Computer-Aided Site Layout Planning

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Abstract: This paper presents an interactive computer-aided site layout model to support site planning in a computer-aided design (CAD) environment and expands upon a model presented earlier by the writers. The developed model performs its task at two levels: Site representation, and site space analysis and allocation. The site representation is carried out using an open architecture supported by object-based concepts. The model offers three tiers of objects: (1) site objects, (2) construction objects, and (3) constraint objects. This structure facilitates the creation of new objects and reuse of domain knowledge, which allows for the gradual expansion and enrichment of the model's knowledge base. At the space analysis and allocation level, the model introduces a geometric reasoning approach to analyze site space for finding an optimum or near-optimum location for facilities. This feature facilitates easy visualization of the site planning process and encourages user participation. The model is structured in three main modules: Database, Project Module, and Layout Control Module. The functionality of each module, along with their interconnectivity is described. The model is implemented using Visual Basic for Applications in AutoCAD environment and Microsoft Access. A numerical example of an actual site layout is presented to illustrate the functionality of the developed model.

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Introduction

Space on construction sites is recognized as a resource that is as important as other resources of money, time, material, labor, and equipment (Tommelein et al. 1992b; Hegazy and Elbetagi 1999). A well-planned site can contribute to decreasing construction cost and time by minimizing travel time, decreasing time and effort spent on material handling, increasing productivity, and improving safety. However, site visits and interviews with superintendents and site managers reveal that site layout planning is often ignored in the planning phase of construction projects. In practice, space allocation on construction sites is typically carried out on a first-come-first-served basis and mainly through human judgment (Tam and Tong 2003), which could result in chaotic sites and may give rise to productivity losses and safety-related incidents.

Due to the complexity and the number of factors involved, computers were identified as an efficient tool to help site planners in their task. Over the last few decades several computer-based site layout systems have been developed. *CORELAP* (Moore 1971) was one of the first computer models developed for plant layout using operations research techniques. Later, artificial intelligence (AI) emerged as a viable tool to analyze site layouts and provide near-optimum solutions. Different AI techniques—such as knowledge-based systems (Hamiani 1987; Tommelein et al. 1991, 1992b; Flemming and Chien 1995; Choi and Flemming 1996), neural networks (Yeh 1995), and genetic algorithms (Philip et al. 1997; Li and Love 1998; Hegazy and Elbeltagi 1999; Harmanani et al. 2000; Mawdesley 2002; Zouein et al. 2002; Tam and Tong 2003)—were explored in the development of site layout systems. The main advantage of AI methods lies in their ability to deal with inexact, incomplete, and/or ill-structured problems (Yager and Stubblefield 1998). Other models have been developed using a hybrid of techniques. MoveSchedule (Tommelein and Zouein 1993a,b; Zouein 1996) is a dynamic space scheduling system that incorporates expert's knowledge in an optimization process. Cheng (1992) integrates a knowledge-based approach in a model using a geographic information system. However, to date no standard tool has gained wide acceptance by industry. This has been attributed to the difference between how domain experts address the problem and the way computer-based systems represent it (Tommelein et al. 1992a). In an effort to bridge this gap, researchers have suggested the use of knowledge-level description that is more abstract and code-independent (Balkany et al. 1991). This description includes the structure, functions, and properties of the components of the model. Such description is particularly important for site layout product models since there are few other such models that contain the domain knowledge. Further, the existing product models do not support the reuse of the knowledge and experience utilized in previous projects (Tommelein et al. 1992a). In general, previously developed site layout models exhibit one or more shortcomings of limited optimization objectives, rigid problem setup factors (e.g., facilities, site bound-

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ary, site conditions), mismatch between user's and systems' approach, lack of user-system interaction, and lack of knowledge recycling tools (Sadeghpour et al. 2004b).

This paper presents a site layout model designed to overcome the limitations cited above. The model addresses these limitations at two levels. At the first level, it tackles data structure and knowledge representation. Site layout-related elements are systematically identified and organized into object libraries. This classification assists in formalizing the representation of site layout problems in a simple format that is comprehensible by practitioners. An open architecture approach is proposed to support the generation of new objects in accordance with the diverse nature of construction sites. Such a characteristic renders the model flexible at the problem setup phase, not only in formation of objects, but also in defining new constraints to satisfy different objectives. Thus, it facilitates user contribution to the expansion and refinement of the knowledge base of the model, which enriches the model's capabilities. As well, it assists in recycling the domain knowledge utilized in current projects for later use on future projects. At the second level, the model performs space analysis and allocation of objects using a geometric reasoning approach by analyzing the site space. This approach resembles the human reasoning process and addresses the gap reported above, between the way domain experts develop site layouts and the way computer-based models approach it. In addition, the proposed model, through its open architecture, engages users in decision making at different stages. The developed model is implemented in computer-aided design (CAD) environment to facilitate users' visualization, comprehension, and interaction.

Proposed Model

Object-based concepts are utilized to formalize the data structure for the objects that represent the site conditions and the temporary facilities to be placed on the site. Based on this formalization, an open-architecture project setup module is developed. This architecture allows for creation and addition of new objects in each category at the user level. The newly created objects are captured by the model and remain in its database for future use. This allows users to populate the model database with new objects and tailor it to their respective work environment. Further, a geometric space analysis methodology is developed to find the optimum or near-optimum location for each object on site. The proposed methodology is applied to place a set of *construction objects* on site, while respecting the presence of a set of *existing objects on site* and satisfying a set of locating *constraints* defined by the user. As such, the site layout elements are clustered into three groups of objects: (1) *site objects*; (2) *construction objects*; and (3) *constraint objects* (Sadeghpour et al. 2002, 2003). Fig. 1 illustrates the general structure of the developed model and the relation between its three basic components: Database, Project Module, and Layout Control Module. Each of the three groups of objects is defined in respective submodules within the Project Module (i.e., Site Module, Construction Module, or Constraint Module), and stored in its respective library in the model's database (i.e., site library, construction library, or constraint library). All objects defined for a given project are then passed to the Layout Control Module, which conducts the search to find the optimum location for each construction object on site. The modules are designed to perform and interact with the user in CAD environment. The project setup phase of the proposed model has been previously introduced (Sadeghpour et al. 2004b). The following two sections, however, provide additional detailed description of its structure and functionality. Further, in the Layout Control Module section, a new methodology for site space analysis is introduced.

