1st Annual Inter-university Symposium on Infrastructure Management (AISIM), August 6, 2005
University of Waterloo

TOWARDS A 3-D CAD SYSTEM FOR ACCURATE CONDITION ASSESSMENT OF THE BUILDING INFRASTRUCTURE

Submission Date : July 8, 2005

Word Count	: Text only	= 3,407 words
	3 Large Figures	= 1,200 words
	Total words	= 4,607 words

Authors : Shipra Singh Ahluwalia[1] and Tarek Hegazy[2]

1.
Graduate Student, Civil Engineering Dept.,
University of Waterloo,
Waterloo, Ontario, N2L 3G1
Canada
Tel: (519) 888-4567 ext.: 3869
E-mail: ssinghah@engmail.uwaterloo.ca

Corresponding Author
2. Associate Professor, Civil Engineering Dept.,
University of Waterloo,
Waterloo, Ontario, N2L 3G1
Canada
Tel: (519) 888-4567 ext.: 2174
Fax: (519) 888-6197
E-mail: tarek@uwaterloo.ca

TOWARDS A 3-D CAD SYSTEM FOR ACCURATE CONDITION ASSESSMENT OF THE BUILDING INFRASTRUCTURE

Shipra Singh Ahluwalia, and Tarek Hegazy
Civil Engineering Department, University of Waterloo, Waterloo, On, Canada

ABSTRACT

This paper investigates the development of a 3-D CAD system to support visual inspection and condition assessment of building facilities. The paper discusses the challenges / options towards the development of the system's three innovative fronts: (1) a CAD system with a depository of all building components and 3-D animation / visualization capabilities; (2) portable design on hand-held devices to support field inspection and documentation of building components through pictures; and (3) a visual guidance system for assessing the condition of inspected components by comparing the inspected pictures with a pictorial database of building components at various condition states. The proposed system, as such, brings many benefits to both the field inspection and the condition assessment processes. Using the proposed system, the inspection process becomes faster, less costly, and suitable for less-experienced personnel at the individual facility location. In addition, the visual guidance system will also make the condition assessment of inspected components a more accurate and less-subjective process. Added to that, the system retains a permanent documentation of component conditions at various points in time and presents this information in a 3-D walkthrough animation. Ultimately, the system will provide timely and sufficient information to a central asset management system that facilitates accurate repair decisions for the building infrastructure.

TOWARDS A 3-D CAD SYSTEM FOR ACCURATE CONDITION ASSESSMENT OF THE BUILDING INFRASTRUCTURE

INTRODUCTION

Infrastructure services are essential for economic growth and prosperity. Currently in North America, however, a large percentage of infrastructure assets, including educational and healthcare buildings, are rapidly deteriorating due to age, aggressive environment, and insufficient capacity for population growth. Sustaining the safety and operation of such infrastructure is not a simple task, particularly under stringent budget constraints on municipalities and public agencies. To facilitate cost-effective repair decisions, accurate assessment of the condition of assets becomes essential. This is particularly true for buildings, which involve a large number of components that have different deterioration mechanisms and consequent repair requirements.

Condition assessment is defined as ”a process of systematically evaluating an organization’s capital assets in order to project repair, renewal, or replacement needs that will preserve their ability to support the mission or activities they were assigned to serve” (*1*). As such, the key benefit of a condition assessment system is to facilitate the ranking of all the components in all assets according to their need for repair. To do that, a condition assessment system needs to track a detailed hierarchy of the components of each asset, which is a database of all components. A condition assessment system should also facilitate speedy inspection and determination of condition indices for the various building components.

Two common approaches are possible for evaluating the condition of any instance of a building component: direct condition rating; and rating based on a distress survey. Direct condition rating is a simple but subjective process of giving the component a global rating to represent its overall condition (e.g., good, fair, poor, or critical). This, however, does not represent the specific problems that need to be repaired. A distress survey, on the other hand, is a more accurate procedure that provides a record of what’s wrong with the inspected instance of a component (*2*). This approach requires more details regarding the possible deficiencies that can affect the component and how to evaluate them.

