During this process, defects of dirt and lint pieces are sometimes introduced to the digital orthophoto image, detracting from the quality of the final product. Also, any scratches in the original photography minimized during optical enlargement are captured and preserved in the scanning process, making them visible in the final product, as shown in Fig. 6.

Fig. 6 Orthophoto Generation after the Scanning Process

The actual orthophoto creation is a computer-based process that marries the rasterized aerial photograph with the DEM. This process allows the software to reposition the pixels of the scanned aerial photo to remove the effects of relief displacement and terrain elevation differences. With pixels properly positioned, the associated X and Y coordinate values are assigned, making the orthophoto ready for viewing. The resulting image becomes a constant scale across the entire image. The images are corrected for tonal differences to complete the process.

2.3.2 Data Quality

The quality issues were categorized into two broad categories. The first is spatial accuracy, and the second is image quality. The survey and mapping division (SMD) of the Lands Commission has national accuracy standards that need to be desired or derived when it comes to the spatial accuracy assessment of the completed orthophoto base map. Horizontal accuracy for maps on publication scales larger than 1:20 000, not more than 10% of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20 000 or smaller, 1/50 inch. These limits of accuracy were applied in all cases to positions of well-defined points.

The image quality considers defects and tonal differences both within and across sheets. The elevation data of the orthophoto were collected in a systematic grid. In order to ensure the resultant product meets minimum accuracy standards, additional points, especially on hilltops, cliffs, pits, and lines, were collected using GPS to enhance the quality of the final product and produce a DEM utility. The DEM collected using the analytical stereo plotter yielded a valuable final product (Fig. 7) due to a combination of mass points, breaklines and significant points obtained. The digital topo sheet of the study area is in an arc coverage format, which was consistently drawn as a check on top of the digital orthophoto during the visual quality verification. In this way, suspicious areas were corrected with GPS readings as checks on existing benchmarks. The checks obtained minimum error in the coordinates of 5 mm and a maximum of 2 cm.

Fig. 7 Final Product of Orthophoto in the Study Area

2.4 Extraction of Vector Data

The image was uploaded onto the Delta/Digitals software, and head-up digitizing techniques were used to capture the data. The features captured were the roads and the buildings. The road features were captured as lines and the buildings as polygons, as shown in Fig. 8.

Fig. 8 Digitization of Buildings as Polygons and Roads as Lines

The buildings were digitized as polygons; however, some of the buildings were so small that the centroids of the polygons were used as points. The digitizing process focused on the foot edge of the buildings. The polygon buildings were converted to point centroid, and a unique number called National Technical Building Key (NTBK) was given to them. The parcel information and digital sectional maps in Fig. 9 were acquired from the Survey and Mapping Division (SMD) of the Lands Commission.

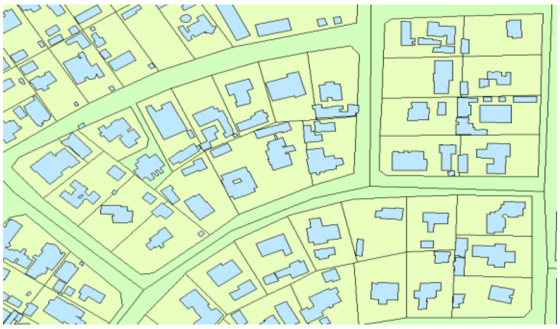

Fig. 9 Parcels Maps of Survey and Mapping Division of Lands Commission

The roads were digitized as lines. The lines were digitized as polylines on the road centerline. The road centerline digitization was made to cover the entire road length, and the road type was designated from the Start Node to the End Node. The line direction of the road was made to correspond with the increase in address from low to high in conformity with the Start Node as the low addresses and the End Node as the high addresses of the centerline segment.

2.4.1 Topology

Topology rules were set across the GIS datasets. Topology is defined as how point, line and polygon features in GIS share geometry, such as the spatial relationships between connecting and adjacent features. Topology defines and enforces data integrity, such as road centerlines needing to be connected where road segments share an intersection. The most common topological errors encountered during the digitizing capturing process were the introduction of dangle errors (overshoots and undershoots), gaps and overlaps (Fig. 10), and centerlines not being broken at intersections, as in Fig. 11. With the help of the topological tools, these errors were flagged for resolution, and corrections were made. Using the topological tools in ArcGIS software made it possible to format the streets in the TIGER (Topologically Integrated Geographic Encoding and Referencing) database system.

