EVALUATION OF DIGITAL PHOTOGRAMMETRY AND 3D CAD MODELLING APPLICATIONS IN CONSTRUCTION MANAGEMENT

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The objective of the paper is to report ongoing research work aimed at developing computer based model that will enable the semi-automatic measurement of construction work in progress. CAD programs are increasingly being used to produce more realistic 3D models of the designed buildings, long before the start of construction on site. These 3D models are usually applied for presentation and visualisation purposes. However, there is greater potential for making use of these 3D CAD models for the development of an automated data capture system. A great deal of time is spent to collect information from the site using conventional measurement techniques. These measurements help project managers to calculate interim payments, monitor progress, analyse productivity and undertake Earned Value Analyses. Recent developments in digital photography and computerised photogrammetry techniques will make it possible to acquire, record and process construction information more rapidly. This paper discusses the potential application of such system and presents a conceptual framework for semi-automated progress measurement system. The paper then outlines the development of the methodology to be used for the automatic comparison of the "data acquired from site" and "data from the existing design documents".

Keywords: construction automation, Photogrammetry, CAD, Progress measurement.

INTRODUCTION

Data Collection Problem in Construction Sites:

It is not too uncommon that shortly after the construction professionals agree on the contractual terms, and even before the construction work begins, problems relating to planning, organising and scheduling emerge. Accuracy in planning, organising, and scheduling is an important way of achieving successful construction management. Projects are widely seen (by clients) as unpredictable in terms of delivery on time, within budget and to the standards of quality expected (Egan, 1998). Although tremendous effort is spent on monitoring the work on the construction site, construction industry is still failing to satisfy more than a third of major clients (Egan, 1998).

Traditionally, obtaining and monitoring this kind of data can be done by going to the site periodically and measuring the progress by conventional surveying techniques. Since the amount of works and quantities to be measured are very large, these periodical surveying activities are often based on visual inspections and subjective judgement.

The results of this problem can be catastrophic; inaccuracies in interim payments, endless and potentially costly conflicts, and lack of quality in financial planning,

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errors in financial reporting with the consequent cost and schedule overruns, and overall client dissatisfaction may be experienced. Clients are concerned about overmeasurement and paying for work that is yet to be carried out. Contractors on the other hand tend to do their best to be paid promptly, in order to maintain reasonable working capital requirement. These conflicts of interests between clients and contractors exacerbate distrust between project team and often cause dispute.
This research introduces a novel technique to greatly reduce the efforts required to monitor project progress. This technique will make it possible to accurately assess the amount of progress on site using semi-automatic computation of digital images and photogrammetry knowledge.

EVA, an Existing Approach to Address This Problem:

Typically, the logical way of monitoring the progress on the construction site is periodically comparing the actual work carried out on site with what was planned during the design and schedule stage.

Earned Value Analysis (EVA) is a common way that conducts these comparisons. What EVA does is basically monitoring the schedule variance (SV) and cost variance (CV) during the construction progress. These variances are calculated as follows;

SV= BCWP - BCWS

CV= BCWP - ACWP

Where BCWP is the Budgeted Cost of Works Performed,

ACWP is Actual Cost of Works Performed and,

BCWS is Budgeted Cost of Works Scheduled is the planned cost of the work scheduled to the milestone date.

SV and CV are very useful parameters in monitoring cost and schedule divergences. When SV is less than zero the work is behind schedule, whilst when the CV is less than zero, the project suffers a cost overrun. Zero cost and schedule variance means the project is on cost and budget. If SV and CV are both larger than zero, it is deemed to be perfect scenario.

Whilst SV and CV seem to be easy to calculate, the real difficulty is when calculating ACWP and BCWP. BCWS can be calculated from the design and the schedule information database, only really accurate ways of calculating ACWP and BCWP are to measure the work on the construction site, collect additional data from the accountancy and human resource department records. The difficulties associated in extracting this information from more complicated and big projects were mentioned early in this paper. One of the solutions to this problem is to automate the process of progress measurement using Information Technology (IT).

