

The Development and Use of a Tablet PC Annotation System for Conditions Surveys

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The Tablet PC Annotation System (TPAS) may revolutionize the way building professionals collect, share, and use conditions-survey data.

In order to understand the existing conditions of a building or structure clearly, diagnose its problems accurately, and prepare construction documents for its maintenance, restoration, and repair, design and building professionals must synthesize information from different media simultaneously, including notes on paper, written reports, digital drawings, and photographs. They must gather and analyze these various forms of data in an efficient and precise manner. However, the true challenge is not simply in collecting and sharing the information but also in transferring the knowledge they have gained in a concise and useful format. Simply collecting information, even if done efficiently and effectively, is not the same as conveying a tacit understanding of the data.

The Tablet PC Annotation System, or TPAS, is a new and practical CAD tool that can assist building professionals not only in efficiently obtaining and sharing conditions information but ultimately in making more informed decisions for planning and intervention. Beyond the professionals and consultants who are typically involved in a restoration project, owners, contractors, subcontractors, municipal workers, insurance companies, and lenders stand to benefit from TPAS.

Past Processes

Traditionally, architects, engineers, and conservators have annotated paper elevation drawings in the field by hand, using codes for different types of materials and conditions, as well as the degree and quantity of deterioration. Supplemental photographs of existing conditions are then keyed to elevations using a variety of techniques to represent their location on the building or

structure accurately. Notes on existing conditions and photo-location identifiers are typically superimposed over the drawing or placed in the margins.

In most cases photographs — whether print or digital format — are sorted, collated, labeled, and presented on paper or in archival sleeves. This type of conditions reporting often includes a separate volume of supporting photographs, sequentially numbered and keyed to elevation drawings. While turning to a photograph identified by number in the elevation drawing is readily accomplished, finding the location of a specific photograph on a complex building when perusing the volume of photographs can be problematic. A related issue is the sequencing of photos taken in the field by different technicians, particularly on large or complicated buildings. As a result, sequentially numbered images in a volume of photos may appear randomly arranged in the final product.

The process of taking field notes by hand on paper, “cleaning up” and re-drafting annotations in the office using CAD, and organizing photos can lead to errors of transcription and interpretation. This process is costly, underutilizes professional personnel, and delays delivery of the work products. For smaller buildings this process may still be the most economical approach because of the short preparation time required to take notes on paper while on site. However, with large-scale projects on complicated structures, the time needed to prepare AutoCAD drawings for use in the field is well spent in anticipation of spending less transcription time in the office and assuring consistent data from different technicians. The management of the graphical, numerical, textual, and supporting data can become overwhelming, not only to produce but also to



Fig. 1. Drawing-tool palette displaying a graphically annotated elevation using the PocketCAD/Compaq iPAQ system.

interpret. This is a problem not only for surveyors of historic buildings. For example, bridge inspectors are required to take notes on multiple connections between numerous structural members, thereby generating large amounts of data. Bridge inspectors have been grappling with collecting and managing large quantities of data related to complex structures for decades.¹

Data Collection and Management

Information management for large, complex buildings with a high density of observations and data points makes existing-conditions surveys challenging. Data collected in the field have both graphical and numerical characteristics, and both are critically important to the success of a restoration project. Because survey teams typically consist of more than one person, observations and data-collection formats will vary slightly between individuals, making it difficult for others to interpret field notes. While training and periodic spot checks of consistency among technicians are a big part of quality control, some variability within a survey crew is inevitable.

Furthermore, observations on overlapping conditions, combined with the sheer number of recorded conditions, often inhibit the clear analysis and interpretation of patterns of deterioration. Structures with a high density of overlapping or contiguous conditions can be portrayed clearly only by producing multiple drawing sheets for every elevation to illustrate each of the faults or types of deterioration identified. Another way to facilitate analysis and diagnosis of existing conditions is on screen, using AutoCAD "layouts" to switch selected layers off and on. Because of the limitations of the size of computer monitors, large-scale images are better projected on a wall or screen, using a video or PowerPoint projector. This approach offers the added advantage of allowing a larger audience to participate in the viewing, interpretation, and discussion of the results.

