TOWARDS A SPATIAL FRAMEWORK FOR SUPPORTING BUILDING CONSTRUCTION INSPECTION

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ABSTRACT: The process and efficiency of monitoring building and construction violations is a concern of the construction industry. The detection of violations requires appropriate and sufficiently accurate spatial information to manage and support a comprehensive inspection process and monitor compliance. A building inspection workflow must extract appropriate spatial and measurement in-formation from a variety of sources, identify potential violations across a range of compliance criteria and determine the quality of resulting inspection reports. This paper presents a framework for supporting building inspections using spatial information and methods to detect construction violations and compliance. Current inspection processes involve issues around 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 the issues identified to establish the requirements for a spatial inspection framework. The results demonstrate how such a framework can support improved decision-making and reduced fieldwork effort in detecting and measuring the accuracy of building violations involving building placements, street offsets and footprint areas.

Keywords: Building inspection, workflow, spatial information, building violation detection, geographic information systems, inspection spatial framework

1. INTRODUCTION

Building inspections and defect management are important processes for ensuring construction quality [1]. Construction projects involve large volumes of data from building sites that are important to collect and process [2]. Better usage and integration of inspection and related data allows for a more efficient inspection process and improved violation detection outcomes [3]. Inspectors check building regulations approval documents and other related information to ensure that building structures follow building regulations both during and after construction [4]. Building inspectors ensure that the construction, repair or alteration of these structures complies with contract specifications, building codes and ordinances, and zoning regulations [5].

1.1 The Building Inspection Process

The process of inspection is an aspect of total quality management aimed at improving the performance of processes in business and industry [6]. The process involves field surveys and process investigations to ensure that project managers make quality decisions regarding sites [7]. A building inspection process can be made easier with geographic information systems (GIS) which provide readily accessible, integrated and quality geospatial data to represent and locate features, and thus provide a platform for meaningful analysis, monitoring and decision making [8].

1.2 Building Regulations and Inspection Criteria

Understanding how the building regulations are used and apply to the inspection processes is essential for improving the inspection process and building regulation compliance. According to Pheng and Wee [9], building regulations are standards that are set for both the design and construction of houses and any other buildings, to ensure the health and safety of the people who are inside or around the building. It is important for the owner of the building together with the building contractor to familiarize themselves with the regulations and put them into practice.

Building regulations should cover the building structure, site preparation issues, access to the building and protection from collisions and falling objects [10]. Some buildings are not bound by building regulations; this is subject to criteria based on size, position and construction. The regulations generally apply to the construction phase as well as post construction, both of which fall within the inspection process [11].

The inspector’s task is to assess the compliance, adequacy and eligibility of proposed projects with regards to the laws and regulations in force [12]. Building monitoring is used to ensure that minimum requirements of building regulations are maintained [13]. To safeguard against this, criteria are developed for building regulations and inspections that take care of all the aspects within a construction project [14]. Building inspections help local governments to maintain the application of building laws and regulations [9].

2. INSPECTION REQUIREMENTS

Identifying key requirements of the building inspection process is important for realizing the aim of the inspection, namely, to monitor compliance. [15]. 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.

The research outlined in this paper investigated in particular the geospatial information support needs for the inspection process. A range of spatial information regarding location, proximity to other features (eg. roads), distances, areas and other measures are valuable and necessary information to support appropriate and reliable decision-making regarding building regulation compliance. Hence this paper proposes a framework that provides the spatial information support for a building inspection process. This framework was implemented in a case study and the resulting violation report outcomes were analysed with regards to the inspection process.

3. METHODS

Figure 1 identifies the research methodology used to understand the issues, develop the requirements for enabling spatial information to support building inspection workflows and develop a framework that encapsulates this. The methodology involved identifying the current issues relating to the building inspection process, determining which issues are associated with or could be enhanced with spatial information, and then developing a framework for spatially supporting a building inspection process.

