An Integrated Spatial Data Model for Multistory Cadastral Systems

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SUMMARY

Typical cadastral data modeling does not support spatial modeling of multistory residential area. This type of modeling is increasingly needed to accurately depict spatial features and their embedded relationships in different cadastral applications ranging from real state to building regulation implementation. A data model to depict multistory spatial data is introduced in this research. In this model, topological rules in object relational database system were utilized and enforced. Special interest was devoted to minimize redundancy in spatial data features representation. Customized code was implemented to facilitate data querying and displaying based on developed model. The model was implemented and successfully tested on part of a sub-division in one the new communities surrounding Cairo, Egypt.

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1. INTRODUCTION

Since, the cadastre 2014 publication of the FIG's commission 7 (Kaufmann, J. and D. Steudler, 1998) defined cadastral systems, based on Henssen (1995), to be a methodologically arranged public inventory of data concerning all legal land objects in a certain country or district, based on a survey of their boundaries, there is a growing need to increase the cadastral model resolution in order to more precisely model the real world. This is becoming more and more feasible with the advances in computer hardware accompanied with the introduction of object-relational data models and the concept of geo-databases. Having these new techniques added more sophisticated topology validation rules, which in turn enabled more sophisticated description of our world. In this context, this study aims at developing a data model for cadastral information that does not stop at the parcel and building levels but also extends its description to include spatial information of individual units in multistory residential buildings. The development of such model involves proposing and enforcing the appropriate topology rules and facilitating the practical analysis aspects that this model can support.

The topological relationships between spatial objects in cadastral systems are very essential to ensure data integrity as it describes how spatial objects share geometry. Without having a valid topological model many of the GIS analysis such as connectivity and adjacency can not or will be impractical to perform (Egenhofer and Franzosa, 1991). Moreover, these relationships provide an essential tool to check and insure spatial data correction and integrity. Topological relationships between two objects are defined by describing the intersection of all or some of these two objects' primitives (Clementini et al, 1994), and (Clementini and Di Felice, 1995). Many commercial GIS software nowadays provides algorithms that automatically detect and help enforce topological relationships between spatial objects. These algorithms are based on models that take into consideration the dimensionality of the objects and put some logical constraints to eliminate the spatial intersection possibilities. A brief description and a comparison between these models can be found in Twumasi, 2002. Defining these topological relationships between spatial objects depends on the geometrical properties in addition to problem-specific semantics of participating data (Cockcroft, 1996).

GIS data models moved from the traditional file system to data that are managed by relational database model. This move imposed many referential and integrity constraints onto the data in the database and made the use of many data semantic constraints possible (Elmasry 1995). However, most current cadastral systems are interested only in depicting spatial cadastral information on the 'parcel' and 'building' levels. This is partially due to the limitations imposed by common GIS systems in modeling semantics and overlapped polygons. More recently, the introduced of object-relational data model and new topological and user-specific semantic description tools, allowed not only the introduction and implementation of GIS data semantic constraints, but also allowed a more accurate depiction of the world by assigning certain behaviors and functionalities to the GIS data objects (Hoel, et al, 2003).

2. OBJECTIVES

As mentioned previously, most current cadastral systems lack a robust modeling of spatial extension of individual building units and only extend the non-spatial data model to depict this type of information. This of course limits many possible queries that involves the spatial information of each floor content and hinders many decision making procedures such as displaying building that do not have enough parking spaces or developing more precise value estimation models for building units taxation based on their location, orientation, and geometrical properties. Emergency evacuation and recovery efforts are another example of applications that require this level of spatial modeling resolution. In this context, one of the main objectives of this research is to introduce a new cadastral data model, which models spatial units in multistory buildings and emphasizes recent advances in GIS data modeling, such as using semantics external to the relational database for geometric and topological data validation. The research also aims at providing needed analysis tools, based on the proposed data model to support decision makers working on the field of building code enforcement in Egypt.