Current Status of Computer Integrated Construction:

In the UK economy, ten percent of Gross Domestic Product is generated by construction industry. Information Technology is recognised as one way of improving the industry’s efficiency. To achieve this there has been more than1500 new software introduced for use of construction professionals (Construction Industry Computing Association, (CICA), 1997).

These software solutions tend to address one individual aspect of design or building progress automation. For example AutoCAD facilitates the drawing of projects and 3D models however it doesn’t directly help the project management progress, while MS Project aid project managing but not 3D modelling. This situation suggests that achieving the real integration of different software solutions is still a challenge that needs to be resolved by industry and academia.

In academia, there have been a growing number of funded research projects on computer integrated construction being undertaken across Europe. This includes “ICON (Aouad et al., 1994), SPACE (Alshawi et al., 1996), COMMIT (Razgui et al.,1996), IDAC-2 (Powell, 1995), COMBINE (Augenbroe, 1993; Dubouis et al., 1995), CIMSTEEL (Watson and Crowley, 1995), ATLAS (Van Nederveen, 1994), COMBI (Ammerman, 1994), RATAS (Bjork, 1998), IRMA (Luiten, 1993), Fenves et al. (1990), Froese and Paulson (1994), Kartam (1994)” (Sighted in Aouad and Sun 1999). The common point between these studies is that they all attempt to integrate different design and construction management processes using IT. This will allow the different project team members to work concurrently on the same project.

3D CAD MODELS AND PHOTOGRAMMETRY: PROPOSED MODEL

In the construction industry, the typical use for a 3D model is the visualisation of the building design for demonstration purposes to the client. The majority of the industry’s clients are inexperienced in building design and construction processes. 3D building models are produced to show the client how their building will look like if they decided to procure the proposed project.

Provided that the 3D model of the building progress is generated as construction progresses, this data can be used for the calculation of interim payments, schedule control and assessment, conflict management or avoidance purposes. For example if the second Friday of every month is the contractual pay day of a contractor, and if the 3D data of building at these points of time are known, this information can be used for the automatic calculations of interim payments. Furthermore, if the actual progress 3D data and scheduled progress’s cost data are known at the same time, this can be used for automated Earned Value Analysis calculations. Given that this data is accurately extracted and recorded, this database can be an invaluable asset for avoiding or resolving disagreements between the project team.

Figure 1 explains how the proposed process works. In the proposed model, the 3D model of the building is produced, at the same time library of the building components, to be used in the building, being designed. This library is basically the full list of building components that constitute the building.

When the actual construction work begins, periodically captured images of the progress will be transferred to the proposed model operator and the operator generates the up to date 3D model of construction by selecting and inserting the pre-generated library objects in to the CAD space.

This 3D model contains the needed measurements information of the production and can be used to extract all the quantitative information relating to the current status of construction progress.