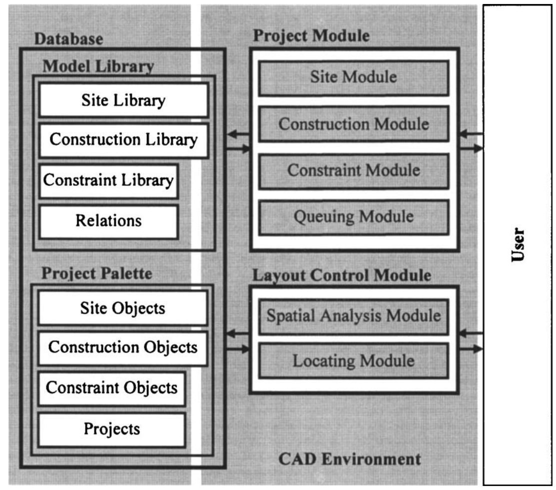

Fig. 1. Model structure

Database

Object-based concepts were utilized to represent the three aforementioned tiers of objects. Object-based approach strongly promotes the formalism of data typing and encapsulation of information, and hence inherently facilitates regeneration of the objects used in the model. Contrary to the object-oriented approach, no explicit inheritance scheme is imposed in the object-based approach (Zamanian 1992). The proposed tiers are designed as object classes, encapsulating their relevant properties. These properties include geometric and non-geometrical data and knowledge. The geometric information of an object can be accessed from a drawing file that contains a graphical instance of that object. The built-in database of the CAD system stores the geometrical and graphical properties of the object, such as area, perimeter, color, and line type. The nongeometrical properties are stored in a relational database, external to the CAD system. Fig. 2 depicts the relationships among the entities of the database. The database is divided into two functional sections: (1) the Model Library (ML) that acts as an object gallery from which the objects can be viewed and selected, and (2) the Project Palette (PP) that keeps record of the objects defined to represent the project at hand. The database consists of eight entities: "Site Library," "Construction Library," "Constraint Library," and "Relations" form the Model Library; where "Site Palette," "Construction Palette," "Constraint Palette," and "Projects" compose the PP.

When a construction or site object is selected from the library, an instance of its geometry is generated on the screen. The "file path" property provides the location of the drawing file, which can be inserted into the screen as a block. Graphical objects have a unique identification property, called *handle*, that is consistent through the life of that object and hence is the best reference to address an object. This property is assigned to the graphical objects upon their creation/insertion on the screen and can be accessed from the built-in database of the CAD system. When a site or construction object is selected from the Model Library to be added to the project, its handle is recorded in the respective table of the PP (i.e., site palette or construction palette). In other words,

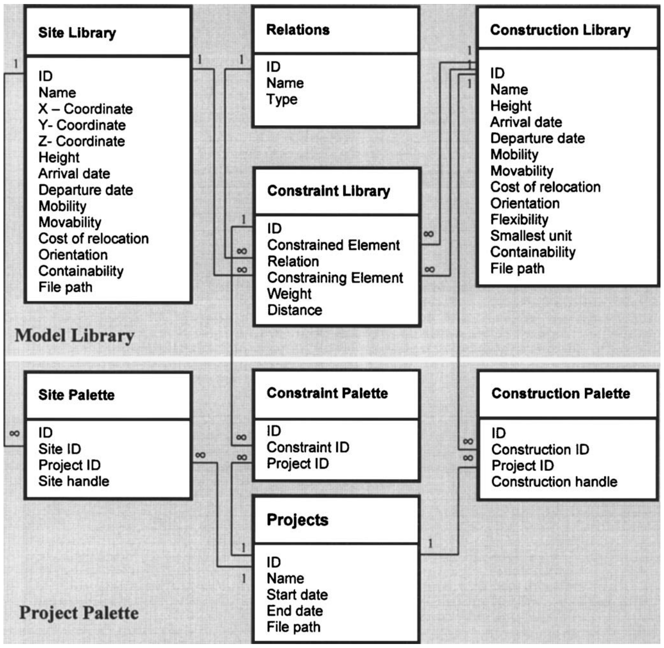

Fig. 2. Relationship diagram of the database

the handle property is the overlap between the built-in database of the CAD system and model's database to ensure connectivity between the two. As such, for each object selected for the project at hand, its nongeometric properties are coupled with the geometric ones read from the built-in database of the CAD system. By knowing the handle of an object, its geometrical information, such as area, perimeter, and/or centroid, can be obtained from the built-in database of the CAD system. Conversely, through the handle property, the nongeometrical properties of an object can be retrieved, modified, and saved from within the CAD system.

Project Module

The design of a site layout project commences at the Project Module, where the constructing elements of the project are defined in each of the respective submodules: Site Module, Construction Module, and Constraints Module, and are lined up in the Queuing Module in the order they are to be placed on site [Fig. 3(a)].

The site module starts by defining the boundaries of the project site. Once the site boundary is set, the site and construction modules prompt the user to *define* site objects and construction objects, respectively. The term *define* denotes two functions in the proposed model: *selecting* objects from the respective library, and *creating* new objects. Each of the site library, construction library, and constraint library, offers a set of related objects from which the user can *select* objects most suited to represent the project at hand. The selected objects will be added to the PP, which stores project-related data. If a desired object is not available from the libraries, the user is provided with tools to *create* it. As such, the model provides an open architecture for setting up a project. Newly created objects are added to the PP and the Model Library for future use. This allows planners to apply their individual problem solving strategies, and thus, directly contribute to the enrichment of the database of the model (Sadeghpour et al. 2003).

When *creating* an object, the model first prompts the user to define the geometry of that object. Depending on the case, this can be carried out using: (1) the readily available geometry of that object, which is directly extracted from a drawing file; (2) model-assisted drawing environment, where coordinates of the corners of the object's geometry are given as text input and the model generates the geometry of the object; or (3) the CAD system, which allows for drawing directly on the work area [Fig. 3(b)]. Once the geometry of an object is generated, the model then prompts the user to input its nongeometric data. The nongeometric data acquisition is conveyed in a text format questionnaire, and stored in the model's database [Fig. 3(c)].

The constraint module defines the interconnectivity among site and construction objects using a set of constraint objects. These objects are rules and preferences defined for locating each construction object. Each constraint object is assigned a proximity weight to indicate its importance with respect to other constraints. Fig. 4 shows the structure of a constraint object consisting of three parts: (1) a construction object for which the constraint object is being defined, referred to as the *constrained element*; (2) a topographic *relationship*, such as "as close as possible to," "west of," "visible from," and "within x meters of"; and (3) a *constraining element*, which can be a construction object or a site object. The developed structure facilitates the creation of new constraint objects in accordance with the open architecture design of the proposed model. A set of constraint objects is assigned to each construction object in the project palette. The construction object, for which the constraint is being defined, forms the *constrained element*. The *topographical relationship* is selected from a list provided by the Model Library. The *constraining element* can be selected from a list of construction and site objects in the PP. More details on the structure of objects and project setup can be found in Sadeghpour et al. (2003, 2004b).

Graph theoretic techniques have been applied earlier by others to decide on adjacency between pairs of objects (Foulds 1983, Foulds et al. 1985). Two other important placement methods are improvement and construction methods (Moore 1980). Improvement methods start from an initial layout and generate alternative layouts by changing the position of objects. Each layout is then evaluated against a predefined objective function and the layout that best satisfies the objective function is identified. Construction methods, used in the proposed model, add one object at a time to the layout, considering the updated status of the site before adding each object. In this case, the order in which construction objects are located on site affects the final layout. Tam et al. (2002) have applied fuzzy logic to evaluate the order of objects based on pairwise comparisons. Zouein (1996) suggested random selection of objects or the use of one of the three heuristics: "area requirement," "duration on site," or "cost of relocation," without articulating a formal structure for the collective application of these heuristics. However, it is important to ensure that the planner is able to queue objects based on experience, intuition, and due considerations of applicable site constraints. In an effort to achieve such an open, dynamic, and user-interactive process in the proposed model, assignment of priorities is established based on a multiattribute queuing score (Q). This score accounts for a combination of weighted heuristics, such as those referred to earlier (i.e., area requirement, duration on site, cost of relocation), as well as other factors such as "Number of constraints," "Total weight of constraints," "Time of arrival," and "Number of *constrained elements.*" The latter refers to the frequency of the object being selected as a *constraining element* in a constraint object. The planner selects applicable attributes to be used in the queuing process of each project and assigns a relative weight to each to indicate its importance compared to others (see Fig. 5). The mul-