3. METHODOLOGY

A database model and several application and analysis tools were developed and implemented on data that represents a section of a subdivision in 6th of October city, which is one of the new communities surrounding Cairo city in Egypt. The area contains 58 buildings, containing 1287 individual units that are used as for residential or commercial purposes. Each building also has units that are specified for common use, such as garages, and service units. More than four template building models, based on actual architecture presentations were utilized I the study area, with varying number of floors ranging from underground up to the seventh floor. Units' representation could vary from one building to the other and from one floor to the next within the same building. Figure 1 shows the used subdivision with a representation of the second floor units in all buildings.

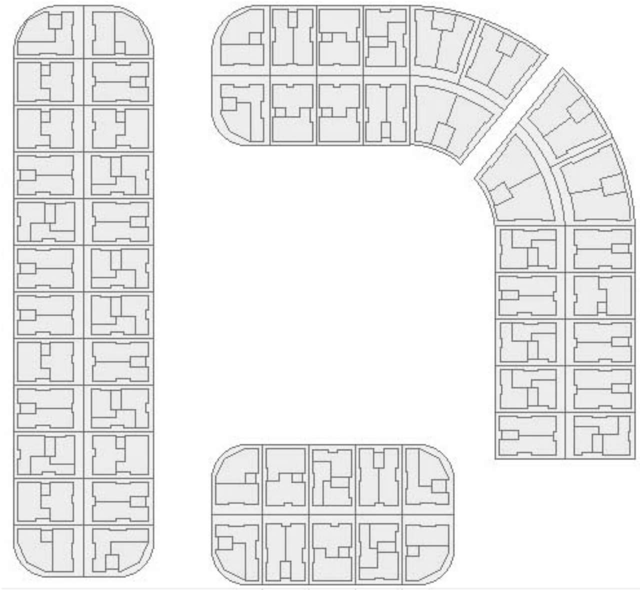

Figure 1: Study area showing parcels and second floor units in all buildings

Accordingly, a GIS layer, in the proposed model, is diverged from the traditional format of a planimetric layer to a more complex format that have a pool of overlapping polygons, where each polygon represents a unique unit in the overall floor layer. In other words, a GIS layer works as a pool of spatial units that are arranged together to form planimetric or multistory layer.

Applications supported by graphical user interfaces were developed and applied on the proposed data model, as a sample to practical analysis tools that are facilitated using the proposed data model. Most of these applications are directed to provide municipality officials with the tools needed to review and check on building code implementation in new developments. Several actual Egyptian building code rules, that should be enforced, were checked automatically through the developed applications. Currently, these rules are checked manually by inspecting hard copy drawings of individual buildings. The following subsections describe in details the developed data model and applications.

4. CONCEPTUAL DATA MODEL

Focus in this implementation is devoted to model the relationships between spatial data classes for multistory residential buildings. Modeling of non-spatial entities such as OWNERSHIP and RESTRICITIONS is described in other studies, e.g. Turker and Kockaman, (2003) and Twumasi, (2002), and will be the focus of future research. In this context, four main classes in an object-relational data model are proposed namely: PARCELS; BUILDINGS; UNITS; and SPATIAL_UNITS. Figure 2 uses Unified Modeling Language (UML) diagram to depict proposed classes and the relationships between these classes in addition to some of the attributes relevant to the model implementation and analysis presented later in this research.