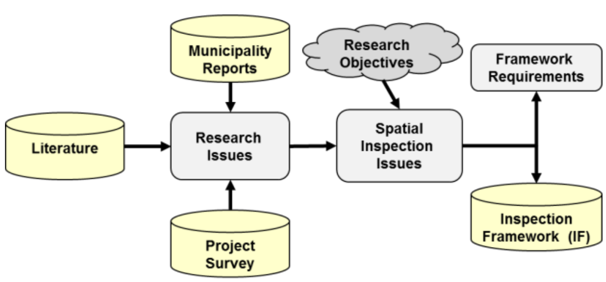

Figure 1. Research methodology for developing a spatially-enabled building inspection framework

The study area selected for this research is the city of Riyadh in Saudi Arabia, chosen due to the high level of observed building violations. Additionally, the current building inspection process is lacking with regards to access and integration of suitable geospatial information, and hence is not as effective as it should be. [15]. Riyadh is a rapidly growing city and the current inspection process cannot keep up and manage the monitoring of compliance that is necessary [16]. The building inspection department of the City of Riyadh still uses manual methods to assess building sites and detect violations. The current inspection process, as shown in Figure 2, is largely based on time-consuming physical field inspections with little access to geospatial information which could often otherwise be used.

In order to better understand the current inspection issues, building inspectors at Riyadh Municipality were surveyed regarding their knowledge and experience, as well as the perceived weaknesses, with the current inspection process. A total of 173 building inspectors were surveyed and a response rate of 83% was achieved. Of the responses, 8.7% were excluded because of missing or invalid data.

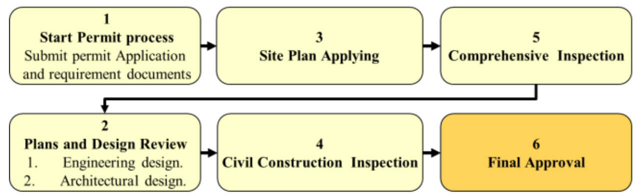

Figure 2. Building Inspection Process in the Riyadh Municipality

4. SURVEY RESULTS AND INSPECTION ISSUES

The survey of building inspectors was used to identify or confirm the commonly occurring building violations, understand the issues related to access to required data, and determine the ability to integrate and use geospatial data in the inspection process.

4.1 Common Building Violations

Past municipality inspection reports reveal the types of violations commonly found in Riyadh [17]. 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 percent 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 non-compliance to regulations regarding inappropriate views from building windows (Figure 3).

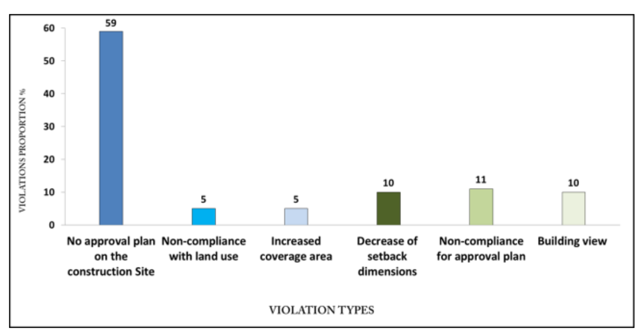

Figure 3. Building violation types as a proportion of all violations %

The inspector surveys revealed further detail regarding building violations and confirmed the high rate of violations found. Figure 4 shows the proportion of inspectors that identified particular violations as occurring often or very often. Overall, the number of violations is high, and the types of violations are varied. Only a few types, such as building without licenses or on inappropriate elevations occurred relatively few times. Violations that were high in frequency included: not adhering to approval plans, violations occurring after construction completion, too large areas for upper annex and main building footprints, and building setback distances less than the minimum regulation requirements.

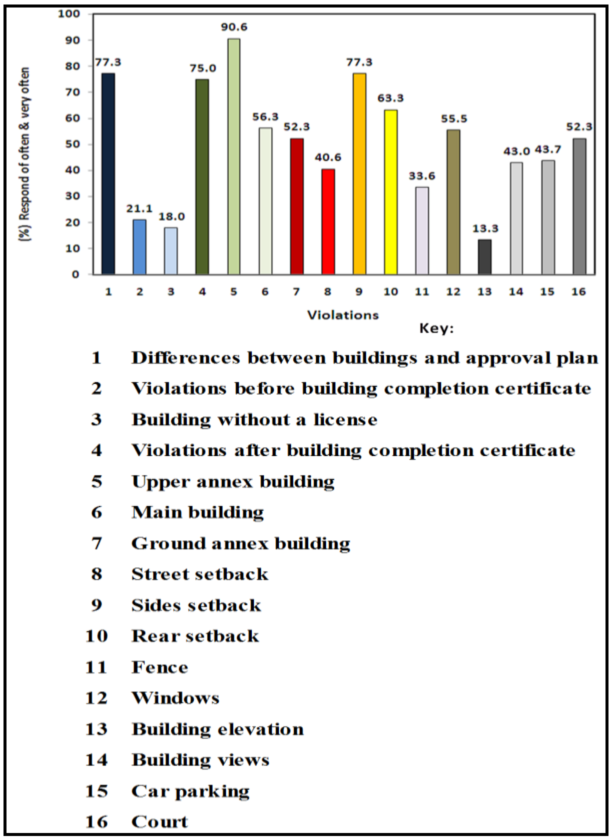

Figure 4. Respond of the often and very often of building violations which the inspector occur within his responsibility area.