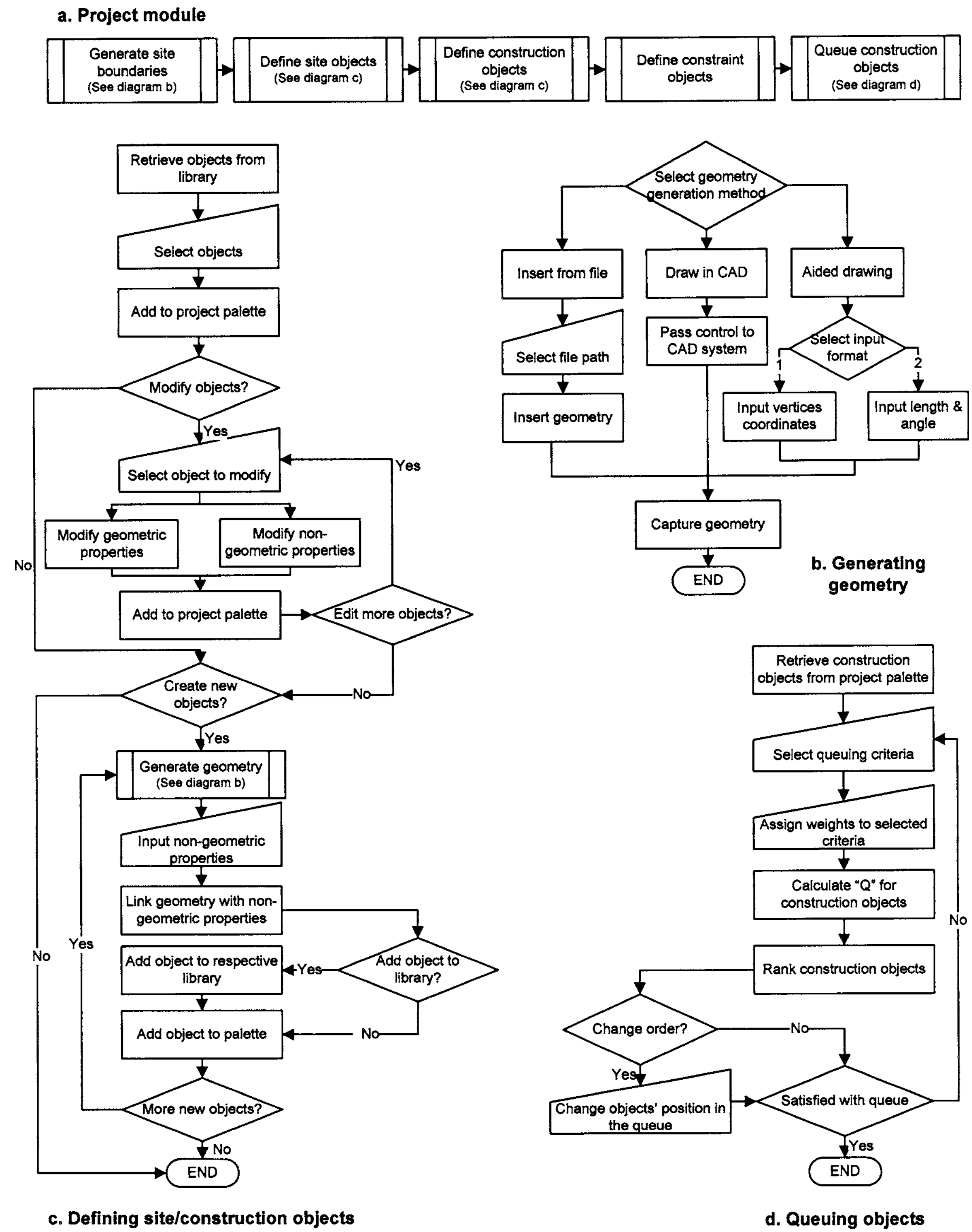

Fig. 3. Dataflow in the project module

tiattributed queuing score (Q) for each construction object is calculated as

$$Q=\sum_{1}^{n}\frac{C_i}{C_{\text{Max}}}\,[00e2][0088][0099]\,Wc_i \qquad (1)$$

where C_i=value associated with the ith attribute; C_{Max}=maximum value of that attribute for all objects; and Wc_i=weight assigned to this attribute. Accordingly, objects are queued in descending order of their queuing score. The planner

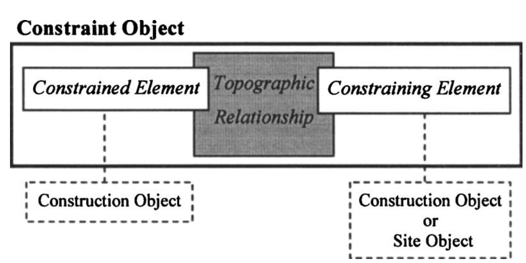

Fig. 4. Structure of a constraint object

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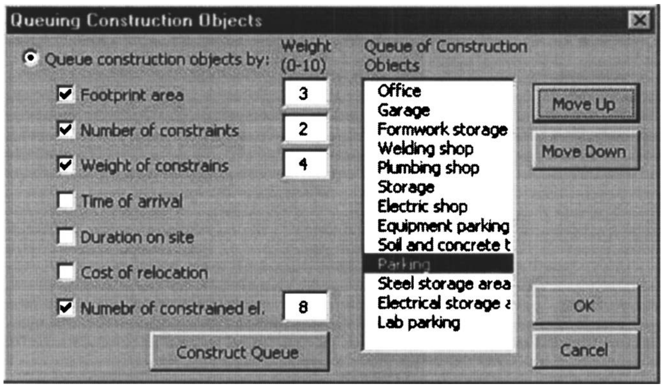

Fig. 5. Queuing of construction objects

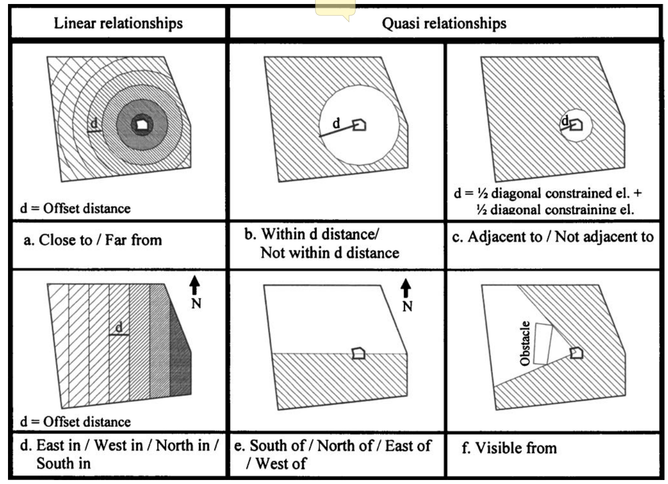

Fig. 6. Geometric representation for six types of relationships

can choose to proceed with that queue or modify the order of its objects [Fig. 3(d)]. As well, different combinations of the attributes leading to different orders of objects can be invoked to study the impact on the final layout.