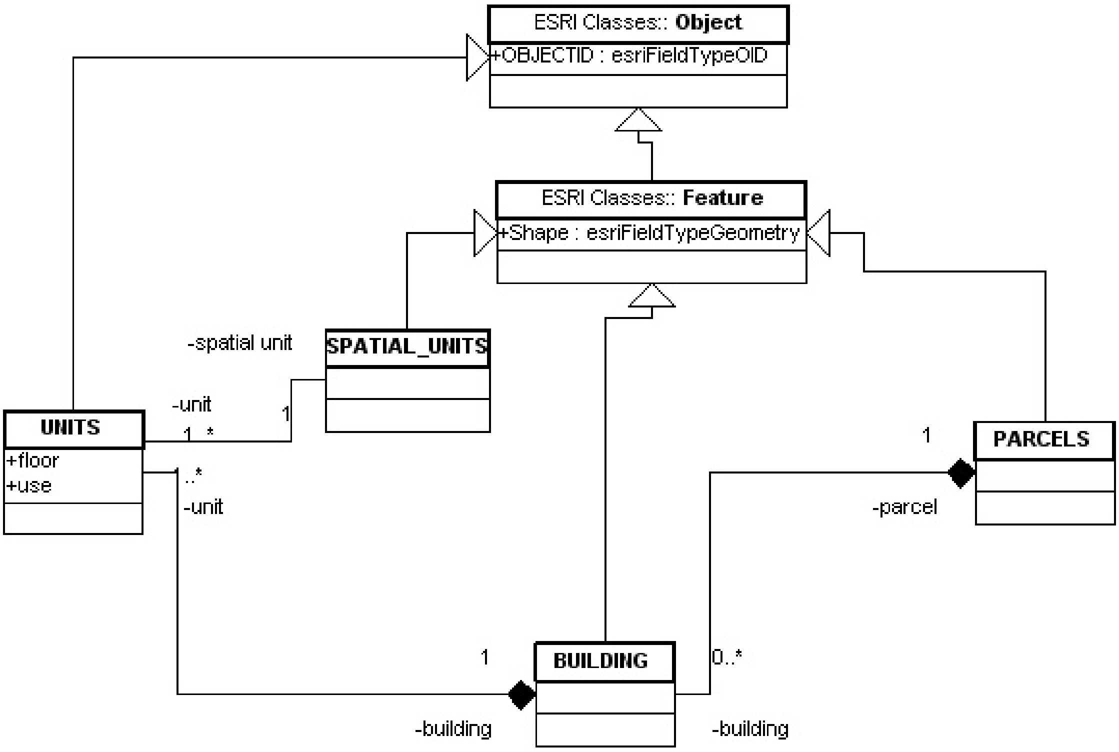

Figure 2: UML diagram for proposed data model showing relevant attributes.

In this representation, the PARCELS and BUILDINS feature classes represent the geometrical description of parcel and building boundaries described as polygon feature class. The SPATIAL_UNITS feature class, uniquely, represents the geometrical description of individual units in a building floor. In other words, if certain unit geometry exists in different floors in the same building, this unit is only represented once in the SPATIAL UNITS layer. Alternatively, if a different architecture plan is used in a different floor of the building, the new unit is also added to the SPATIAL_UNITS feature class. This means that, in the proposed data model, the SPATIAL UNITS feature class is used as a pool for unique spatial units. This means that overlay of spatial units in the same building is allowed if different architecture is used for the UNITS in different floors. Figure 3 represents part of the fifth floor units representation Comparing this figure to figure one above, which shows all units in the third floor of the study area buildings, we can notice some parcels in the fifth floor representation that do not have any units due to the fact that the buildings in these parcels do not have any fifth floor units.

