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INTEGRATING MICROCOMPUTER CADr AND BILL OF MATERIAL ROUTINES USING AUTOCAD.

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Abstract.

Through the integration of microcomputer-aided draughting (CADr), and in particular with AutoCAD, the industries most extensively used CADr program, and automated routines for the production of bills of materials, a dramatic increase in productivity is possible in the architectural design domain. Working from a variety of material take off methods complete cost estimates may be achieved through the manipulation of drawing data and exchanging the information with third-party estimating software. However, the area of study is currently at a formative stage of development and full integration, although technically feasible, is rarely attempted. Therefore, the paper comments on the development of 'in-house' routines using AutoCAD's data extraction features and AutoLISP; reviews current commercial systems of interfacing AutoCAD with bills of materials and automated specification routines; and, finally, discusses possible future advances in this major area of study.

Introduction

The College of Architecture at Georgia Tech. offers a number of taught CAD courses that utilize AutoCAD (1), the most extensively used computer-aided draughting (CADr) program in the U.S.A. The College has two computer-laboratories equipped with twenty and twenty-eight Tandy 4000-386 microcomputers, VGA colour monitors, and ancillary equipment including plotters, printers, SONY overhead projectors, respectively. The laboratories are available for instruction at the undergraduate and graduate level to all students within the College. The CAD laboratory microcomputers are equipped with 70mb hard drives partitioned to accommodate AutocAD v10.0, the AEC package, and standard business software packages such as WordPerfect, Lotus and dBASE. Space is also allocated for student generated files. A NOVELLE networking system is to be introduced during the 1989-1990 academic year.

CAD courses taught within the College explore the draughting and 2-D/3-D modelling capabilities of AutoCAD; apply AutoSHADE and AutoFLIX to architectural modelling problems; develop routines with AutoLISP; and, finally, examine the potential of integrating bill-of-material routines with AutoCAD. The last course is taught by the author to a class of approximately 25 construction, architecture and civil engineering students as a senior level undergraduate special topics subject, and forms the basis for discussion within the paper.

Automated Bills-of-Materials

Procedures for the production of automated bills of materials are an inevitable development of the process of CADr in the construction industry, with users desiring to maximize the usefulness of the graphic information generated during the drawing stage. At its most basic level this may simply reflect a desire to interrogate the graphic database for the line lengths and other simple geometric properties. On the other hand, at its most sophisticated, a complete integration of drawing and cost estimating data may be desired, with the user attempting to merge the graphic and non-graphic data associated with the building project into a single description of the building. In order to achieve the latter objective using AutoCAD the user typically assigns non-graphic information to the graphic elements and, subsequently, transfers that information, along with the graphic element's database, to third-party software. This software may either be a standard business package, e.g. Lotus 1-2-3. dBASE III +/IV etc., or a custom developed software routine that manipulates the extracted data to form a bill-of-materials.

With AutoCAD, non-graphic data is termed an attribute, ie. words or numbers that may be attached to a drawing entity that allows the user to define the characteristics of the entity. Attributes assigned to an entity may either be displayed on the drawing or hidden, ie. embedded, in the entity description. However,

attributes created using AutoCAD are required to be associated with a **BLOCK**, ie. a collection of graphic entities that form a drawing element such as a door, a window or a wall element, etc.

User defined attribute descriptions may include the manufacture's written description of the product, e.g. the part number, size, colour, or cost. In addition, additional graphic information associated with the **BLOCK** may be extracted from the drawing element , e.g. **LAYER, BLOCK NAME,** Cartesian cc-ordinate geometry of the various entities that form the element, etc. Attributes may be associated with a single entity, all similarly identified entities, or as parts of a complex entity where the original **BLOCK** is embedded within a more elaborate **BLOCK.**

Attribute Commands

Attribute commands associated with AutoCAD include:

* **ATTDEF** - defines how attribute text will be stored.

* **ATTDISP** - controls how attribute text will appear on the screen

* **ATTEDIT** - allows the user to change attribute text once it has been inserted into a drawing BLOCK.

* **ATTEXT** - extracts attribute text and formats the text into a report.

(The following abbreviated descriptions may be expanded by reference to either the AutoCAD manual (1) or Raker and Rice's "Inside AutoCAD" (2).)