In the literature, much research has been directed towards identifying proper evaluation criteria to assess the performance of buildings (*3,4,5*). Many asset management systems have also been introduced on the market with condition assessment features. While these systems allow either a direct rating or a distress survey approach to evaluate asset components, still their results are much dependant on the accuracy of the subjective visual inspection process. Such systems require experienced users to judge the condition of a component during the inspection process itself. Such experienced inspectors are costly and require long time to do the assessment in the field. In most existing systems also, the resulting condition assessment is not fully documented and may not be directly tied to the central database of the building asset hierarchy, which includes design details, CAD drawings, repair history, financial data, etc.

CAD AND VISUALIZATION TOOLS

CAD models have been utilized for many years in almost all types of projects. In the past, the use of CAD was primarily restricted to the design and drafting at the pre-construction phase (6). Currently, however, the use of CAD has been extended beyond its drawing capabilities (7, 8, 9, 10). Many efforts in the literature, for example, have successfully used CAD to automate existing technical construction services such as preparing estimates, schedules, and building simulation models. Other uses of CAD include the control of material handling on site (7), construction schedule generation (8), construction simulation, and graphical presentation of construction simulation results (9). Current advancements in CAD technologies also allow developers greater flexibility in extending CAD functionality to increase timeliness and accuracy of drawings, improve communication of technical information, and increased field productivity (10).

Among the recent and widely increasing applications of CAD are 4D modeling and visualization, which are perceived to provide improved relationships between designers and constructors (11). 4D CAD has been viewed as a natural progression to 3D CAD models, as it adds a further dimension which is time (12), i.e., linking a 3D CAD model to a construction schedule through a third party application (13). It has been demonstrated that creating a 3D model over time assisted in the planning process (14). This technology has the potential for legibly presenting ideas to clients and to identify bottlenecks in the design (15, 16). Additionally 4D simulation has proven useful as a medium for training inexperienced planners (17).

Imaging and data visualization tools on the other hand, can bring substantial benefits, which the present research seeks to extend to the building asset management domain, including:

(i) Images provide an easily understandable view of activities, processes and methods and assist not only in the easiness of comprehending complex engineering work but also in the marketing of projects to local communities;

(ii) Visual data along with Internet technologies represent reliable means to remote progress monitoring and visual inspections, with great potential for time and cost savings;

(iii) Productivity information can be used to obtain trends and thus make it possible to develop tools to support estimating and resource planning functions with less time and cost;

(iv) Visual data are permanent documentation of situations and events. In the case of litigation, visual data provides evidence that supports conflict resolution among parties (18).

3D CAD SYSTEM FOR BUILDING CONDITION ASSESSMENT

To support the condition assessment process for buildings, a portable 3D CAD System has been proposed in this paper as an economical approach to speed field inspection of buildings, to minimize the subjectivity associated with the interpretation of field inspection data, and to provide permanent documentation of assets at various stages of their life cycles. A schematic diagram of the proposed condition assessment system is shown in Figure 1. The three main features incorporated into the system are: a 3D-CAD-based building information model, Portable design for use during field inspection, and a visual guidance system with a pictorial database of building components at various condition states. A brief description of these three features is provided in the following subsections. While the system is currently being under development, the description of the system's three features establishes the specifications and the interactions that are required in each feature. Such specifications will enable the selection of the proper tools to use in developing the system.

Building Model with 3D-CAD

Before a condition assessment can be carried out, a detailed inventory of all assets and their individual components has to be established. To represent this inventory and tie it to the organization structure (departments, resources, supervisors, etc.) for reporting and administrative matters, a logical representation of data in the form of a hierarchy becomes necessary. The hierarchy clusters the components under different meaningful categories. For example, a building can be divided into different systems such as, electrical, mechanical, and structural, which can be divided further into detailed levels, till the component level (e.g., interior doors, exterior doors, windows, and ceiling, etc.). Various asset hierarchies have been proposed in existing asset management systems. An analysis of existing systems, therefore, will enable the establishment of a generic representation of the building hierarchy.