The procedure described above is applied for queuing 13 construction objects presented in Table 1. Fig. 5 depicts a sample screen for the queuing process in the developed model. The four attributes selected in Fig. 5 are used to form the queuing criteria. Each is assigned a weight to signify its importance to the planner in assigning the space on site. The data associated with the attributes selected for this case are summarized in Table 1 (Columns 3 to 6). It should be noted that these data were retrieved directly from the model's database, upon forming the queuing criteria. Table 1 also contains the calculated queuing score (Q) and the rank of each object in the queue.

Layout Control Module

The queue of construction objects is passed to the layout control module to place the objects on site. This module performs two major tasks: Analyzing site space to find the optimum or near-optimum location for each construction object in the queue, and placing the construction objects on site. Each of these tasks is performed by "spatial analysis" and "locating" submodules, respectively.

The spatial analysis submodule scans the available site area to find the best location based on the knowledge and information provided by the PP. The process of finding the location is done through a geometric reasoning search (Sadeghpour et al. 2004a). When locating a construction object, the model retrieves the constraint objects assigned to it. For each constraint defined for the construction object at hand, the site is divided into segments. Each site segment represents a different degree of satisfaction for that constraint. The discretization method differs according to the type of topographical relationship used to define the constraint. Fig. 6 shows the discretization method for six types of relationships. These relationships are obviously not exhaustive, but are sufficient for defining most of the cases. These relationships are divided into two groups: (1) linear relationships; and (2) quasi-relationships. Linear relationships represent a gradual transformation in the satisfaction score of each site segment, whereas

Table 1. Data Pertaining to Queuing of Objects

		Queuing attributes					
Number	Construction object	Area (m^2)	Number of constraints	Weight of constraints	Number of constrained elements	Q	Rank
1	Office	500	7	560	8	14.23810	1
2	Parking	750	2	160	0	2.071429	10
3	Garage	750	2	130	5	6.857143	2
4	Storage	320	5	340	0	4.009524	6
5	Welding shop	150	3	200	3	5.357143	4
6	Plumbing shop	600	2	130	3	4.785714	5
7	Electric shop	150	2	150	2	3.714286	7
8	Formwork storage area	6,300	3	190	1	6.214286	3
9	Steel storage area	100	2	150	0	1.690476	11
10	Electrical storage area	200	1	100	0	1.095238	12
11	Equipment parking	1,200	4	260	0	3.571429	8
12	Soil and concrete test labs	144	3	190	1	3.282857	9
13	Lab parking	90	1	100	0	1.042857	13
Max value (C_{Max})		6,300	7	560	8		
Weight (Wc)		3	2	4	8		

quasi-relationships divide the site in two segments and demonstrate a strict preference of one segment over the other (Brans et al. 1986). For example, "close to" or "far from" relationships are represented by means of circles circumscribing the *constraining element*, dividing the site into ring-shaped regions. Assuming the area inside a ring has the same distance from the *constraining element*, each ring represents a different degree of satisfaction for the closeness or farness relation (see Fig. 6).

As geometric representation for all the *constraint objects* associated with the construction object in hand are generated, the site is divided into smaller and smaller segments resulting from intersections of various geometrical representations as will be shown later in the case example. Considering the fact that the intersection of two areas contains the attributes of both, the satisfaction score for the area of intersection is calculated as the sum of the scores associated with the two intersecting areas. As such, the utility score (U) for each site segment is expressed as

$$U = \sum_{1}^{n} S_i [00e2][0088][0099] W_i \tag{2}$$

where S_i=satisfaction score for the ith constraint; and W_i=weight assigned to the ith constraint. Based on Eq. (2), the utility score for each site segment is calculated and they are sorted accordingly. The geometric representation of constraints divides the site into a set of irregular segments that are neither of equal size nor of the same shape. The utility function of site segments is calculated at their respective centroids, which form an irregular network of grid points. The width of the rings representing linear relationships, such as farness and closeness, affect the shape and size of this grid.

The size of the solution segment found by the model depends on the offsetting width in linear relationships and indicates the precision of the answer. The smaller the offset width chosen, the smaller the size of the grid, and consequently the more precise the location of the construction object. If higher precision is required, the model allows for refining the analysis within the solution segment. The grid refining process can take place in several iterations, zooming down on the near-optimum location, until the precision of the location, and in other words the size of the solution segment is deemed satisfactory. The planner can accept the location found by the model, or veto the model's solution and select another location based on the analysis and results provided by the model. The grids and geometries resulting from each analysis iteration are stored in a separate drawing layer and can be viewed separately or simultaneously to assist the planner in deciding the final location of the object at hand. If a location other than those ranked by the model is selected, the model can calculate the utility score of that location for comparison purposes.

Once the final location of a construction object is decided, the locating module proceeds with laying the object on the identified location. By default, the model matches the controid of the object in hand with that of the identified segment for the object location. The user then could choose to fine-tune the location of the object as required using corner-to-corner adjacency [Fig. 7(a)], vertical and horizontal alignment [Fig. 7(b)], and/or rotating the object (not shown in Fig. 7). The locating module further verifies whether the object overlaps with an existing object on site to satisfy the nonoverlap condition.

When the object is positioned on site, the layout module deducts its footprint area from the available site area. Once all the construction objects are located, the total utility function (f) of the layout can be calculated as

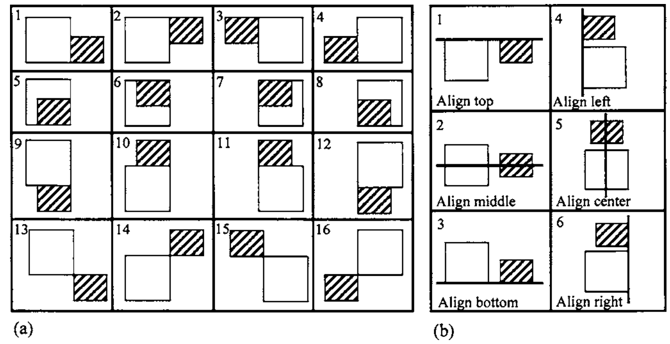

Fig. 7. Alignment of objects: (a) corner-to-corner adjacencies; and (b) vertical and horizontal alignments

$$f = \sum_{1=i}^{n} \sum_{1=j}^{m} S_{ij} [00e2][0088][0099] W_{ij} \tag{3}$$

where S_{ij}=satisfaction rate of ith constraint defined for jth object; and W_{ij}=weight of ith constraint defined for jth object. Eq. (3) is useful in comparing the fitness of different layouts generated by different project setup factors.

Implementation

The model described above, was implemented as proof of concept, using Visual Basic for Applications (VBA) in AutoCAD environment, and Microsoft Access to develop the model's database. VBA is an object-oriented programming environment with development capabilities similar to those of Visual Basic (VB). Unlike VB, VBA runs in the same process environment as AutoCAD, providing seamless integration and fast execution of the program. It also provides integration with other VBA-enabled applications, such as MS Access. This enables AutoCAD to be an automation controller for such applications, using their respective object libraries (Autodesk 2001). As such, VBA provides a seamless link between the main components of the model, supported by a powerful graphical user interface (GUI). The model has been demonstrated to practitioners from the industry at several stages of its design and development and their recommendations were considered at each stage.

