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Mobile GIS for construction quality managers and surveyors

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Abstract

In any mega construction project, quality survey managers play a vital role in judging quality of work done by different contractors and sub-contractors. Usually a quality survey manager uses a hard copy form to records the survey information and for reporting to the client. Typically, this entire process takes a week's time or even more, there is no workflow in place for recording information and analyzing trends in irregularity by the quality managers. The requirement to capture and report quality survey observations in real time evoked a need to research on mechanism for recording the observations using smart phone and existing GIS infrastructure without any development on smart phone and mobile devices. An integrated solution using an editable ArcGIS Server feature service and ArcGIS online web maps was developed in order to perform the quality survey.

The paper describes the mobile GIS solution for construction projects. The solution allows recording observations in a real time environment through a user-friendly interface and workflow driven process. It also allows users to capture the picture and attach it to an editable feature service. The client can view this information in real time using ArcGIS online or in the enterprise geodatabase. The use of the Esri online ensures restrictions on accessibility of the content and takes advantage over other application because no programming or development is required. In addition, the information is stored in Oracle database and used for analysis in future, based on the changing reporting requirements. The developed solution saved on time, money and is easy to use and deploy.

Keywords

construction project, quality survey manager, construction inspection, smart phones, GIS infrastructure

Introduction

The construction projects are complex in nature due to its dependence on multitude of external agencies which are involved at various levels from initial concept planning till the successful implementation of projects. The success of the projects to be implemented on ground further depends on various factors depending on the type of projects like, small scale, medium scale and large scale projects. One of the aspects of successful project management is to deal with issues regarding construction quality management and the compliance of requirements at various levels. Several studies have shown number of factors in construction delays, these are mainly: cost overruns, quality, safety, productivity, human and management related problems. Due to these factors, the projects never get finished on time, and remain within the budget and to the clients/ stakeholders satisfaction [1]. Any delay during construction phases mean loss of revenue or higher overload costs due to various unpredictable factors like: performance of parties, resource availability, environmental conditions [2]. In construction projects, the quality management is often overseen by the client's representative as well as from the contractor's side. The quality of completed work on the projects is often not up to the satisfaction of the client's representative/agents, and there are defects of inappropriate nature. As seen from international practices, the construction projects are required to comply with inspection and test plans (ITPs), for monitoring, auditing and reporting the construction phases. The impact of these site specific quality management systems and inspection test plans are not much documented in terms of its impact on the practices of quality reporting, and effective construction management systems [3].

The key objectives of quality inspection clauses laid in construction projects is to bind the parties so that constructed project meets all the contract requirements at any of the construction stages. The inspection and testing performed in construction projects are not limited to specific phases of the project like – receipt, storage, fabrication and erection. The quality inspection and testing is required to cover the aspects of quantitative and qualitative aspects of construction materials and workmanship [4]. "Quality assurance in construction activities guides the use of correct structural design, specifications and proper materials ensuring that the quality of workmanship by the contractor /sub-contractor is achieved and finally maintaining the structure after construction is complete through periodic assessments for maintenance and repairs. Quality control has to be imposed by the contractor whereas quality assurance is carried out by a separate third party agency engaged by the owner" [5].

Mechanisms for recording construction quality

Need for quality inspection systems

In construction projects, the complexity of quality matters vary from an informal inspection methods to well defined methods as laid down in ISO standards on quality systems. The clauses covered in such standards often cover areas like: inspection and testing, handling, storage, finished products, preservations etc. The quality compliance in these areas is often seen as a major gap during various construction phases [4]. The inspection system at construction sites / projects is required to have at various levels of execution of construction of works at initial stages to final / finished stages. These also include the aspects of safety management and environmental management at project sites, and often involve multiple stakeholders in the entire process. The roles and responsibility of construction quality manager and surveyors is more to handle the site inspections at various stages and report for its compliance and deviations if any [6]. The quality inspection is part of the daily routine system on a construction project, during any construction phase. The aspects of quality control are very critical during any stages of construction projects. These quality control measures relate to various tasks like civil works, structural works and other stages of construction processes [7].

