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A Knowledge-Based System for Construction Site Level Facilities Layout

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Abstract. The choice of good construction site layout is inherently difficult, yet has a significant impact on both monetary and time saving. It is desirable to encapsulate systematically the heuristic expertise and empirical knowledge into the decision making process by applying the latest artificial intelligence technology. This paper describes a prototype knowledge-based system for the construction site layout, SITELAYOUT. It has been developed using an expert system shell VISUAL RULE STUDIO, which acts as an ActiveX Designer under the Microsoft Visual Basic programming environment, with hybrid knowledge representation approach under object-oriented design environment. By using custom-built interactive graphical user interfaces, it is able to assist designers by furnishing with much needed expertise in this planning activity. Increase in efficiency, improvement, consistency of results and automated record keeping are among the advantages of such expert system. Solution strategies and development techniques of the system are addressed and discussed.

1 Introduction

Construction site layout, involving the assignment of locations for the temporary facilities, is an important planning activity. It is recognized that a good layout has a significant impact on cost, timeliness, operational efficiency and quality of construction, which manifest on the larger and more remote projects. Improper layout can result in loss of productivity due to excessive travel time for laborers and equipment, or inefficiencies due to safety concerns. In spite of its potential consequences, construction site layout generally receives little advanced planning, and hardly any planning during construction. It is often determined in an ad hoc manner at the time the siting requirement arises. In the evaluation process, it involves many decisions to be made by the designer based on empirical rules of thumb, heuristics, expertise, judgment, code of practice and previous experience. It is desirable to encapsulate systematically this knowledge into the decision making process by applying the latest artificial intelligence technology.

With the recent advent in artificial intelligence (AI), a knowledge-based system (KBS) is able to furnish a solution to this decision making process through incorporating the symbolic knowledge processing. During the past decade, the potential of AI techniques for providing assistance in the solution of engineering problems has been recognized. KBS are considered suitable for solving problems that demand considerable expertise, judgment or rules of thumb, which can be broadly classified into the following categories: interpretation; design; diagnosis; education; and planning. Areas of early applications of KBS technology include medical diagnosis, mineral exploration and chemical spectroscopy. KBS have made widespread applications in different fields and are able to accomplish a level of performance comparable to that of a human expert [1-5].

This paper describes a prototype KBS for the construction site level facility layout, SITELAYOUT, which has been developed using a commercially available microcomputer-based expert system shell VISUAL RULE STUDIO [6]. It is intended not only to emulate the reasoning process followed by site practitioners, but also to act as an intelligent checklist that comprises site objects and activities for expert advice to its users. The blackboard architecture with hybrid knowledge representation techniques including production rule system and object-oriented approach is adopted. Its knowledge base comprises representations of the site and the temporary facilities to be located, as well as the design knowledge of human experts. It opportunistically applies varying problem solving strategies to construct the layout incrementally. Through custom-built interactive graphical user interfaces, the user is directed throughout the planning process. Solution strategies and development techniques of the system are also addressed and discussed.

2 The Construction Site Layout Problem

Site layout design are engineering problems that are solved daily on each construction site. Temporary facilities are essential to support construction activities, but do not constitute the completed project. These facilities are diverse in nature depending on the size and location of the project. They range from simple laydown areas, material handling equipment, access roads, warehouses, job offices, fabrication shops, maintenance shops, batch plants to lodging facilities, etc. These may be on site during part or all of project construction. Very often, after the bidding stage and the startup of the project, continuous advance planning is seldom carried on. The detailed site layout is left to the day-to-day scheduling of foremen and superintendents. Inappropriate location then requires material handling that could have been avoided.

The choice of good layout is inherently difficult since it is constrained by both the site topography and the location of the permanent facilities. The nature of the problem is such that no well-defined method can guarantee a solution. In the literature, some guidelines have been proposed for laying out construction sites [7-9]. Construction site layout can be delimited as the design problem of arranging a set of predetermined facilities on the site, while satisfying a set of constraints and optimizing layout objectives. Good layout demands fulfilling a number of competing and yet often conflicting design objectives. Some objectives are to maximize operation efficiency by promoting worker productivity, shortening project time, reducing costs and to maintain good employee morale by providing for employee safety and job satisfaction, to minimize travel distance and time for movement of resources and to decrease material handling time. Besides, legal obligations may impose safety and permit constraints, and technical and physical limitations cannot be neglected. Managers who set out to meet several objectives must prioritize them, which is a nontrivial and highly subjective task.

