D4AR- 4 Dimensional Augmented Reality- Models for Automation and Interactive Visualization of Construction Progress Monitoring

The Innovation - In this work, D4AR - 4D Augmented Reality - models for fully automated tracking of construction progress and visualizing as-built (actual) and as-planned models as well as performance deviations are presented. The main practical motivations for development of this technology is to overcome challenges in systematic implementation of project monitoring (I) current methods include manual as-built data collection and extensive as-planned data extraction from construction drawings, schedules and daily construction reports, (2) due to extensive workload, monitoring is sometimes infrequent and performance is measured with non-systematic metrics; (3) Progress reports are visually complex and require more time to be spent in communicating status of a project in coordination meetings. To that extent, D4AR models generated with unordered daily photo collections and Building Information Models (BIM) can overcome these challenges.

The main technical motivation for developing an automated visual data collection system is availability of cheap and high resolution digital cameras, low cost memory and increasing bandwidth capacity which have enabled capturing and sharing of daily construction photos on a truly massive scale. For example, on a 200,000 S.F. building project in Champaign, IL an average of 500 photos/day is being collected by the Architecture/Engineering/Construction (AEC) professionals. Such a large and diverse set of imagery - which captures dynamic construction scenes at minimal cost and effort - allows as-built sites to be fully observed from almost every conceivable viewing position and angle during construction. In the meantime, BIMs are also increasingly turning into binding components of AEC contracts. For example, as of July 2009, Wisconsin established itself to be the first state requiring BIM for public projects. Despite the growing interest and popularity, BIMs are mostly used during design or pre-construction phases. If linked with project schedules, BIMs can form chronological models that allow schedule to be revised and controlled, and expected performance be analyzed. Furthermore they can serve as powerful baselines for tracking and visualization of performance discrepancies.

In order to automatically generate D4AR models, our system uses a set of unordered and uncalibrated daily construction photographs to reconstruct a dense point cloud and automatically geo-registers photos in a virtual environment (Fig. I a to d). Next point clouds generated with different photo collections captured in different days are superimposed over one another, in turn generating 4D (3D + time) point clouds. Subsequently 4D point clouds are superimposed over 4D BIM (BIM + time in form of construction schedule), generating the D4AR models in an augmented reality fashion (Fig. I e & f). Using a probabilistic model within a machine learning scheme, at presence of occlusions and different lighting conditions, our system automatically measures progress and visualizes deviations with an intuitive traffic-light metaphor. Thus, the BIM components that are ahead-of-schedule are color-coded in green and the ones behind-schedule are color-coded in red (Fig. 2- b & c).

it is innovative - From practical point-of-view, D4AR models (I) allows remote virtual walk through on the as-built scene, (2) facilitates remote control decision making, especially revision of construction schedules, (3) minimizes the time required to discuss the as-built scene through quick and intuitive access to actual construction information and (4) significantly cuts in travel time and cost for project executives, architects and owners. Using the D4AR, AEC professionals can remotely access a project, visualize integrated as-built and as-planned scene and assess progress, productivity, safety, and quality plus site logistics (Fig. 3). The automated monitoring scheme built upon the D4AR is the first probabilistic model for progress tracking and visualization of deviations that incorporates both as-planned models and unordered daily photos in a principled way. Unlike other methods that focus on application of laser scanners or time-lapse photos, this approach is able to use existing information without adding the burden of explicit data collection on project management. It also reports competitive monitoring accuracies compared to laser scanning techniques, especially at presence of occlusions. Compared to conventional photogrammetry techniques for generation of as-built models, D4AR as-built reconstruction module is uniquely able to use existing photo collections and automatically generate dense point clouds. D4AR along with a Mobile Workstation Chariot which is based on the popular Segway platform (Fig. 4), has been recently used to reconstruct buildings more systematically and utilize generated D4AR models especially for disaster management scenarios.