The **ATT**ribute **DEF**inition command, **ATTDEF**, when invoked, prompts the user to define the attribute text as well as to control the appearance of the text associated with user defined element. For example, attribute text may be inserted as **invisible** to the drawing, **constant**, ie. a standard "boilerplate" entry, or in **verify** mode. The last facility allows the user to edit variable attribute text before inserting it into the drawing file. (Attributes may be invisible, constant or verified at the same time.) Continuing, **ATTDEF** requires the user to define an attribute **tag**, ie. the name of the text that is to be inserted, an optional attribute **prompt** and, finally, the text associated with the attribute. This last request follows normal AutoCAD **TEXT** prompts. Once all attributes have been assigned to a particular drawing entity, the user is required to combine all graphic and non-graphic elements into a **BLOCK**. At each subsequent **BLOCK INSERT** all normal graphic prompts will be invoked along with all user defined attribute prompts. If the BLOCKs are to be used as separate drawing files, the **WBLOCK** command should be used.

An example of **ATTDEF** is given below. The written specification relates to two external walls used in domestic construction,

table 1 .

```
Table 1
-----------------------------------------------------------------------
0412521110 EXTERIOR BRICK VENEER:

STANDARD BRICK, 4" THICK, RUNNING BOND               S.F.    7.10
WOOD STUDS, 2" x 4", @ 16" CRS                       L.F.    0.77
EXTERIOR GRADE PLYWOOD SHEETING                      S.F.    0.74
BUILDING PAPER, ASPHALT TYPE                         S.F.    0.09
FIBER GLASS INSULATION, BATTS, 3 1/2" THK            S.F.    0.36
MISCELLANEOUS COMPONENTS                                     0.00
-----------------------------------------------------------------------


-----------------------------------------------------------------------
041412165 EXTERIOR BEVELED SIDING:

WOOD STUDS, 2" x 4", @ 16" CRS                       L.F.    0.91
EXTERIOR GRADE PLYWOOD SHEATHING                     S.F.    0.74
BUILDING PAPER, ASPHALT TYPE                         S.F.    0.09
FIBER GLASS INSULATION, BATTS, 3 1/2" THK            S.F.    0.36
EXTERIOR STAIN, 2 COATS & SEALER                     S.F.    0.67
CEDAR SEV. SIDING, 1" x 5"                           S.F.    2.28
-----------------------------------------------------------------------
```

Each line of description relates to a single **ATTDEF.** The writer descriptions may or may not appear on the drawing at the user's request. Default tags and prompts may be used to minimize data entry, e.g. the **TEXT** description for the first wall, the exterior brick veneer, may be used as a default setting. With this particular example this would be appropriate since three of the specification clauses are identical to both wall types. Additionally, the cost and unit parameters may either be separately defined as attributes within the **BLOCK** description, or they may be identified later after the attribute extraction procedure during the bill-of-material part of the work.

Once an attribute has been assigned to a **BLOCK or WBLOCK** it is possible to control the display visibility of an attribute with **ATTDISP** or to edit the assigned data using the **ATTEDIT** command. However, for the purpose of this paper, no further comment on **ATTDISP** or **ATTEDIT** features will be given. Continuing, the **ATTEXT** command allows the user to extract the **ATTDEF** data from the drawing file and to either print that information as a separate report or to transfer the data to another software routine.

AutoCAD currently provides three ways to extract attribute text from a drawing file and format it in a disk file, ie. **CDF** (Comma Deliminated Format), **SDF** (Standard Data Format), or **DXF** (Drawing Exchange File). (The SDF format is similar to the CDF format, but without the commas. In this case, the data field length is standardized to a pre-formatted length. Data extracted to an SDF file that is larger than set data value length is

truncated.) The SDF extract file is a standard ASCII file that may be read by many standard software packages including Lotus 1-2-3 and dBASE III +/IV.

In order to extract the attribute data, the user must first create an ASCII file that defines the order of the data extraction. For example, the following template file may be used to extract the facing material assigned to the previous external wall attributes, shown table 2.

Table 2.

```
------------------------
BL:NAME          C015000
BL:X             N006002
BL:Y             N006002
DUMMY            C002000
DESCRIPTION      C050000
UNITS            C005000
COST             N010002
------------------------
```

The left hand column defines the attribute tag, the second column the format by which the data should be extracted, with the prefix C or N defining a (C) character or (N) numeric data file, respectively. Attribute tags shown BL:(nnnnnn) indicate a predefined BLOCK title (nnnnnn). In this case the **BLOCK** name (user defined) and the X and Y co-ordinates relate to the **BLOCK** entry point. The DUMMY line facilitates ease of reading the extracted data, indicating two additional columns between the "y" coordinate column and the attribute description.