The site layout problem involves multiple sources of expertise with often conflicting goals, requiring scheduling of activities with leveling of multiple resources and space consideration. Project managers, superintendents and subcontractors may jointly agree upon the location of major pieces of material and equipment, by using their past experience, trial and error, insight, preference, common sense and intuition. Mathematical optimization techniques such as operation research have been employed to aid layout design [10]. However, they did not gain general acceptance in industry due to the difficulty to learn and use, complexity and unavailability of the computer implementations, and the requirement of a quantifiable objective.

The designer solves the problem by employing two techniques, namely, iconic representation and decomposition. The iconic representation of the problem's physical components, such as engineering drawings, templates or three-dimensional models, is useful in allowing the designer's perceptual vision to operate on it. Human can only manipulate a smaller number of symbols in the mind at any one time. This limited symbolic processing power forces a decomposition of the problem into sub-problems, which are then dealt with relatively independently. The search for a solution is then the search for a succession of facility selection and location that achieves a satisfying solution to the layout problem. The layout problem can then be viewed as a search through a tree whose nodes are partial layouts. The search proceeds by stepping from state to state through the problem space, starting from an initial state comprising an empty job site and a list of facilities to be located, and ending at a state comprising a layout of all facilities satisfying the set of constraints.

3 Features of SITELAYOUT

A prototype KBS, SITELAYOUT, has been developed to assist construction practitioners in their complex task of designing spatial layout planning. It allows site management to continuously monitor and update the plan as site activities proceed. It integrates domain heuristics and layout strategies, reasons about spatial and temporal designs, and dynamically changes its behavior based on design strategy. SITELAYOUT uses a plan-generate-test strategy. The solution will depend entirely on the strategies the user wants to implement, the objects and constraints involved in the layout. SITELAYOUT manipulates the facilities, extracts information from the site layout, generates alternative locations for the facilities, tests constraints, selects a location and updates the layout. Site objects are first assembled into partial layouts and constraints are successively applied to identify feasible positions for them. Several partial layouts are combined to form a complete solution. The system is compiled and encrypted to create a run-only system. The user can always overrule any design options and recommendations provided by the system. It thus plays the role of a knowledgeable assistant only. Its strength lies in its flexibility for deciding what actions to take. It allows for users to fine-tune the system to their preference style, yet to let them benefit from its thoroughness, speed, and overall effectiveness for designing a site layout.

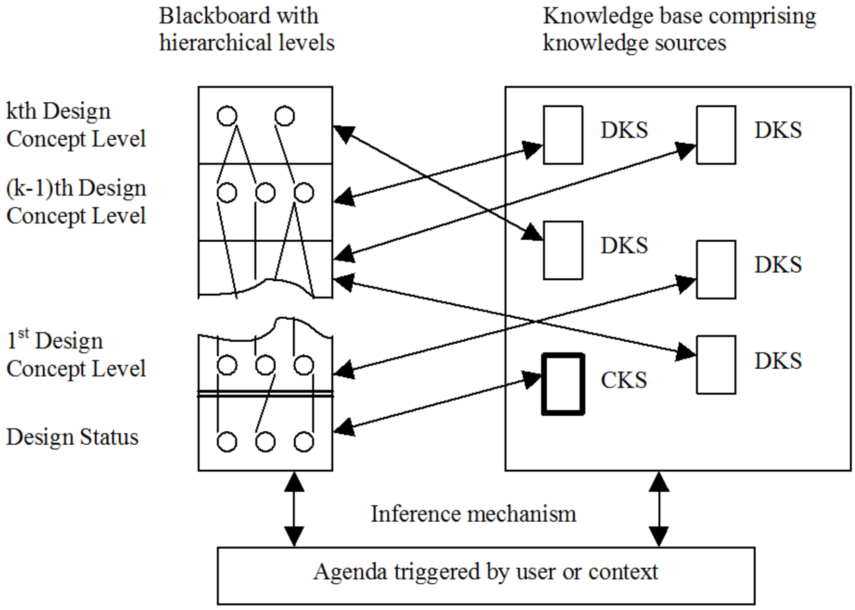

Fig. 1. Blackboard architecture of the prototype expert system (DKS and CKS denote Domain Knowledge Source and Control Knowledge Source respectively)

3.1 Development Tool

In order to facilitate development of the KBS on site layout planning, expert system shell containing specific representation methods and inference mechanisms is employed. This system has been implemented with the aid of a microcomputer shell VISUAL RULE STUDIO, which is a hybrid application development tool under object-oriented design environment. VISUAL RULE STUDIO acts as an ActiveX Designer under the Microsoft Visual Basic 6.0 programming environment. Production rules as well as procedural methods are used to represent heuristic and standard engineering design knowledge. By isolating rules as component objects, separate from objects and application logic, it produces objects that can interact with virtually any modern development product and thus rule development becomes a natural part of the component architecture development process.