What it changed or replaced - Early detection of actual or potential schedule delay or performance deviation in field construction is critical to project management. It provides an opportunity to initiate proactive actions to avoid them or minimize their impacts. Given mentioned challenges of current practice, D4AR models support project managers with easy and intuitive tools to design, implement, and maintain systematic approaches for project monitoring. It further allows them to promptly identify, process and communicate discrepancies between as-built and as-planned performances as early as possible.

Where and when it originated, has been used, and is expected to be used in the future - In 2008, in a collaborative project between Civil & Env. Eng. department of Univ. of Illinois at Urbana-Champaign and Electrical Eng. and Computer Science of Univ. of Michigan at Ann Arbor, the concept, framework and the system for automated generation and visualization of D4AR models were developed. D4AR has been continuously generated for two ongoing construction projects for Turner Construction and is currently being tested for W. E. O'Neil Construction for an ongoing project in Chicago, IL. Throughout implementation, D4AR has been generated and tested for 5 other building construction projects in Champaign, and Chicago, IL as well as Kansas City, MO. Currently automated detection of interior and Mechanical/Electrical/Plumbing components are being investigated which enables construction project managers and executives, safety and quality inspectors, architects as well as owners to extensively use D4AR models in their projects.

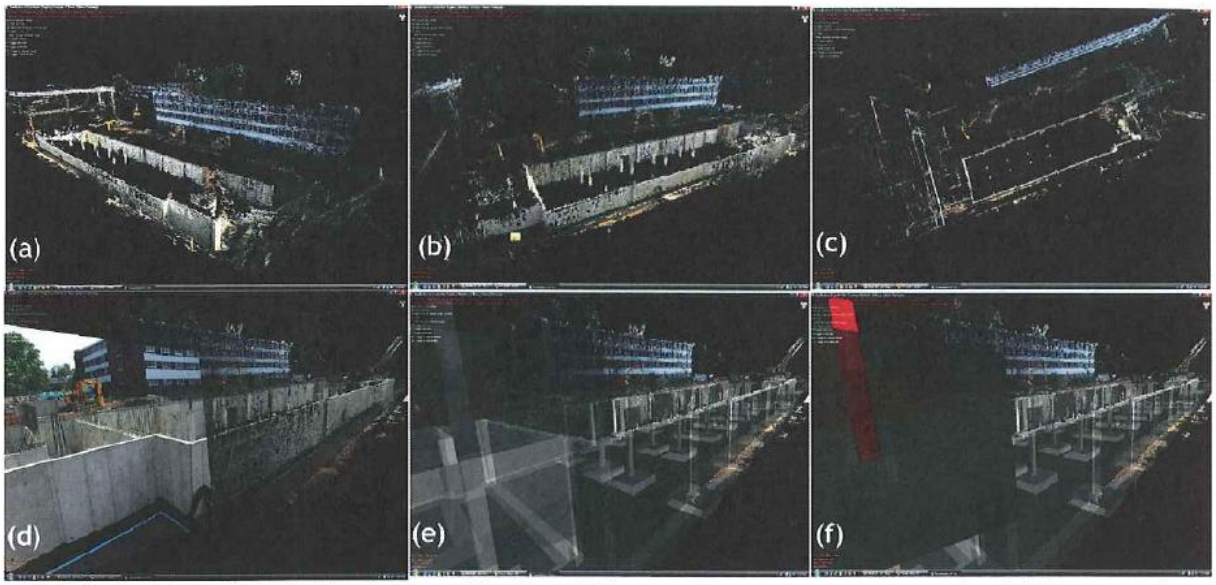

Figure 1. The D⁴AR model for Student Dining and Residence Hall construction projects reconstructed with 160 images collected along the sidewalk @ 2Mpixels. (a) to (c) visualizing point cloud of the basement and project surroundings from synthetic views, (d) joint image and point cloud representation; (e) see-through image visualized along with 4D BIM plus the as-built point cloud; (f) A BIM element is color-coded according to progress and is visualized in the D⁴AR model.

