28 ESSCAD: EXPERT SYSTEM INTEGRATING CONSTRUCTION SCHEDULING WITH CAD DRAWING

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Abstract

This paper presents an expert system ESSCAD developed for integrating construction scheduling with CAD drawing. The system, which was developed mainly with knowledge-based system programming technique and software integrating technique, can automatically interpret the CAD drawings of a building and extract data of its building components, breakdown the project into activities, determine the logic dependencies among activities, estimate the work quantities and durations of activities, finally generate a primary construction schedule for the project. As it was integrated with a CAD drafting system AutoCAD and a scheduling software MS-Project, it retains the advanced functions of CAD drafting and network analysis. A sample application of ESSCAD to schedule a reinforced concrete frame structure building directly from its AutoCAD drawings is also presented.

Keywords: *CAD, IT application, expert system, network analysis, construction schedule*

INTRODUCTION

Network analysis technique as key planning tool is widely used in modern construction industry. Many software based on it have been developed and proven effective in improving the construction management especially scheduling of building projects. These software provide sophisticated functions of analyzing network model of a project so as to scheduling the project. However, due to the complexity of building projects and the limitation of traditional software programming technique, these software are applicable only to a prepared network model of a project. They are mainly used to carry out computations on input data provided by construction planner. The input data required normally comprise an activity list complete with their estimated durations and logic dependencies. Even if the design is CAD-based, the data needed for establishing such model can not be extracted directly by these software from the data existing already in the CAD drawings generated at design phase while have to be re-input by the planner. This indeed has constrained the application of the network planning technique and the construction scheduling software based on it. The current situation in design and construction affords the main reasons. On one hand, the data expressed in drawings can only be understood and extracted by human. Namely, the delivery of data from design phase to construction phase is manipulated by human and suffers from numerous shortcomings. On the other hand, the building design and construction scheduling are very professional and different and require engineers in respective discipline of different background and professional knowledge. The process is also difficult and tedious. Therefore, it is difficult and non-practical for engineers in one discipline to do the job in another discipline (Levitt et al, 1988). If the construction schedule of a building can be generated directly and automatically from its drawings provided at design phase, it will benefit in at least two ways: a) to predict the construction schedule at design phase, hence to facilitate the optimize of the design; b) to fully utilize the data existing in the drawings for managerial purposes in construction phase, such as scheduling and estimating, so as to reduce the tedious human manipulation of data and the potential source for numerous errors.

The development of information technology and its application in construction industry have brought about some changes to the industry. Firstly, the application of CAD grants a CAD drawing with two meanings: a) to engineers, it consists of a series of graphic symbols representing a building; b) to computer, it is a processable data file which contains data related to the building, and this makes it possible to interpret the CAD drawing and to extract from it the data needed for construction management. Secondly, the development of artificial intelligence technique makes it possible to store construction expert's experiences and knowledge into knowledge bases of an expert system to facilitate the auto-generation of construction schedule of a building project.

There are already different expert systems that have been offered for construction planning and new ones are still continuously emerging (Mohan, 1990). These systems deal in various manners with some or all of various aspects of automated construction planning. In most cases expert shells have been used, but some researchers design their own rule-based systems using a suitable programming language. Kahkonen (1994) has reviewed in details the research within the last three decades of preparation and updating of construction schedules, including the development of manual techniques, project networking techniques, expert systems, and research within the logic of schedules. However, many of them seem to have never passed the prototype phase or posses several methodological problems and only a few of them have addressed the CAD drawing interpreting and auto-extracting data needed for scheduling directly (Cherneff et al, 1991; Darwiche et al, 1989; Kunz et al, 1999; Fischer et al, 1996; Parfitt et al, 1993). Furthermore, almost every of these systems require great changes to the designers' conventional and traditional drafting method and procedure as well as the format of drawing. Namely, they proposed and adopted object-orient CAD model or other models for building design and/or Architecture/Engineering/Construction (A/E/C) integration. This definitely hinders their possible application as changing the tradition is very difficulty and needs time. Therefore, the authors believe that the object-orient or other integration of A/E/C is certainly the direction of research. It should not, however, at least at present, require fundamental change to the traditional CAD drafting method and procedure. To the contrary, the researchers should contribute more effort to programming and providing sophisticated integration between the current popular CAD system and scheduling software to facilitate the data sharing of building design and construction scheduling. The authors also believe that it is possible to do so through the experience of developing ESSCAD, especially by applying the principle of expert system (Lu et al, 1992; Wang, 1996; Wang et al, 1995), and that it is possible for integrated computer tools to provide knowledge to a designer to the knowledge provided by the multiple engineers on a project design team, e.g. construction planners, or vise versa (Clayton et al, 1994).