3.2 System Architecture

The blackboard architecture has been successfully applied in solving a wide range of domain problems, such as speech recognition, signal processing, and planning [11]. A blackboard system consists of diverse knowledge sources that communicate through a blackboard and are controlled by an inference mechanism. Figure 1 shows the blackboard architecture of the prototype system. The blackboard serves as a global data structure, which facilitates this interaction. This architecture is adopted since the reasoning with multiple knowledge sources is essential to solve the site layout problem. Besides, the actual layout design follows from quite opportunistic decisions, which are often made incrementally. Many factors contributing to the decisions can be unpredictable based on personal preference depending on the condition. Since not all information is initially available or relevant, the initial layout plans are often modified as construction proceeds.

Apart from the usual components in a typical KBS, namely, knowledge base, inference mechanism, session context, user interface, knowledge acquisition and explanation modules, it also incorporates database. The database chosen is Microsoft Access due to its popularity as a user-friendly relational database within industry, reasonable cost, and Visual Basic support by means of Visual Basic for Applications. The system can retrieve information from a library of partial arrangements, which were gleaned from actual site conditions.

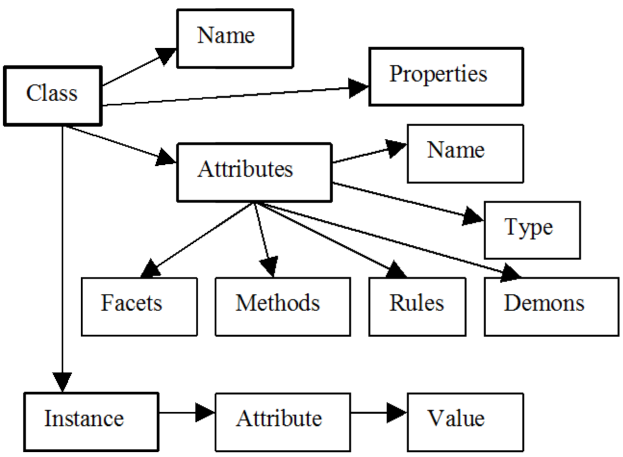

Fig. 2. Structure of VISUAL RULE STUDIO components

3.3 Object-Oriented Programming

Under the declarative knowledge representation environment, objects are used to encapsulate knowledge structure, procedures, and values. An object's structure is defined by its class and attribute declarations within a RuleSet. Object behavior is tightly bound to attributes in the form of facets, methods, rules, and demons. Figure 2 shows the structure of VISUAL RULE STUDIO components. Each attribute of a class has a specific attribute type, which may be compound, multi-compound, instance reference, numeric, simple, string, interval, and time. Facets provide control over how the inference engines process and use attributes. Methods establish developer-defined procedures associated with each attribute. The set of backward-chaining rules that conclude the same attribute is called the attribute's rule group. The set of forward-chaining demons that reference the same attribute in their antecedents is called the attribute's demon group. SITELAYOUT combines expert systems technologies, object-oriented programming, relational database models and graphics in Microsoft Windows environment. By defining various types of windows as different classes, such as Check Box, Option Button, List Box, Command Button, Text Box, etc., they can inherit common characteristics and possess their own special properties.

3.4 Knowledge Base

In this prototype system, the knowledge is represented in object-oriented programming and rules. Its knowledge base contains representations of the permanent facilities, the temporary facilities and the design knowledge of the expert.