Fig. 10 Topology Dangles

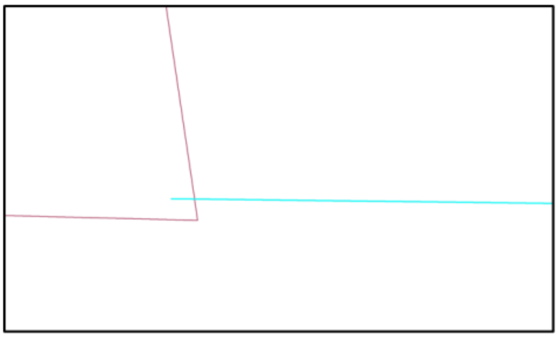

Fig. 11 Improperly Snapped Road Centerline

The TIGER database contains information about features like the streets in terms of their location in latitude and longitude, the name, the address ranges, the geographic relationship to other features, and other related information.

2.5 The Geospatial Addressing System

A model has been created (see Fig. 12) in this research work to enhance the municipalities and the district assemblies in services in relation to street naming and house numbering.

The system's primary purpose is to manage data effectively to reach an optimum decision. A Geospatial Addressing System (GAS) is vital for local governments to provide valuable services to individuals. These systems can establish an excellent relationship among the primary geospatial data layers for city works and directly link these geospatial data with corresponding objects. These are:

i. Relationship in terms of Segments, the Roads, the Building Permit, the Roadway, the Parcels and the residents (owners)
ii. Real Tax Collection
iii. Emergency Analysis
iv. Distribution Applications
v. Route Services
vi. Real Estate valuation (Land Valuation)

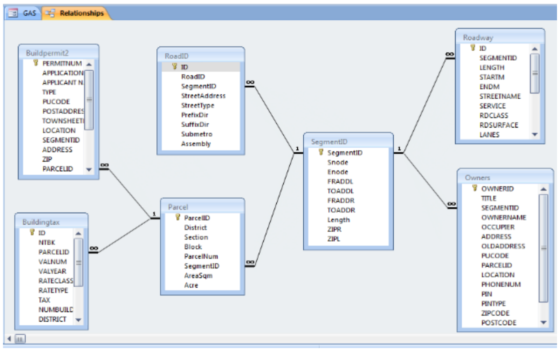

Fig. 12 The Relationships of the Field of the Geospatial Data Mode

3 Results and Discussions

3.1 Results

Kokomlemle has commercial and industrial activities, and their match rate was compared to residential ones. The following were categorized into the commercial and industrial areas. They are retailers, institutions and schools, supermarkets, markets, Banks and Financial operators, and any business activity that falls under this category. The rest was considered residential as far as those properties did not have business operating permits.

Table 1 Match Score of the Data Model

Category	Commercial and Industrial		Residential	
	Block	Street Line Segment	Block	Street Line Segment
Matched (Score = 100)	135	135	1484	1484
Tied (Score = 100)	0	0	0	0
Matched (Score < 100)	90	120	1298	1448
Tied (Score < 100)	15	3	47	8
Unmatched (Score < 60)	30	12	139	28
Matched rate (%)	67	89	87	98

Some of the most challenging addresses to geocode correctly were commercial and multi-unit residential addresses after the match rate, as shown in Fig. 13, which illustrates the location, the address, and the match type.

Table 1 shows the comparison of commercial industrial properties to that of residential properties. Results indicate that the residential properties match rates for street segment address-level are higher than for parcel boundary geocoding, which confirms the poor performance of parcel boundary geocoding for multi-unit residential addresses.