The objective of this research is therefore firstly to study the feasibility and principles for interpreting CAD drawing and auto-generating network-based schedule of a building project. It then aims to, using the knowledge-based system programming technique and software integrating technique, develop an expert system (i.e. ESSCAD) which can integrate the construction scheduling with CAD drawing, i.e. automatically interpret the CAD drawing of a building project and extract data of its building components, breakdown the project into activities, determine the logic dependencies among activities, estimate the work quantities and durations of activities, finally generate a primary construction schedule for the project. The system should also be integrated with popular CAD drafting system, e.g. AutoCAD, and popular construction scheduling software, e.g. Microsoft Project 4.0 for Windows (PROJECT), so as to retains their advanced functions of CAD drafting and network analysis. As the first step of ESSCAD development, the CAD drawing to be interpreted is confined to the reinforced concrete frame structure buildings because only knowledge bases for this kind of buildings are constructed presently. However, the principle and method described in the paper are applicable to other types of buildings provided related knowledge bases established.

The research was carried out during 1994 to 1996 and is the implementation work of a former research entitled Hybridized System for Construction Management and Claiming Based on Network Planning Techniques (Lu et al, 1992).

Due to constraints on its length, this paper will describe only the model, structure, components and programming of ESSCAD. A sample application of ESSCAD to schedule a reinforced concrete frame structure building directly from its AutoCAD drawings will also be presented. Readers may refer to (Wang et al, 1995) for information on the principles for interpreting CAD drawing and auto-generating construction schedule based on the data extracted from the drawing.

STRUCTURE AND COMPONENTS OF ESSCAD

Introduction

Taking into account its characteristics and functions, ESSCAD was programmed with the knowledge-based system programming method. Being a typical expert system, ESSCAD consists of Knowledge Base, Knowledge Base Management System (KBMS), Inference Engine, Dynamic Database and User Interface as shown in Figure 1.

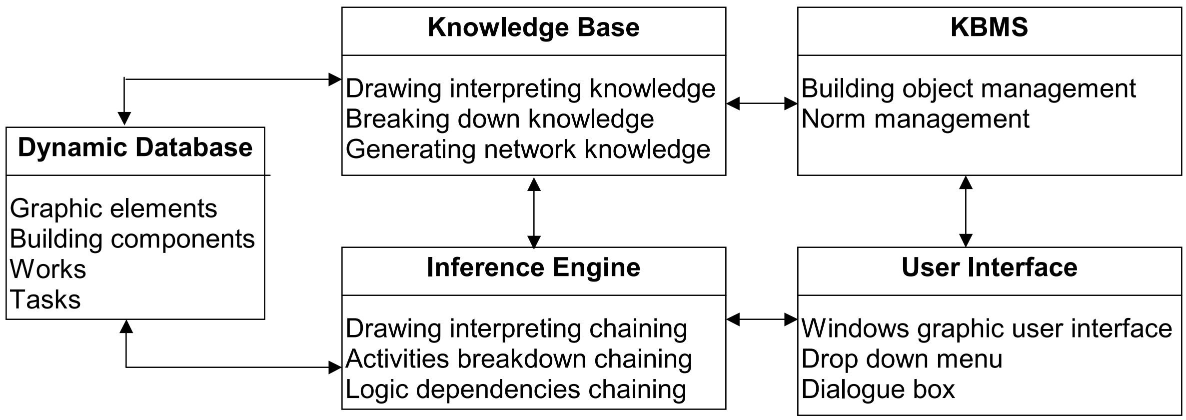

Figure 1. Components of ESSCAD

ESSCAD processes the data in the flow shown in Figure 2 from which it can be seen that the link established between AutoCAD and PROJECT is semi-dynamic, i.e. once there is any change in CAD drawing, user could run ESSCAD again to generate a new construction schedule.