The challenge in coordinating and organizing existing-conditions information, CAD drawings, and associated photographs, video, and written reports requires optimization of the time and effort spent on site making observations

and collecting survey data. Ideally, a direct system of digital data collection and presentation accomplishes the following objectives. Such a system

- facilitates and streamlines note taking in the field.
- increases the quality and sophistication of data recorded.
- saves technicians time preparing project deliverables in the office.
- eliminates errors of transcription and interpretation.
- makes more efficient use of professional employees by reducing repetitive manual labor and tedious tasks in report preparation.
- maximizes the utility of the final product by providing more accessible and useful conditions reports to clients.

PocketCAD and the Compaq iPAQ

About ten years ago, Vertical Access started to imagine and explore better methods for inputting and presenting existing-conditions survey information. At the time, hand-held, pen-based computers were relatively new, and there were few choices of compatible or relevant software. This was the day of the Apple Newton, a brilliant device conceived well ahead of its time but without adequate hardware or software. We envisioned a field-annotation system that would integrate data collection in a digital format, saving technicians time both in the field and in the office and making presentation and interpretation of conditions reports more accessible and readily useful for clients. Recently, hardware and software capabilities have improved, converging to the point where these visions of the future have now become reality.

In 1999 we began working with a software product known as PocketCAD, which was designed to run on hand-held, pen-based computers with a Windows CE operating system (like the iPAQ made by Compaq) and was fully compatible with CAD using ".dwg" file formats. With this software running on the Compaq iPAQ, a number of commonly used drafting "tools," such as lines, points, circles, and squares, are used to annotate vector-based CAD drawings (Fig. 1).

In AutoCAD pre-drawn and reusable graphical symbols are called block attribute tags (BATs). Using block attribute tags saves time by allowing a CAD drafter to draw something once and then use it many times. After a BAT is created, it can be inserted within a drawing as many times and in as many locations as the user chooses. Furthermore, BATs can be exported from one drawing to another.

With the PocketCAD/iPAQ system, BATs containing information about building conditions may be directly associated with these specific graphical symbols and are embedded in the drawing for subsequent extraction and manipulation in CAD, spreadsheet, or database programs. BATs are more than mere notes on paper because they contain numerical or descriptive information embedded in database records that are associated with the graphical icon portrayed on the screen. They are "smart" notes that provide data for future extraction and analysis in the office.

In this system, one uses the iPAQ stylus to select a drawing tool that reveals a dialog box with drop-down menus, allowing the specification of various criteria associated with that fault location. These criteria are automatically entered into database fields. Four data fields are available for each BAT, designed to hold information on the type of material, the class or type of fault, the fault severity or extent, and the photo-identification number. The last field may also be used for notes on outlying or unusual conditions not covered otherwise. Upon completion of the menu selections, the menu screen closes, and a stylus is used to place an icon that is appropriately scaled to the drawing in the relevant location on the elevation. On site, data entered in this system is invisibly embedded in the PocketCAD file to avoid on-screen clutter.

There are limits to any menu-based system of data collection because such systems do not allow for long or descriptive notes, free association, or creative thinking while on site. However, the menu-driven approach levels the playing field for multiple-party investigations, providing consistent or standardized notes that are easier and faster to interpret after the field work is completed.