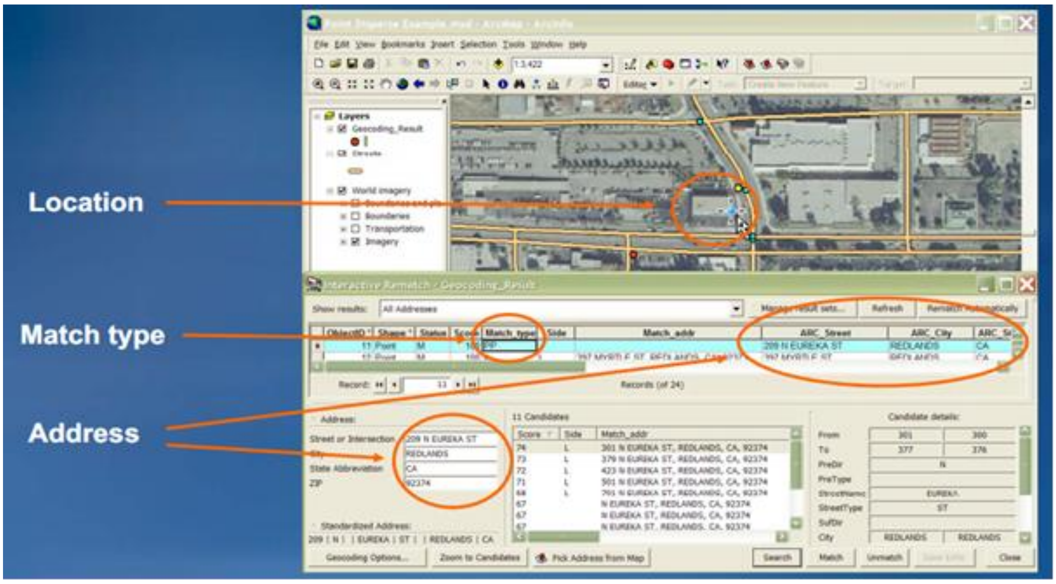

Fig. 13 Identifying a Location After the Match Rate on Addresses

The results from the implemented data model show the Parcel_ID, the District, the Section, the Block in which it is situated, the Parcel Number, and a link to the map. The personal details of the property owners are also displayed in Fig. 14.

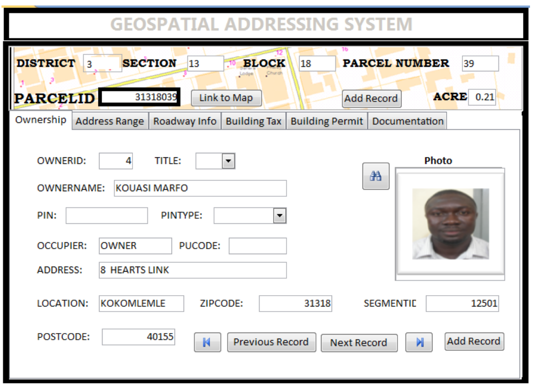

Fig. 14 The Ownership Information of Residential People

Apart from the properties addressing system, the model could cater to the road, its interpolation, and its naming system, displayed in a user-friendly form that gives adequate information about the roads in the area. Fig.s 14 and 15 illustrate the implementation of the model. For tax purposes, the model has a facility aiding in the accurate taxation system that correctly indicates all areas involved. Fig.s 16 and 17 illustrate the taxation and the road network that helped in the implementation of the data model

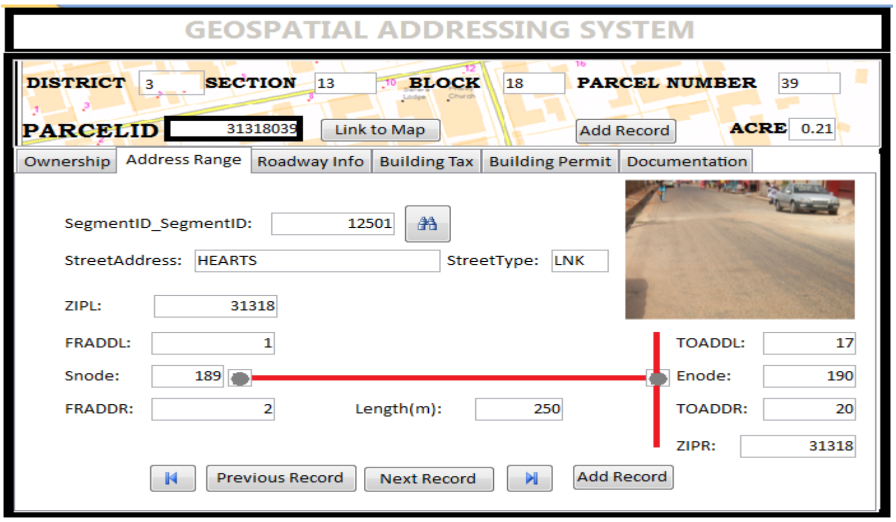

Fig. 15 The Roads Database with Address Ranges (RDAR)