The Dynamic Database

The Dynamic Database of an expert system stores data of the current state of the system when it is running, such as its starting, intermediate and final results. For ESSCAD, the Dynamic Database stores mainly two kinds of data, i.e. knowledge for modules of CAD drawing interpreting and network generating. Most of the data in the Dynamic Database are organized with Frame method, which is widely used for effective representation of knowledge for expert system.

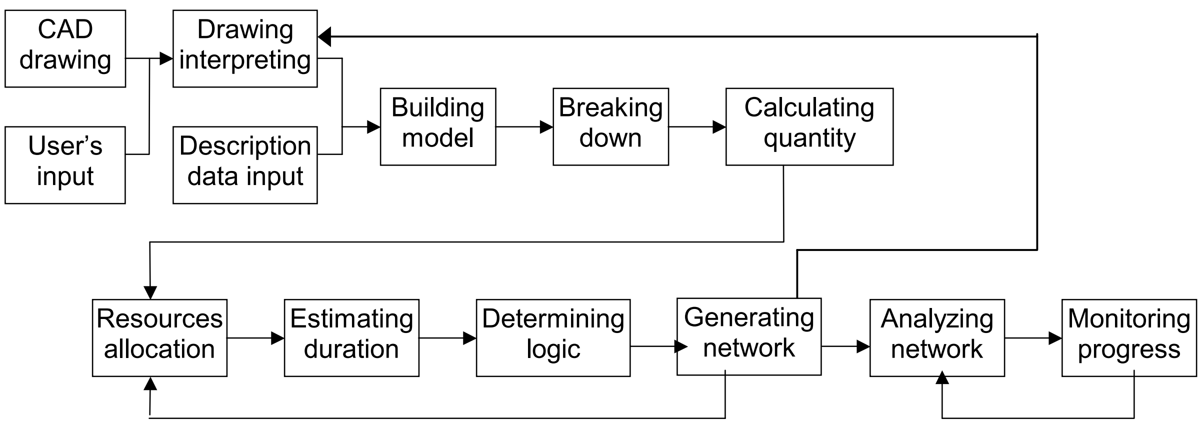

Figure2. Process Flow of ESSCAD

Dynamic Database for CAD Drawing Interpreting Module

As mentioned above, the interpreting of CAD drawing can be divided into two steps: a) extracting data of geometric graphic elements from the DXF of CAD drawing; b) extracting data of building components in the drawing by processing the data extracted in the first step. The data flow of dynamic database in this module is shown in Figure 3.

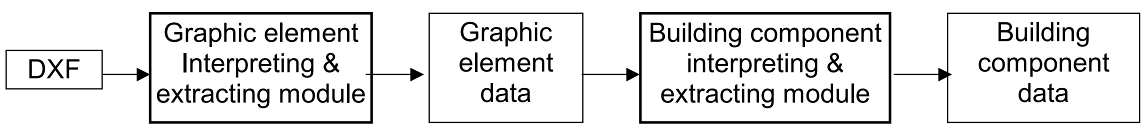

Figure 3. Data Flow in Interpreting CAD Drawing

The graphic elements interpreted includes line, circle, text, dimension. The data content of a graphic element is determined by its geometric characteristics and is shown in Table 1. A tag for a graphic element was used to indicate whether the element has been processed or not.

Table 1. Data Contents of Basic Graphic Elements

Graphic Element	Usage for Drafting Building Component	Data Content
Line	Drafting various building components	Layer, coordinates of both ends, line type and color, tag
Circle	Drafting the components	Layer, coordinate of center, radio, tag
Text	Letter or number, describing properties of components	Layer, text content, font, height, coordinate, rotate angle, tag
Dimension line	Describing sizes and locations of the components	Layer, coordinates of both ends, length, rotate angle, dimension text/number, tag

As mentioned before, the building component includes beam, slab, column, wall, window and door, etc. In ESSCAD, however, axes are also treated as one type of building component as they control the locations and sizes of building components in a drawing and hence very important for CAD drawing interpreting. The data content of a building component is described in Table 2 taking axis, beam and column as examples. Because ESSCAD can interpret only 2D CAD drawing, the user should input the heights of beams and the heights of columns (the latter usually equal to the floor height).