4.2 Inspection Data Accessibility

As previously mentioned, the research outlined in this paper focuses specifically on those building regulations that involve spatial information, related to either the cadastre or buildings. Figure 5 shows basic spatial information of the cadastre including dimensions, area, road frontages and adjacency to other parcels. Examples of spatial building information are area of buildings, street setback distances, side and rear setbacks of buildings and spatial dimensions as identified in the approval plans (Figure 6).

The survey of inspectors 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 digital map data available to them to identify the current stage of construction, 37.5% could access building background information prior to going on an on-site inspection and 55.5% reviewed the history of violations prior to conducting an inspection. These results indicate poor access to much needed data that would inform the inspection process, reduce the amount of field work required and assist in making decisions. The net effect is that either the inspections are incomplete, or that they actually don't eventute, generating a greater level of non-compliance and risk due to violations not being attended to.

Figure 5. Basic spatial information of the cadastre including dimensions, area, road frontages and adjacency to other parcels

In regards to the inspection process, the surveys revealed that 52.3% of inspectors felt that the current process clearly defined the inspection criteria, 46.1% thought that the processes were using for managing the recording of defects, 26.6% felt that the processes adequately supported inspection job between clients and the builder. In other words, not only are the inspection processes not well supported by necessary (spatial) data, but the processes themselves were either not clearly defined or not clearly understood by the inspectors who use them.

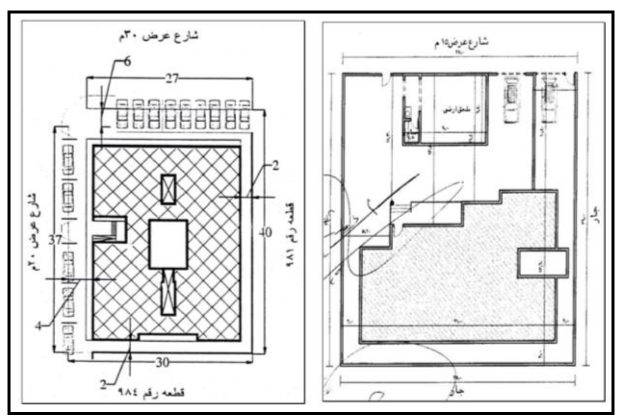

Figure 6. Spatial building information identified in the plans including building footprint areas and setback distances to parcel boundaries and road centerline.

4.3 Geospatial data integration and usage

From the survey conducted, 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 method of reporting the violation is 95.5% in the current process and 72.2% of allow freehand drawing to store inspection data. On the other hand, current methods support usage of aerial photography 17.2% and satellite imagery 18.8% in the inspection workflow.

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 not able to easily access and integrate data for a particular inspection target, and further, are not able 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 needed geospatial information is poor and 73% indicate that the current processes using that spatial information are inadequate. According to Akinci et al [18] to perform appropriate monitoring during construction, and to improve violation detection, it is necessary to have effective tools such as spatial information to support the visualization of the construction defects.

5. A SPATIALLY-ENABLED INSPECTION FRAMEWORK

To address the issues regarding the lack of support for a building inspection process, a framework was developed to provide the spatial information and integration tasks and necessary to support decisions regarding building violations. The framework comprises components for capturing and extracting required data, preparing the data by identifying thresholds and violation class types, violation detection determination, quality assessment and inspection reporting (Figure 7).

5.1 Inspection Data Input Component

The Inspection Data Input component identifies data from multiple sources which are required or able to support the inspection process. For each dataset entered, the appropriate information and measures then need to 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 sensing imagery, potentially at different spatial scales and geographic coverage. From these data sources, measures and values need to be extracted 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 the digital imagery, and the threshold values for minimum setback distances and proportion of land parcel covered by building footprints can be obtained from the building regulations

5.2 Quality Assessment Component

The quality assessment component uses the quality information for each of the data sources to categorise the various inspection measures according to the error contained. Quality values are assigned to the boundaries of these categories which are then used in other components to be able to associate measures of quality to the violation detection outcomes. For example, multiple aerial images at different spatial resolution 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 confirmation that no violation has occurred.

