N92-16601

IMPROVING NAVFAC's TOTAL QUALITY MANAGEMENT OF CONSTRUCTION DRAWINGS WITH CLIPS

by

Albert Antelman AIA
Shore Facilities Department
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

ABSTRACT This paper describes a diagnostic expert system to improve the quality of Naval Facilities Engineering Command (NAVFAC) construction drawings and specification. CLIPS and CAD layering standards are used in an expert system to check and coordinate construction drawings and specifications to eliminate errors and omissions.

INTRODUCTION

Designing and constructing naval shore facilities for the United States Navy is a complex process. The quality of construction documents is a major factor in this process. The review and coordination of construction drawings and specifications is one of the critical tasks performed by NAVFAC architects and engineers. Defective drawings and specifications can lead to change orders, time delays, and litigation.

Experience has shown that more than half of the errors and omissions found in construction drawings and specifications result from inadequate coordination between architectural and engineering disciplines (Nigro, 1984). A recent study by the U.S. Army Corps of Engineers found that more than 95 percent of all review comments addressed coordination issues (Kirby, 1989).

In response to the problem, NAVFAC implemented a quality assurance program in April of 1986. An interdisciplinary coordination review checklist was developed to check for in-consistencies, interferences, errors and omissions, both technically and graphically, that may exist in or between disciplines. A recent survey by Charles Markert, NAVFAC's Deputy Assistant Commander for Engineering and Design found that NAVFAC has discovered significant benefits from conducting interdisciplinary coordination checks at the final design stage of projects (DCQI, 1990).

The NAVFAC interdisciplinary coordination checklist contains over 500 review items. The checklist, when used conscientiously, can eliminate many of the design deficiencies which have occurred in past construction projects. Current procedures calls for each checklist item to be analyzed for applicability to the project's drawing and specification content. This is accomplished by manually reviewing the drawings and specifications with the checklist. If an item is found not applicable, the letters "NA" will be inserted adjacent to the checklist item. The remaining checklist items are used to perform the interdisciplinary coordination review.

PRECEDING PAGE BLANK NOT FILMED

THE PROBLEM

The development and application of quality control coordination checklists is a step in the right direction, but does not provide a production oriented solution to the problem. Often checklists contain several hundred items which may not be applicable to the drawing and specification content. Typically, due to quantity and nonapplicability, checklist items are often ignored during the review process. The process of editing, comparing, and coordinating checklist items with the drawings and specifications is time consuming considering it is not unusual for project drawings to exceed 50 sheets. Checklist editing also assumes a level of experience the reviewer may not possess and may well result in the non-prioritizing of the issues being checked.

The majority of NAVFAC's construction drawings are produced using manual drawing procedures, but this is rapidly changing. NAVFAC as well as architectural/engineering firms under contract to NAVFAC have made heavy investments in computer-aided design (CAD) hardware and software. Receiving construction drawings delivered in a CAD format is becoming common. Despite the self-coordinating aspects of CAD drawings, coordination and omission errors can still arise. No matter what process (manual drafting, systems drafting or CAD) is used to produce a set of construction drawings, all drawings need to be checked (Duggar, 1984).

OBJECTIVE

The objective of this project is to produce an easy-to-use, automated, expert system, capable of quickly analyzing project data (drawing and specification content), recognize potential coordination issues, establish review priorities and provide quality control guidance specific to the project being reviewed. The expert system must function as an intelligent assistant which provides the user with knowledge (advice) based on expert experience and lessons learned from past projects with similar drawing content.

SOLUTION

The solution to the problem of automating the quality review of construction drawings and specifications is to develop a rule-based diagnostic expert system capable of reading the drawing contents of CAD drawing database files. The C Language Integrated Production System (CLIPS) was selected as the expert system shell and AutoCad software running in conjunction with the CadPLUS Total Architectural/Engineering software was selected to produce the CAD drawings.

The CAD Data Base

The CadPLUS Total Architectural/Engineering System is a powerful facility design tool developed by the Naval Civil Engineering Laboratory and CadPLUS Products Company of Albuquerque, NM under a Cooperative Research and Development Agreement. The software runs in conjunction with AutoCad and implements the CAD Layering Guidelines published by the American Institute of Architects (AIA).

In order to insure reusability of CAD drawings during a facility's life cycle, NAVFAC has adopted a standard approach for the use of CAD layers. Layering is "the basic method most CAD systems use to group information for display, editing, and plotting purposes" (Schley, 1990a). NAVFAC along with the American Institute of Architects, the American Consulting Engineers Council, the American Society of Civil Engineers, International Facility Management Association, United States Army Corp of Engineers and the Department of Veterans Affairs sponsored the development of a standard approach for the use and naming of CAD layers.