Implications of absence of quality inspections

The large construction projects are complex in nature to manage the documentation / get the status of quality aspects related to various tasks of construction projects. Due to these limitations, the line managers, project managers, construction quality managers and surveyor are often constrained with the limited information about the construction projects on various dimensions. There are number of reasons which have been observed to be linked to the rise of construction defects at early or later stages of the construction phases. Some of these reasons include: defective components, material and system failures, unskilled human resources and insufficient supervision of construction works. The status of construction project phases is dynamic in nature and most of the time the quality performance is dependent on limited capacities of the technical resource persons like supervisors, quality managers and surveyors [8]. The established contractors / accredited contractors are required to adopt well-documented procedures for inspection at various construction stages/ phases. Various methods adopted by them include use of tags, marks, or routing cards to distinguish between inspected and uninspected construction items. Using these methods, manual documentation / recording is done on pre defined inspection quality checklist [4].

Existing solutions and approaches

Construction quality managers have approached the issues of onsite project quality compliance through various automation efforts. However theses automation efforts have been limited in nature and often restricted to the areas of digital drawings, specifications, checklists, reports etc [9, 10]. Accessing the real time information is still a challenge in light of the gap between the collection of information, inspection and reporting. These gaps have various impacts on terms of productivity, quality compliance and efficiency. With the advent of ICT, internet, mobile computing, spatial technologies, the construction field has adopted some of the measures which appears to be in hybrid form to mange some of the solution for the challenges faced on construction projects [7, 11]. One of the largely discussed technologies is about mobile device usages on construction projects. The mobile computing has been seen to enable the faster / efficient field work on construction sites, and to improve the productivity and management. The computing measures have been seen to rationalize the management practices and cost savings [6].

With the advent of adoption of ICT technologies in construction projects, the use of radio frequency identification (RFID) has been observed to handling the quality management operations [11, 12]. The other adoption of technologies includes mobile devices (PDAs), and web applications to enhance the effectiveness and flexibility of information reporting systems. The quality compliance details are required by various actors of the construction projects [9, 13]. The existing approaches of paper based/ other automated systems are much dependent on the manual judgment systems. The web based information provides the opportunity to share the information to several intended users within the construction site and beyond. The use of mobile devices in construction sites have been observed for several benefits: inspection systems, data acquisition systems, surveys, information sharing and supply chain management. [14, 15, 16].

“Mobile GIS is the expansion of GIS from the office into the field. Wireless connectivity, geoservices, and Web mapping applications enable communication with and coordination of service technicians and contractors in the field. This increases efficiency and provides access to previously unavailable data for users who may have limited GIS experience” [17, 18]. Another tool used for geographic investigation is the use of geospatial video which uses the combination of two approaches of geographic investigations: GPS and video. The technology has opened up the opportunity for field data collection of spatiotemporal phenomenon [19]. The automated solutions developed for construction quality management system using various technologies have significantly improved the communication efficiency and reporting mechanisms to enable construction quality managers to systematically collect, accumulate and mange useful data related to project milestones [20]. With the advent of integrated of GIS, internet, and mobile computing, the technology has the potential for adoption in areas of construction quality management system during

any construction phases [21, 22]. ArcGIS Mobile technology follows the surveyor to the field and supports individual data needs. Mobile GIS provides mapping, GIS, and GPS integration to field users via mobile devices. Wireless connectivity, geoservices, and Web mapping applications allow the field crew to complete database transactions in near real time. Surveyors rely on ArcGIS Mobile to collect spatial information within a GIS while in the field to improve the quality and accuracy of the data" [23].

Case Study: Sabah Al- Salem University City – Kuwait University

This section provides details about the mobile GIS application tool for performing quality inspections for a construction project. The following section details out the case study of Sabah Al-Salem University, Kuwait.