Case Example

Case Description

A case study from industry was developed to illustrate the flexibility and capabilities of the developed model. The case involved the design of a layout for the site of a major hydro project, LG-2, constructed in Quebec, Canada. The site has an area of 28'178 m^2 and was required to accommodate the 13 facilities listed in Table 1. Fig. 8 shows the layout of the facilities on site as designed by the project team. The numbers refer to the construction objects listed in Table 1. It should be noted that the site engineer, who was involved in the preparation of the original site layout, was requested to carry out the analysis and generate the layout using the developed model with the assistance of a computer operator. Further, to enable a comparison, the set of constraints used in the original layout were also imposed in the case analysis performed using the developed model.

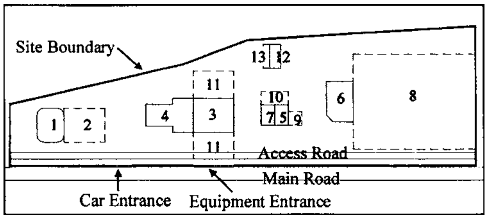

Fig. 8. Actual site layout of LG-2 project

Generation of Layout

To map the presented project in the proposed model, the project module starts with generating the required objects. After generating the boundaries of site, three site objects were identified and their respective representations were generated: Car entrance, equipment entrance, and access road. The geometry of these objects was generated using the features in the model and they were placed on their known location on the site. Thirteen facilities were modeled as the construction objects and added to the PP. For each construction object, a number of constraints were defined. To enable a comparison, the constraints were identical to those considered at the time of actual site design by members of the project team. Table 2 summarizes the constraint objects, their composing elements, and their respective priority weights. Once the PP is set, the Queuing Module ranks the order of construction objects based on four attributes as described earlier in the queuing example (see Fig. 5) and summarized in Table 1.

Upon the queuing of objects, the Spatial Analysis Module is activated to find a location for each object according to the constraints defined for them. At the beginning of site analysis, three regions on the site, highlighted in Fig. 9 as A, B, and C, were recognized as "unavailable." Region A is a 10 m wide space inside the site boundary, provisioned to keep construction objects from being located on the edge of the site. Regions B and C indicate 20 m of clearance around the entrances to the site. As an

Table 2. Constraint Objects Defined for the LG-2 Project

Number	Constrained element	Relation	Constraining element	Weight
1	Office	Far from	Electrical shop	90
		Far from	Welding shop	100
		Far from	Plumbing workshop	90
		Not within *d* of	Garage	50
		Not within *d* of	Access road	50
		Close to	Car entrance	80
		West of	Site	100
2	Parking	Next to	Office	90
		Close to	Car entrance	70
3	Garage	Within *d* of	Equipment entrance	80
		Not within *d* of	Office	50
4	Storage	Close to	Office	50
		Visible from	Office	70
		Next to	Garage	100
		Close to	Car entrance	40
		Close to	Equipment entrance	80
5	Welding shop	Next to	Plumbing workshop	40
		Far from	Office	100
		Not within *d* of	Formwork storage area	60
6	Plumbing workshop	Close to	Welding shop	40
		Far from	Office	90
7	Electrical shop	Close to	Plumbing workshop	60
		Far from	Office	90
8	Formwork storage area	Not within *d* of	Welding shop	60
		East of	Site	80
		Close to	Access road	50
9	Steel storage area	Next to	Welding shop	90
		Far from	Office	60
10	Electrical storage area	Next to	Electrical shop	100
11	Parking lot for equipment	Next to	Garage	100
		Close to	Car entrance	10
		Close to	Equipment entrance	70
		North of	Garage	80
12	Soil and concrete test labs	Close to	Garage	60
		Close to	Electrical shop	80
		North of	Site	50
13	Lab parking	Next to	Soil and concrete test labs	100

Note: d=distance specified by user.

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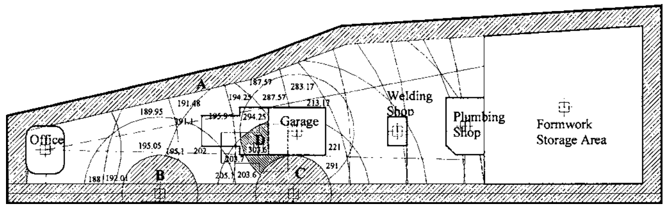

Fig. 9. Site analysis for Storage

example, Fig. 9 shows the site analysis for the "Storage" as the sixth construction object to be laid on the site (see Table 1), considering five constraint objects (see Table 2). These constraints indicate that the storage should be located close to the two entrances to ease deliveries; close to the office since several visits to the storage were predicted, and visible from the office to maintain security. The constraint object specifying the adjacency between the Storage and Garage was specifically created for this project since the site manager intended to use the same structure for the two. When the available site area is analyzed based on the constraints, the segment highlighted as D receives the highest satisfaction score, and accordingly, the object is first placed at that location. It should be noted that the numbers shown in Fig. 9 represent the satisfaction score (U) for a set of site segments closer to the segment D. The locating module further fine-tunes the location of Storage and aligns it with the Garage, invoking the corner-to-corner adjacency feature shown in Fig. 7.

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Fig. 10 shows the layout of the site after the analysis is performed for all the construction objects in the queue. The numbers refer to the construction objects listed in Table 1. It is interesting to note the similarities and dissimilarities between the generated layout and the original one. Equipment Parking (11) is moved to one side of the Garage (3) to maintain to clearance area defined for the Equipment Entrance. Also its shape was redefined in accordance with the clearance defined for the site boundary while providing the same area. Similarly, the shape of Formwork Storage Area (8) was slightly resized to take advantage of the unused corner of site and give space on its left, which is in continuity with the open space. Electrical Shop (7) in the proposed model is shifted to the right of the site to better accommodate the two constraints of closeness to the Plumbing Shop (6) and farness from the Office (1). In general, the model was able to generate a layout that is close to the original site arrangement in shorter time. The differences between the generated layout and the original layout can be attributed to the fact that the generated layout better satisfied the defined constraints.

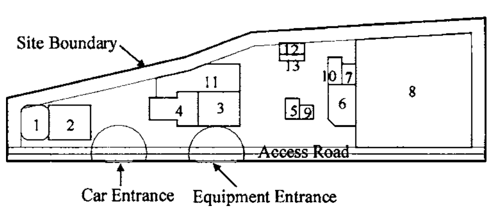

Fig. 10. Site arrangement for LG-2 generated using the proposed model

Discussion

The case example presented here demonstrated the capabilities of the model in overcoming the limitations of other models referred to earlier in the paper. The model was capable of creating project requirements, which consisted of multiple facilities with irregular shapes and a variety of locating constraints. The objects and constraints defined in this project were added to the database and can be recycled for future projects. Due to model's flexibility in defining constraints, the model was able to include optimization objectives other than minimum travel distance, such as security. The geometry-based approach utilized in the presented model, as well as its data flow, facilitate its use by practitioners. Additionally, the open architecture referred to earlier supports the user interaction, and provides users with the opportunity of utilizing their own knowledge and experience.

The model improves the current practice on two points: (1) in the project setup phase, the model provides a central platform that supports users in defining relevant objects and applicable constraints. (2) In the site analysis and allocation phase, the model was able to analyze the constraints defined for each object and find a location in a considerably shorter time compared to the actual time it took site planners. When the analysis was performed on a regular office computer (Pentium IV processor with 2 GHz processor), on average it took the model 30 s to find a near-optimum location for each construction object; whereas the design of the original layout was the product of several meetings of various decision makers.