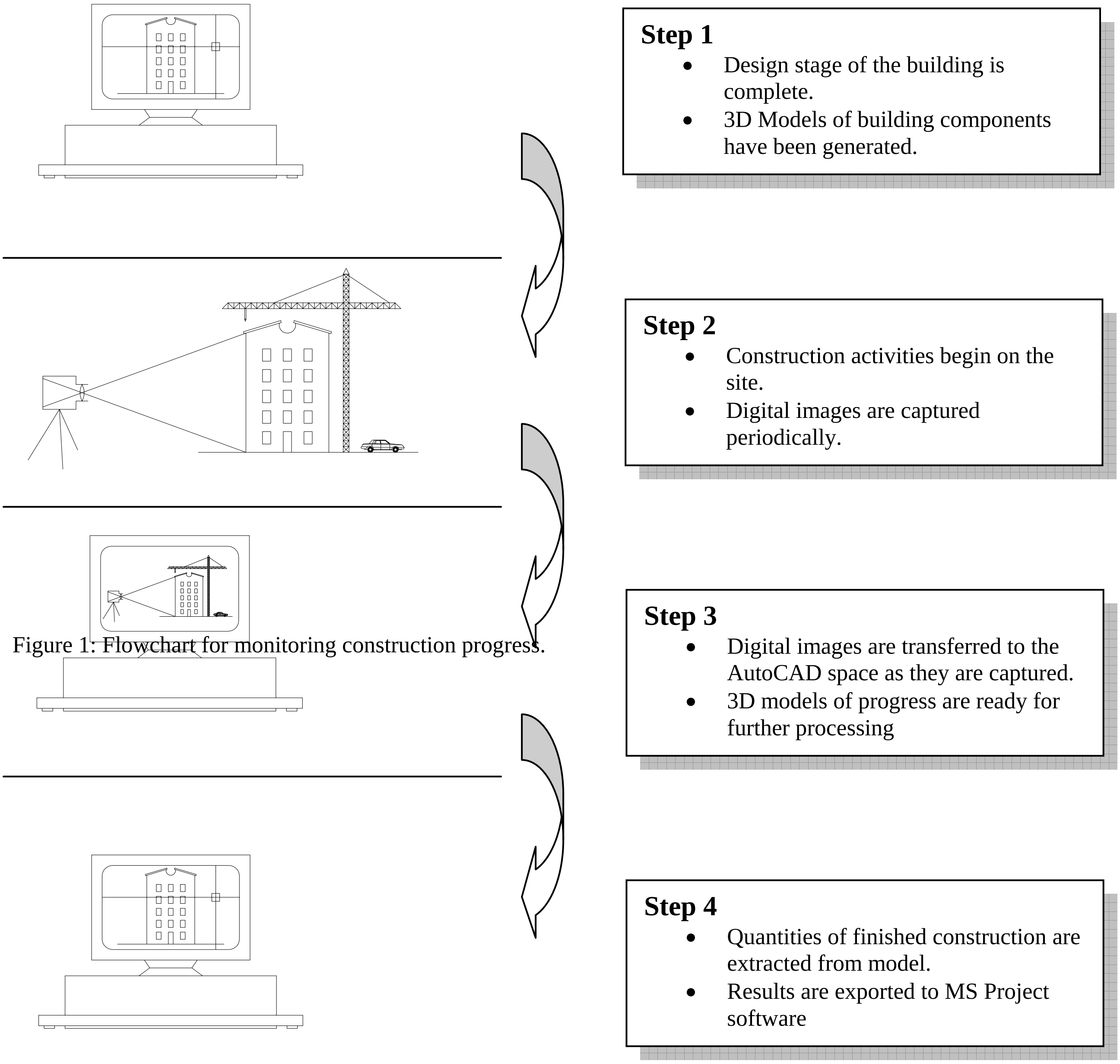

Figure 1: Flowchart for monitoring construction progress.

The proposed model is expected to save a great deal of time when compared with conventional progress monitoring techniques. Digital cameras can be attached to the construction site to make it possible to monitor construction progress from head office of the construction company or clients headquarters via internet.

Potentially one of the biggest improvements is expected at the productivity. Since the actual progress of the construction can be quickly and accurately obtained at any point in time, quality of the information will be improved. Also as the use of resources and the outcomes of the expenditure can be monitored more rapidly, much higher productivity levels can be achieved than is traditionally possible.

In this research, photogrammetry knowledge is employed to generate semi-automatic data extraction. Since the complexity of building design and process makes it practically unfeasible to generate 3D models completely using photogrammetry, a partial employment of photogrammetric knowledge together with a pre-generated building components library were selected to be used in this proposed model. Although there have been attempts at creating a fully automatic system for recognition of objects directly from site images, it has been noted that the current status of technology doesn't allow the use of such systems in complex and highly occluded site conditions. (Trucco and Kaka 2004)