Background

Sabah Al Salem University City – Kuwait University project is one of the most ambitious campus development projects in the world. This gigantic University City will emerge over the next few years of construction as part of infrastructure development initiative [24]. The visionaries of Kuwait University decided to include GIS during the conceptualization stage, as recognized a need for using geographic information system (GIS) for monitoring and reporting construction progress at Sabah Al-Salem University City project. Kuwait University GIS System developed on geospatial concepts support the entire construction lifecycle, and later to use if for operating the huge New University City at Shadadiyah Campus. In order for the plan to be successful, the needs of both project management and construction management consultant (Turner Projacs) and Kuwait University were to be incorporated in the details of design and construction of the project. Those needs included using GIS to bring value to each stage of the facility life cycle from site analytics and design to planning and construction as well as operations, security and sustainability. This ambitious vision posed many challenges, and represented a level of enterprise data development unmatched in the world today [24]. Sabah Al Salem University City is currently under construction, the huge investment made by the university on GIS infrastructure is being harness to develop smart applications to support decision makers in reducing time, effort, and cost; using applications such as Mobile Application for Construction Quality Manager and Surveyors.

Existing system / problem

On a mega construction project, there is typically more than one contractor; the number of contractors in a normal mega construction may go to 10 – 30 in numbers. On such mega projects the conventional methods of caring out the quality survey, logging the survey information and ensuring that the information reaches to decision makers is a challenge, it is very essential for decisions makes to know the ground realities in order to ensure that the construction is done as per the design specification. The old methods used by quality surveyors using a hard copy form for collecting information and then using the same form for reporting to the construction manager and client was time consuming and had the possibility of information being manipulated or misunderstood. Typically, entire process of collecting quality survey reports and sending it to the concerned managers took a week's time or even more, and more over there was no workflow in place for reporting the trends of the quality survey and reporting was on judgments of the quality managers. The requirement to capture and report quality survey observations in near real time evoked to research on a mechanism for recording the observations using smart phone and existing GIS infrastructure without any development on smart phone and mobile devices.

The innovation: mobile GIS for quality inspection

Mobile GIS Application for Quality Managers and Surveyors designed on server oriented architecture fully leverages the Existing GIS Infrastructure and ArcGIS Online. The mobile GIS application allows the quality surveyors to record and save observation at the inspection site using ArcGIS for Smartphone for iOS and Android. The picture below shows high-level workflow for carrying out quality survey using mobile GIS application.

Fig. 1: Workflow for high-level quality survey using mobile GIS. Source: Sabah Al Salem University City Project – Kuwait University.

This entire process is performed though a defined workflow and the information collected during the survey is stored in a central database server. Managers and other coworkers can view this information while the surveyor is still on the field or back on his way to office. The managers can use ArcGIS online, ArcGIS Desktop for viewing the observations made by individual surveyor. The steps involved in the entire process are given below:

Step 1: The application allows users to mark the geographic location of the incident based on the inbuilt GPS and associated information such building name, floor and space for conducting the survey. Thematic map service published from ArcGIS Server renders and displays the building information to the mobile GIS application. The surveyor can select from the predefined domain values to identify the building name, floor and space under survey for reporting.

Step 2: The surveyor can further submit his survey observation using the predefined form and attaches a picture of the irregularities using the smartphone in built camera. The information collected by the surveyor is uploads to the central geodatabase server.

Step 3: The information uploaded by the surveyor is modified/managed to filter out the required for reporting.

Step 4: The filtered information by the quality manager could be use by different stakeholders for reporting, and analyzing problem area for each contractor.

Step 5: The information collected by the quality surveyor and manager can be achieved and can be used a supporting document when needed.

Fig. 2: ArcGIS Online and ArcGIS for iOS. Source: Esri ArcGIS.com website and Sabah Al Salem University City Project – Kuwait University.

System architecture

The mobile GIS application is developed using Esri technology. The system architecture is three tired consisting of database tier, application tier and end user applications. Fig. 3 below illustrates the system architecture:

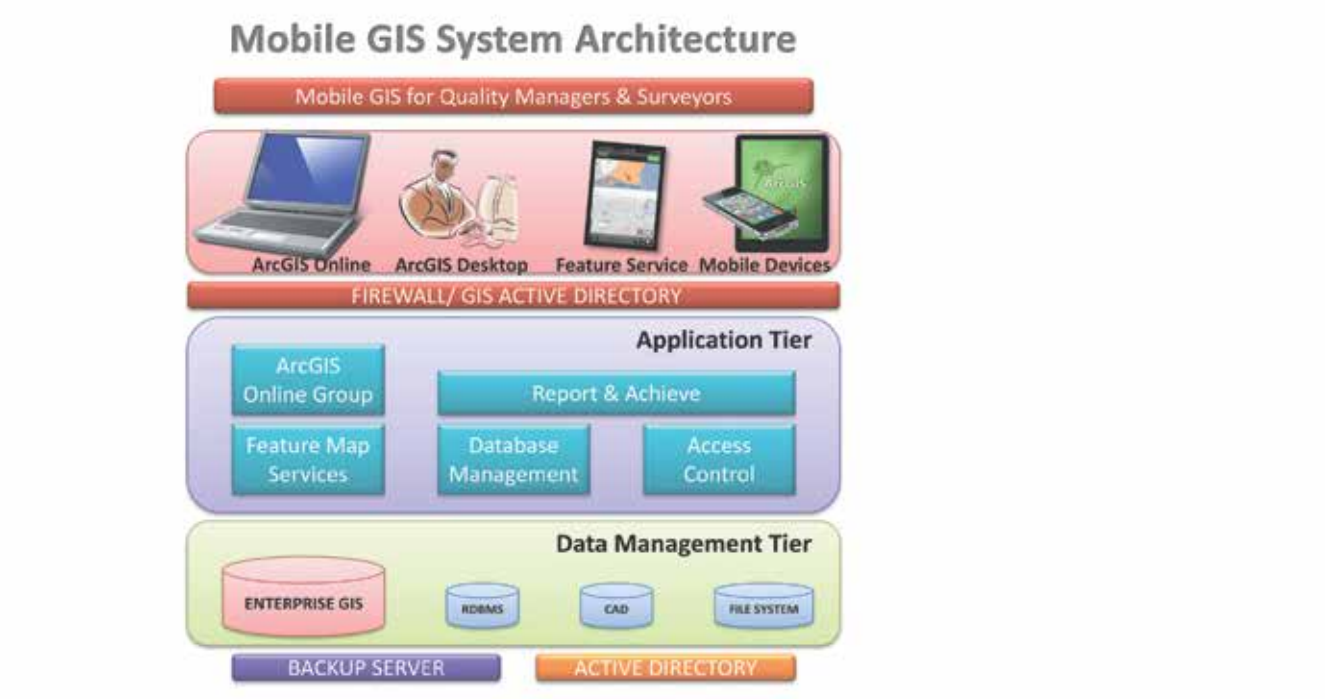

Fig. 3: Mobile GIS system architecture. Source: Sabah Al Salem University City Project – Kuwait University.

Database tier: The database tier comprises of the GIS database. ArcGIS Server for Oracle and Oracle 11g is used to store the GIS data and information collected by the mobile GIS application. The GIS database consists of master plan, building floor plans, user information etc. that is served to the mobile GIS application though feature service.

Applications tier: The application tier consists of ArcGIS Desktop, ArcGIS Server for authoring the maps and published them to the mobile users though ArcGIS Online. The user of this tier also performs analysis of the data continuously fed by the mobile users and generates custom reports for decision makers.

End use application: The end user application consists of ArcGIS for iOS and Android Smartphone and Map Services. This application allows the mobile users to access, add, edit and upload information collected during the quality survey.

Other GIS mobile solutions

There are other similar applications available for different palm-top devices in the market. The performance of these applications depends on GIS software, hardware, connectivity, and functionalities. It is difficult to provide a comparison with other similar products, as there are number of factors which differs from each other like: platform/operating system; time response system/speed, feature support (vector and raster support), processors, and among others. The following matrix provides selected details of functionalities among similar products.