Summary and Concluding Remarks

This paper presented a CAD-based site layout model designed to aid site planners in developing layouts in an interactive manner. The developed model provides users with a design support tool that helps its users to utilize their knowledge in design of efficient site layouts. The basic components of the model—including its database, Project Module, and Layout Control Module—were described and the functionality of each module was described. The paper discussed a formalized data structure for site layout modeling in detail and introduced a new methodology for site space analysis and allocation. This methodology is geometry-based to support visualization and facilitate user-system interaction. A case example of an actual site layout was analyzed using the developed model. The model was able to generate a layout close to the one created by site planners. The differences between the two layouts are attributed to the degree of satisfaction associated with the constraints considered in the project. The developed model resulted in a layout that better satisfied the specified constraints.

The case example demonstrated that the developed model was capable of overcoming the limitations of the models developed by others. The model has been validated through a number of case studies, including those from literature (Sadeghpour 2004). The model improves current practice by providing site planners and decision makers with a centralized computer environment for defining the required site objects and constraints in a project. As well, it notably reduces the time required for site analysis. To realize a site layout model that is acceptable in the industry, the user interface of the developed model should be further validated through hands-on experiments with participation of industry practitioners.

Acknowledgment

The writers would like to acknowledge Mr. German Cardinal, practicing consultant, for his interest and for sharing his valuable time and experience in preparing the case study presented in this paper.

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Computer-aided site layout planning

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이 백서는 컴퓨터 지원 설계“CAD”환경에서 사이트 계획을 지원하기위한 대화식 컴퓨터 지원 사이트 레이아웃 모델을 제시하고 작가가 이전에 제시 한 모델을 확장합니다. 개발 된 모델은 사이트 표현과 사이트 공간 분석 및 할당이라는 두 가지 수준에서 작업을 수행합니다. 사이트 표현은 객체 기반 개념이 지원하는 개방형 아키텍처를 사용하여 수행됩니다. 이 모델은 共 1 兲 사이트 객체, 共 2 兲 구성 객체 및 共 3 兲 구속 객체의 세 가지 계층 객체를 제공합니다. 이 구조는 새로운 객체의 생성과 도메인 지식의 재사용을 용이하게하여 모델의 지식 기반을 점진적으로 확장하고 풍부하게합니다. 공간 분석 및 할당 수준에서이 모델은 시설에 대한 최적 또는 거의 최적의 위치를 찾기 위해 사이트 공간을 분석하기위한 기하학적 추론 방식을 도입합니다. 이 기능은 사이트 계획 프로세스를 쉽게 시각화하고 사용자 참여를 장려합니다. 이 모델은 데이터베이스, 프로젝트 모듈 및 레이아웃 제어 모듈의 세 가지 주요 모듈로 구성됩니다. 각 모듈의 기능과 상호 연결성에 대해 설명합니다. 이 모델은 AutoCAD 환경 및 Microsoft Access에서 Visual Basic for Applications를 사용하여 구현됩니다. 개발 된 모델의 기능을 설명하기 위해 실제 사이트 레이아웃의 수치 예제가 제공됩니다.

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건설 현장의 공간은 돈, 시간, 자재, 노동 및 장비의 다른 자원만큼 중요한 자원으로 인식됩니다. 1992b; 헤 가지와 엘베 타기 1999 兲. 잘 계획된 현장은 이동 시간을 최소화하고 자재 취급에 소요되는 시간과 노력을 줄이고 생산성을 높이며 안전성을 향상시켜 건설 비용과 시간을 줄이는 데 기여할 수 있습니다. 그러나 현장 방문 및 교육장 및 현장 관리자와의 인터뷰는 건설 프로젝트의 계획 단계에서 현장 레이아웃 계획이 종종 무시되는 것으로 나타났습니다. 실제로, 건설 현장의 공간 할당은 일반적으로 선착순으로 이루어지며 주로 인간의 판단에 따라 수행됩니다. 共 Tam and Tong 2003 兲 혼란스러운 장소가 될 수 있으며 생산성 손실과 안전을 초래할 수 있습니다. 관련 사건. 복잡성과 관련된 여러 요인으로 인해 컴퓨터는 사이트 플래너가 작업을 수행하는 데 도움이되는 효율적인 도구로 식별되었습니다. 지난 수십 년 동안 여러 컴퓨터 기반 사이트 레이아웃 시스템이 개발되었습니다. CORELAP 共 Moore 1971 兲는 운영 연구 기법을 사용하여 플랜트 레이아웃 용으로 개발 된 최초의 컴퓨터 모델 중 하나입니다. 나중에 인공 지능 共 AI 兲는 사이트 레이아웃을 분석하고 거의 최적의 솔루션을 제공하는 실용적인 도구로 등장했습니다. 지식 기반 시스템과 같은 다른 AI 기술 共 Hamiani 1987; Tommelein et al. 1991, 1992b; Flemming and Chien 1995; Choi and Flemming 1996 兲, 신경망 共 Ye 1995 兲 및 유전자 알고리즘 共 Philip et al. 1997; Li and Love 1998; 헤 가지 및 엘벨 타기 1999; Harmanani et al. 2000; Mawdesley 2002; Zouein et al. 2002; Tam and Tong 2003 兲 — 사이트 레이아웃 시스템 개발에 대해 살펴 보았습니다. 인공 지능 방법의 주요 장점은 부정확하고 불완전하며 구조적 문제를 다루는 능력에있다 (Luger and Stubblefield 1998). 다른 기술은 하이브리드 기술을 사용하여 개발되었습니다. MoveSchedule-Tommelein and Zouein 1993a, b; Zouein 1996 兲는 최적화 프로세스에 전문가의 지식을 통합 한 동적 공간 예약 시스템입니다. Cheng 共 1992 兲는 지리 정보 시스템을 사용하여 모델에 지식 기반 접근 방식을 통합합니다. 그러나 현재까지 표준 도구는 업계에서 널리 인정받지 못했습니다. 이는 도메인 전문가가 문제를 해결하는 방법과 컴퓨터 기반 시스템이 문제를 나타내는 방식의 차이로 인한 것입니다. 共 Tommelein et al. 1992a 兲. 이러한 격차를 해소하기 위해 연구원들은보다 추상적이며 코드에 독립적 인 지식 수준의 설명을 제안했습니다. 1991 兲. 이 설명에는 모델 구성 요소의 구조, 기능 및 특성이 포함됩니다. 도메인 지식을 포함하는 모델이 거의 없기 때문에 이러한 설명은 사이트 레이아웃 제품 모델에 특히 중요합니다. 또한 기존 제품 모델은 이전 프로젝트에서 활용 된 지식과 경험의 재사용을 지원하지 않습니다. 1992a 兲. 일반적으로, 이전에 개발 된 사이트 레이아웃 모델은 제한적인 최적화 목표, 시설, 사이트 경계, 사이트 조건과 같은 까다로운 문제 설정 요소, 사용자와 시스템 간의 접근 불일치, 사용자 시스템 상호 작용 부족의 하나 이상의 단점을 나타냅니다. 지식 재활용 도구 부족 共 Sadeghpour et al. 2004b 兲.

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인공 지능 방법의 주요 장점은 부정확하고 불완전하며 구조적 문제를 다루는 능력에있다 (Luger and Stubblefield 1998).