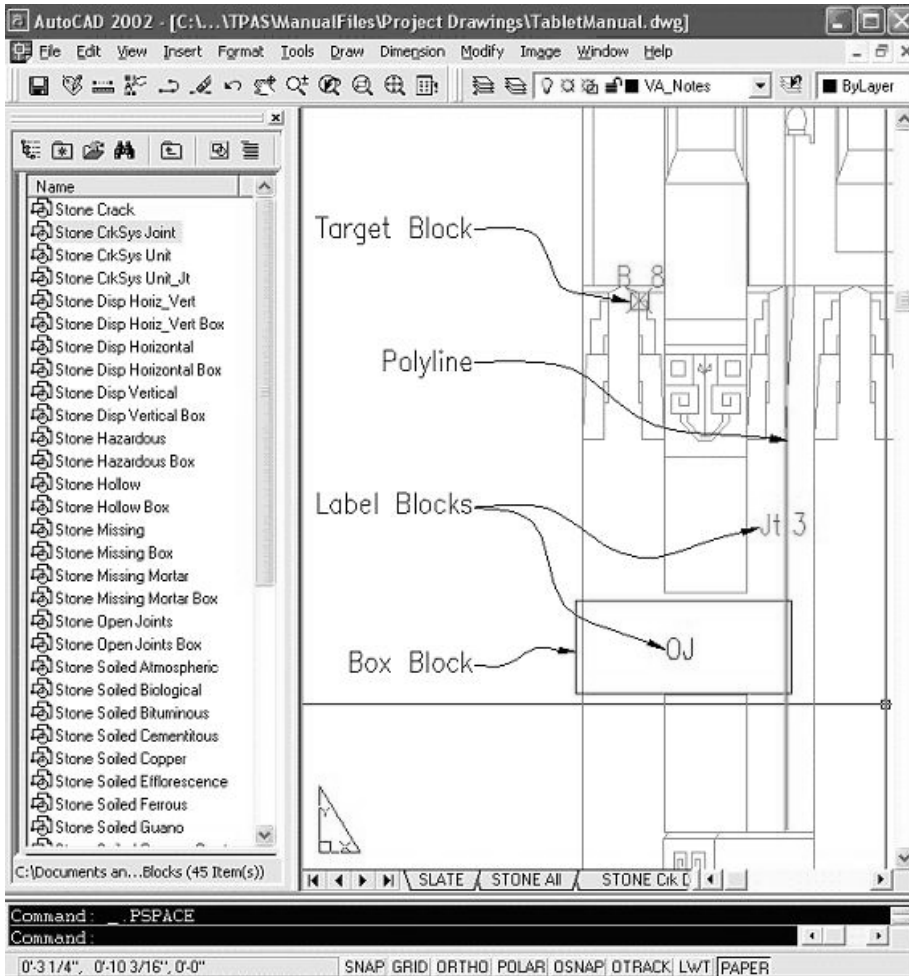


Fig. 2. TPAS block-attribute-tag (BAT) symbols.

Perhaps the greatest benefit of this data-input system is that all incidents of each unique permutation of material, fault type, and extent of condition are automatically assigned to individual CAD layers. This system allows for selective graphical display of the various fault types, a feature that helps in interpreting the graphical data. This feature is a particularly useful tool for identifying and interpreting patterns of deterioration or distress, especially on monumental buildings with thousands of overlapping data points and conditions.

Unfortunately, extraction and layout of the BATs on elevation drawings are accomplished later, in a desktop environment after importing the PocketCAD (.dwg) files into AutoCAD. Extraction of the data entails revealing the tag on the desktop, dragging it to a margin, and drafting a leader from the tag to the icon identifying the location of the

condition. This process is time-consuming, tedious work and offers only a marginal advantage in production time over redrafting hand-annotated field notes with AutoCAD.

Despite this tedium, several benefits were realized with the PocketCAD/iPAQ system, including minimization of interpretive and transcriptive errors combined with automatic layer management. Additionally, because all surveyors using the system are constrained by the same conventions, use of a menu-driven system has a distinctly homogenizing effect on data recorded by different surveyors. Placing data directly into a block-attribute-tag format saves significant time over entering that information in the field and transcribing it into AutoCAD in the office. However, pre-site CAD time is required to partition drawings into smaller sizes or sections that are more easily navigated within the

iPAQ's small screen. (Large elevation drawings require more regeneration time, taking up more time and iPAQ memory.) These partial elevations must then be installed on the laptop and hand-held computers for use in the field.

As with all emerging technologies, gains are accompanied by distinct new liabilities or shortcomings. In a sense, everything becomes more complicated: another level of battery management is required, the data and media are much more ephemeral, and everyone on the crew must be facile with both Windows XP and CE operating systems. A number of scenarios involving version management can lead to a loss of data due to overwriting of files, thus making the loss of productivity a real possibility. Like other emerging technologies, significant up-front costs are associated with the purchase of new hardware and software. Some of these capital costs are related to ensuring on-site security of expensive electronic equipment and valuable data against the inevitability of electronic equipment failure, theft, or damage while on site. To mitigate these possibilities, data is frequently backed-up to a one-gigabyte micro-drive that is stored remotely, away from the field office. This system of direct digital input may have been more efficient in the field and produced a better product with more organized information, but it did not necessarily simplify the logistics of data collection, management, or presentation. Furthermore, we were not entirely happy with the presentation of the graphical data, despite the improvements in other areas, due to the necessity of drawing leaders between the graphical and numerical data associated with individual faults.