It was not the intention of the CAD Layering Guidelines to attempt to use layers to carry "drawing intelligence" (Schley, 1990a), however the CAD Layering Guideline's structure and format, see Figures 1 through 5, provide a detailed description of a project's drawing content. Drawing content is the key to determining the applicability of interdisciplinary coordination checklist items.

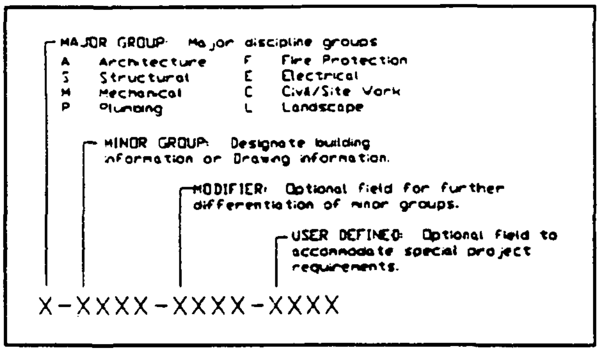

Figure 1. AIA layer name format (Schley, 1990b)

ARCHITECTURE	
A-WALL	WALL
A-DOOR	DOORS
A-GLAZ	WINDOWS
A-FLOR	FLOOR INFO
A-EQPM	EQUIPMENT
A-FURN	FURNITURE
A-CLNG	CEILING INFO
A-ROOF	ROOF
A-SHBD	SHT/BORDER
A-PFLR	FLOOR PLAN
A-PLGS	LG SCALE PLAN
A-PCLG	REFLECTED CEILING PLAN
A-PROF	ROOF PLAN
A-PEQM	EQUIP PLAN
A-ELEV	ELEVATIONS
A-SECT	SECTIONS
A-DETL	DETAILS
A-SCHD	SCHEDULES

PLUMBING	
P-ACID	ACID, ALKALINE AND OIL
P-DOMW	DOMESTIC HOT & COLD WATER SYS
P-SANR	SANITARY DRAINAGE
P-STRM	STORM DRAINAGE
P-EQPM	PLUMBING MISC EQUIPMENT
P-FIXT	PLUMBING FIXTURES
P-SHBD	SHT BORDER/TITLE
P-PPLM	PLUMBING PLAN
P-PDRA	STORM DRAINAGE
P-PSAN	SANITARY DRAINAGE
P-RISR	PLUMBING RISER DIAGRAM
P-ELEV	ELEVATIONS
P-SECT	SECTIONS
P-DETL	DETAILS
P-SCHD	SCHEDULES

STRUCTURAL	
S-GRID	COLUMN GRID
S-FNDN	FOUNDATION
S-SLAB	SLAB
S-ABLT	ANCHOR BOLT
S-COLS	COLUMN
S-WALL	BEARING/SHEAR WALL
S-FRAM	BEAMS/JOISTS
S-SHBD	SHT BORDER/TITLE
S-PFND	FOUNDATION PLAN
S-PSFR	FRAMING PLAN
S-PCOL	COLUMN PLAN
S-ELEV	ELEVATIONS
S-SECT	SECTIONS
S-DETL	DETAILS
S-SCHD	SCHEDULES

ELECTRICAL	
E-LITE	LIGHTING
E-POWR	POWER
E-CTRL	ELEC CONTOL SYSTEM
E-GRND	GROUND SYSTEM
E-AUXL	AUXILIARY SYS
E-LTNG	LIGHTNING PROTECTION SYS
E-FIRE	FIRE ALARM SYS
E-DATA	DATA SYSTEMS
E-SOUN	SOUND/PA SYSTEMS
E-TVAN	TV ANTENNA SYS
E-CCTV	CLOSED CRT TV
E-NURS	NURSE CALL SYS
E-SERT	SECURITY SYSTEM
E-SHBD	SHT BORDER/TITLE
E-PLIT	LIGHTING PLAN
E-PPOW	POWER PLAN
E-PCOM	COMMUNICATION SYSTEM PLAN
E-PROF	ELEC ROOF PLAN
E-LEGN	LEGEND
E-1LIN	ONE LINE DIAGRAM
E-RISR	RISER DIAGRAM
E-ELEV	ELEVATIONS
E-SECT	SECTIONS
E-DETL	DETAILS
E-SCHD	SCHEDULES