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그러나 현재까지 표준 도구는 업계에서 널리 인정받지 못했습니다. 이는 도메인 전문가가 문제를 해결하는 방법과 컴퓨터 기반 시스템이 문제를 나타내는 방식의 차이에 기인합니다 (Tommelein et al. 1992a).

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이전 모델의 문제점 - 기존 제품 모델은 이전 프로젝트에서 활용 한 지식과 경험의 재사용을 지원하지 않습니다 (Tom- 멜 레인 et al. 1992a).

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이전 모델의 문제점2 -
일반적으로, 이전에 개발 된 사이트 레이아웃 모델은 제한된 최적화 목표, 엄격한 문제 설정 요소 (예 : 시설, 사이트 경계, 사이트 조건), 사용자와 시스템의 접근 방식 불일치, 사용자 시스템 상호 작용 부족의 하나 이상의 단점을 나타냅니다. 지식 재활용 도구가 부족하다 (Sadeghpour et al. 2004b).

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이 논문은 위에서 언급 한 한계를 극복하도록 설계된 사이트 레이아웃 모델을 제시합니다. 이 모델은 두 가지 수준에서 이러한 제한 사항을 해결합니다.

첫 번째 수준에서는 데이터 구조와 지식 표현을 다룹니다.
사이트 레이아웃 관련 요소는 체계적으로 식별되고 객체 라이브러리로 구성됩니다. 이 분류는 실무자가 이해할 수있는 간단한 형식으로 사이트 레이아웃 문제의 표현을 공식화하는 데 도움이됩니다. 건설 현장의 다양한 특성에 따라 새로운 객체 생성을 지원하기 위해 개방형 아키텍처 접근 방식이 제안됩니다. 이러한 특성은 물체의 형성뿐만 아니라 다른 목표를 만족시키기위한 새로운 구속 조건을 정의 할 때 문제 설정 단계에서 모델을 유연하게 만듭니다. 따라서 모델의 지식 기반을 확장하고 개선하는 데 사용자가 기여할 수있어 모델의 기능이 강화됩니다. 또한 향후 프로젝트에서 나중에 사용하기 위해 현재 프로젝트에 사용 된 도메인 지식을 재활용하는 데 도움이됩니다.

두 번째 수준에서 모델은 공간 분석 및 사이트 공간 분석을위한 기하학적 추론 접근 방식을 사용하여 객체 할당을 수행합니다. 이 접근법은 인간의 추론 과정과 유사하며 도메인 전문가가 사이트 레이아웃을 개발하는 방식과 컴퓨터 기반 모델이 접근하는 방식 사이에서 위에서보고 된 격차를 해결합니다. 또한 제안 된 모델은 개방형 아키텍처를 통해 사용자를 다양한 단계에서 의사 결정에 참여시킵니다. 개발 된 모델은 CAD (Computer-Aided Design) 환경에서 구현되어 사용자의 시각화, 이해 및 상호 작용을 용이하게합니다.

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그림 6은 6 가지 유형의 관계에 대한 이산화 방법을 보여줍니다. 이러한 관계는 명백하지는 않지만 대부분의 경우를 정의하기에 충분합니다. 이러한 관계는 두 그룹으로 나뉩니다. 兲 1 兲 선형 관계; 그리고 共 2 兲 준 관계. 선형 관계는 각 사이트 세그먼트의 만족도 점수에서 점진적인 변환을 나타내는 반면 준 관계는 사이트를 두 세그먼트로 나누고 한 세그먼트를 다른 세그먼트보다 엄격하게 선호 함을 나타냅니다. 1986 년. 예를 들어, "가까운"또는 "먼"관계는 구속 요소를 둘러싸는 원으로 표시되어 사이트를 고리 모양의 영역으로 나눕니다. 링 내부의 영역이 구속 요소와 동일한 거리를 갖는다 고 가정하면, 각 링은 근접 또는 원거리 관계에 대한 서로 다른 만족도를 나타냅니다 (그림 6 참조).

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위에서 설명한 모델은 AutoCAD 환경의 VBA (Visual Basic for Applications) 및 모델 데이터베이스를 개발하기 위해 Microsoft Access를 사용하여 개념 증명으로 구현되었습니다. VBA는 Visual Basic 共 VB 兲와 유사한 개발 기능을 갖춘 객체 지향 프로그래밍 환경입니다. VB와 달리 VBA는 AuCAD와 동일한 프로세스 환경에서 실행되므로 프로그램을 원활하게 통합하고 빠르게 실행할 수 있습니다. 또한 MS Access와 같은 다른 VBA 지원 응용 프로그램과의 통합도 제공합니다. 이를 통해 AutoCAD는 해당 객체 라이브러리 인 "Autodesk 2001"을 사용하여 이러한 응용 프로그램의 자동화 컨트롤러가 될 수 있습니다. 따라서 VBA는 강력한 그래픽 사용자 인터페이스 인 GUI (GUI)에 의해 지원되는 모델의 주요 구성 요소 간 이음새없는 링크를 제공합니다. 이 모델은 설계 및 개발의 여러 단계에서 업계의 실무자에게 입증되었으며 각 단계에서 권장 사항을 고려했습니다.

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개발 된 모델의 유연성과 기능을 설명하기 위해 업계의 사례 연구가 개발되었습니다. 이 사례는 캐나다 퀘벡에 건설 된 주요 수력 프로젝트 LG-2 현장 레이아웃 설계와 관련이 있습니다. 부지 면적은 28'178m2이며 표 1에 나열된 13 개 시설을 수용해야했습니다. 그림 8은 프로젝트 팀이 설계 한 시설 내 시설 배치를 보여줍니다. 숫자는 표 1에 나열된 구성 객체를 나타냅니다. 원래 사이트 레이아웃 준비에 관여 한 사이트 엔지니어는 분석을 수행하고 개발 된 모델을 사용하여 레이아웃을 생성하도록 요청했습니다. 컴퓨터 운영자의 도움. 또한, 비교를 가능하게하기 위해, 개발 된 모델을 사용하여 수행 된 사례 분석에서 원래 레이아웃에 사용 된 일련의 제약 조건도 부과되었다.

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객체 큐잉시 공간 분석 모듈이 활성화되어 객체에 대해 정의 된 제약 조건에 따라 각 객체의 위치를 찾습니다. 현장 분석 시작시, 그림 9에서 A, B 및 C로 강조 표시된 3 개의 지역이 "사용할 수 없음"으로 인식되었습니다. 지역 A는 현장 경계 내부의 10m 너비의 공간으로, 건설 물체가 사이트 가장자리에 있지 않도록하십시오. 영역 B와 C는 사이트 입구 주변의 간격이 20m임을 나타냅니다. 예를 들어, 그림 9는 5 개의 구속 조건 객체를 고려하여 현장에 놓을 6 번째 시공 대상인“저장소”에 대한 현장 분석을 보여줍니다 (표 2 참조). 이러한 제약 조건은 보관이 배송을 용이하게하기 위해 두 입구 가까이에 위치해야 함을 나타냅니다. 스토리지에 대한 여러 번의 방문이 예상되었으므로 사무실과 가까우며 보안 유지를 위해 사무실에서 볼 수 있습니다. 사이트 관리자가 두 프로젝트에 동일한 구조를 사용하려고했기 때문에이 프로젝트에 대해 저장소와 차고 사이의 인접성을 지정하는 제한 조건 오브젝트가 특별히 작성되었습니다. 가용 사이트 영역이 제약 조건을 기반으로 분석 될 때 D로 강조 표시된 세그먼트가 가장 높은 만족도 점수를 받으므로 대상은 먼저 해당 위치에 배치됩니다. 그림 9에 표시된 숫자는 세그먼트 D에 더 가까운 일련의 사이트 세그먼트에 대한 만족도 점수 共 U 兲를 나타냅니다. 위치 지정 모듈은 저장소의 위치를 추가로 미세 조정하고 차고와 정렬하여 호출합니다. 도 7에 도시 된 코너 대 코너 인접 기능.