Table 2. Data Contents of Building Components

Building Component	Graphic Elements Involved	Data Content
Axis	Dimension line, circle, text	Identify number (ID), line, text
Beam	Line, text	ID, name (text), width, length, axis the beam is in, axes the beam's both ends are in, height
Column	Line, text	ID, name, widths of both sides, axes the column is in, height

Dynamic Database for Network Generating Module

The needed data for network generating is shown in Table 3. The Zone, Functional System and Work are three types of objects suggested by Shaked et al (1995) for representing a building. Their data are very important and fundamental for network generating. The adjust factor for Work is a proportion used to convert the quantity of a Functional System to the quantity of the Work according to the Norm.

Table 3. Contents of Data for Network Generating

Data Type	Definition/Usage	Data Content
General data	Describing general aspect of a building	Building ID, name, total height, number of floors, total building area, foundation type, roof type, door and window type
Zone data	Spaces of group of spaces serving as autonomic units in planning process.	Zone ID, name, type (horizontal/vertical), beginning and ending floors, its beneath floor, functional systems and adjacent zones
Functional system data	Group of components serving a function purpose	Functional system ID, name, works, quantity and unit
Work data	Operations for installing a functional system	Work ID, name, beginning and ending status, quantity and unit, work teams, adjust factor
Activity data	Basic operations a project is broken down into, based on the above three objects	Activity ID, name, zone, functional system, work, duration, time unit, preceding/succeeding activities, activities with Start-Start (SS) relation with it, earliest start/finish, latest start/finish, total/free float, planed start/finish, actual start/finish, % completed
Flow data	Describing arrangement of flow process construction	How a building is divided into sections, number of sections, resources availability

