INCORPORATING THE PROGRESS MEASUREMENT DIMENSION TO AN INTEGRATED BUILDING INFORMATION SYSTEM: A RESEARCH FRAMEWORK

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ABSTRACT: The accurate measurement of work in progress on construction sites is important for calculating interim payments as well as for business and project management functions like schedule and cost control. Currently it still takes place using traditional building surveying techniques and visual inspections. However the usually monthly measurements are not frequent and accurate enough, incorporating judgement and shortcuts.

An EPSRC funded collaborative research is looking at supporting the measurement of work in progress on construction sites using computer vision technology within the context of an integrated building information system. In particular, the research aims to develop a system that automatically measures the progress of construction from digital images captured on site, analyses the progress against the original schedule in order to identify any potential delays and calculates interim payments. The paper presents the initial findings from the research and a development framework for the proposed system.

KEYWORDS: progress measurement, integrated building information system, computer vision.

1 INTRODUCTION

Site managers spend a significant amount of time measuring, recording and analysing the progress of work on construction sites, as the accurate measurement of this progress is essential for many business and project management functions such as cost and schedule control, financial reporting, claims, and productivity measurement. In order for these functions to be reliable and effective, regular and accurate measurement is required.

Many construction companies consider the measurement of the work in progress to be one of the most challenging problems faced by project management (Saidi et al. 2003). The measurement of work in progress currently takes place using traditional building surveying techniques and visual inspections (Navon and Sacks 2007). However, the usually monthly measurements are not frequent enough and incorporate judgement and shortcuts, giving rise to under or over-measuring and inaccurate cost/progress control data. In addition, tasks such as cost and schedule control have to be manually performed by cross-examining and updating several independently maintained documents, a time consuming and error-prone task. In short, the lack of real-time progress information handicaps the managers' ability to monitor schedule, cost and other performance indicators therefore reduces their ability to manage the variability inherent in construction operations.

The use of advanced measurement and sensing technologies provides the opportunity for automatically measuring the work in progress on construction sites, as a number of studies have indicated (Wu and Kim, 2004; Oh et al., 2004). One promising technology in particular is computer vision (Trucco and Kaka, 2004). Computer vision is concerned with modelling and replicating human vision using computer software and hardware. It is a discipline that studies how to reconstruct, interpret and understand a 3D scene from its 2D images (Fisher et al. 2005).

The use of digital cameras in recording the progress of work on construction sites for archival purposes is fast becoming a common practice (Brilakis et al. 2006). The use of computer vision provides the opportunity for extending this use by automatically capturing the work in progress and providing real-time measurement information. In particular, the use of computer vision provides the opportunity for machine interpreting the digital images and measuring the progress of construction. Within the context of an integrated building information system, this progress can be used along with design, cost and schedule information to measure the work in progress (in terms of the completed activities in the schedule), identify delays and calculate interim payments.

An EPSRC funded project, undertaken by the Heriot-Watt University and the University of Salford, aims to examine such use of computer vision and integrated information technology in supporting the project management task. The work at Heriot-Watt in particular aims to examine the feasibility of using computer vision to capture the progress of construction from digital cameras installed on site (Lukins et al., 2007). The work at Salford aims to examine the feasibility of using the captured construction progress within the context of an integrated building information system to measure the work in progress, identify delays and calculate interim payments. The focus of the research is limited to the superstructure of a building.

The paper presents the initial findings from the ongoing project. Firstly, the challenges in integrating design, cost and schedule information are examined. Integrating this information is important in translating the construction progress to the work in progress and in calculating interim payments. A semi-automated approach for creating a Work Breakdown Structure (WBS) that assists the integration task is described. Secondly, the paper discusses the available methods for measuring the work in progress on construction sites and calculating interim payments. Thirdly, an architecture for the proposed system is outlined and several technical approaches in the development of the system are discussed. Finally, the paper concludes with some findings and thoughts for future research in the area.