Brand	**Esri**	**Esri**	**Esri**	**Intergraph**	**Javad GNSS**	**Leica Geosystems**
System	ArcPad	ArcGIS for iOS	ArcGIS for Windows Phone 7	Field automation	GISmore	Zeno 15
Date of introduction	2010 (ArcPad 10)	2010	2010	2007	2009	2010
Main design elements: hardware/software/both	software	software	software	software	both	both
GIS Software						
Name of GIS package	ArcPad	ArcGIS for iOS	ArcGIS for Windows Phone 7	Field Automation	Tracy	Zeno Field and Zeno Office
Zooming [Y/N]; Panning [Y/N]; Map rotation [Y/N]	Y; Y; Y	Y; Y; N	Y; Y; N	Y; Y; N	Y; Y; Y	Y; Y; Y
Editing: points [Y/N]; lines[Y/N]; polygons; [Y/N]; Attributes [Y/N]	Y; Y; Y; Y	Y; Y; Y; Y	Y; Y; Y; Y	Y; Y; Y; Y	Y; Y; Y; Y	Y; Y; Y; Y
Query [Y/N]	Y	Y	Y	Y	N	Y
Sketching notes on map [Y/N]	Y	Y	Y	Y	N	Y
Display of external data, e.g. photos [Y/N]	Y	Y	Y	Y	N/A	Y
Measurements: length [Y/N]; area [Y/N]	Y; Y	Y; Y	Y; Y	Y; Y	Y; Y	Y; Y
Hardware support						
Store data on hard disk [Y/N]	Y	Y	Y	Y	Y	Y
Built-in GPS support [Y/N]	Y	Y	Y	Y	Y (SD, CF)	Y (SD, CF)
Built-in camera support [Y/N]	Y	Y	Y	Y	N	Y
Operating system(s)	iOS, Android	Windows Mobile 6.1	Windows Mobile 6.1	Windows	Windows Mobile 6.1	Win CE 6.0
Connectivity						
User interface (touch, stylus pen, keys, etc)	Y, touch, keys	Y, stylus, keys	Y, stylus, keys	Y	touch, keys	Y, stylus, keys
Wireless data transfer	Y	Y	Y	N	2 Mbps	Y
GPRS	Y	Y	Y	Y	Y	Y
Remote server: download [Y/N]; upload [Y/N]	Y; Y	Y; Y	Y; Y	Y; Y	Y; Y	Y; Y

Table 1: Functionality matrix – similar mobile GIS solutions (Y-Yes; N- No; N/A: Not applicable). Source: Compiled from (http://en.wikipedia.org/wiki/Comparison_of_geographic_information_systems_software) [25].

There are steps that the GIS experts have to perform before the quality surveyors can use the application for quality survey. There steps are call background preparations and are elaborated more is the coming paragraph.

Background preparation

The background preparations for the Mobile GIS Application for Quality Managers and Surveyors involve modeling the GIS data to meets the requirements of the task performed by the managers and surveyors. Appropriate GIS data is used to Author Map that shall server for publishing map resources. While publishing the resources "feature access" is enables as capability of the published features service. The next step is to add the feature service as content of your ArcGIS Online using global account and create a Web map. Once the Web map is created it is shared to group for surveyors and managers. The managers and surveyors should have an account on ArcGIS Online or they can create a new one and add them self to the group in order to access the featured maps content.

Fig. 4: Authoring and publishing featured contents. Source: Sabah Al Salem University City Project – Kuwait University.

The surveyors can download the Esri ArcGIS for iOS or Android from Apple store on their Smartphone. This application allows viewing feature service from the content of ArcGIS Online and provides tools to perform editing or adding new information based on the information collected by the surveyor during inspection to the GIS data. The information uploaded by the surveyors saved and shared to the managers in near real time. The managers can view this information using ArcGIS Online web map or ArcGIS Desktop.

Traditional methods of quality survey vs mobile GIS application

The following table provides the comparison between the traditional methods of quality survey and mobile GIS application:

Traditional method	**Mobile GIS application**
Pre survey preparation	
The surveyor requires to print survey forms, take a printed copy of the master plan, site plan, shop drawings etc.	The mobile GIS application is installed and relevant map service is added to the application for use of the surveyor/ end users.
Carry stationery, camera, phone, GPS and other accessories for recording and communication.	Mobile application has easy to use drop down menu to fill in the form and contains inbuilt phone, camera and GPS receiver.