The Knowledge Bases

Methods for Knowledge Representation
Three methods, i.e. the Production Rule, Frame and Logic, have been adopted in ESSCAD to represent knowledge. The following is an example of Logic method for estimating the quantity of one type of building component:

```
Procedure Quantity_Calculate
        Define the type of the component;
        Calculate the quantity of each component;
        Calculate the quantity of this type of components;
        Output the quantity of this type of components.
Exit
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Construction of Knowledge Bases

A lot of knowledge are needed for ESSCAD which are classified into mainly three parts, i.e., knowledge relating to CAD drawing interpretation, activity breakdown and logic dependencies establishment respectively.

Knowledge relating to CAD drawing interpreting

Most of this kind of knowledge is represented in production rules, such as the knowledge for differentiating Axis:

IF: there is line in Layer of Axis;
AND the line is with characteristics of axis (e.g. it is dot line);
AND there is circle in the same Layer;
AND the distance between one end of the line and the circle is less than a threshold value;
AND there is a text in the circle;
AND the text describes the characteristics of axis,
THEN: this line is an axis;
AND generate an axis element;
AND tag the line as processed;
AND tag the circle as processed;
AND tag the text as processed.

In fact, a rule of this kind usually consists of several sub-rules. For example, “if the line is with characteristics of axis” and “if the text describes the characteristics of axis” are sub-rules that have further more detailed sub-rules.

Knowledge for breaking down project into activities

This kind of knowledge consists of all typical activities for constructing a building and the activities are grouped according to work breakdown structure. The knowledge was extracted from either the general construction knowledge or practical experiences of related professional personnel in China. For example, the typical activities for the construction of a reinforced concrete component consist of setting out, installing formwork, laying steel bar, pouring concrete, curing concrete and stripping formwork. ESSCAD could then, based on these typical activities, break down project into activities according to the Zone, Functional System and Work data, which, as described above, are either input by user or already exist in the Dynamic Database. The structures and contents of Activity, Zone, Functional System and Work data are the same as described in Dynamic Database. Because the size of this kind of knowledge bases in ESSCAD is large (there are, at the moment, about 60 typical activities