MECHANICAL	
M-BRIN	BRINE SYSTEM
M-CHIM	PREFAB CHIMNEY
M-CMPA	COMPRESSED AIR
M-CONT	CNTRL & INSTR
M-DUST	DUST & FUME COLLECTION
M-ENER	ENERGY MNGT
M-EXHS	EXHAUST SYSTEM
M-FUEL	FUEL SYS PIPING
M-HVAC	HVAC SYSTEM
M-HOTW	HOT WATER HEATING SYSTEM
M-CWTR	CHILLED WATER SYSTEM
M-MDGS	MEDICAL GAS SYS
M-PROC	PROCESS SYSTEM
M-REFG	REFRIG SYSTEM
M-SPCL	SPECIAL EQUIP
M-STEM	STEAM SYSTEM
M-SHBD	SHT BORDER/TITLE
M-PPIP	PIPING PLAN
M-PDUC	DUCT PLAN
M-PEXD	EXHST DUCT PLAN
M-PHVA	HVAC PLAN
M-PSTM	STEAM PIPING PLAN
M-PWCH	CHILLED WATER PIPING PLAN
M-ELEV	ELEVATIONS
M-SECT	SECTIONS
M-DETL	DETAILS
M-SCHD	SCHEDULES

LANDSCAPE	
L-PLNT	PLANTING & LANDSCAPE MATERIALS
L-IRRG	IRRIGATION SYSTEM
L-WALK	WALKS & STEPS
L-SITE	SITE IMPROVEMENTS
L-SHBD	SHT BORDER/TITLE
L-PSIT	SITE PLAN
L-PPLA	PLANTING PLAN
L-PIRR	IRRIGATION DRAWING
L-PWLK	WALKS/PAVING PLAN
L-ELEV	ELEVATIONS
L-SECT	SECTIONS
L-DETL	DETAILS
L-SCHD	SCHEDULES

CIVIL/SITE	
C-PROP	PROPERTY LINE & SURVEY BENCHMARKS
C-TOPO	PROPOSED CONTOUR LINES & ELEV
C-BLDG	PROPOSED BLDG FOOTPRINT
C-PKNG	PARKING LOTS
C-ROAD	ROADS
C-STRM	STORM DRAINAGE
C-COMM	SITE COMMUNICATIONS
C-WATR	DOMESTIC WATER
C-FIRE	HYDRANTS
C-NGAS	NAT GAS MANHOLES, METERS & TANKS
C-SSWR	SANITARY SEWER
C-SHBD	SHT BORDER/TITLE
C-PSIT	SITE PLAN
C-PELC	SITE ELEC SYS PLAN
C-PUTL	SITE UTILITY PLAN
C-PGRD	GRADING PLAN
C-PPAV	PAVING PLAN
C-ELEV	ELEVATIONS
C-SECT	SECTIONS
C-DETL	DETAILS
C-SCHD	SCHEDULES

FIRE PROTECTION	
F-CO2S	CO2 SYSTEM
F-HALN	HALON
F-SPRN	FIRE SPRINKLER SYSTEM
F-PROT	FIRE PROTECTION SYSTEM
F-SHBD	SHT BORDER/TITLE
F-PSPR	SPRINKLER PLAN
F-RISR	SPRINKLER RISER DIAGRAM
F-PFPE	FIRE PROTECTION EQUIPMENT PLAN
F-ELEV	ELEVATIONS
F-SECT	SECTIONS
F-DETL	DETAILS
F-SCHD	SCHEDULES

Figure 2. Typical building and drawing layers without modifiers (Schley, 1990b).

The layer modifiers listed below may be used with any building iformation layers.

*-****-IDEN	IDENTIFICATION TAG
*-****-PATT	CROSS-HATCHING AND POCHE
*-****-ELEV	VERTICAL SURFACES (3D DRAWINGS)
*-****-EXST	EXISTING TO REMAIN
*-****-DEMO	EXISTING TO BE DEMOLISHED OR REMOVED
*-****-NEVW	NEW OR PROPOSED WORK (REMODELING PROJECTS)

EXAMPLE:
A-WALL-EXST   USED TO DESIGNATE WALLS TO REMAIN

Figure 3. Building information layer (Schley, 1990c).

The layer modifiers listed below may be used with any drawing iformation layers.

*-****-NOTE	NOTES, CALL-OUTS AND KEY NOTES
*-****-TEXT	GENERAL NOTES AND SPECIFICATIONS
*-****-SYMB	SYMBOLS, BUBBLES, AND TARGETS
*-****-DIMS	DIMENSIONS
*-****-PATT	CROSS-HATCHING AND POCHE
*-****-TTLB	TITLE BLOCK, SHEET NAME AND NUMBER
*-****-NPLT	NONPLOT INFORMATION AND CONSTRUCTION LINES
*-****-PLOT	PLOTTING TARGETS AND WINDOWS

Figure 4. Drawing information layer modifiers (Schley, 1990c).