2 MEASURING THE ON-SITE WORKING PROGRESS, INTERIM PAYMENT AND PRODUCTIVITY

Construction control is about calculating variances between actual measured progress and cost on one hand and target schedules and budgets on the other to determine if operations are being performed as intended. To support this, the prototype system will need a function to measure the on-site work progress based on the input from computer vision module and compare with the planned schedule and budget.

By definition, "progress" means advancement to an improved or more developed state, or to a forward position. The degree of 'advancement' for a construction project can be determined in base on different performance criteria. It can be the completeness of a work package or cost. Also there are different approaches to measure working progresses, e.g. physical measurement, earned value and estimated percentage completion. Each approach has its strengths and weaknesses (Jung and Kang, 2007).

In the prototype, the percentage completion of construction activity will be used to calculate the work progress and interim payment due to its advantages. Partial completion measurements and calculations are easiest to perform for linear and continuous processes that produce a single output. Measuring work progress in the work package context can be accomplished by a variety of methods, with the objective of estimating the progress (% complete) of every control account, and then aggregating these % complete values to arrive at an overall estimate for the project's progress (Abudayyeh and Rasdorf, 1993). One method used for measuring work progress utilizes the units completed in a work package (Neil 1987, Riggs 1987). In this method, the percentage completion of a work package is estimated by the following formula:

% completion = actual units completed / total units budgeted

The cost of the building components could be calculated based on its percentage completion information in associated with the corresponding cost rate that is predefined. The sum of the cost of all the building components is the estimated interim payment. Percentage completion of activities are multiplied by the corresponding total quantities and divided by time taken to achieve level of progress will be produce the rate of progress per week, day or even hour.

As motioned earlier, the manual capturing and calculation of the working progress information are time consuming, expensive and error-prone. One promising technology for the automated data capturing is computer vision (Trucco and Kaka, 2004). However deriving information on structure from images is a hard problem, especially in cases where the data are incomplete and noisy such as from construction sites. The process of converting an unstructured point cloud that represents the local geometry into a consistent polygonal model often requires days or even weeks. A new approach, which is a model-based recognition, would effectively quicken the process. It is proposed to derive the "as-built" 3D structure with the help of the design phase output which are normally 3D "as-planned" models (Lukins et al., 2007). The 3D "as-planned" models play a role like a guide points where the computer should look at the images for new activity. It is therefore significantly reduce the processing time. An integrated building information could help the automated process by proving the 3D "as-planned" model and help the calculation of the working progress, interim payment and productivity rates.

3 INTEGRATION OF BUILDING INFORMATION: DESIGN, SCHEDULE, COST

The integrated building information system here refers a system that includes building design, schedule and cost information. Ideally the links between the information would be bi-directional. In this way not only cost and schedule could be developed from the original plan but also based on the percentage completion information of each building elements, it is possible to measure the progress on-site and interim payment. Therefore the establishment of the linkage will fundamentally impact the measurement of work progress in the later stages of the research.

The integration work has attracted the attention of some researchers and commercial companies in last two decades (Chau et al. 2005; Jung and Woo, 2004). However the current common software can only support part of the links (Figure 1). The main challenge for the integration is the compatibility problem caused by the different data structures of design, cost and the schedule items. Normally, digital construction design is drawn based on physical components e.g. slab, beam, column. The cost items are also specified in terms of the building components (Navon, 2007), while the schedule is specified in terms of work tasks. Consequently, the relationship between design, cost and schedule is complex: on the one hand a given schedule may relate to only one cost/design items; on the other hand, and more often, the resources of a cost item are related to several schedule/design items, and these are necessarily associated with more than one cost item. Thus the problem inherent in the integration is how to make the computer recognize these relationships and allocate the appropriate resources to the corresponding tasks. In most cases, the linking process is still manually done.