In the proposed developments, it is necessary to structure a suitable building asset hierarchy to be easily visualized and used for condition assessment. The proposed system, therefore, uses visual CAD objects defined in the existing CAD drawings to create a visual hierarchy of the typical components in a building. As such, existing CAD drawings will be utilized to create a library of building objects, in 3-D representation, to enable the utilization of CAD's sophisticated features for animation and visualization. A variety of CAD systems are currently being investigated to be used for this purpose. Ideally the CAD tool must be flexible enough to allow automation and visualization capabilities. In addition, it should support the Industry Foundation Classes (IFC) and be suitable for use on portable devices such as tablet PCs and pocket computers. The Industry Foundation Classes (IFCs) are integrated object models of building projects (*19*) developed by the International Alliance for Interoperability (IAI). The IFCs support will facilitate the exchange of data among the building hierarchy, the condition assessment system, and any industry processes across multiple domains such as architecture, building services, structural engineering, construction and facilities management (*20*).

Currently, there exist several commercial CAD tools that can be potential candidates for use in the present developments. Two examples are the AutoCAD and the REVIT Building 8 software systems, both by Autodesk.

Revit Building 8 is a powerful conceptual modeling and design environment that is customized to buildings. It allows the user to conceptually describe any building form and accordingly it maps it to real world entities. Revit's Parametric Components (i.e., wall windows, doors, etc.) offer an open graphical system for design and form making, which is simpler than the generic AutoCAD tool. Other development options include the use of Architectural Punch software or the Design CAD 3D MAX software, as basis for the proposed developments. Architectural Punch has visualization capabilities and can be customized using C++ programming language. Design CAD 3D MAX, on the other hand, uses programming languages such as: Visual Basic, Visual C++, Delphi or C++ Builder with the Developer's Toolkit to make custom applications.

Once a CAD system is selected for the development, a CAD-based building hierarchy will be developed and used to help the user easily select the building component being assessed and automatically record the assessment information (text and digital picture) on its CAD object. The CAD software will also be customized to present the current assessment pictures in a 3-D walkthrough animation. As such, a visual comparison can be quickly made among the component's condition states at various time periods, as indicated in the schematic representation of Figure 2.

Portable Field Inspection

Traditionally, field inspection of building assets has been carried out by experienced and knowledgeable inspectors who perform both the inspection and the analysis on-site, to decide on the component's current condition. This process consumes a large amount of time from the experts in doing tasks that not necessarily require their expertise, such as moving from one location to the other, taking pictures, writing notes, etc. The process can also be extremely expensive, when the number of facilities increases. A typical school board, for example, may administer several hundred schools that require detailed assessment. Hence, the approach proposed in this research is to develop a fast and simple approach of recording the state of current assets using pictures by less-experienced individuals, simultaneously at the various facility locations. Afterwards, the recorded pictures would be sent to a central office for presentation to the experts in a 3-D animation to productively finalize the condition assessment of the building components. The recorded images at different stages of component's life cycle then become a permanent documentation of the component's condition.

Currently, there exist very affordable commercial tools that can be used for visual recording of asset images, such as digital cameras, which are getting cheaper, better in image quality, and very easy to use (*18*). The acquired images are also stored in digital format and can be uploaded effortlessly to a computer. In addition, portable handheld computers and personal digital assistants (PDA) such as Pocket PCs and Palm devices are also gaining acceptance as useful tools at the construction site (*21*). Software applications previously confined to the engineer's office, are now available on these devices. They also provide a means to access project / asset information through a wireless Internet connection. Information can also flow in the opposite direction where the PDA is used to collect data in the field and is communicated back to the central database for subsequent processing (*19, 20*).

For the present system, it is essential to provide a portable system that connects to a digital camera. The key aspect to consider in the implementation is to automate the link between the images taken by the digital camera and their link to the corresponding CAD objects of the inspected component. One possible design of the proposed system is a Tablet PC connected to a digital camera and equipped with the proposed 3-D CAD software. During the actual use of the proposed system, digital pictures of each building component will be directly attached to its corresponding CAD object. Afterwards, a full 3-D animation can be automatically used to view the current condition of the asset, assign condition indices to the components, and transfer the indices directly to a central asset management system.