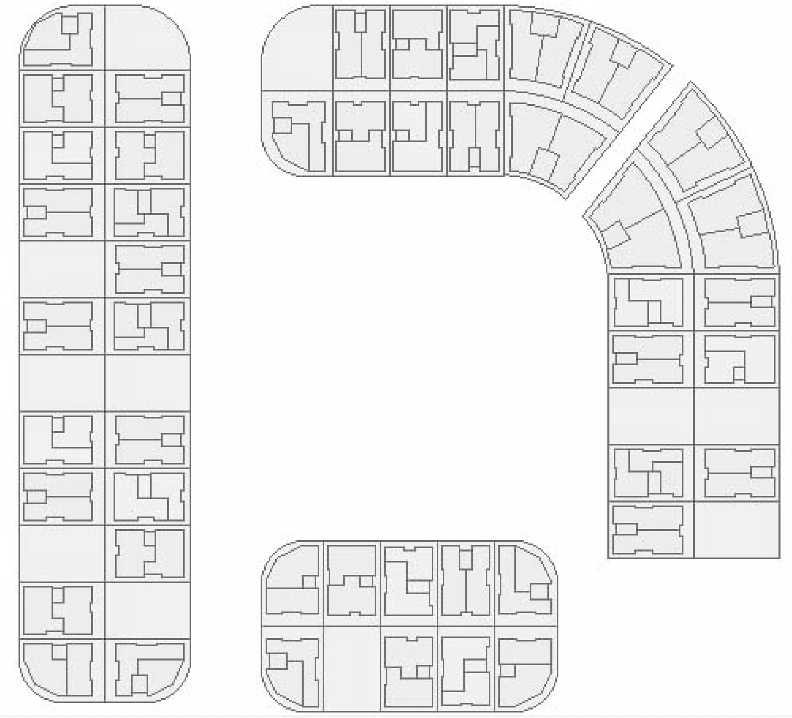

Figure 3: Fifth floor units' representation.

The UNITS object class uniquely represents each individual unit regardless of its geometrical properties. Each object has a foreign key that references primary keys in its spatial representation in the SPATIAL_UNITS feature class. Other unit-specific attribute such as floor number, unit use, address, etc are also included. References to other objects such as owner can also be added as extension to the developed model.

The relationship between the SPATIAL_UNITS, the BUILDINGS, and the PARCELS feature classes in this model could be extracted from the geometric properties of the objects. However, this relationship is defined explicitly through the model using explicit references keys that reference primary keys of other entities. Although this explicit definition of the relationship increases the burden of data maintenance and is, generally against the 3rd normalization function of a relational database model (Elmasry, 1995), this definition is needed to enhance query and analysis performance.

This prototype model could be expanded to include more attributes that can enrich further data analysis, more than the ones described in this paper. For example adding a height attribute to the BUILDINGS objects could facilitate a query that checks for buildings that violate maximum height rule in an airport area. Alternatively, this height attribute could be automatically deduced using the number of floors in each building in addition to the floor height, or units' height in each floor. It should be mentioned here that this spatial data model acts as a portal, into which other non-spatial and temporal information such as ownership, building status, etc could be attached. The detail and integration of this non-spatial and temporal information is outside the scope of this study.

5. PHYSICAL IMPLEMENTATION

The suggested model and analysis were implemented on ESRI ARCGIS software v 8.30 using Microsoft Access Database Management System (DBMS) on a Pentium 4 PC. Graphical User Interface (GUI) for analysis tools were developed through ARCGIS software customization using Visual Basic for Application (VBA) and ESRI ARCOBJECT (ESRI, 1999).

As mentioned earlier, data used in this study represents a part of a new community design in a Cairo city suburb in Egypt. The development is a high residential area of multistory buildings, with at least one apartment unit in each floor. Building law in Egypt mandates the existence of enough parking area for each unit in the building. This parking area is typically implemented on the underground or ground floor.

Three feature classes representing parcels, buildings, and spatial units were imported from Computer Aided Drafting (CAD) software as DXF files. Topological and semantic rules were developed to manage the relationships between feature classes. The following is a list of the developed topologically rules:
A unit must be included in a Building
Units must cover the whole area of a building
Buildings must not overlap
Units in Each floor must not overlap
Parcels must not overlap

Topological rules and references between different feature and object classes were checked. Identified violations, were generally due to geometrical errors in the source CAD layers. Most of the errors were automatically corrected. However, some errors were manually treated.