5.3 Data Preparation Component

The Data Preparation component takes the measures and quality values obtained thus far and prepare them for the next stage of violation determination. Threshold values such as minimum distances, minimum areas, etc. are extracted from the building regulations and rules. Further, this component takes the quality categories defined in the Quality Assessment component and generates the rules for the violation classes and boundaries to be used to represent the violation detection outcomes.

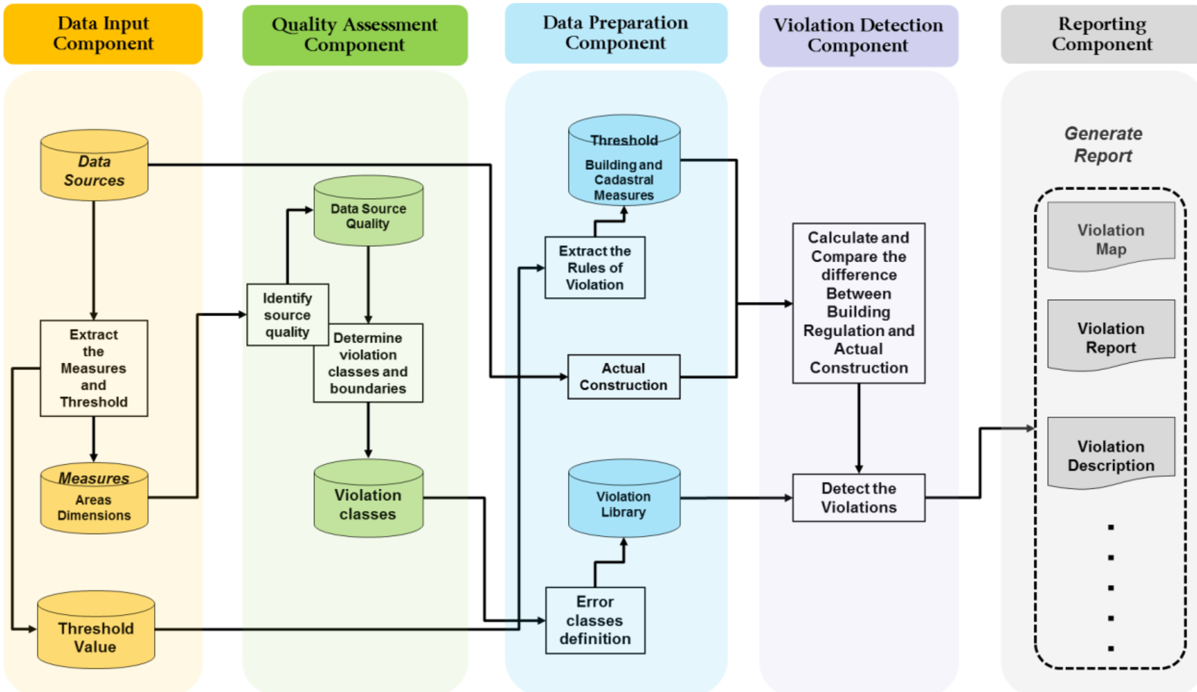

Figure7. Spatially-enabled Inspection Framework Components

5.4 Violation Detection Component

The Violation Detection component analyses the actual building construction measurement 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 as to whether a violation is definite is possible or there is no violation (ie. compliant). The positive and negative assessment regarding a violation occurrence can only be made when the input information clearly supports this beyond its error limitations. If such a determination cannot be clearly made, then the outcome is a possible violation occurrence. 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.

5.5 Reporting Component

The aim of the Reporting component is to generate various inspection outcomes and reports to inform the various steps of a building inspection workflow. 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 in their inspection tasks 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 non-compliant 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 or provide measures on-site.

6. RESULTS AND DISCUSSION

The spatially-enabled inspection framework was implemented in a prototype using ArcGIS. The prototype implemented each of the components of the framework for a selection of violation types: area of building footprint relative to cadastre area, distance of building footprint from front road, and setback distances of building from side and rear boundaries of the land parcel.