GIS for Facade Conditions Surveys

Geographic Information System, or GIS, software has been used for a variety of applications relevant to this discussion, such as the management and inventory of cultural resources, tracking of building maintenance, and mapping the layers of history at archaeological sites. GIS programs such as ArcGIS, published by ESRI, have the ability to associate a wide variety of graphical, numerical, and supplemental data with different objects within a map or draw-

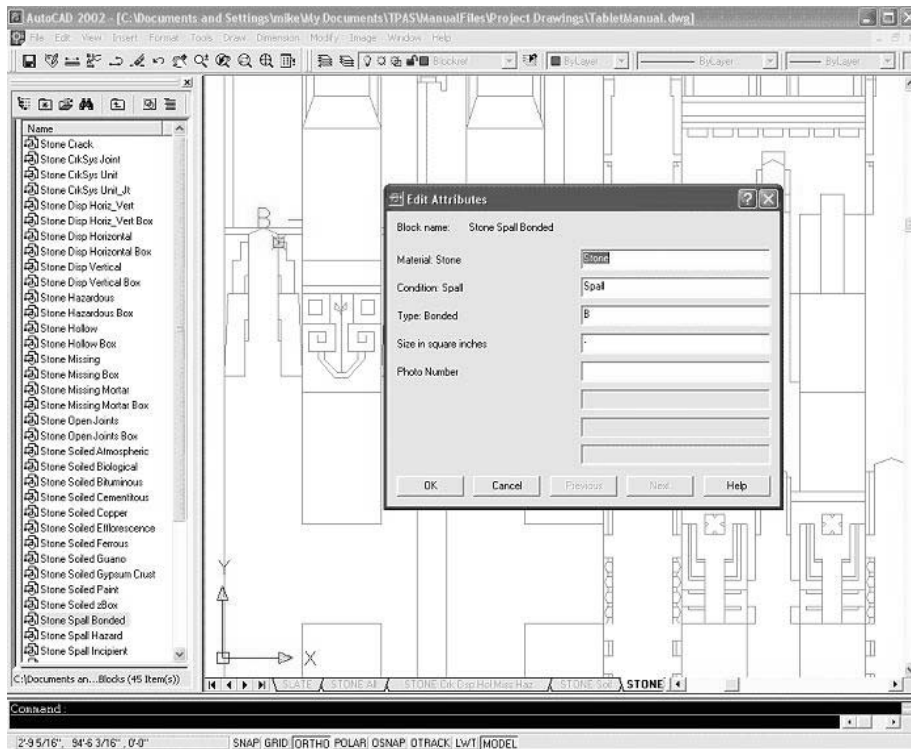


Fig. 3. When inserting a block attribute tag from the design center, the user drags the icon from the list at the left into the drawing, upon which the Edit Attributes dialog box prompts the user for information on the size of the condition in question (in square inches in this case).

ing. Text information, photos, and databases may all be linked to map information using GIS in much the same way that a database may be linked with AutoCAD files.

GIS technologies have great potential for collection and portrayal of facade conditions. Instead of referring to separate drawings, tags, photos, videotapes, and written reports, all this information is linked together in a relational database using GIS. GIS software also has the ability to read AutoCAD files. However, the major limitation with GIS for facade surveys is the difficulty in translating GIS data to a useful format for architects and engineers (i.e., AutoCAD or another CAD program). In mid-2006 it was not possible to convert GIS data to AutoCAD, and because AutoCAD is the standard in the architecture, engineering, and construction industries, there is little practical use for GIS unless the client already works with GIS. (Users of GIS are generally large governmental or institutional organizations, such as the Department of Transportation, the National Park Service, and other planning and infrastructure agencies.)

Other professionals have used GIS-like systems customized and developed from visual-information applications, such as Aperture, for conditions surveys of buildings, structures, and objects.² Unlike ArcGIS, Aperture is compatible with AutoCAD. With the latest version of Aperture Client, one can import AutoCAD drawings to an Aperture project and then export them, making this a very useful tool for CAD users. For some professionals, the combination of Aperture and AutoCAD has proven to be a powerful tool for recording and managing existing-conditions data.