Modifiers may be added to layer names for further differentiation. For example, ceiling information (A-CLNG) may be categorized as:

A-CLNG-GRID	CEILING GRID
A-CLNG-OPEN	CEILING AND ROOF PENETRATIONS
A-CLNG-TEES	MAIN TEES
A-CLNG-SUSP	SUSPENDED ELEMENTS
A-CLNG-PATT	CEILING PATTERNS

Figure 5. Typical ceiling modifiers (Schley, 1990c).

CLIPS Expert System Shell

CLIPS is a forward chaining rule-based expert system shell, "designed at NASA/Johnson Space Center with the specific purpose of providing high portability, low cost and easy integration with external systems" (Giarratano 1989a). The three major components of the CLIPS expert system shown in Figure 6 are:

1. Fact-list: global memory for data
2. Knowledge-base: contains all the rules
3. Inference engine: controls overall execution

"In order to solve a problem, the CLIPS program must have data or information with which it can reason. A chunk of information in CLIPS is called a fact" (Giarratano 1989b). The programs fact-list is a product of the CAD drawing database. A LISP program within the CAD system is used to generate an ASCII file (layer.dat) listing all layers present within the CAD graphic database. The CLIPS load-facts function is used to input the facts into the program. The following are examples of facts :

Fact List	Description
(a-wall-new)	Architectural wall, new
(a-prof)	Roof Plan
(s-psfr)	Structural Framing Plan
(p-strm-rfdr)	Roof Drain
(e-prof)	Electrical Roof Plan

A rule is the method that CLIPS uses to represent knowledge. An example of a possible rule for checking drawing coordination is:

> **IF** the project drawings contain a Roof Plan and Roof Framing Plan.
> **THEN** coordinate the Roof Plan with the Roof Framing Plan and verify direction of roof slope.

The rule expressed in CLIPS format would appear as:

```
(defrule coordinate-roof-plan-and-roof-framing-plan
   (a-prof)
   (s-psfr)
   =>
   (fprintout t "Coordinate the Roof Plan with the Roof Framing
   Plan" crlf)
   (fprintout t "Verify direction of the roof slope."
   crlf))
```