6. ANALYSIS

Several applications were developed to test the functionality of the suggested model and to provide essential analysis tools needed by decision makers responsible for monitoring the implementation of building code in residential areas. Several analysis tools were developed using VBA and ARC-OBJECT on ARCGIS software as previously mentioned. Queries needed for the application were developed and embedded within the code. GUI, which is presented in figure 4, was developed to facilitate this implementation. In the developed application, the user chooses the cadastral feature class representing the spatial units, which in turn, has a relationship with the units object class. The user also is required to select certain analysis type from a list of available analysis tools. In the following, four of these analysis tools are described:

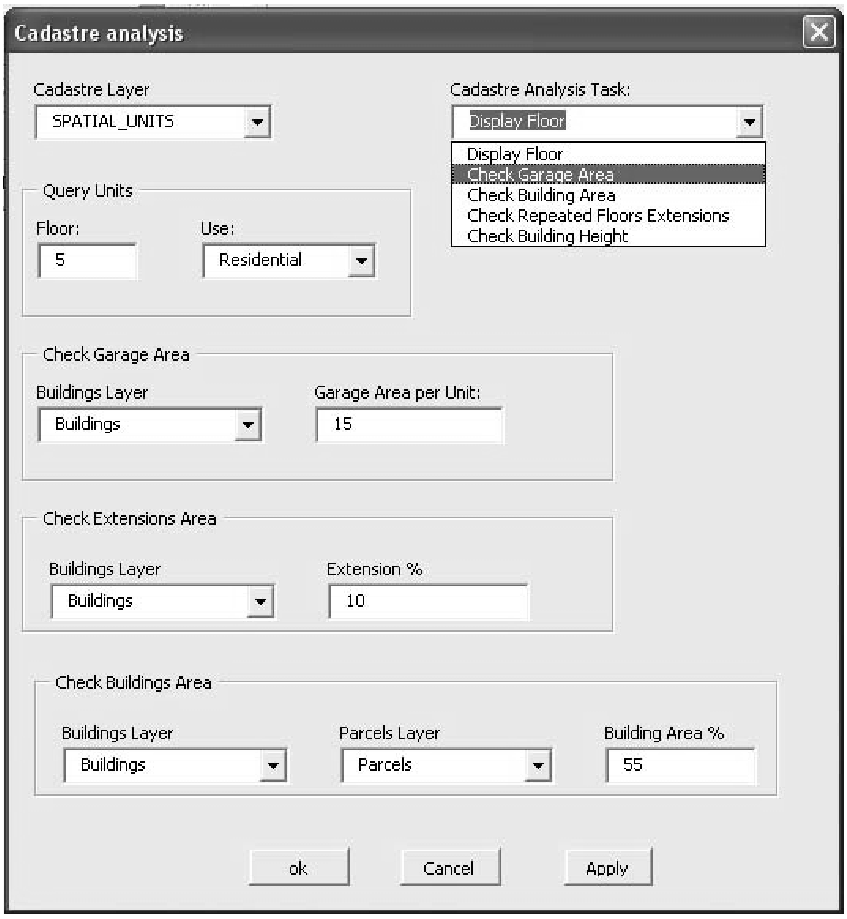

Figure 4: Graphical User Interface (GUI) used to support implemented analysis tools

6.1 Display of Units Satisfying Certain Query

Due to the nature of used data model, which has allows spatial units to overlap if they are geometrically different in different floors of a building, a special application was developed to only display units that lie in a certain floor and also that satisfy certain query such as those used as residential units. This implementation depends mainly on relating the UNITS and SPATIAL_UNITS classes and supplies the resulting relationship with an SQL query containing the attribute constraints. UNITS also can be queried and displayed based on other non-spatial attributes such as units use.

6.2 Check Parking Area

This implementation queries the data for buildings that violates a building code that requires each building to have a parking area that is proportional to the number of units in the building. The user inputs the minimum area specified for each unit by law. The application, programmatically, reports the buildings that do not have any units that are used as parking. Then, the program selects all units in each building coded for parking use and sums their area together. This total parking area in each building is compared with the total area required by law, which results from multiplying the number of units in each building, other than parking and general benefit units, by the minimum area required as parking for each unit.