Visual Guidance System with Pictorial Database

Although images are useful for providing information to be used for assessing the current condition of the asset, yet the accurate identification of the deterioration levels of various building components still remains highly subjective. It is often difficult to specify the exact level of deterioration by just viewing a photograph of the building component. Therefore, the need arises for guidance and support to reduce the subjectivity of the condition assessment process.

One simple approach for providing adequate guidance for deciding the condition of a component is through a pictorial database of similar components at different condition states. This makes the process faster, less costly and less subjective. Earlier work to develop such a system has been presented in (*22*), relating to the assessment of windows in buildings. The study collected a database of windows with different deficiencies and different condition states. The present study will build upon this earlier effort to identify the most frequently deteriorated building components and their possible deficiencies. For each of the identified components, a pictorial database will be developed from a large number of components at different severity levels for the various deficiencies. The pictorial database will be created by taking pictures to real buildings through a field survey, in addition to collecting pictures from previous condition assessment reports. After the various component pictures are taken, they will be ranked according to their deterioration levels, as shown in the window example of Figure 3 (22).

Once the visual guidance system is developed, the three components of the proposed portable system for visual inspection and condition assessment will be integrated. Afterwards, extensive testing will be carried out on actual buildings to examine its usefulness and practicality.

CONCLUDING REMARKS

Among the various techniques and technologies that can be used for condition assessment of building facilities, only visual inspection can suit the nature of buildings assets, which have multiple diverse components with different requirements. This paper has discussed the challenges / options towards the development of a proposed system for visual inspection and condition assessment of buildings. The system is expected to be easy to use, provide permanent documentation of the asset condition, and makes the field inspection process suitable for less experienced individuals (local caretakers of each facility). As such, inspection can be done simultaneously at various buildings and then sent to the central office. Experienced staff at the central office (not in the field) can then productively complete the assessment by visualizing 3-D animations of the inspected buildings, with the aid of a visual guidance system based on a pictorial database of similar components. The proposed system is expected not only to speed up the overall condition assessment but also to decrease the subjectivity associated with the process. In addition, the system enables assessment visualizations to be compared at different times, thus providing a permanent record of the asset along it's life cycle. Ultimately, the proposed system will provide timely and sufficient information to facilitate accurate repair decisions for the building infrastructure.

REFERENCES

(1) Rugless, J. Condition Assessment Surveys. *Facilities Engineering Journal*, 21(3), 1993, pp. 11-13.

(2) Uzarski, D. R. Condition assessment Manual for Building Components for Use with BUILDER Version 2.1, 2002.

(3) Assaf. S., Al-Hammad, A., and Al-Shihah. M. The Effect of Faulty Construction on Building Maintenance. Build Res. Info., 23(3), 1995, pp.175-181.

(4) Ashworth, A. Estimating the life expectancies of building components in life-cycle costing calculations. Stuct Surv., 14(2), 1996, pp. 4-8.

(5) Chew, M. Y. L. and De Silva. N. Maintainability problems of wet areas in high-rise residential buildings. Build Res. Info., 31(1), 2003, pp. 60-69.

(6) AbouRizk, S, and Mather, K. Simplified Simulation Modeling through Integration with 3D CAD. *Journal of Construction Engineering and Management*, Vol. 126, No. 6, November/December, 2000. pp. 20589

(7) Beliveau, Y., Dal, T., and Dixit, S. ‘‘CAD applications for material handling in the construction environment.’’ Proc., 5th Int. Conf. of Comp. in Civ. Engrg., ASCE, New York, 1993, pp. 125–128.

(8) Cherneff, J., Logcher, R., and Sriram, D. Integrating CAD with construction schedule generation. *Journal of Comp. in Civ. Engrg*., 5(1), 1991, pp.64–84.

(9) Wichard, D., Bill, R., Gates, K. H., Yoshinaga, T., and Ohcoshi, S. Construction CAE integration of CAD, simulation, planning and cost control. Proc., Am. Power Conf., Vol. 51, Illinois Institute of Technology, Chicago, 1989, pp.983–987.