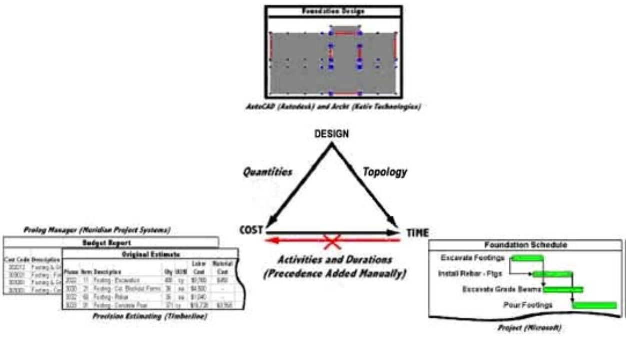


Figure 1. Building information integration (Modified from: Staub and Fischer, 1999).

This integration of design and schedule task requires establishing the relationships between CAD objects and schedule tasks. Some commercial 4D software e.g. 4D suite, JetStream provides functions to link the designed building components with construction tasks manually. There are also attempts to automate the process by generating a construction plan from 3D CAD model based on the topology of building components (Veries and Harink, 2007) although total automated process may still not be feasible (Bakis et al., 2007).

The project cost and schedule information are closely interrelated as they both refer to the use of project resources with the first from a cost and the second from a time perspective. This close interrelation between the cost estimate and project schedule calls for the integration of the cost and schedule information. This integration requires that cost performance and schedule performance share a WBS (Sears 1981, Rasdorf and Abudayyeh 1993, Carr 1993).

The WBS is defined as “a deliverable-oriented grouping of project elements, which organizes and defines the structure of the entire project. Each descending level represents and increasingly detailed definition of a project component” (PMI, 1996). The significance of WBS in project control are twofold; one is its classifying mechanism, which decomposes the project elements into a manageable level, and the other is its integrating mechanism, which provides a common perspective to relevant construction business functions (Jung and Woo 2004).

There are two main issues in developing a WBS, the decomposition criteria and the level of detail. There are quite some criteria used by the construction industry. In a recent survey, element type, work section, construction aids distinguished themselves as the most used criteria (Ibrahim et al. 2007). The divide of work packages often changes dramatically based on the criteria used. The difference makes it impossible for the development of a general linkage between schedule and cost information that can suit all projects. However the difficulty of integrating schedule and cost information stems primarily from the level of detail required for effective integration (Hendrickson 1998). Usually, a single project activity will involve numerous cost account categories. For example, an activity for the preparation of a foundation would involve labourers, cement workers, concrete forms, concrete, reinforcement, transportation of materials and other resources. Even a more disaggregated activity definition such as erection of foundation forms would involve numerous resources such as forms, nails, carpenters, labourers, and material transportation. Again, different cost accounts would normally be used to record these various resources. Similarly, numerous activities might involve expenses associated with particular cost accounts. For example, a particular material such as standard piping might be used in numerous different schedule activities. To integrate cost and schedule information, the disaggregated charges for specific activities and specific cost accounts must be the basis of analysis.

A straightforward means of relating time and cost information is to define individual work elements representing the resources in a particular cost category associated with a particular project activity. Work elements would represent an element in a two-dimensional matrix of activities and cost accounts. A numbering or identifying system for work elements would include both the relevant cost account and the associated activity. More generally, modern computerized databases can accommodate a flexible structure of data representation to support aggregation with respect to numerous different perspectives.

A flexible mechanism is developed for a semi-automatic creation of a WBS in this research (Figure 2). Different criteria will be used in a multilevel decomposition process in order to divide the designed construction model into detailed work packages. For example, at the tope level, the “work section” criterion is used. Then all the building components are grouped into different work package based on their “work section” attributes. If user feels the work package is too big then he can choose another criterion, for example “floor level”, to subdivide the existing work packages. The process can be repeated until users satisfied with the level of detail. Therefore human intervention is required to make sure that work packages are in an appropriate level of detail from user’s perspective. The created WBS forms the basis for the integration of design, cost and schedule information, work progress measurement, and calculation of the interim payment and productivity rate.