Tablet PC Annotation System (TPAS)

Given the recent development of pen-based tablet computers capable of running AutoCAD 2002 and considering the fact that most of our architectural and engineering clients use AutoCAD, we decided to pursue the development of direct digital data collection using CAD-based capabilities. The Tablet PC Annotation System (TPAS) approach was developed in our office beginning in 2003 and is increasingly

being utilized for our field-survey work, particularly on larger projects. Since the approach builds on the native properties of AutoCAD, we do not consider development of this approach as proprietary. As a result, we intend to share our work as widely as possible.³

To improve TPAS functionality, several customized, non-native tools have been integrated into AutoCAD using the Lisp programming language to further automate the annotation process of recording conditions. The name Lisp is derived from the term *list processing* because the programming code itself is comprised of lists of linked data. Lisp is one of the earliest programming languages that has been used to implement many innovations in computer science. Our custom programming provides enhanced functionality in three important areas:

1. Calculation of area and insertion of the value into the "area" field of an associated label
2. Calculation of the length of a crack as indicated by a polyline and insertion of the corresponding value in an associated label
3. Linking of digital photos with specific AutoCAD BATs, essentially automating the process of photo capture and labeling and locating photos on the drawing

With the third feature, each photo corresponds to a specific fault or condition and is automatically placed and rationally sorted in a volume of appended photographs. This is accomplished via a USB connection between a Canon digital camera and the tablet computer in the field. The Lisp application renames each photo with the x-y or Cartesian coordinate of the associated insertion point of the BAT and automatically creates a new BAT that is hyperlinked to the photo stored on the hard drive. Because every point in an AutoCAD drawing is identified by a unique Cartesian coordinate, this component of the custom TPAS programming constructs an unbreakable hyperlink in the appropriate database field between the photograph and its representative location on the drawing. Photographic images associated with specific faults are graphically indicated on the drawing by individual asterisks that appear adjacent