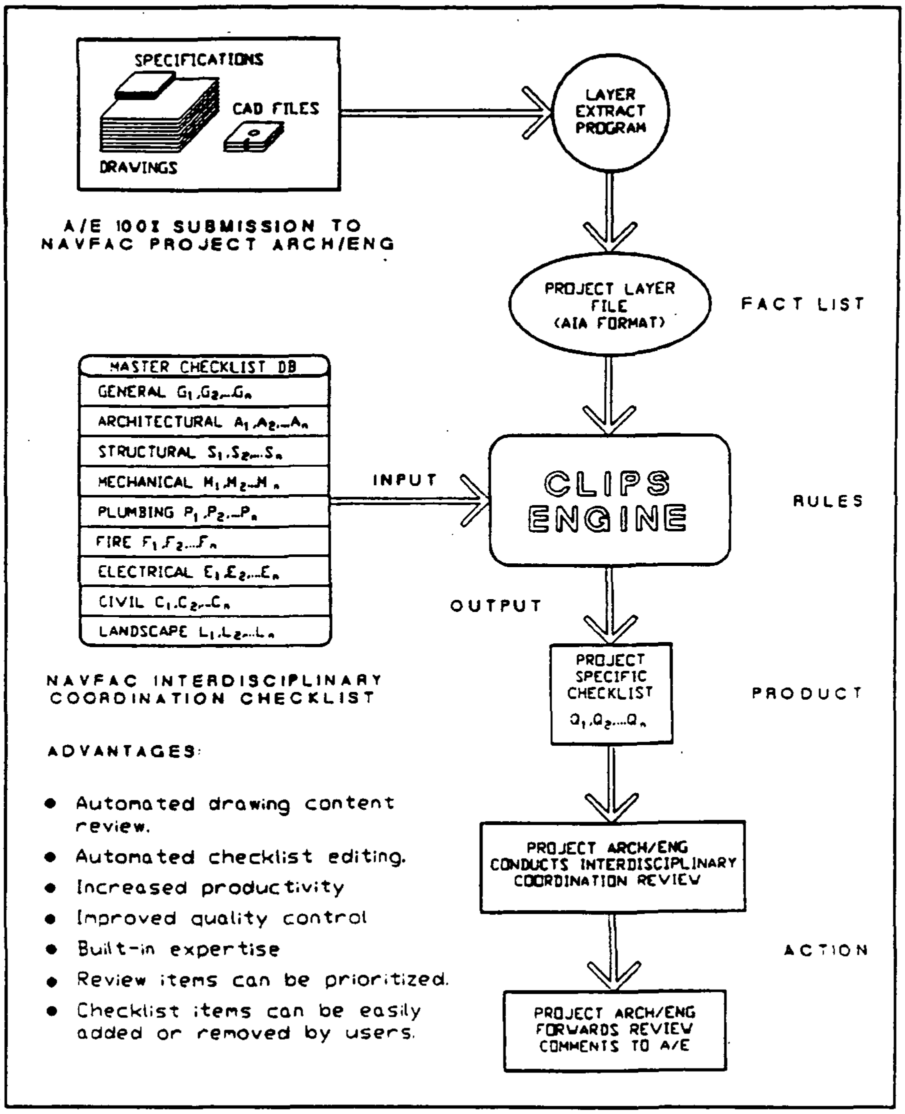

Figure 6. Prototype work model.

The knowledge-base rules are a product of the existing NAVFAC interdisciplinary coordination checklist and REDICHECK. REDICHECK, which was developed by LCDR William T. Nigro, CEC, USN (Ret) is a structured coordination review system that is also implemented by using a manual checklist.

The CLIPS inference engine makes inferences by deciding if a rule is satisfied by the facts. For example, if a project under review contained a Roof Plan (**layer a-prof**) and a Framing Plan (**layer s-psfr**), then pattern matching would occur in the previously defined defrule and the knowledge-base would consider the review comment as applicable. In this application, the CLIPS knowledge-base consists of rules that when activated by matching facts, outputs a project-specific quality control coordination checklist.

The rules required to generate a project-specific checklist are embedded in the CLIPS program. In order to reduce the size of the program, the master checklist items are stored outside the program and accessed by the CLIPS read function.

CLIPS also has a feature to control the execution of rules called salience. Salience values are used to order the rules in terms of increasing priority and will activate rules to assemble a prioritized project specific checklist.

FUTURE WORK

To date, much progress has been made in understanding the problem domain and developing the knowledge-base. Future development plans include:

1. Development of a menu driven interface.

2. Development of rules that identify omissions, duplications, and inconsistencies between reference/identification symbols (detail bubbles, door reference symbols, equipment numbers, etc.) and details, sections, and schedules.

3. Development of rules that identify omissions, duplication, and inconsistencies between labels/keynotes and project specifications.

4. Development of an interface between the CAD geometric data base and the CLIPS knowledge-base.

CONCLUSIONS

At a recent Naval Sea Systems Command conference, Admiral Frank B. Kelso, II, Chief of Naval Operations commented that we have "to learn to do things more efficiently; with better quality than we had in the past." In this application, CLIPS provides NAVFAC with a powerful tool to improve the total quality management of the construction document review process.

ACKNOWLEDGMENTS

The author acknowledges the advice and assistance of Dr. Jens Pohl, CAD Research Unit, School of Architecture and Environmental Design, California Polytechnic State University, San Luis Obispo, California.

REFERENCES

DCQI, (1990). Design & Construction Quality Institute Newsletter, Spring 1990, Washington D.C., pg 1.

Duggar III, J.F. (1984). Checking and Coordinating Architectural and Engineering Working Drawings, McGraw-Hill Book Company, New York, pg. 4.

Giarratano, J. (1989a). Expert Systems, Principles and Programming, PWS-KENT Publishing Company, Boston, pg. 373-374.

Giarratano, J. (1989b). Expert Systems, Principles and Programming, PWS-KENT Publishing Company, Boston, pg. 379.

Kirby, J. G. (1989). Constructibility and Design Reviews: Analysis and Recommendations for Improvement, USACERL Technical Report P-89/15, US Army Corps of Engineers, Construction Engineering Research Laboratory, pg. 25.

Nigro, W.T. LCDR (1984). REDICHECK: A System of Interdisciplinary Coordination, DPIC Communique, Vol. 11, No. 6, Montery, pg. 3.

Schley, M. K. (ed) (1990a). CAD Layer Guidelines: Recommended Designations for Architecture, Engineering, and Facility Management Computer-Aided Design, The American Institute of Architects, Washington D.C., pg. 11.

Schley, M. K. (ed) (1990b). CAD Layer Guidelines: Recommended Designations for Architecture, Engineering, and Facility Management Computer-Aided Design, The American Institute of Architects, Washington D.C., pg. 13 and 16-20.

Schley, M. K. (ed) (1990c). CAD Layer Guidelines: Recommended Designations for Architecture, Engineering, and Facility Management Computer-Aided Design, The American Institute of Architects, Washington D.C., pg. 21 and 23.