(10) Mahoney, J., and Tatum, C. Construction Site Applications of CAD. Journal of *Constr. Engrg. and Mgmt*., ASCE, 120(3), 1994, pp.617–631.

(11) Barrett, P. Construction Management Pull for 4D CAD, in Walsh, K.D. (ed.) Construction Congress VI,ASCE, Orlando, FL, February, 2000, pp. 977–83.

(12) Phair, M. Software Model Builders Add an Extra Dimension to 3D CAD. *ENR*, 6 March, 2000.

(13) Collier, E. and Fischer, M. Visual Based Scheduling: 4D Modeling on the San Mateo County Health Centre, in Proceedings of the 3rd ASCE Congress on Computing in Civil Engineering, Anaheim, CA, 1996.

(14) Coles, B.C. and Reinschmidt, K.F. Computer-Integrated Construction: Moving beyond Standard Computeraided Design to work in three and even four dimensions helps a project team plan construction, resolve conflicts and work more efficiently. Journal of Civil Engineering, ASCE, 64(6), 1994.

(15) Fischer, M. The frontier of virtual building, presentation given to the Workshop on Virtual Construction, organized by ENCORD, 26–27 November, 2001, Essen, Germany.

(16) Heesomi, D, and Mahdjoubi, L. Trends of 4D CAD Applications for Construction Planning. *Construction Management and Economics*, ISSN 0144-6193 print/ISSN 1466-433X online © 2004

(17) Jaafari, A., Manivong, K.K. and Chaaya, M. VIRCON: interactive system for teaching construction management. ASCE. *Journal of Construction Engineering and Management*, 127(1), 2001, pp.66–75.

(18) Brilakis, I and Soibelman, L. Content Based Search Engines for Construction Image Databases. *Automation in Construction*, vol. 14, 2005, pp. 537 – 550.

(19) Lee, K., Chin, S, and Kim, J. A Core System for Design Information management Using Industry Foundation Classes. *Computer–Aided Civil and Infrastructure Engineering*, July 2003, vol. 18, no. 4, pp. 286-298.

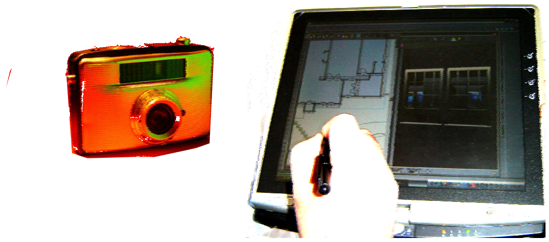
(20) Wix, J., Yu, K, and Ottasen, P.S. The Development of Industry Foundation Classes for Facility Management. Durability of Building Materials and Components 8. Edited by M.A. Lacasse and D.J. Vanier. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, 1999, pp. 2724-2734.

(21) Saidi K., Haas C., Balli N. The value of handheld computers in construction, Proceedings of the 19th International Symposium on Automation and Robotics in Construction, Washington, DC, September, 2002, National Institute of Standard and Technology, Gaithessburg. NISTIR SP 989.

(22) Elhakeem, A and Hegazy, T. Towards a Visual Guidance System for Condition Assessment of the Building Infrastructure “CD-ROM”. CSCE Specialty Conference on Infrastructure Technologies, Toronto, Ontario, Canada. June 2-4, 2005.