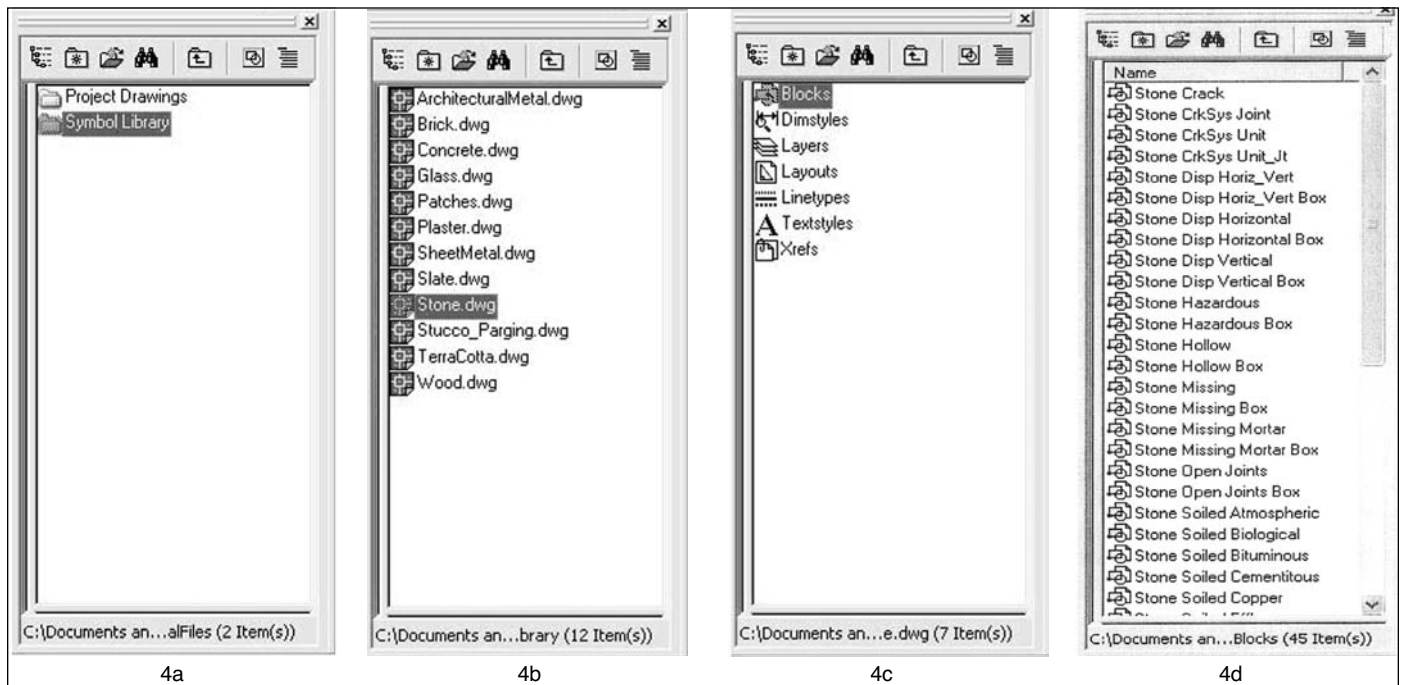


Fig. 4. Double-tapping the Symbol Library folder in Figure 4a brings up the list of block-library drawings shown in Figure 4b. Double-tapping Stone.dwg in Figure 4b generates a list of content types available from that drawing, shown in Figure 4c. Double-tapping Blocks in Figure 4c produces a list of all the blocks in the stone block library, shown in Figure 4d. The blocks in Figure 4d can be dragged and dropped into the open drawing.

to the BAT they represent. We use Canon cameras because they are supplied with Remote Capture software and firmware programs, which allow the photographer to save images to a folder on the computer instead of on the camera's memory card. While Remote Capture is readily available from Canon, the hyperlinks between the photographs and BATs are made by custom Lisp programming.

As mentioned earlier, most of the features and techniques in the Tablet PC Annotation System are native to AutoCAD Releases 2002 and 2004, and AutoCAD is obviously a requirement for utilizing TPAS. TPAS currently utilizes five native features of AutoCAD:

- Block libraries
- Block attribute tags (BATs)
- AutoCAD Design Center
- Selective display of layers within layout viewports (also known as floating viewports)
- Extraction of numerical data contained in BATs to spreadsheet or database programs

Block libraries. It is often convenient to save a number of BATs that have similar

content in a single drawing, so they will be easy to find and reuse; we call this type of drawing a *block library*. Block libraries are a key feature of TPAS and are organized by building material. For example, a block library called “Stone” is made up of symbols for conditions found in stone masonry. The stone block library contains BATs named “Stone Displacement Horizontal,” “Stone Spall Incipient,” or “Stone Crack System Joints,” among others.

BATs. TPAS BATs are graphical symbols that identify locations of fault conditions on survey drawings. The four types of symbols used are targets, polylines, boxes, and labels (Fig. 2).

Targets. To identify the location of a fault condition with a small, discrete location, a symbol resembling a target is placed on the drawing at the fault location. Examples of conditions marked with targets include stone spalls, individual failed fasteners, and punctures in sheet metal. In addition to the graphical symbol, a target includes survey codes identifying the fault condition.

Polylines. In TPAS a polyline is one or more line segments drawn end to end to form a single graphical entity. Polylines

are used in TPAS mainly to indicate cracks and crack systems on a survey elevation.

Boxes. In TPAS boxes are rectangular symbols used to delineate the location of conditions involving areas of the building that are too large to be represented effectively with discrete target symbols. Examples of this type of condition are areas of soiling or open mortar joints. When a box is inserted into a survey drawing, it is stretched to delineate representative areas of interest. Irregular or polygonal areas of fault locations would be generally addressed with a rectangular box.

Labels. Labels are dragged and dropped from the design center just like targets. For example, labels are placed on the drawing adjacent to a “crack” polyline to describe the type and severity of cracks. Similarly, labels can be placed within boxes indicating additional information. Using custom programming, numerical or descriptive label information can be linked with its associated polyline or box block. At this time, other than proximity to each other on the drawing, no associative link exists between polylines and boxes and their respective labels.

AutoCAD Design Center. BATs are inserted by “dragging and dropping” from a block library placed in the AutoCAD Design Center directly into an elevation drawing during a survey. The Edit Attributes dialog box shown in Figure 3 includes descriptions explaining the survey codes and prompting the user to input variable data (crack length, spall size, etc.). Each block attribute tag represents a database record, which can be exported to a spreadsheet or database application.