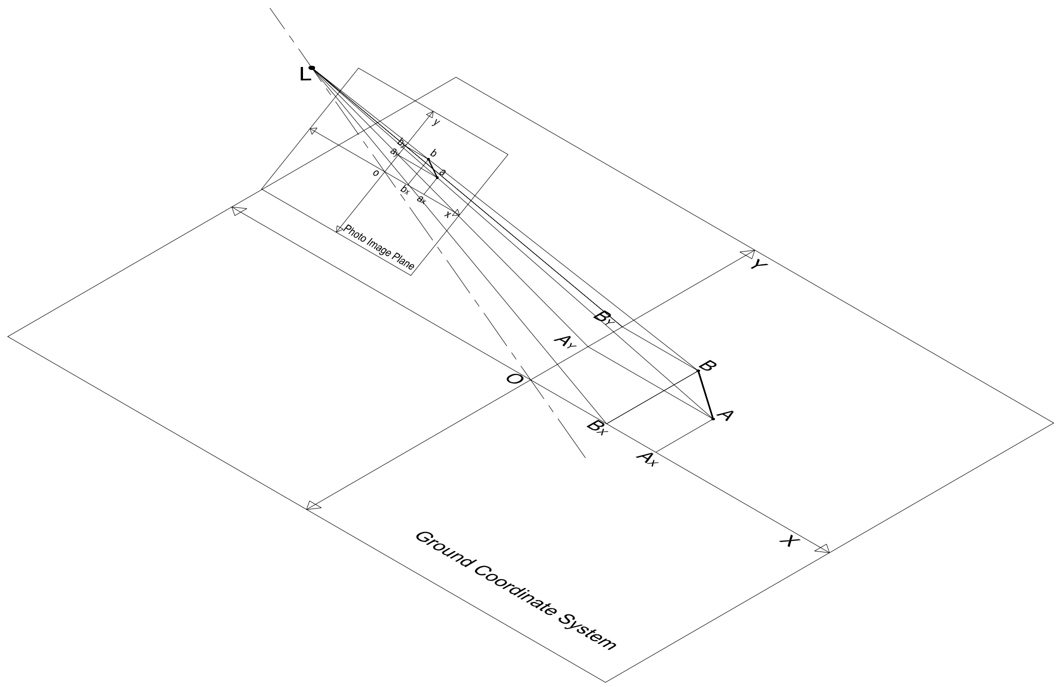

Figure 2: Projection of an item (AB) to the photosensitive surface (ab).

Figure 2 shows how an oblique photo projection of a line (AB) appears on a photosensitive surface (ab). Dashed line passing through the origins of the paper and a ground coordinate system represents the optic axis of the camera. Because of the angle between the optic axis and the ground coordinate system, this image is called an oblique photo. A straight angle between the optic axis and the ground system is defined a vertical photo where the parallel optic axis to the ground is called horizontal. Although there are seldom cases of perfect vertical or horizontal photos, in construction sites, photographs are generally from oblique type. Since the size of AB is known from the design documentation, provided that the focal distance of the camera (Lo) is known, it is possible to calculate the approximate position and direction of the camera in AutoCAD space, relatively to a building component just by using the dimensions measured from photos and photogrammetry knowledge.
In practice, that means it is possible to generate a 3D model of the building components that are seen on a photograph, by inserting additional building components to the drawing space as they are seen on the image. At the current status of the research, this is performed manually; however it is possible to calculate relative camera position automatically in AutoCAD using AutoLisp applications.
As a case study, the authors have generated an example library of building units for the construction project of Standard Life Headquarters in Edinburgh. The summary of these units are shown in Figure 3. Each building component was modelled from the original design. Lines were added to the components to help the operator on how the next building component will be attached to the previous ones. Components from the

similar production activities were grouped in the same folders so that it becomes easy to access them when they are needed.