Reasoning knowledge, both heuristic and judgmental, including the constraints between the objects, is represented as rules. Knowledge represented in the IF/THEN production rules with confidence factors can be assigned either automatically, or in response to the user's request. Site planning strategies expressed in rules form a natural representation and are easily understood. These rules are a formal way of specifying how an expert reviews a condition, considers various possibilities, recommends an action and ranks the potential layout solutions. The following is a typical example of the production rules.

```
Rule to find ScoreRebarSubcontractor: 3 of 10

IF RebarSubcontractor.DistanceToWorksArea >= 200

AND RebarSubcontractor.Area >= 100

THEN RatingScore.ScoreRebarSubcontractor:= Low CF 85
```

The objects define the static knowledge that represents design entities and their attributes, which can be either descriptive or procedural in form. This allows a description of physical objects including the facilities and of other requisite abstract objects such as the locations. Procedural knowledge, such as numerical processing and orientation of the facilities, is represented in the form of object-oriented programming. Generic construction objects are structured in a hierarchical knowledge base with inheritance properties. Besides, it comprises a blackboard together with two sets of knowledge sources, namely, Domain Knowledge Sources and Control Knowledge Sources.

Blackboard. Objects inherit properties from the class to which they belong. Each one of the objects of the representation such as points, sides, polygons, facilities and, at the highest level of the hierarchy, the site itself are represented as objects. It describes facilities by their type, possible zoning requirement, geometry, dimensions, duration on site, and mobility. In order to keep track of the design status and related information, SITELAYOUT uses a hierarchical level named Design Status that has attributes whose values change in time to represent the different states of the layout process. These states are partial layouts obtained from the previous state by the selection of a location for a certain facility. This unit keeps track of the facility being located, the alternative locations generated and the alternative selected at the previous level of the design process.

Domain Knowledge Sources. Diverse Domain Knowledge Sources, functioning independently and cooperatively through the blackboard, encode the actions to take for constructive assembly of the layout. They add particular domain specific objects to the arrangement, modify their attributes and roles, call the constraint satisfaction system to generate the appropriate possible locations for that object, and display objects on the computer screen. They encompass all construction management domain knowledge necessary to design site layouts. The expert’s design knowledge consists of heuristic and rules of thumb acquired through years of experience, which is represented as a set of rules. Constraints in SITELAYOUT are desired qualities of the layout due to relationships amongst the facilities, the work area and the outside world emanating from the functionality of the facilities. They include zoning constraint, adjacency constraint, distance constraint, non-overlap constraint, access constraint, spatial constraint, position constraint, view constraint and preference constraint. When several constraints relate to an object, it satisfies them according to the heuristic ordering that reflects the order in which a human expert would satisfy them. It first picks the largest object and positions the other objects in order of decreasing of size by meeting their constraints relative to the former. The problem-solver in SITELAYOUT selects through the rules the constraints that need to test the instantiated locations for the facility at hand, instantiate them and test them.

Control Knowledge Sources. The Control Knowledge Sources involve meta-level knowledge, which establishes the problem solving strategy and controls the execution of the Domain Knowledge Sources. They delineate the strategy in selecting which action to take next and in what order to take for different site planning problems. Besides, they modify dynamically the strategy the problem-solving system uses to choose a knowledge source for execution on each problem-solving cycle.

3.5 Inference Mechanism

The inference engines control the strategies that determine how, from where, and in what order a knowledge base draws its conclusions. These inference strategies model the reasoning processes an expert uses when solving a problem. The Control Knowledge Sources evaluate the Design Status and decide what action should be performed mainly in data-driven forward chaining mechanism. The knowledge representations of the Domain Knowledge Sources, however, need both forward and backward chaining inference mechanism to arrive at the solution. At each cycle the knowledge sources recommend separate actions for which the preconditions are satisfied. Based on the rated heuristic scores, the scheduler then selects the best action and proposes it for execution. The system asks the user to accept or override the recommended action. The scheduler then executes the action, which may be to perform detailed design or change strategy. This cycle is repeated until a finite set of feasible solutions satisfying all constraints is found. In this way, it mimics human opportunistic and incremental reasoning about problem-solving actions. The solution tree is pruned intelligently beforehand, by selecting, at each step, the best possible action, and to limit an object's possible locations on site to a small finite set. The evaluation of a particular design can then be rated.