TPAS uses a hierarchical, or tiered, structure for its survey codes:

Material
 Condition
 Type or Severity
 Amount or Extent
 Photo Location Identification Number

The dialog box to the left of the drawing in Figure 3 shows a list of BATs from the stone block library. The dialog box is called the AutoCAD Design Center. This feature allows the user to drag and drop information from one drawing to another, but during a field survey, Design Center is needed only to bring BATs from a block library into an elevation drawing to mark conditions.

In Figure 3 at the bottom of the design center, the block attribute tag “Stone Spall Bonded” is highlighted. To insert it into the drawing, one selects the tag symbol in the design center and drags it into the drawing, placing it at the correct location on the elevation. Immediately after placing the tag, the Edit Attributes dialog box opens so the user can input the size information. To finish annotating the spall, one enters a number for the size and taps the OK button. The Edit Attributes dialog box closes, and the surveyor moves on to the next observation. While in the field, surveyors must be careful in the placement of BATs so as not to overlap existing ones or move those previously placed.

Figure 3 shows the block named “Stone Spall Bonded” as it is inserted into a drawing. The symbol includes a target graphic to show where the spall is located on the building and attribute codes describing the spall. Above the target the condition and size codes appear: “B” for bonded and a hyphen



Fig. 5. TPAS in action at the Thurgood Marshall Federal Courthouse, New York, N.Y. Photograph by Kent Diebolt.

where the dimensional data will appear after the user enters it into the dialog box. A photo number will appear automatically below the target if the user has taken a picture of the spall. Notice that the attributes “Material” and “Condition” appear in the dialog box but not in the onscreen symbol. In order to reduce on-screen graphical clutter, these two attributes have been preset to be “invisible” in the inserted block.

AutoCAD Design Center uses a familiar folder-type system to find information within drawings. Figures 4a-4d illustrate how to navigate from a file folder that contains several block libraries to a list of the blocks available in the stone block library.

Selective display of layers. When using TPAS very little layer management is required in the field. BATs maintain their separate, individual layer properties when they are inserted from a block library into a survey drawing.

If one is experienced with AutoCAD, then the concept of layers is familiar. When a graphical or textual object is created in AutoCAD, it is associated with a particular group of other objects that together comprise a layer within the drawing. This group of objects (the

layer) can be brought in and out of view by turning the layer on and off. The objects of a layer can also be protected from changes by “locking” the layer. In AutoCAD the states of being “turned off” or “locked” are said to be properties of a layer. Layers have several other properties as well and are viewed in a dialog box called the Layer Properties Manager.

Layer properties appear in the Layer Properties Manager as column headings:

- Name describes the unique identifier of AutoCAD entities that are grouped by common properties.
- On/Off, Frozen/Thawed properties determine whether objects on a layer are visible or not.
- Locked/Unlocked determine when a layer can or cannot be edited.
- Color is an object property usually controlled by layer.
- Plot/No Plot layers can be set to print or not.

A drawing can include an infinite number of layers. In a complex drawing, the number of layers can easily run into the hundreds.

Extraction to databases and spreadsheets.

After field work is completed, one may use the native features of AutoCAD to extract and import survey data to a database program such as Access or a spreadsheet such as Excel. In these formats qualitative field-survey data can be sorted and quantified according to material or condition for the purposes of analysis and cost estimating.

TPAS: Practicalities and Promises

The process of documenting existing conditions with TPAS has proven to be an effective and efficient means of recording and presenting facade-survey data. For those experienced with pen-based computers, such as a Palm Pilot or a similar device, the stylus will be familiar. Anyone accustomed to working in a Windows-based environment on a desktop computer will find TPAS’s library of BATs easy to navigate. As with all new tools, there is a learning curve associated with TPAS, and the more one uses it, the easier and faster it becomes. Even if more time is spent in the field due to the constraints of the menu-

driven system, entering data, typing notes using a stylus, and utilizing a computer that is connected to a camera, there is no doubt that TPAS greatly reduces time in the office after the survey work is completed (Fig. 5).

While use with AutoCAD drawings is standard, TPAS can also be used with rectified photographs or scanned images. Rectified photography and photogrammetry are both used to correct perspective problems or distortion from the lens of a camera. These techniques combine photographs taken at slightly different angles and correct their perspective using computer software to produce elevations that are approximately to scale. So-called "photo-elevations" are often used by architects and engineers when drawings are not available or time and budgets do not allow for development of measured drawings.