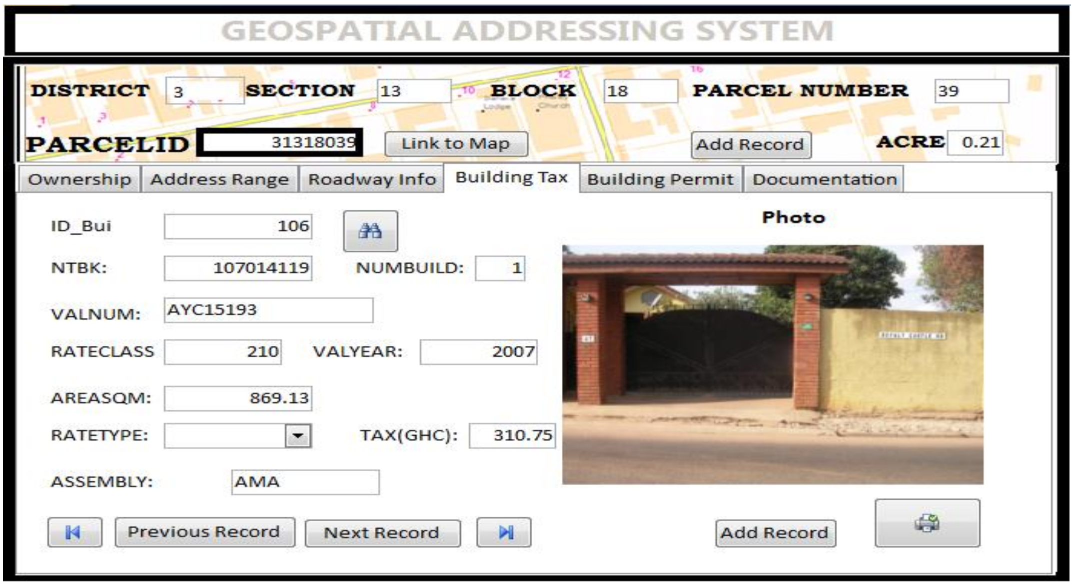

Fig. 16 The Building Tax Information on Tax Collection

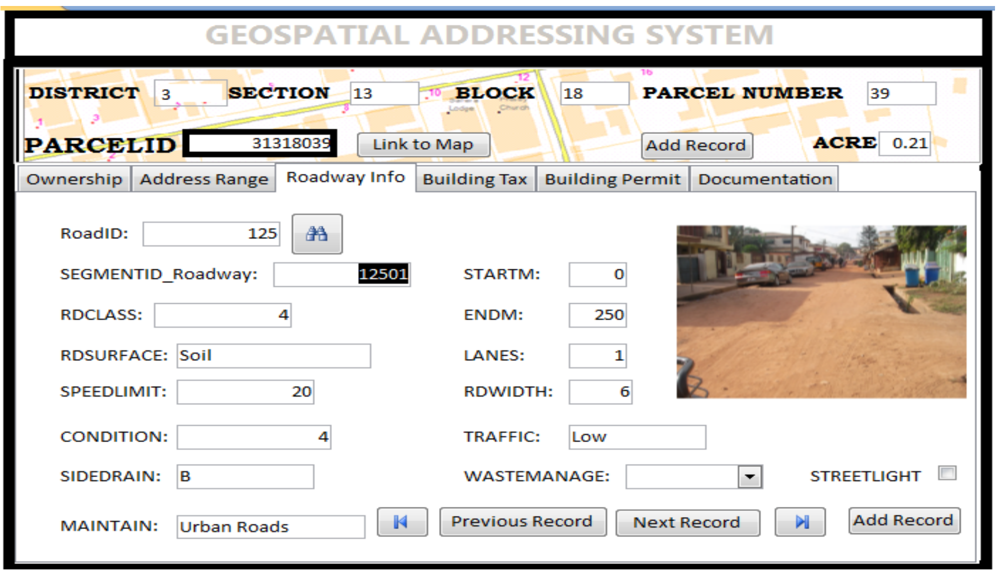

Fig. 17 The Roadway Information System

3.2 Discussion

This study has empirically compared addresses on parcel boundary and street segment addressing level geocoding. Match rates for address on parcel boundary geocoding are only slightly lower than for street geocoding. The higher rate for street geocoding could partly be due to false positives, but confirming this requires extensive field validation. Match rates using parcel boundary geocoding are much lower, but this varies by database type and geographic area.

