THE DEVELOPMENT OF AN AUTOMATED PROGRESS MEASUREMENT SYSTEM FOR CONSTRUCTION WORK PACKAGES

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Abstract. The challenges associated with collecting accurate data on the progress of construction have long been recognised. Traditional methods often involve human judgment, high costs, and are too infrequent to provide managers with timely and accurate control data. The aim of this study is to propose a prototype system that employs Computer Vision (CV) techniques to report on progress for components supplied from an integrated Building Information Model (BIM). This model stores and relates this feedback to a representation of the work breakdown structure (WBS) that assigns components to work packages. In this paper we present an overview of the actual system – from the theoretical and technical challenges encountered.

1. Introduction

Delivering projects on time and within budget is crucial to the success of a project. A key concern with the traditional project control systems is that they rely on manual data collection. This has been shown to be costly, and too infrequent to allow for prompt control action (Navon, 2007). The most economical way to measure performance, according to Navon and Sacks (2006), is to automate the process. This entails automating not only data capture but also, as much as possible, the planning phase of the project, since this will ensure the optimum benefits of using a computer integrated system.

This study proposes a system that provides a means for automatic generation of work packages and assessing their progress using computer vision. In the rest of the paper, we give an overview of the system framework and then elucidate the automatic work package generation and assessment modules of the system.

2. Framework Overview

Our proposed system focuses on the interaction between the project planning phase and the physical reality of what has actually been performed to date. Key to this idea is the use of a work breakdown structure to represent the grouping of components into more meaningful blocks. A work package can then be said to be completed if it is possible to confirm that all of its constituent components are themselves finished.

The framework (Figure 1) is built as a natural extension to existing Building Information Models. At its core is a database, comprising instances of building components (such as columns, walls, beams, etc.). In addition to basic planning information relating to scheduling and cost estimates, these components are populated with additional attributes by the WBS assignment module to define what package they belong to. The project manager can easily update this information based on generated progress reports, or whenever the need arises.

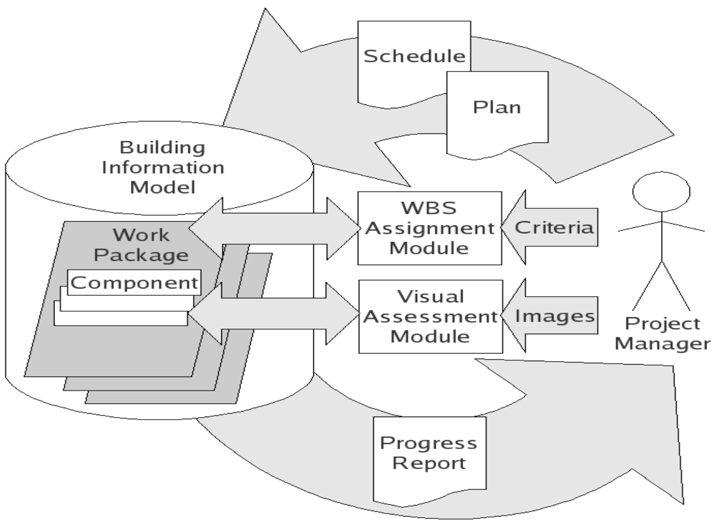

Figure 1 : The automated progress measurement framework.(Ibrahim et al, 2007)

The visual assessment module can then interface with the BIM and provide, for a particular view and set of images, its assessment of completed components, and the dates at which they underwent a significant change. From this, additional attributes can be used to infer the status of other components, even if not visible. Finally, this collated information can be used to generate on-demand progress reports as to the current status of the project, as feedback to the project manager.

3. Automatic Work Packaging

As Wideman (1989) states: building up effective work packages is perhaps the most difficult and challenging task in project management. Key to the to the formulation of an effective WBS is the choice of appropriate decomposition criteria by which the project can be subdivided. The decomposition criteria reflects the facets of information that can be used as the basis for subdividing the work at various levels of the WBS. However, the identification of these criteria presents a particular challenge, since there are various classifications of construction information which may be used. For example, the International Organisation for Standardisation identified eight facets which include facility, space, element, work section, construction product, construction aid, attributes, and management. In addition to these, Chang and Tsai (2003) proposed lifecycle, function and tasks while Kang and Paulson (1997) identified operation and resource.

In order to address the problem, a survey was conducted, aimed at identifying the most frequently used criteria in the formulation of the WBS. This survey was based on our earlier work (Ibrahim et al, 2007). First, various criteria for the classification of construction information were identified from the literature. Respondents were then asked to indicate those criteria they actually use in developing a WBS. This was achieved through postal questionnaires sent to the top 100 UK contractors and 80 randomly selected additional contractors. A total of 40 (22%) useful responses were received and analyzed. Respondents included planners, bidders, project managers, quantity surveyors and estimators. The results suggest that the most frequently used criteria (used by at least 50% of respondents) are ``Elements'', ``Work Section'', ``Construction Aids'' and ``Physical Location''.