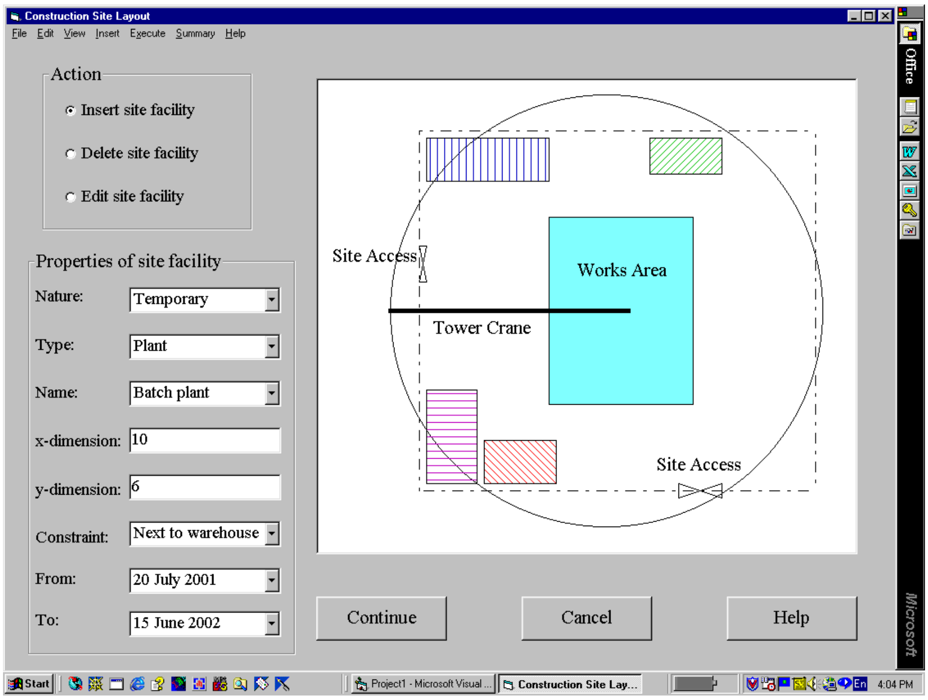

Fig. 3. Screen displaying interactive user interface of SITELAYOUT

3.6 User Interfaces

The system offers a friendly user interface such that a combination of mouse and keyboard can be used to navigate the application. Whilst input data entries are kept at minimum, they are provided by the user mostly through selection of appropriate values of parameters from the menus and answers to the queries made by the system. The input data provided by the user will be rejected if it is not within the specified range. The system provides multi-window graphic images combined with valuable textual information, which is extremely valuable to novice designers.

A set of temporary facilities has been represented into the system. The user needs to indicate which one is needed for the problem at hand and specify the size of each. In order to pick one feasible alternatives of the layout to be the solution, the choice is based on some evaluation functions taking into account user preferences and other criteria. Users can observe SITELAYOUT perform its preferred actions or they can make their own changes on the position of an object to the layout on the interactive display. That information is then sent back to the Domain Knowledge Sources which can monitor incoming information and update the blackboard for further reasoning. A computer graphics screen with multiple colors is a natural representation of possible object positions in layout design and a powerful medium for human-machine communication. The output is displayed graphically on the screen, indicating the location of every facility on the site, which facilitates expert user interface, visualization, critique and feedback. Figure 3 shows a typical screen displaying interactive user interface of SITELAYOUT.

3.7 Knowledge Acquisition Facilities

Knowledge plays an important role in a KBS, yet the major difficulty in designing a realistic site layout is the acquisition of necessary data. In order to acquire knowledge, it is better to work with the expert in the context of solving particular actual problems, instead of directly posing questions about rules. The knowledge used has been acquired mostly from written documents such as code of practice, textbooks and design manuals and conversations with several site practitioners.

3.8 Explanation Facilities

HELP command buttons provide definitions of a variety of parameters involved in order that the user can select the appropriate options. Their primary functions are to aid the user to comprehend the expert's approach to the problem of construction site layout, and to gain synthetic experience. In fact, the explanation facility is one of the distinct differences between the conventional computer programs and KBS, which is designed to explain its line of reasoning for acquiring an answer.

4 Conclusions

A prototype microcomputer KBS, SITELAYOUT, which assists in making decision on the construction site layout problem, was developed and implemented. It is shown that the hybrid knowledge representation approach combining production rule system and object-oriented programming technique is viable with the implementation of blackboard system architecture under a Windows platform for this domain problem. It comprises a detailed checklist of all activities and objects on site. The knowledge base is transparent and can easily be updated, which renders the KBS an ideal tool for incremental programming. Besides, its explanation facilities are capable of offering valuable information to the user, which can lead to a more efficient planning procedure. By using custom-built interactive graphical user interfaces, it is able to assist designers by furnishing with much needed expertise and cognitive support in a planning activity that when overlooked, results in cost overrun and schedule delays. Increase in efficiency, improvement, consistency of results and automated record keeping are among the advantages of such expert system.

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