in the basic knowledge base and more could be added. Nevertheless, this is as another limitation of ESSCAD at present), they are stored and managed by applying a database management system, i.e. FoxPro for Windows, to take its advantages of effective data management. The database management system and the expert system are separated parts in ESSCAD but are closely coupled through programming. At the moment, only knowledge bases for reinforced concrete frame structure building were established for ESSCAD and need to expand further.

Knowledge for network generating

This kind of knowledge consists of knowledge about construction arrangement, activity quantity and duration estimation, logic dependency establishment and network reasonability check.

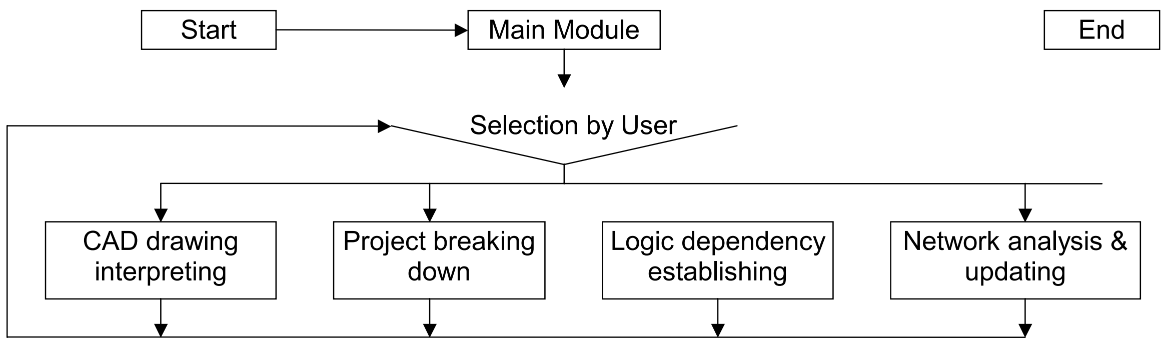
- Construction arrangement knowledge relates to how the manpower is arrangement. They are also stored with Frame method and consist of ID, work type, work team name, work team size (number of labor), quantity unit, norm, and adjust factor.
- Logic dependency knowledge consists of the logic dependency of activities in one horizontal zone, in two adjacent horizontal zones, in one horizontal zone and one adjacent vertical zone. The following example shows how to establish the logic dependency of two activities in the same horizontal zone.

IF: there are activity A and activity B existing in one horizontal zone;
AND the finish state of activity A coupled with the start state of activity B;
AND the duration of activity A for constructing a flow section in the zone is d,
THEN: there is a logic dependency of "SS+d" between activity A and Activity B.

- Network reasonability knowledge consists of rules for deleting unnecessary logic and identifying logic loop in the network diagram generated. For example, the rule for deleting unnecessary logic is shown below.

IF: activity A is a preceding activity of activity B;
AND activity A can reach activity B via a path P;
AND the path P is not the path that activity A links directly to activity B,
THEN: activity A is not necessary a preceding activity of activity B;
AND delete this unnecessary logic dependency.

Again, only knowledge for reinforced concrete frame structure building was established for ESSCAD and this is another limitation of ESSCAD at the moment.



Knowledge Bases Management
For ESSCAD, the knowledge bases to be managed fall into two catalogues, the knowledge about project breaking down and the Norm. They are general knowledge and suitable for any buildings of the same type. They should, however, be updated and expanded timely to cope with the real situation. This kind of knowledge is relatively dynamic which is different from the static knowledge. The latter is relatively "static", for example the knowledge for checking network loop and for deleting unnecessary logic dependencies, hence was embodied in ESSCAD during programming.