SDF Exchange and AutoLISP Examples

A recent graduate project (3) at Georgia Tech. demonstrated the ease of using the SDF extraction routine, transferring the data to Lotus 1-2-3 where the information was subsequently manipulated to create a generalized bill-of-material for a set of office equipment and furniture, table 3. (In this example, the ASCII format data was imported into the Lotus 1-2-3 spreadsheet as a text file using the **FILE IMPORT** command. Subsequently, invoking the **DATA PARSE** command, the various numeric and text data fields were assigned to unique cell addresses from the original imported single text field. A simple count macro thereafter determined the itemized graphic elements.)

Table 3.

ITEM	STYLE	MANUFACT	MATERIAL	COLOR	FABRIC	COST
CHAIR(A)	124	IVAN ALLAN	Polyurethane	Black	n/a	$100
CHAIR(B)	130	IVAN ALLAN	Polyurethane	Red	n/a	$100

```
CHAIR(C)   167      STOREHOUSE   Timber        Black    wool     $150
DESK(A)    208      HABITAT      Timber        White    n/a      $220
DESK(B)    250      STOREHOUSE   Metal         Grey     n/a      $320
FILE       400      IVAN ALAN    Metal         Grey     n/a      $120
SOFA       310      STOREHOUSE   Timber        Black    wool     $450
---------------------------------------------------------------------
```

```
-----------------------------------------
ITEM          NUMBER    COST    TOTAL COST
=========================================
CHAIR(A)      1         $100    $100
CHAIR(B)      1         $100    $100
CHAIR(C)      4         $150    $600
DESK(A)       2         $220    $440
FILE          2         $120    $240
SOFA          2         $450    $900
=========================================
TOTAL COST              $2380
-----------------------------------------
```

A further refinement of these procedures may be illustrated by reference to a
second project (4) where all user defined **WBLOCKs** were inserted into the
drawing file using user-defined POP-down menus. In this instance the student
created a catalogue of building elements, including doors, windows, and
partitions, as well as the various range of office furniture and equipment.
(The creation of custom menus within AutoCAD are relatively easy. The user
simply creates an ASCII text file of the various commands required within the
menu, invoking the **MENU** command to change menus. Architectural students at
Georgia Tech. are first encouraged to adapt the main **ACAD** menu, and then to
subsequently to experiment with various user defined menu options.) Table 4
illustrates the coding for a pop-down door menu.

```
Table 4.

---------------------------------------
***POP6
[Doors]
[ Single]
[ 30 in.]^Cinsert sw30 drag \ drag
[ 36 in.]^Cinsert sw36 drag \ drag
[ 60 in.]^Cinsert sw60 drag \ drag
[ 72 in.]^Cinsert sw72 drag \ drag
[FOLDING]^Cinsert fw24 drag \ drag
---------------------------------------
```

Attribute information relating to the size and position of the doors is taken
automatically from the coded element inserted into the drawing. In addition.
data prompt built into the **WBLOCK** request the user to define the supplier
and cost of each element. Default values are also built into the model should
the user not have the information requested to hand. As with the previous

example, the extracted information is subsequently transferred via a SDF(ASCII) file to a Lotus 1-2-17 template file.

Further refinements are possible utilizing the AutoLISP command structure in an attempt to semi-automate the drawing and attribute assignment procedures. in this case (5), as an illustration of the methodology, two parametric drawing elements were created, ie. the two external wall details described earlier, table 1. Using the AutoLISP programming language, user defined macros were created that allowed the operator to set construction variables such as wall length, direction, connectivity etc., and to transfer the data automatically to the Lotus 1-2-3 spreadsheet. In addition, the operator was able to "place" on the walls selected doors and windows, the procedure being sufficiently automated to recalculate the split wall lengths and to identify the materials required for their construction. (The doors and windows were selected from a previously defined range.) As an illustration. the following sequence of prompts and commands shows the construction of a simple wall, the user selecting from a user defined tablet menu the desired wall construction, e.g. the exterior brick or beveled wood siding, table 5.

```
Table 5.
----------------------------------------------------------
Start point of wall: [POINT]
Length of wall {F'I"}; [A DISTANCE]
Direction of wall: [AN ANGLE]
Length of next wall {F'I"): [A DISTANCE]
Direction of wall; [AN ANGLE]
Which side is the inside face of the wall?: [Point]
Do you want to draw another wall?. [Y OR N]
Does the next wall close to the start point?: [Y OR N]
----------------------------------------------------------
```

(User responses are shown in the above illustration underlined.)