The prototype was tested and evaluated using a geographic region of approximately one square kilometer within the city of Riyadh. This area comprises approximately 776 land parcels and 937 buildings.

A number of different sources of imagery were used to evaluate the effect of the quality assessment and measures on the violation map results. In the example described in this paper, two images obtained from the Riyadh Municipality Aerial imagery project in 2002 were used for the King Fahd District study region, one with a low resolution and the other with a high resolution [19]. The low accuracy map source is aerial photography at a scale of 1:5000 with an error range ± 6.65 m^2 for each feature. In essence, this means that the worst case combined error range for the cadastre and buildings is ± 13.3 m^2. The higher accuracy map was obtained from aerial photography at a scale of 1:2500 with an error range ± 2.85 m^2 for each building feature. Using the building measurements from this high resolution imagery together with cadastral data obtained from the land subdivision plans which have a relatively extremely high accuracy (ie. Assuming zero error), the combined worst case error range was assumed to be ± 2.85 m^2.

The prototype was executed and evaluated for the setback (both side and rear) distance violations for the two image sources mentioned earlier. The results are illustrated in Figure 8. Where the low accuracy source data was used, 56% of the buildings were identified as being non-compliant and only 28% could be assessed as definitely being compliant. For the remaining 16% of buildings, compliance could not be determined because of inaccuracies and errors in the available data, and hence are classified as "possible violation". When the high resolution source image was used in the violation detection process, the number of occurrences in the possible category of detection was reduced to 7% (Figure 8). The number of definite violations increased to 61% and the number of compliant buildings increased to 32%. Hence, with the utilization of higher accuracy source image data, the quality assessment and violation detection components of the prototype were better able to determine the compliance of a greater proportion of buildings. However, even with lower accuracy source imagery, the prototype provides an assessment for a greater proportion of buildings than the current manual system, which is of benefit in itself. In fact, the remaining occurrences classified as having a possible violation have quality values associated with each building, making it easy to prioritise which require further information, either by utilizing higher accuracy data, or by conducting further fieldwork to obtain higher accuracy data.

Figure 8. Results of side and rear setback violation detections based on lowest and highest resolutions of source imagery

6.1 Advantages of Implementing the Construction Inspection Framework.

The framework provides the capability to enhance and speed up the current work flow in a variety of ways. Firstly the use of digital data throughout provides a clear audit trail of processes and decisions. Secondly the use of data from remote sources such as aerial photography and remote sensing reduces the need for invasive and costly onsite inspections. Thirdly, the quality of all data used in the process is monitored reducing the possibility that any decision can be challenged or that any data is missing. Finally, the improved information base for decision-making results in a reduction in the number of field inspection visits that are required, with consequent manpower savings.

6.2 Requirements for Framework Implementation

In order to change the building inspection workflow from the current to the proposed method, there are some essential technical preparations to be made. The requirements are as follow: a) an updated imagery archive of both aerial photography and satellite images, b) the construction of a Geospatial Model of construction violation detections, c) training of people to run and operate the systems, d) training to enhance the current inspector capability to use and manage the framework techniques, e) hardware and software to implement the framework, and f) establishing integration between all necessary departments.

6.3 Ongoing Costs Required for Supporting Proposed Framework

Once the infrastructure needed to support the framework is in place, the major cost will be the provision of updated imagery. At this stage no costing has been done on the relative merits of using high resolution satellite imagery or dedicated acquisition of aerial images. It is anticipated that new images would be required on a fortnightly basis. In Riyadh this can easily be covered using satellite imagery since cloud is rarely a problem. In other locations aerial images with its more flexible acquisition schedule may be better suited.

7. CONCLUSIONS

This study presents a spatially-enabled inspection framework to address the issues of: 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. The framework supports an inspection workflow by enhancing the effectiveness and efficiency of the use of information in the building inspection workflow, improving the detection of violations and assessing the quality of the inspection decisions regarding compliance to building regulations. This study addresses common building violations such as building footprint areas being greater than those specified in the regulations, street setback of the buildings outside of the permissable minimum distances, and side/rear setbacks of buildings not being within the permissible limits.

The framework for the spatially-enabled support of the inspection workflow developed as part of this research comprises five components: a) inspection input data, b) data preparation, c) quality assessment, d) violation detection and g) reporting.

This framework addresses the issues surrounding multiple datasets and formats, digital source imagery of varying scale, resolution and geographic location, quality of measures and determinations, and decisions regarding violations to support the building inspection process. A range of violation reports and associated quality information can be used to support decision making within various steps in the building inspection workflows.