In applying such module on the given data, with a 15 square meters parking area per each unit only 10 buildings violated the required area criteria. These buildings are shown in figure 5. However, when performing the same analysis with 20 square meters parking area limit, 28 buildings were found to violate the same criteria.

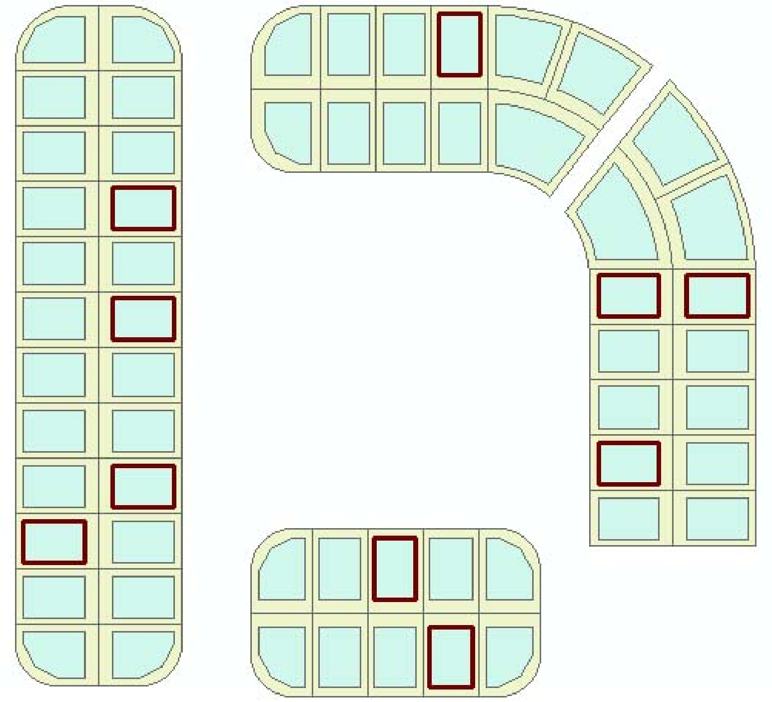

Figure 5: Buildings violating the parking area criteria using a 15 square meters limit.

6.3 Check on Outer Building Extension

Another criterion that needs to be checked is the total area that each floor could extend, starting from the first floor, outside the actual building boundary on the expense of the space area surrounding each building. This extension area should not exceed a percentage of the total area of the building. To check on this criterion, the user has the option to enter the percentage of allowed building extension. The application, automatically, computes total area of units in each floor of every building and compares it with the area of each building. If units' area in certain floor violates the pre-specified allowed percentage, the building is selected and marked as a violation to building code. Figure 6 shows buildings violating a 10% allowable extension in the study area.

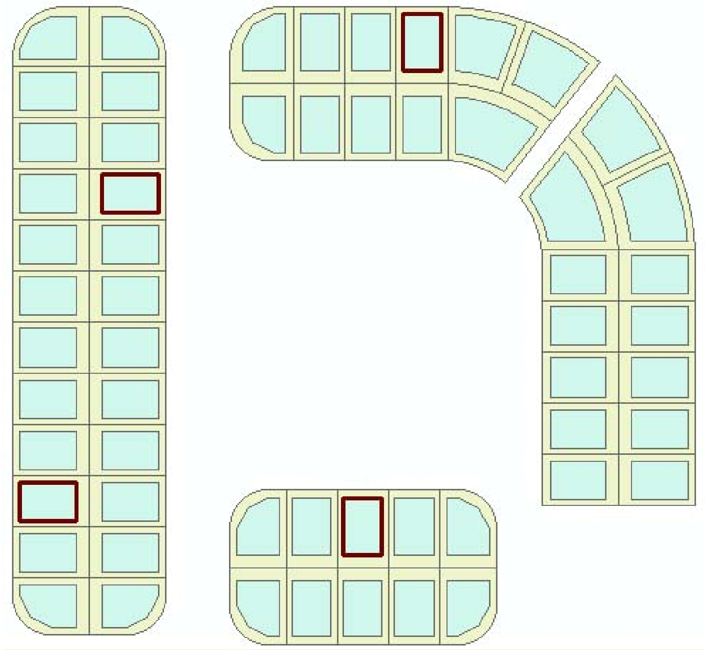

Figure 6: Buildings with perimeter extension that exceeds 10% of total building area