The Inference Engine

ESSCAD employs mostly the forward chaining (reasoning) and sometimes the backward chaining. When ESSCAD performs forward chaining, it starts searching in the related knowledge bases according to the starting data input by user and continues till all rules are matched. When ESSCAD performs backward chaining, it firstly assumes a conclusion then searches rules in the knowledge bases to prove this conclusion. If the rules are found, the conclusion is justified. Otherwise it will be rejected. For example, the process of judging whether a line in a CAD drawing is an axis during interpreting CAD drawing is a backward chaining. When a line is encountered, ESSCAD firstly assumes it is an axis. It then searches whether there is a circle exists near one end of the line within a threshold distance and, if there is, whether the circle possesses the characteristics of an axis's end circle. If all rules are matched, the line is justified an axis. If not, the line is not an axis.

The inference engine consists of the main module and some sub-modules. The main module performs functions of confirmation, selection and loading of sub-modules while the sub-modules perform various sub-functions chosen in main module. The architecture of ESSCAD is shown in Figure 4.

Figure 4. Architecture of ESSCAD

Due to the length constrains of the paper, only flowchart of the CAD Drawing Interpreting module is shown here as in Figure 5. For flowcharts of other modules, please refer to (Wang et al, 1995).

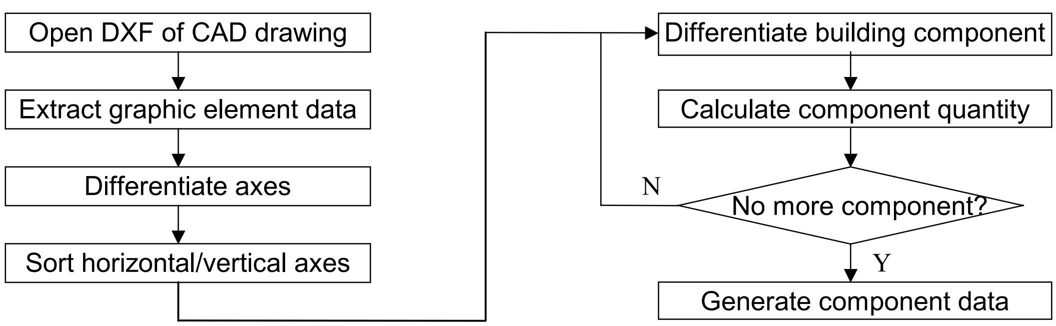


Figure 5. Flowchart of CAD Drawing Interpreting Module

SYSTEM ENVIRONMENT AND APPLICATION EXAMPLE

System Environment

The main frame of ESSCAD is programmed with Borland C. The knowledge bases and database are programmed with ForPro for Windows while their links with the main frame are also programmed with Borland C. The user interface of ESSCAD is programmed with Borland Object Windows. ESSCAD can run on IBM PC or compatibles installed with Microsoft Windows 3.1/95, AutoCAD 12.0 and PROJECT 4.0.

Application Example

The sample project is a reinforced concrete frame structure commercial complex that consists of seven floors. The floor 1 and 2 are for shop, floor 3 and 4 are for office and floor 5 to 7 are for residence purposes. Its CAD plan drawing is shown in Figure 6. If the Zone Data was input as shown in Table 4 and resource data as (only labor is considered): 20 for laying steel bar, 15 for installing formwork, 15 for pouring concrete and 10 for masonry, ESSCAD can extract data from the CAD drawing, e.g. the data on beams in X-direction as shown in Table 5, and generate the network schedule as shown in Figure 7.