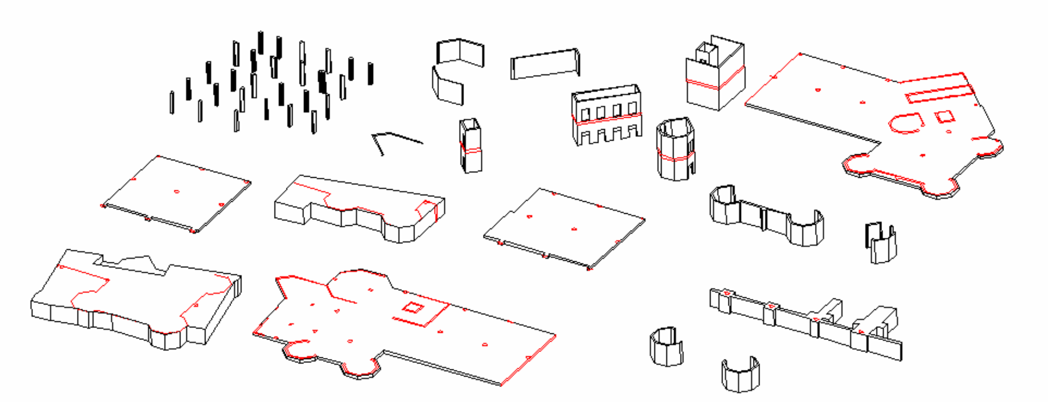

Figure 3: Full list of building components that has been used for the case study.

During the case study, as the new photos were captured and delivered to the operator, finished building units appearing on the new coming photos were visually identified and matching 3D objects from the library added to the CAD space. For instance, in the first step, foundation concrete was poured, and was, photographed in the first site visit. As soon as the photos arrived to the operator, a new drawing file was created and one of the foundation components that are seen on the picture is inserted into the drawing. Now that the image and the 3D model of the component are both simultaneously visible to the operator, he or she could create the same vision of the image by adding in all the components that is seen in the image into the 3D model, once the camera position in the AutoCAD space is found using photogrammetry applications. Each image/ 3D model pair can be saved under different dates of the project progress and any necessary calculations can then be extracted from 3D models.

One of the obvious problems associated with the proposed model is the generation of the comprehensive building components library. Currently it is assumed that 3D models are generated at the design stage for demonstration and communication purposes. Therefore rather then generating this library of building components from scratch, system operator would extract them from the original 3D model. The only additional effort that the system causes is the generation of block libraries from the solid CAD objects as they are being designed.

Therefore, the proposed system can save a great deal of time especially in modular construction or various prefabrication applications of the industry once the standard modules are generated as component library items.