A prototype was developed and implemented to test and evaluate the framework. Results for assessing side and rear setback distances of buildings showed, for example, that with the use of low accuracy imagery, a violation determination (either positive or negative) could be made for 84% of buildings, whereas with higher accuracy source imagery being used, this figure rose to 92%. Results such as this show the great value that a spatially-enabled violation detection GIS brings to the building inspection process.

In fact, the prototype demonstrated a substantive improvement over the existing manual method where it was not possible to make a definite determination for that high a proportion of buildings. The current inspection system relied on a large amount of fieldwork to further inform the inspection process and decisions. With the support of a violation detection GIS, much of the assessment can be made by integrating and evaluating existing data and much less time-consuming fieldwork needs to be employed.

The initial prototype results of evaluating the spatially-enabled framework demonstrate that the inspection process can be enhanced with better integration and quality assessment of geospatial data. Further research will investigate how effective the framework is over a broader range of violation types and data sources.

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REFERENCES

[1] Dong, A., M. L. Maher, et al., "Construction defect management using a telematic digital workbench", *Automation in construction*, Vol. 18(6), pp. 814-824, 2009.

[2] Kim, H., "Data preparation process for construction knowledge generation through knowledge discovery in databases", *Journal of Computing in Civil Engineering*, Vol. 16(1), pp. 39-48, 2002.

[3] Wang, L. C., "Enhancing construction quality inspection and management using RFID technology", *Automation in Construction*, Vol. 17(4), pp.467-479, 2008.

[4] Pedro, J. B., F. Meijer, et al., "The Portuguese building regulation system: a critical review", *International Journal of Law in the Built Environment*, Vol. 1(2), pp. 156-171, 2009.

[5] Hollis, M. and K. Bright., "Surveying the surveyors", *Structural Survey*, Vol. 17(2), pp.65-73,1999.

[6] Olian, J. and S. Rynes., "Making total quality work: aligning organizational processes, performance measures, and stakeholders", *Human Resource Management*, Vol. 30(3), pp. 303-333,1991.

[7] Harris, F., R. McCaffer, et al., *Modern construction management*, Wiley-Blackwell, Oxford, 2006.

[8] Ghose, R., "Use of information technology for community empowerment: Transforming geographic information systems into community information systems", *Transactions in GIS*, Vol. 5(2), pp.141-163, 2002.

[9] Pheng, L. S. and D. Wee., "Improving maintenance and reducing building defects through ISO 9000", *Journal of Quality in Maintenance Engineering*, Vol. 7(1), pp. 6-24, 2001.

[10] Pheng, L. S. and B. Abeyegoonasekera., "Integrating build ability in ISO 9000 quality management systems: case study of a condominium project", *Building and Environment*, Vol. 36(3): 299-312, 2001.

[11] Hess, S. A., J. V. Bales, et al., *Design professional and construction manager law*, Amer Bar Assn, Chicago, 2007.

[12] Lake IR, Lovett AA, Bateman IJ, Day B., "Using GIS and large-scale digital data to implement hedonic pricing studies", *International Journal of Geographical Information Science*, Vol. 14(6), pp. 521-541, 2000.

[13] Meijer, F., H. Visscher, and L. Sheridan., *Building regulations in Europe*, DUP Science, Rotterdam, 2003.

[14] Barrows, C. W., M. B. Swartz, et al., "Framework for monitoring multiple-species conservation plans", *The Journal of Wildlife Management*, Vol. 69(4), pp. 1333-1345, 2005.

[15] Alterkawi, M., "Measures towards a comprehensive municipal GIS: the case of Ar-Riyadh Municipality", *Habitat International*, Vol. 29(4), pp. 689-698, 2005.

[16] Al-Hathloul S. Mughal M., " Urban growth management-the Saudi experience". *Habitat International*, Vol. 28(4), pp. pp.609-623.2004.

[17] Riyadh Municipality, Annual report of building inspection department, 2009.

[18] Akinci B, Boukamp F, Gordon C, Huber D, Lyons C, Park K., "A formalism for utilization of sensor systems and integrated project models for active construction quality control", *Automation in Construction*, Vol. 15(2), pp. 124-138, 2006.

[19] Ministry of Municipality and Rural Affairs, *National Aerial Photography Projec*t, 2002.