Substantial differences were observed between commercial, industrial and residential addresses and between different residential addresses. Generally, higher match rates were obtained for residential addresses than commercial ones. For single-family residential addresses, match rates were relatively high for all two geocoding techniques. However, parcel boundary geocoding is unreliable for multi-unit residential addresses, while results for address points and street segment addressing level geocoding are much better.

Geocoding match rates were found to vary substantially by type of address database and by geographic area, suggesting that determining an ‘‘acceptable” or ‘‘good” match rate requires very context specific considerations.

Variability in match rates between address models is only one of several considerations. The lack of consistency in match rates between geographic areas using the same type of address database and the exact address model also suggests that geocoding quality is a function of the quality and consistency of local reference data. Substantial differences in match rates between the commercial and residential databases also suggest that the input data quality is a critical contributor to the final geocoding match rate.

3.2.1 Description of Reference Data

A summary of the number of features in each reference dataset is provided in Table 5.8. The number of residents per parcel for Kokomlemle is 21.72. This shows that the population is more than that of houses. This number is also strongly influenced by multi-family units with many residents residing on a single parcel.

When comparing the number of address points to the number of residents in Kokomlemle, the value obtained was 20.28. The number of street segments within Kokomlemle is much lower than the number of parcels or address points. The number of parcels and address points per street segment is 7.26, as in Table 2.

Table 2 Descriptive Summary of Reference Data Used in Geocoding and Model

Summary	**Values**
Population (2010)	35,159
Parcels in Blocks	1619
Number of Blocks	20
Residents per Parcel	21.72
Address Points	1734
Residents per address point	20.28
Average Household per Size	4.7
Parcels without Address Point	115
Number of Street Line Segments	239
Parcels per Street Line Segments	6.77
Address points per Street Line Segments	7.26

Table 2 also reveals that there are many parcels without an address point. Most undeveloped parcels do not get assigned addresses represented as points on the map. Most parcels have only a single address point – this is typical of single-family residential housing, but it also applies to many other types of commercial, industrial, and institutional properties. A smaller number of parcels have two address points, which are typical of residential duplex units. An even smaller number of parcels have more than two address points, and these were typical of larger multi-family complexes and commercial sites with many individual businesses located on the same parcel.

4 Conclusion

This study has brought to light that addresses can be directly associated with graphic features such as points, polygons, and lines through a GIS. For points or polygons, addresses are associated with individual tax lots as situs addresses. When linked to lines (i.e., street centerlines), addresses are stored as address ranges, which makes it possible to interpolate the location of an address along the length of a linear segment. It can be said that addresses linked to points and polygons are explicit, while those matched to lines are implicit. Another way of describing this relationship is that point/polygon addresses are real addresses since they are associated with the actual place where the address occurs, while address ranges are only theoretical locations since they approximate location along the line by parsing the line segment according to its associated range of valid address values. The development of zip codes is crucial to our national development. This research has provided some suggestions for creating zip codes in Ghana. Home delivery services (parcels, letters, goods, etc.) are limited in many parts of Ghana. The Post Office Box method is often the common means of contact, especially when sending letters and parcels via courier or postal services. Another method uses landmark and 'fuzzy' directions to provide an approximate location. This absence of a system of accurate and precise physical addresses leads to lengthy descriptions of the addresses. The lack of a zip code system means that proxy descriptions are often used. Such proxy locators include expressions such as "opposite to, behind, next to, 30 meters from, fifth house on your left, ask the shop owner on your right-hand side, behind the avocado tree, front of the XYX sign, call me when you get to the roundabout", etc. An addressing system could go a long way to assist in developing a uniform, precise location, which any person could use to access an address without attracting additional costs in time, money and lengthy description.

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