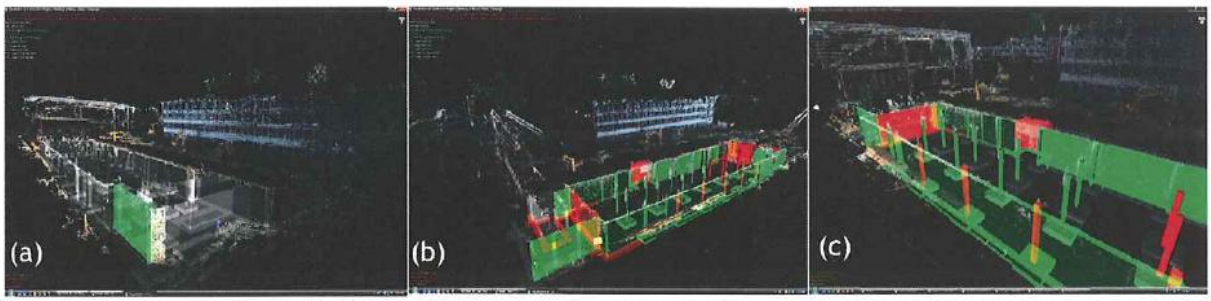

Figure 2. The underlying BIM in the D⁴AR is fully automatically color-coded for progress according to the construction schedule. The BIM components that are ahead-of-schedule are color-coded in green, the ones behind-schedule are color-coded in red and the ones with zero visibility (fully occluded) from photos as all color-coded in gray.

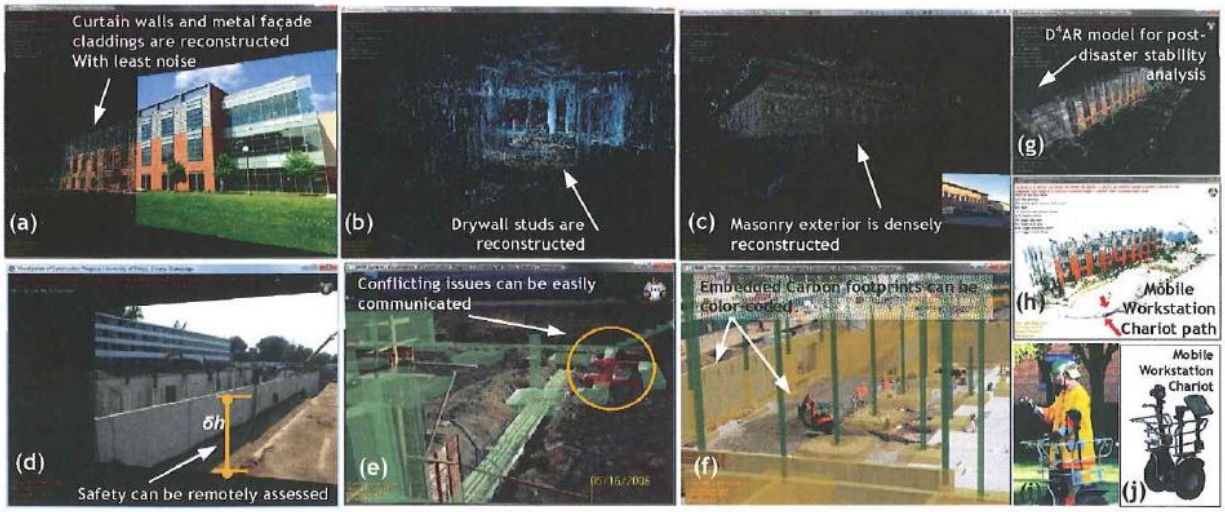

Figure 3. Technical and practical significance of the D⁴AR modeling (Experienced in 8 construction projects). The D⁴AR modeling is recently used for two Turner Construction projects and is currently being tested for W.E. O'Neil Construction Co. on an ongoing Hospital Pavilion project.