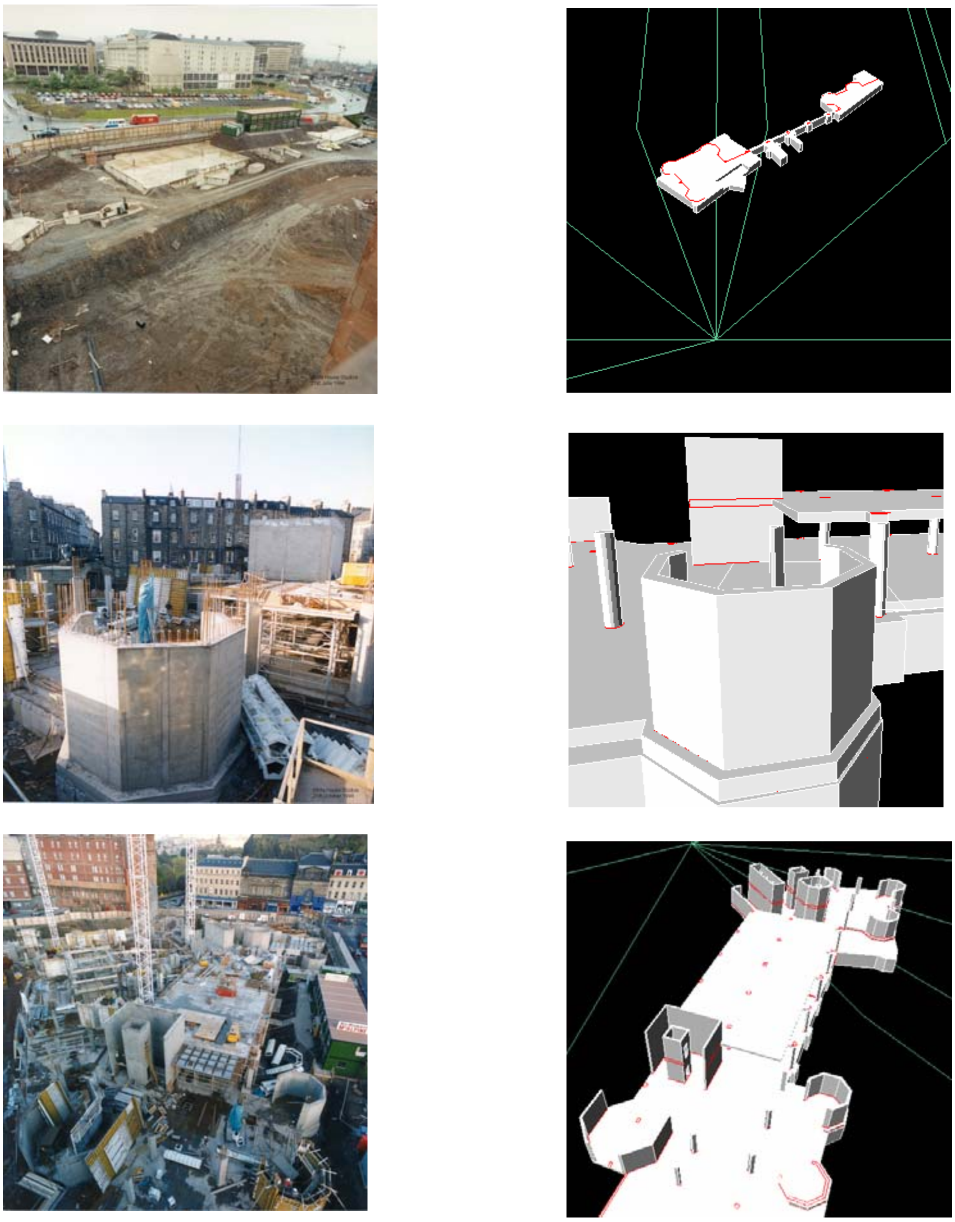

Figure 4: Generation of 3D construction model as the site work progresses.
Source of Photographs: Standard Life House Building Case Study

Another problem of the proposed system is the lack of details in the evolving 3D CAD models. Indeed, at the current level of research, it seems only theoretically possible to generate later construction progress results in the 3D model. For example after generating the 3D models of walls, covering them with plaster and then painting the plastered walls with three (sometimes less or more) layers of synthetic paint in CAD space is practically unfeasible, electrical, heating or cooling systems are very difficult to capture from the incoming images, given that those elements may be hidden.
At the current level of the research, results of such a study are only able to generate 3D models that are showing different early levels of construction in progress. Quantities of the building component types that are seen in the photos can be automatically counted and only simple quantity surveying operations can be done. In fact, it is possible to extract more information from such models if the library units were produced containing additional information about the time, cost, quality and quantity kind of parameters of building design.

CONCLUSIONS

In the near future, it will be possible to create 3D models of construction progress directly from photos periodically taken during construction. These models can then be used to make automatic measurements and comparisons with expected progress on the construction site.

Although the current stage of study doesn't allow the full automation of this process, it demonstrated that a semi-automatic construction progress monitoring system is feasible and can save a great deal of time and effort. This can potentially lead to an improvement in productivity, reduction in conflict. Better information flow can reinforce the trust between project team members.

This paper also argued that this technique may be further developed to allow for the full automatic recognition of building progress from captured digital images. The following stage of the research aims to achieve;

- More user friendly interface to operate this technique via a sophisticated Lisp application,
- More comprehensive model generation including window frames, walls, floors and ground or ceilings with greater level of detail then achieved so far,
- Development of an algorithm for image recognition,
- Establishing a link between AutoCAD and Microsoft Project application in order to automatically compare progress with schedule,

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