6.4 Check on Buildings to Parcels Percentage Area

Building area as a percentage of parcel area can be checked programmatically. The PARCELS and the BUILDINGS feature classes are joined, and then all buildings with an area that exceeds certain percentage of its parcels area can be selected. This analysis tool was applied to the test data, with a maximum of 60% percentage threshold between building and its parcel areas. The only building that was found to violate this criterion is shown in figure 7.

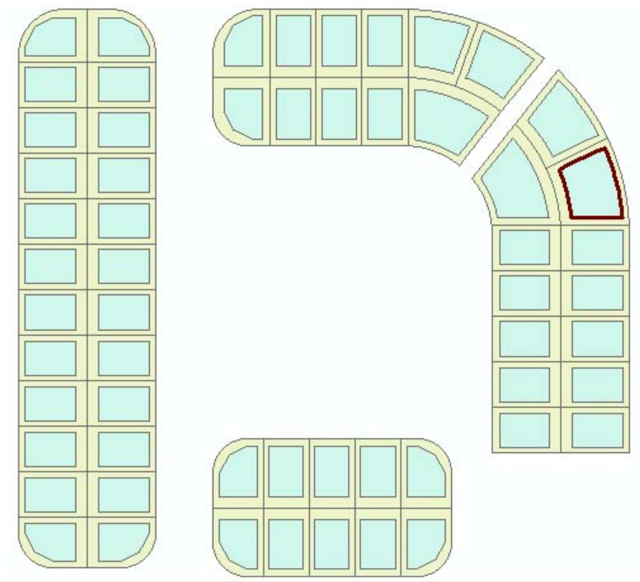

Figure 7: Building with total area exceeding a 60% of its parcel area

7. CONCLUSION

In this study, a new data model that extends typical cadastral data model to include spatial information about individual units in multistory buildings was developed. The model is based on an object-relational data model supported nowadays by many commercial GIS Software. Interfacing other non-spatial classed to the suggested model is recommended to be the topic of further research. The model was successfully implemented on a segment of a new development in Cairo city Suburb. Different topological and semantic rules were developed and implemented during the data conversion from CAD software to GIS software.

The developed model proved feasible for providing analysis needed by municipality personnel and decision makers responsible for enforcing building regulations. Several applications were developed programmatically using VBA as a customization tool with ARCGIS software. Queries were embedded in the customized code using SQL language. Special Graphical GUI, together with its embedded programmed functions, was proven to be necessary in order to facilitate performing analysis to the average user. These analysis tools were successfully tested on the study area.

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BIOGRAPHICAL NOTES

Dr Amr Abd-Elrahman, is currently an assistant professor at the Faculty of Engineering of Ain Shams University. Dr Abd-Elrahman got his MSc degree form Ain Shams University in 1995 in the field of GIS and digital mapping. He acquired his PhD in 2001 from University of Florida, US in the Geomatics field with a minor in computer engineering. He worked for 18 months at University of Central Florida as visiting research scholar in developing desktop and web based GIS applications for transportation applications. He conducted research and published several papers in the fields of image processing, remote sensing and GIS. Throughout his career, he taught many undergraduate and graduate GIS/LIS, remote sensing, and image processing courses in addition to several surveying courses. He is currently supervising several PhD students in the same fields. Dr Abd-Elrahman is currently the co-principle-investigator of a project funded by the Egyptian Higher Education Ministry to establish land information lab and academic curriculum at Ain Shams University.

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