Continuing, the user is prompted to draw all internal walls. The command structure is similar to the external wall commands. The command for placing doors and windows may be illustrated below, table 6.

```
Table 6.
----------------------------------------------------------
Indicate point on the outside face of the wall: [POINT]
Model number of Door/Window?: [TEXT]
Manufacturer of the Door/Window?: [TEXT]
----------------------------------------------------------
```

The specification data for the doors and windows in this example

had previously been assigned to various **WBLOCK** drawing files, their insertion point being selected by the user directly to the drawing via the door/window type established from the tablet menu. Finally, to invoke the bill-of-material take-off procedure the user simply selects the **take-off** command from the tablet menu. A typical cost estimate sheet is shown in table 7. With this example, a refinement of the previous procedures may be demonstrated by reference to the area calculations for wall and floor coverings. The raw data for these items has been extracted from the AutoCAD embedded **BLOCK** data relating to line length and area.

Table 7.

```
--------------------------------------------------------------------
Window and Door Schedule
WIDTH      HEIGHT    MODEL     MANUFACTURER      COST     AREA     MARK
====================================================================
3'0"       4'2"      3042DH    ACORN            120.00   12.5      W
2'6"       4'2"      2642SH    ANDERSON         100.00   10.4      W
3'0"       6'8"      4977FL    ACORN            145.00   19.0      D
====================================================================
Wall and Floor Extracted Data


ROOM      AREA      PERIMETER    WALL TYPE    FLOOR TYPE     WALL AREA
====================================================================
GROSS     1297      1779         WT1                         14323
--------------------------------------------------------------------
BATH      317       865                       FT4            6920
SED1      362       1090                      FT3            8720
LIVING    321       950                       FT2            7600
====================================================================


EXT DOOR    WINDOW      NET WALL    WALL      FLOOR     ROOF
AREA        AREA        AREA        COST      COST      COST
====================================================================
37.78       33.34       14160       $154778   $2010     $3968
====================================================================
```

Review

The various routines developed by the students clearly demonstrates the flexibility of AutoCAD. The program's command structure is sufficiently flexible and comprehensive to enable a relatively unsophisticated user to create a working bill-of-material from an architectural design. However, it should be added that a number of commercial systems (6,7,8,9,10,11 and 12) are available that add a more polished output to the student exercises previously illustrated. (Most commercial systems allow the user a degree of flexibility in the use of their systems, e.g. produce alternative pricing depending upon unit volume; generation automatically order forms; inclusive of extensive

symbol and parts libraries, etc. In addition, most of these systems may be customized by the user, an invaluable feature in the construction industry where working methods and billing procedures often vary from company to company. Nevertheless, it could be argued that the development of "in-house" routines by the students aids their understanding of CADr, in particular the principal of sharing common data between the various modelling aspect of construction. In addition, the ability transfer data from one software package to another through their creation of custom menus and database extraction files is extremely valuable for it tends to broaden the scope and flexibility of commercial software. The eventual creation of elementary billing procedures in a spreadsheet format demonstrates to the students that their professional abilities need not be limited to the stereotype.

As a further development of the work, it is intended to explore in future courses the formal link between Timberline's' Precision Estimating Plus construction estimating program (13) and AutoCAD. A formal, sole licensing agreement was recently signed between the two companies to develop an industry standard automatic billing routine. This has resulted in the introduction of Timberline's CADLink program, a package that will enable users to embed within their drawings building specifications directly from the Precision Plus database. In addition, a bill-of-materials and quantities will be generated from the geometric and attribute data described on the architectural drawing. (A separate cost-estimation course offered within the College of Architecture currently uses the Precision Plus package. Hence, the future development work is a logical extension of the previous AutoCAD course.)

In summation, these current and future developments clearly demonstrate the additional power that the most rudimentary of CADr systems offer to the contractor and designer. The drawing becomes more than a simple geometrical representation of shape and configuration, and becomes a repository of information for cataloguing, costing and design appraisal. Information shared by all within the construction industry.

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