On site survey	
Carries a printed hardcopy form, master plan, shop drawing and stationary to complete the survey on site.	Quality surveyor carries an ArcGIS for iOS or Android application preloaded on a smartphone device with access to the preconfigured Map Service displaying master plan, shop drawing and editable feature service for recording information.
Requires a mobile phone to communicate with supervisors and contractor while carrying out the survey at various locations of the site.	The smartphone containing the mobile application can be used to make call to supervisors and contractors.
Requires carrying a camera or is accompanied by documentation experts.	The smartphone contains camera and can be used to click picture and attach to the observations.
Location is not captured as space identification like plot number, building id, floor number etc.	Location is captured as spatial data with other information such as plot number, building id, floor number etc.
In case of landscape survey revisiting to the place of survey is based on assumption.	The application allows the user to revisit the same location using the inbuilt GPS in the smartphone and the stored location without missing the locations on defined tracks.
Post survey preparation	
The information captured by the surveyor during the onsite survey is stored in Excel spread sheets and as hardcopy.	The information captured using mobile application stores the information in oracle database soon after the information is saved by the surveyor.
The surveyor analyzes and submits the report to the client.	The client can view uploaded information and photos soon after the survey is completed and information uploaded by the surveyor in real time.
Once the survey is recorded and stored, the filled forms and excel sheets are stored in DVD to store the information. A log for the DVD and forms is maintained and forwarded various relevant sections.	The information is stored in a database like Oracle and does not require extra effort to log or store as DVDs. The same information can be used and retrieved multiple numbers of times for different purposes and analysis.
The findings are presented either by graphs or figures in tabular format.	The findings are presented on maps with graphs and tables which is more informative.

Table 2: Comparison between the traditional methods of quality survey and mobile GIS application (Source: Authors Analysis, 2012).

Advantages and adoption

The advantage of using Mobile GIS Application for Quality Managers and Surveyors are as follows:

- *No paper work:* The application uses state of art technology such as smartphone to collect, save and upload the observations made during the quality survey with minimal or no use of paper form for collect, storing quality survey data.
- *Time is money:* Quality surveyors spent hours on collecting the information on paper forms at first, and then storing this information on excel sheets for storing and analysis. The mobile GIS application does this on the go, surveyor after recording the observation submits for upload to the central database server. The information is available to the manager and decision makers immediately with no delays or back office processing.
- *Saves money:* It reduces the amount of human resources required to perform the job as the back office process of the survey data is performed simultaneously.
- *ArcGIS Online:* Esri's ArcGIS Online is a free tool to share and manage GIS data using Map Services and Web maps. The mobile GIS use ArcGIS for Online to share and access Map Services and Web Maps with no development on iOS or Android smartphones.
- *Easy pre-configured feature service:* Surveyors are granted access to featured group on ArcGIS Online thus allowing them to view and access the contents of the group on iPhone/ iPad or Samsung Galaxy Note.
- *Easy-to-use application:* The quality surveyor uses the application to carry out survey for metal works, doors and windows, thermal and moisture, site work, finishing, concrete work, masonry work, word work, mechanical work etc. They have option to draw on the map, add comments, select from predefined drop down for domain values and attach picture for the inbuilt camera. Once the incident location on the map is drawn, one can accept by clicking on the accept button.

Conclusion

Construction quality managers and surveyors can adopt the mobile GIS as a convenient tool to collect, manage and share information pertaining to quality inspection during different phase of construction. The information is collected though a well-defined procedure and workflows. The information is stored and shared in near real time saving time, effort and money as compared to the conventional method of quality surveys. The parties/multiple stakeholders involved in the project are well informed about the phases as well as compliance of quality systems. The tool enhances the reduction of construction delays by quality compliance at various stages, as well as coordinate efficient project management systems.

The approach using ArcGIS Online and ArcGIS for iOS and Android Smartphone is highly robust, secure and affordable or almost with no additional cost. Integration of the available free software resources by Esri i.e. ArcGIS for Smartphone and ArcGIS online with organization's existing GIS infrastructure investment is highly recommendable solution for collecting, storing and sharing qualitative and quantities information in short and long-term development construction projects.

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