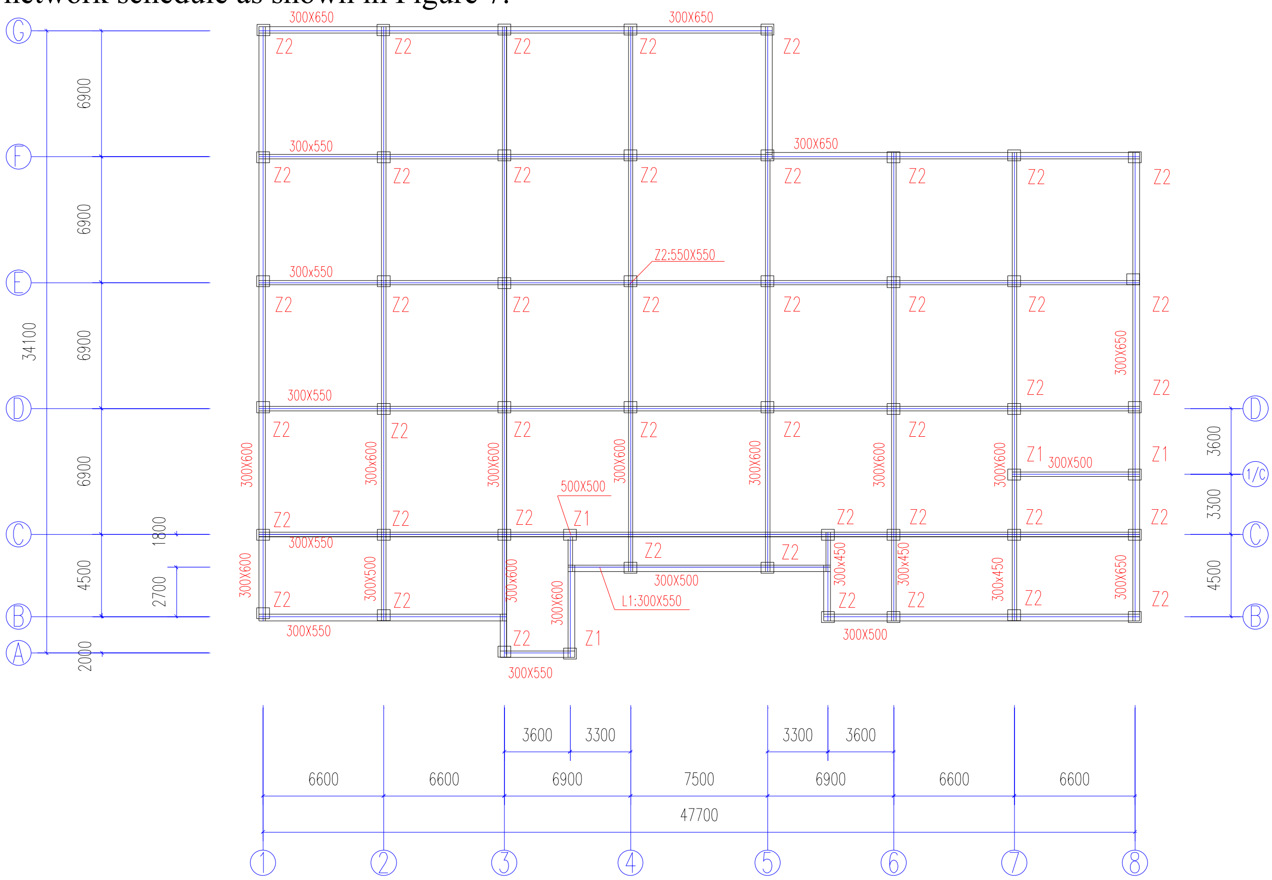


Figure 6. CAD Plan Drawing of Sample Project

Table 4. Zone Data of Sample Project

Zone Name	Characteristic	From Floor No.	To Floor No.
Horizontal Zone 1 (HZ1)	■ Foundation	1	1
HZ2	Shop	2	3
HZ3	Office	4	5
HZ4	Residence	6	8
HZ5	Roof	9	9
Vertical Zone 1 (VZ1)	External Wall	2	8

Table 5. Interpreted Data of Beams in X-Direction

Beam No.	Axis of End 1	Axis of End 2	Axis of Beam	Width (mm)	Height (mm)	Length (mm)
1	3	Unnamed	A	300	550	3600
2	1	3	B	300	550	13200
3	Unnamed	8	B	300	550	16800
4	Unnamed	4	Unnamed	300	550	3300
5	4	Unnamed	Unnamed	300	500	10800
6	1	8	C	300	550	47700
7	7	8	1/C	300	500	6600
8	1	8	D	300	550	47700
9	1	8	E	300	550	47700
10	1	5	F	300	550	27600
11	5	8	F	300	650	20100
12	1	5	G	300	650	27600

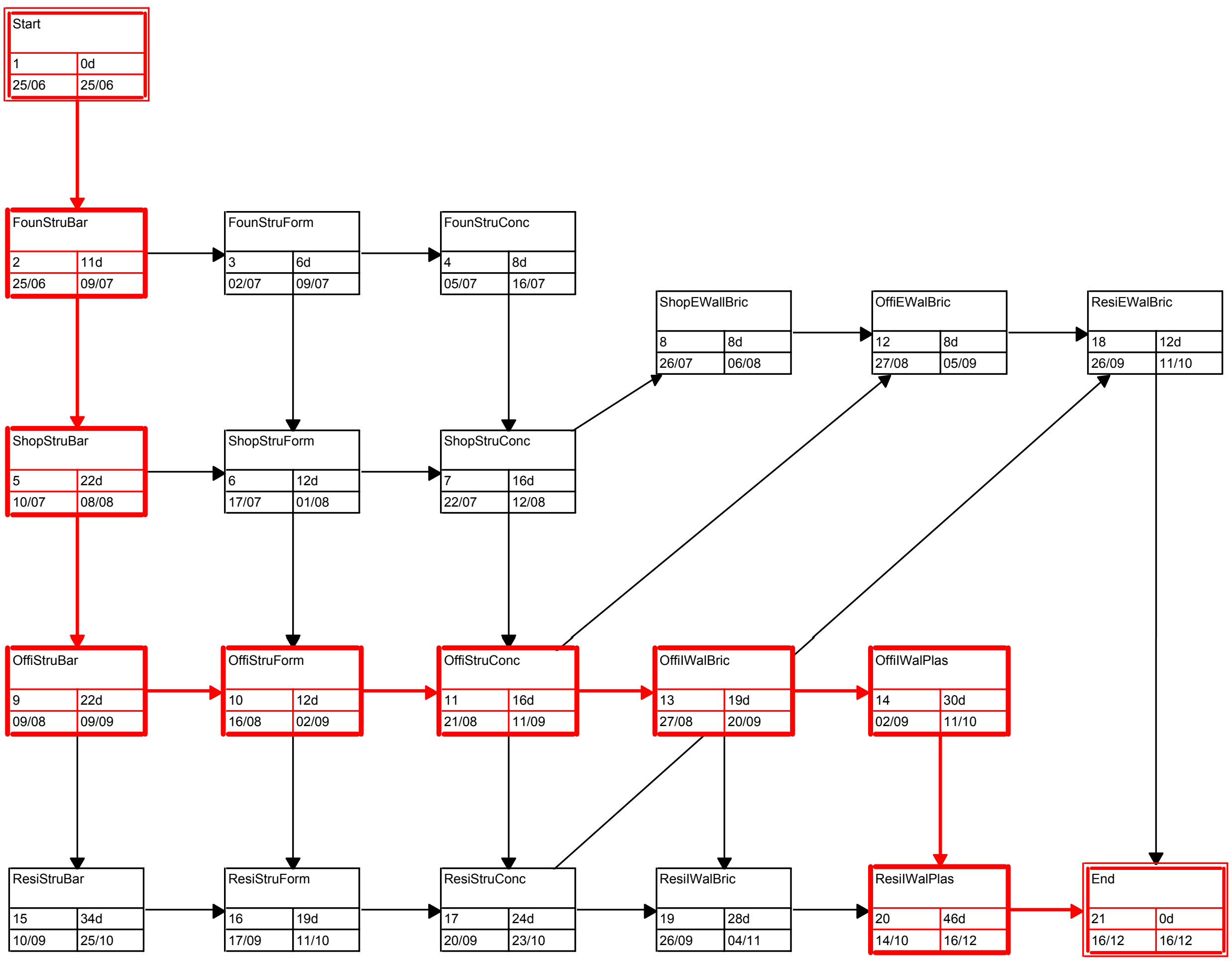


Figure 7. Network Diagram Generated for the Sample Project

From the results shown in Table 5 and Figure 7, it can be seen that the interpreted results by ESSCAD from the CAD drawing are correct and the network diagram and schedule generated are also reasonable and practical. It is worthy to mentioned again that, if there is any change in CAD drawing, user could re-run ESSCAD to interpret the drawing again and to generate a new construction schedule. In other word, a semi-dynamic link has been established between AutoCAD and PROJECT.

CONCLUSIONS AND RECOMMENDATIONS

This paper described in detail the development and application of ESSCAD aiming at illuminating the idea of data sharing in building design and construction management phases of a project. ESSCAD, which was developed with knowledge-based system programming technique and software integrating technique, can automatically interpret CAD drawing of a reinforced concrete frame structure building, extract data needed and generate a primary construction schedule. In addition, as ESSCAD has integrated the AutoCAD and PROJECT, their advanced functions of CAD drafting and network analysis are retained. The presented example shows that the network schedule generated by ESSCAD for the sample project is practical and applicable and the expert system does work. However, ESSCAD is far from perfect and needs to be improved especially in the followings:

- To enhance its drawing interpreting function by either further standardizing drawing drafting rules as mentioned before or by improving its programming so as to make it more sophisticated;
- To expand the knowledge bases and databases so as to extend the applicable scope from only reinforced concrete frame structure building to other building type.

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