Prior to on-site survey work, AutoCAD drawings and TPAS must be loaded on to the tablet computers. In order to save time, Vertical Access has developed a large library of materials and conditions encountered on historic buildings that can be utilized for most projects. For example, standard materials such as architectural metals, brick, concrete/cast stone, glass, plaster, sheet metal, slate, stone, stucco, terra cotta, and wood are a part of the existing TPAS library. If additional or customized BATs are required for a particular survey, they would necessitate additional preparation time. As new BATs are developed, they can be added to the library and will always be available for use in future projects. For unanticipated materials or conditions, TPAS provides a separate "Notes" layer in which text or written descriptions may be included anywhere in the AutoCAD drawing.

One challenge still remains in bringing TPAS into the field for on-site data collection in real-world situations, such as on pipe scaffolding and swing staging or in an industrial rope-access environment. In these situations ruggedized tablet PCs are optimal but typically cost twice as much as less robust or hardened machines. An alternative to the significant up-front capital cost of ruggedized tablet computers is to purchase extended warranties, which cover accidental damage to the machine.

Key issues of overall durability, battery life, and screen visibility in bright sunlight are crucial factors in the process of selecting a tablet PC for use with TPAS. In our experience, a normal indoor-viewable TFT (thin film transistor) or active matrix LCD screen is generally not suitable for use in the field. The alternative is a transreflective screen that is lighted from the sides, rather than TFT or LCD screens, which are lighted from the back. No doubt, newer tablet computers offering still better screen technologies will appear in the future. At the time of publication Vertical Access used M1400 computers with the View Anywhere indoor/outdoor display by Motion Computing, which provides enhanced visibility.

Conclusion

One question for the future is how the preservation community as a whole can benefit from standardization in recording and presenting existing-conditions information. An unintended but potentially useful consequence of a broad acceptance of TPAS, or a similar system, may be the development of a standardized, universally understood glossary of fault codes and conditions. TPAS and other systems like it may offer an incentive for standardization in the representation of existing-conditions information, similar to terminology established by the American Concrete Institute for concrete faults and deficiencies.⁴

The ultimate goal of TPAS is to help prepare comprehensive conditions-survey documents and accurate cost estimates, resulting in better-informed construction documents and maintenance plans. Having extracted the quantities of repairs into a spreadsheet, gross quantities can be established for cost estimating. In proceeding to the next step of turning the survey data into construction documents, it is possible to overlay treatment codes or repair tags onto the same drawing. While treatment codes can be generally assigned to the BATs, interpretation of the material/condition is still required on a case-by-case basis. Not all the same conditions will require the same repair. The advantage in interpreting the survey data using

TPAS is that all the information (including photographs and quantities) is available from within the AutoCAD drawing, thereby eliminating going back and forth between paper drawings, photographs, and notes.

Additional applications for TPAS include assisting in cultural-resource or facilities management, archaeological sites, and the documentation of as-built or repair conditions during construction.

In the field and office, building professionals must synthesize, evaluate, and share various forms of data and media to accurately document and understand existing conditions. The Tablet PC Annotation System makes a significant contribution to the work of preservationists by creating a potent and systematic means of directly recording, managing, and interpreting this information.

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Notes

1. Albert Leung, Sanjiv Nathwani, and Avanti Shroff, "Implementation of Total Electronic Inspections for Bridges" (paper, International Bridge Conference, Pittsburgh, Penn., June 1997), 1. The authors state that the collection and management of the overwhelming amount of information generated in bridge inspections take away from the tasks of engineering assessment and decision making.

2. Michael Lengyel and Alfonso Narvaez, "New Approaches to Historic Site Management" (paper, Traditional Building Exhibition and Conference, New Orleans, La., October 2001). The Preservation Management Program was developed by John Milner Associates, Inc., Alexandria, Va.

3. TPAS may be downloaded via the Vertical Access Web site, www.vertical-access.com/resources.html.

4. American Concrete Institute, *Guide for Evaluation of Concrete Structures Prior to Rehabilitation 364.1R-94* (Farmington Hills, Mich.: 1994, reapproved 1999), 12. American Concrete Institute, *Guide for Making a Condition Survey of Concrete in Service, ACI 201.1R-92* (Farmington Hills, Mich.: 1992, reapproved 1997), 5–16.