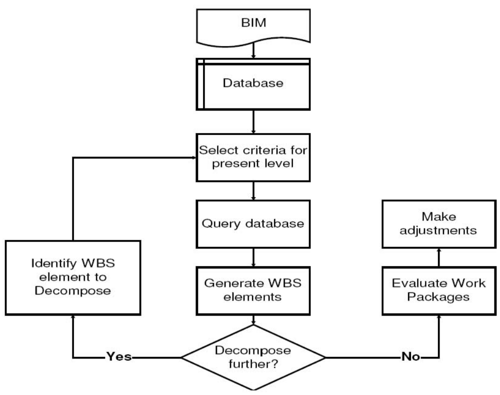


Figure 2. A flexible approach to generate WBS (Source: Ibrahim et al. 2007).

This semi-automatic WBS creation process requires that each building component has a one-to-one or many-to-one relationship with each chosen criteria. For example, a building component can only be categorised in one of the work sections. If a building component has two attributes in regard to one criterion, for example, one component belongs to two different work sections. This will cause conflict or duplication when the model is decomposed and problem in the later stages e.g. progress calculation, interim payment calculation. This is one of the limitations of the process and hopefully will be addressed in the future work.

4 THE ARCHITECTURE OF THE PROTOTYPE SYSTEM

The proposed prototype system (Figure 3) has three main processes/modules: data integration, computer vision, progress assessment and valuation. In the first stage, all the building information will be integrated and stored in a central database. It is in this stage that a WBS is created. As motioned earlier the WBS is used as a bass for the integration as well as for the later stage of progress measurement and the calculation of the interim payment.

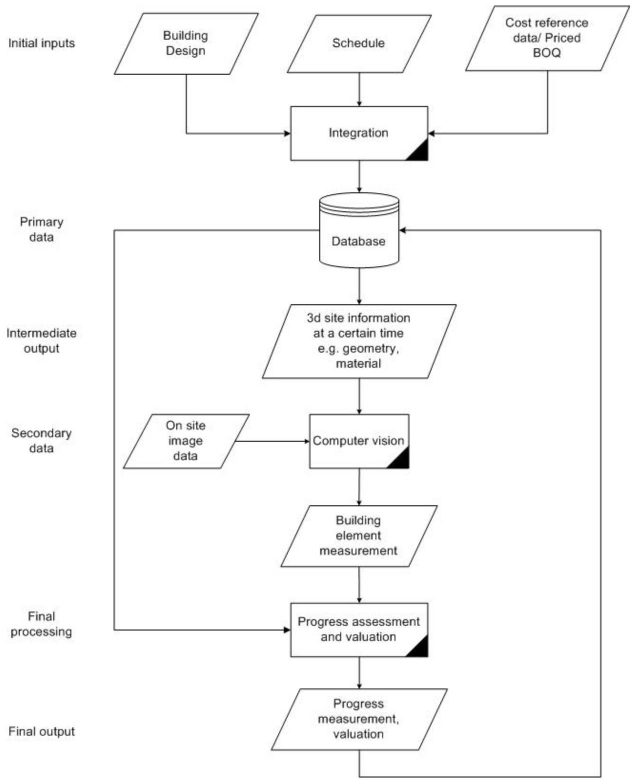
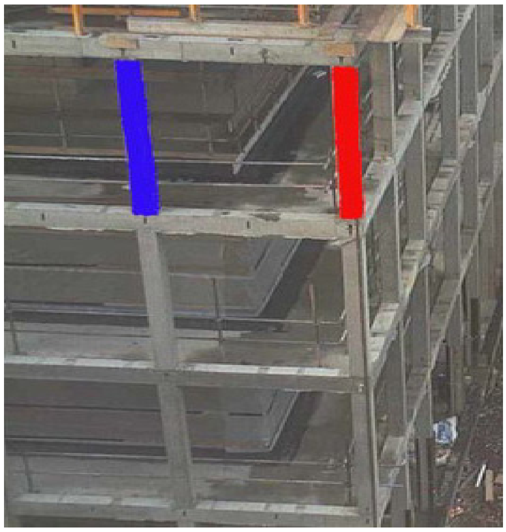


Figure 3. Prototype System Architecture.