LIST OF FIGURES

On Site: *Proposed portable system is carried on a Tablet PC connected to a digital camera. The system directly attaches digital pictures of each inspected component to its CAD objects. After field inspection, the building plan and the digital images are sent to the main office for condition assessment.*



In Office: *Full 3-D Animation is generated to view the pictures taken for each component to facilitate condition assessment by expert. Condition Indices are transferred directly to an Asset Management System.*

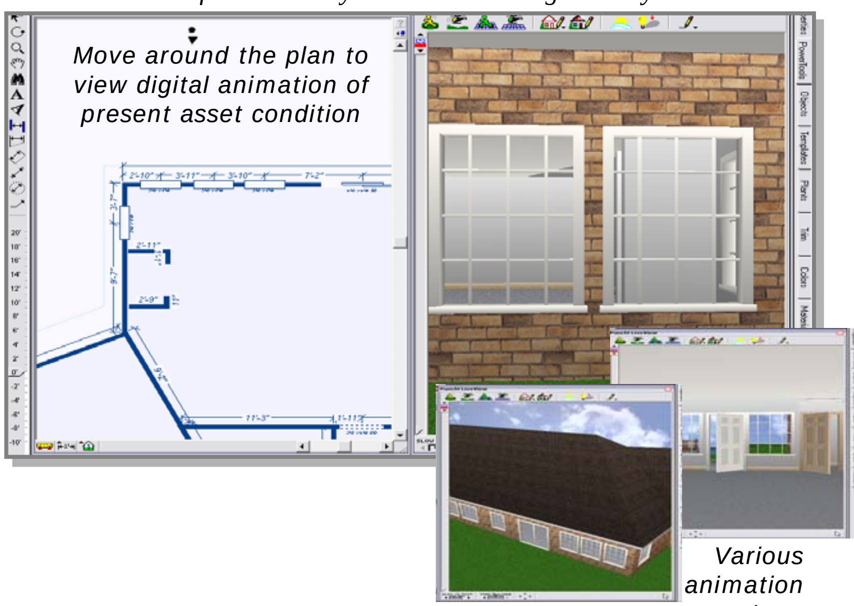


FIGURE 1 Schematic Representation of the Proposed System

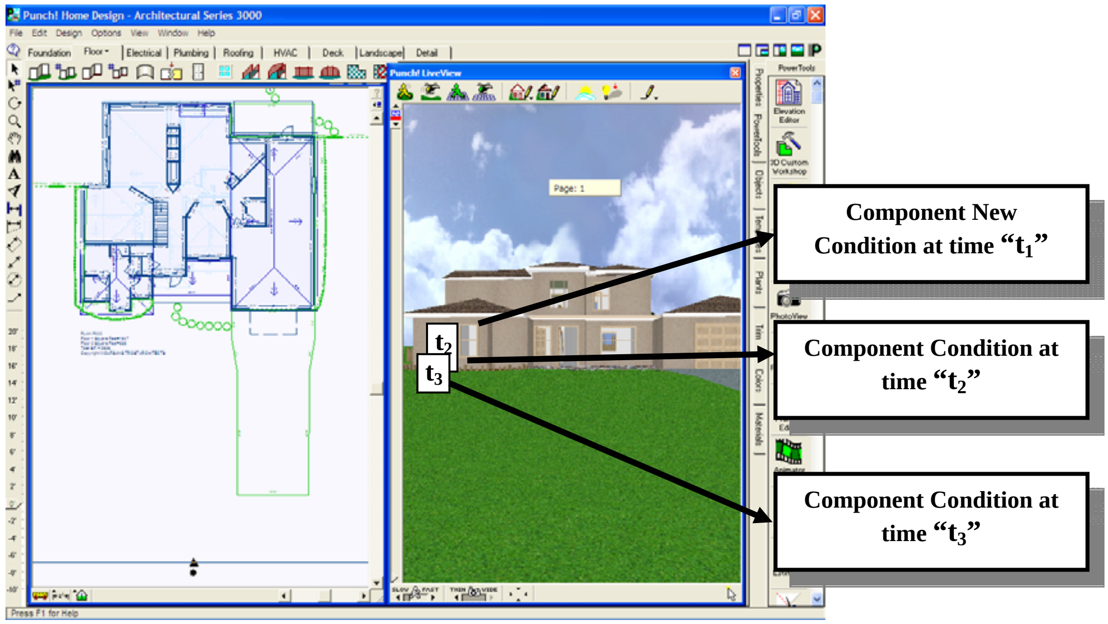


FIGURE 2 Schematic of time-dependent visualization of component condition

FIGURE 3 Ranked pictures at different deterioration levels