Recent developments in the area of Building Information Models have made it feasible to store vast amount of information in computer interpretable format. In addition to basic geometry information, attributes relating to each decomposition criterion can be defined for each instance of every building component in the BIM. The building model is thus made up of a collection of components, and each component can be assigned one of the four decomposition criteria. These values are based on standardised construction classification documents that define each decomposition criterion. For example, for the ``Elements'' criterion, each component can take one value from the standard list of elements developed by the Building Cost Information Service (BCIS). For Values relating to ``Work Section'' criterion would be based on the Standard Method of Measurement (SMM7) classification of work section, while those relating to ``Construction Aids'' would be based on the table M of UNICLASS classification of construction aids. It should be noted that the authors are not currently aware of any standard classification document based on ``Physical Location'' of work. For the present study, we simply adopt a classification developed by Blythe et al, (2004) which is based on floor levels (e.g., 1st floor, 2nd floor, etc.).

Once each design object has been allocated based on these criteria, work packages can be generated in a hierarchical fashion, by querying the building model database. Figure 2 depicts the relationship amongst the various classes of objects in the proposed system, in *uml* notation. The building model class is a composition of the component class. The work package class is an 'association' class resulting from the association between the building model class and the user class. The model also shows that a work package may contain other work packages. The four decomposition criteria are in turn associated with each component using an aggregation relationship.

Both the WorkPackageStore and CriteriaStore classes realize the *Store* interface to store generated work packages and their associated criteria.

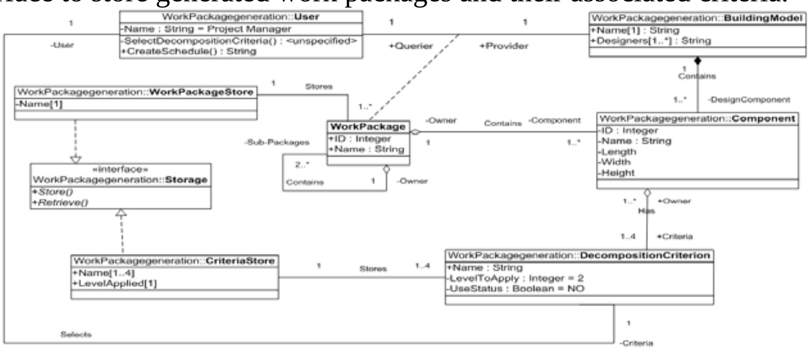

Figure 2: WBS class view

3. Visual Assessment

Images form a naturally quick and easy way to capture information on site. However, the interpretation of those images is a particularly difficult problem – especially given the clutter and rapid change that occurs during construction. The task can be made harder if the location of the components within the site is not known a priori, as this then involves exploiting the contextual and geometric aspects of the scene to try and estimate the location of the camera. Our approach is to exploit images that are captured from a fixed position which means that we need only perform alignment once for that specific camera. The first task of the Visual Assessment module is thus to determine the pose of the camera in relation to the building model.

This is performed using our "Align To" application, which forms the interface to the core BIM database. This allows the user to visualize the scheduling and presence of the components as a 3D "site'' view (see on the left in Figure 2) and to view at a glance the status of the project. The actual work in alignment is performed while in "camera" view (on the right in Figure 2) where the images in question are overlaid on top of the model and the camera position optimized to line up based on the visible structure in the scene – for example lines and corners.

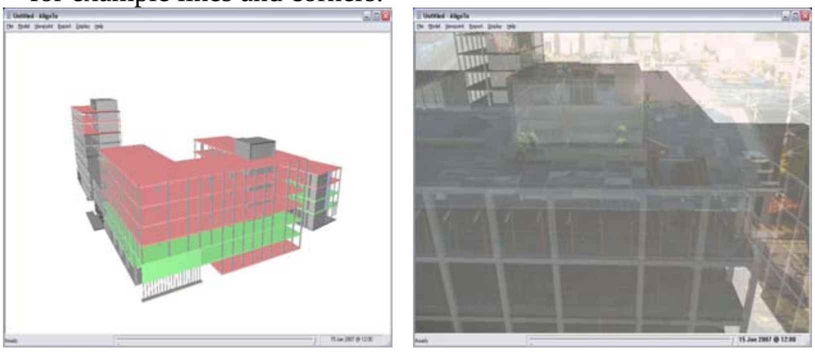

Figure 3: The Align To application.

From this position the application is then able to determine those particular images regions where the individual components should appear. Each incoming image for a given date is treated as an array of pixel values, across which are observed changes for each local component region. Some of these changes can be normalized to accommodate illumination and other variable conditions, but more fundamentally there should also be larger, localized changes related to events of greater significance, represented by a consistent change (Radke et al, 2005).

Having detected such events, the application looks to further verify the ultimate presence of the component in question. To achieve this it uses an implementation of a classifier that has been trained on prior examples of that type of component. Using this it is able to confirm he absence of those components immediately prior to the event, and to check that it then occurs afterwards. This ultimately leads to the automatic assignment of a confirmed time for the components completion. This is then reported back to the BIM to facilitate reporting and updates to schedule information at the work-package level.

4. Conclusions

We have reported on a conceptual framework based on an expanded BIM, which is capable of managing and automatically assessing work packages. We have focused on the two main components of the system: the work breakdown assignment module and the visual assessment module. Our work breakdown approach is based on the results of an industry wide survey which provides us with a useful set of criteria to group components by. For visual assessment we apply the concept of change detection to determine when components are visibly in situ. By illustrating how these aspects can be implemented we hope to have also shown the feasibility of this approach, and potential benefits.

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