At the start of the second stage, the computer vision module sends a request to the database for a 3D "as-planed" model by a certain time (Figure 4a). The model will first help align a sequence images taken from a particular position and angle with related building components within the site. Then it guides the computer vision module to spot changes occurring over time by identify building components (Figure 4b). It also helps the module to compare the current site images with the input 3D "as-planed" model and calculate the percentage completion of identified building components which then will be feed into progress measuring and valuation process.

a



b

Figure 4. (a) 3D as-planed model; (b) Image align and building component identification (Modified from: Lukins et al. 2007).

In the final stage, the progress assessment and valuation module calculates the actual working progress on the construction site, interim payment and productivity rate based on the input from computer vision module and the existing information in the database, e.g. cost, schedule. The result will then be saved back to the database and archived for the future use.

5 THE PROTOTYPE DEVELOPMENT

In the research, a few technical approaches have been investigated in order to develop the prototype system (Table 1). Every approach has its strengths and weakness. As mentioned earlier, commercial software like JetStream from NavisWorks and 4D Suite from D-Studio already have functionalities for linking building components with schedule activities which is useful. However the linkages are capsulated inside the software and inaccessible to external applications. This will make it difficult to communicate with computer vision module in regard to the working progress measurement.

At the end of the investigation, the authors decided to use the self-developed application for the first prototype development. In a previous research project, a relevant application had been developed (Zhang et al., 2005) used Visual Basic and MS Access database. It has some similar functionalities and can be used as a base for the prototype development. For example, it has a functionality to retrieve 3D geometry information of building components from IFC files and then save into the Access database. With further development it will be able to retrieve other attributes of building component e.g. work section information. This will be a quick solution and the user interfaces will not as good as commercial software. The rational for the decision is to engage the industry people as soon as possible which would be difficult without a working prototype.

Table 1. Investigated approaches for the prototype development.

	Strength	Weakness
Revit	– Good user interface – Powerful CAD tools – .NET API	– No time concept
JetStream	– 4D function ready – Mature user interface – API	– 4D linkage unable to be accessed externally – One way link to ODBC database (only import)
4D Suite	– 4D function ready – Bi-direction link with MySQL database	– 4D linkage unable to be accessed externally – Poor user guide – Own script language API
Self-developed application	– More flexible	– 4D functions need to start from scratch

6 SUMMARY AND CONCLUSION

Accurate and up-to-date working progress information is essential for real-time construction control and management therefore is vital for the success of a construction project. The current methods are time consuming, expensive and inaccurate. An ongoing EPSRC funded project that is carried out by the Heriot-Watt University and the University of Salford is exploring an approach that could automate the process. This research combines different methods, e.g. applying flexible WBS, integrated building information system and computer vision, to solve the problem of on-site working progress measurement and updating. The wider aim is the promotion of better access and integration of real-time site data within future communication and management system needed for a truly global construction industry.

By integrating plan and construction information, the designed prototype system can provide 3D “as-planned” information to the computer vision module. The module then could automatically obtain “as-built” model of existing building structure and measure the percentage completion of building components. Based on the measurement, the progress on-site can be assessed. By comparing with the initial design and plan, the prototype could inform the project manager the potential delay. Furthermore the interim payment and productivity rate can be estimated.

The designed prototype system still has some limitations. For example, it only considers the components of main framework of a building e.g. slab, beam, column. This is due to the limited resource of the project. Also all the attributes of those components regarding the WBS decomposition criteria need to be pre-defined as well as cost rates. But this is only the first attempt for the development of a proof of concept system. Furthermore users have the freedom to change the WBS as well as the cost rates in the procedure of data processing to better reflect his/her understanding. In the future, the limitations could be further investigated and tackled.

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