그림 10은 대기열에있는 모든 시공 개체에 대해 해석이 수행 된 후 사이트의 레이아웃을 보여줍니다. 숫자는 표 1에 나열된 구성 객체를 나타냅니다. 생성 된 레이아웃과 원래 레이아웃의 유사점과 비 유사성을 주목하는 것이 흥미 롭습니다. 장비 파킹 共 11 兲은 차고 共 3 兲의 한쪽으로 이동하여 장비 입구에 정의 된 여유 공간을 유지합니다. 또한 그 형상은 동일한 면적을 제공하면서 부지 경계에 대해 정의 된 간극에 따라 재정의되었습니다. 마찬가지로 거푸집 보관 영역 共 8 shape의 모양은 사용하지 않은 부지의 코너를 이용하고 왼쪽에 공간을 제공하기 위해 약간 크기가 조정되었으며, 이는 열린 공간과 연속적입니다. 제안 된 모델의 전기 공장 共 7 兲은 배관 공장 共 6 兲에 대한 친밀감과 사무실 共 1 兲에서 멀어짐의 두 가지 제약 조건을 더 잘 수용 할 수 있도록 사이트 오른쪽으로 이동합니다. 일반적으로이 모델은 원래 사이트 배치에 가까운 레이아웃을 더 짧은 시간에 생성 할 수있었습니다. 생성 된 레이아웃과 원래 레이아웃의 차이점은 생성 된 레이아웃이 정의 된 제한 조건을 더 잘 충족 시켰다는 사실에 기인 할 수 있습니다. 무화과.

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제시된 프로젝트를 제안 된 모델로 매핑하기 위해 프로젝트 모듈은 필요한 객체를 생성하는 것으로 시작합니다. 부지의 경계를 생성 한 후 세 개의 부지 객체가 식별되고 각각의 표현이 생성되었습니다 : 자동차 출입구, 장비 출입구 및 진입로 이러한 객체의 형상은 모델의 형상을 사용하여 생성되었으며 사이트의 알려진 위치에 배치합니다. 13 개의 시설이 시공 대상으로 모델링되어 PP에 추가되었습니다. 각 시공 객체에 대해 여러 가지 구속 조건이 정의되었습니다. 비교를 가능하게하기 위해 프로젝트 팀 구성원이 실제 사이트를 디자인 할 때 고려한 것과 동일한 제약 조건이 적용되었습니다. 표 2는 구속 조건 객체, 구성 요소 및 각각의 우선 순위 가중치를 요약합니다. PP가 설정되면, 대기열 모듈은 대기열 예에서 설명한 바와 같이 (그림 5 참조) 표 1에 요약 된대로 4 가지 속성을 기준으로 구성 객체의 순서를 정합니다.

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토론

여기에 제시된 사례 예는 이전에 언급 된 다른 모델의 한계를 극복하는 데있어 모델의 기능을 보여줍니다. 이 모델은 불규칙한 모양과 다양한 위치 구속 조건을 가진 여러 시설로 구성된 프로젝트 요구 사항을 작성할 수있었습니다. 이 프로젝트에 정의 된 개체와 제약은 데이터베이스에 추가되었으며 향후 프로젝트를 위해 재활용 할 수 있습니다. 모델은 구속 조건을 정의 할 수있는 유연성으로 인해 보안과 같은 최소 이동 거리 이외의 최적화 목표를 포함 할 수있었습니다. 제시된 모델에서 사용 된 지오메트리 기반 접근 방식과 데이터 흐름은 실무자가 사용하는 것을 용이하게합니다. 또한 앞에서 언급 한 개방형 아키텍처는 사용자 상호 작용을 지원하고 사용자에게 자신의 지식과 경험을 활용할 수있는 기회를 제공합니다.

이 모델은 두 가지 점에서 현재 관행을 개선합니다.
(1) 프로젝트 설정 단계에서이 모델은 사용자가 관련 개체 및 해당 구속 조건을 정의 할 수 있도록 지원하는 중앙 플랫폼을 제공합니다.
(2) 사이트 분석 및 할당 단계에서 모델은 각 오브젝트에 대해 정의 된 제한 조건을 분석하고 실제 사이트 플래너가 소요 한 시간과 비교하여 훨씬 짧은 시간에 위치를 찾을 수있었습니다.
일반 사무실 컴퓨터 "2GHz 프로세서가 장착 된 펜티엄 IV 프로세서"에서 분석을 수행 한 경우, 평균적으로 각 건설 물체에 대한 최적의 위치를 찾는 데 30 초가 걸렸습니다. 원래 레이아웃의 디자인은 다양한 의사 결정자들의 여러 회의의 결과물이었습니다.

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이 백서는 사이트 플래너가 인터랙티브 방식으로 레이아웃을 개발할 수 있도록 CAD 기반 사이트 레이아웃 모델을 제시했습니다. 개발 된 모델은 사용자에게 효율적인 사이트 레이아웃 디자인에 대한 지식을 활용할 수있는 디자인 지원 도구를 제공합니다. 데이터베이스, 프로젝트 모듈 및 레이아웃 제어 모듈을 포함한 모델의 기본 구성 요소가 설명되었고 각 모듈의 기능이 설명되었습니다. 이 논문은 사이트 레이아웃 수정을위한 공식화 된 데이터 구조를 자세하게 논의하고 사이트 공간 분석 및 할당을위한 새로운 방법론을 소개했습니다. 이 방법론은 시각화를 지원하고 사용자 시스템 상호 작용을 용이하게하기 위해 형상 기반입니다. 실제 사이트 레이아웃의 사례는 개발 된 모델을 사용하여 분석되었습니다. 이 모델은 사이트 플래너가 작성한 레이아웃에 가까운 레이아웃을 생성 할 수있었습니다. 두 레이아웃의 차이점은 프로젝트에서 고려한 제약 조건과 관련된 만족도에 기인합니다. 개발 된 모델은 지정된 구속 조건을보다 잘 만족시키는 레이아웃을 만들었습니다.

사례

사례는 개발 된 모델이 다른 모델에서 개발 한 모델의 한계를 극복 할 수 있음을 보여주었습니다. 이 모델은 문헌 『Sadeghpour 2004』의 사례를 포함한 여러 사례 연구를 통해 검증되었습니다. 이 모델은 사이트 계획자와 의사 결정자에게 프로젝트에서 필요한 사이트 개체 및 제약 조건을 정의 할 수있는 중앙 집중식 컴퓨터 환경을 제공함으로써 현재 관행을 개선합니다. 또한 현장 분석에 필요한 시간이 현저하게 줄어 듭니다. 업계에서 수용 할 수있는 사이트 레이아웃 모델을 실현하려면 개발 된 모델의 사용자 인터페이스를 산업 실무자의 참여를 통한 실습 실험을 통해 추가 검증해야합니다.