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A Knowledge Support Component for a Site Optimisation Algorithm

Système à base de connaissances pour l'organisation optimale de chantiers

Eine wissensbasierte Komponente für einen Baustelleneinrichtungs-Optimierungs-Algorithmus

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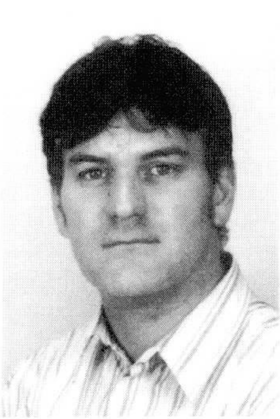

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SUMMARY
ESBE is a hybrid object-oriented system to generate optimised construction site layouts. To keep the number of possible locations small for ESBE's mathematical optimisation algorithm, the expert system provides rectangular areas valued according to the given rules. This paper describes two methods to generate these suitable areas, namely the generating method and the grid method. Thorough evaluation proves a modified generating method to be best suited for ESBE.

RÉSUMÉ
ESBE est un système hybride orienté-objet destiné à optimiser l'organisation de chantiers. Un système expert crée des surfaces rectangulaires selon des règles données, de façon à limiter le nombre des solutions possible, à l'aide d'algorithmes d'optimisation. Cet article présente deux procédés générateurs de surfaces appropriées, à savoir la méthode de réseau et la méthode de génération. Après avoir comparé les deux, l'article conclut qu'une méthode de génération modifiée convient le mieux au système proposé.

ZUSAMMENFASSUNG
ESBE ist ein hybrides objektorientiertes System zur Generierung optimierter Baustellenlayouts. Um die Anzahl der möglichen Positionierungen beim mathematischen Optimierungsalgorithmus gering zu halten, liefert ein Expertensystem anhand der vorhandenen Regeln bewertete Flächen (Rechtecken). Dieser Artikel stellt zwei Verfahren zur Erstellung geeigneter Flächen vor, das Raster- und das Generierungsverfahren. Nach eingehender Bewertung stellt sich ein modifiziertes Generierungsverfahren als am besten geeignet heraus.

1. Introduction

The hybrid object-oriented system ESBE for the optimization of construction site layouts consists of three major parts: a construction site database which contains general and company specific data of the construction site facilities and the building data; a hybrid system with mathematical optimization algorithms and an expert system (knowledge based system) as well as a well-tailored user-interface with a 3D visualization component. Its task is to dimension and arrange the individual construction site facilities. The publications [1, 2] are giving an overview about the system ESBE and the related research.

This paper deals with a problem that occurred realizing the expert system component of ESBE: How to model suitable areas (rectangles) for the location of a specified facility. These areas serve as input to the mathematical algorithms, set up to optimize the location of the facility element inside the given suitable area considering the suitability value. The optimization algorithm with its objective function constraints and decision variables will be considered as a black box in this paper. The full description of the algorithm will be published soon.

The expert system component is based on a list of 161 original rules which have to be taken into consideration regarding the location of the site facilities. There are two different kinds of rules [3]:

- rules arising from regulations and laws with the relation ("must", "must not") (binding rules). In this case the suitability value for the areas is 1 or -1, and these areas must / must not be considered for the location of the facility element.
- rules derived from experience and expert knowledge with the relation ("shall", "can", "shall not", "shall if possible") (non binding rules). In this case a representation and aggregation of the knowledge is necessary to get one suitability value within (-1;+1) for the area and thus to rank the different areas.

Some of the original rules are not suitable for the rule processing system due to uncertain reference objects, missing weighting or redundancy. The residual rules (applicable rules) of which the system is constituted implement uncertain knowledge ("shall", "can", "shall not", "shall if possible") and vague knowledge ("at", "nearby", "far away" etc.). The vague and uncertain knowledge, that occurs in the given rules and the aggregation of both to get a suitability value within [-1, 1] for the areas have to be aggregated to get a ranking of these areas. This function in the paper called **agg** has been realized by a new-developed approach using a linear combination of fuzzy and probability functions and will be published soon [5].

2. HOW TO MODEL SUITABLE AREAS (RECTANGLES) - COMPARISON OF GRID- AND GENERATING METHOD

Independent of the choice of the knowledge representation manner, there are two different classes of methods for the expert system component to generate suitable rectangles serving as possible locations for the site facilities.

A) Grid Method

Rectangles are generated by the expert system component prior to the rule processing. This can be done by laying a grid over the construction site, so that every grid element is a rectangle. Subsequently the rule evaluation determines the suitability of these individual rectangles for the location of the site facility under consideration.

B) Generating Method

The rectangles are generated not before but by the rule processing. Thus the extension of the rectangles is not defined before the rule processing is finished.

An example for the generation of suitable areas to locate storage areas will illustrate the two methods. An evaluation of the following three rules for ascertaining of storage areas will be simulated with an actual construction site layout using both the grid and the generating method.

1. "storage area should be between site road and building" valuation: 0.5
2. "storage area should be within the crane's jib range" valuation: 0.7
3. "storage area should be located at the site road" valuation: 0.3

The following restrictions given by the mathematical optimization component must be taken into account:

- per call of the rule processing system suitable rectangles for only one site facility are ascertained.
- the shape of the construction site as well as that of every object located on the site is based on rectangles.
- the construction site is described by means of a coordinate system.
- all rectangular objects of the construction site are arranged right-angled in the coordinate system.

In the given actual layout, there are three objects located: a site road, a building and a crane (Fig. 1).

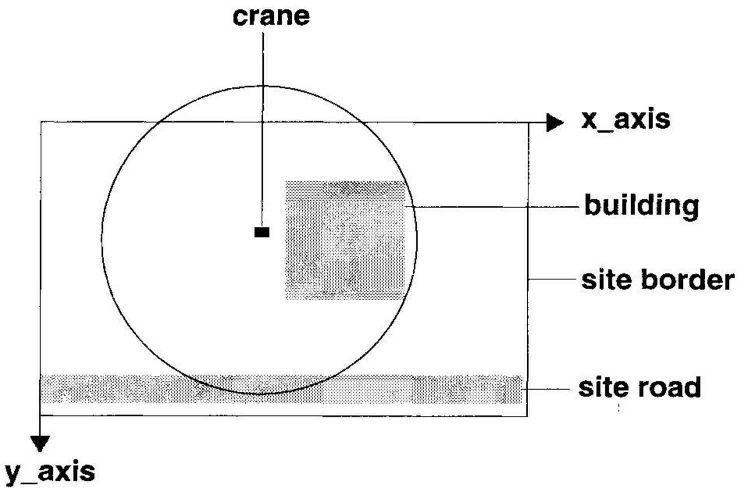


Fig. 1: Actual layout

2.1 GRID METHOD

A grid is laid over the construction site, so that every grid element is a rectangle. The size of the rectangles is arbitrary. A grid element shall be identified by its north-western corner. The size of the grid elements must be at least the extent of the respective site facility element. A coordinate system to describe any individual point of the construction site is given by the x-axis and the y-axis. In the following, the three rules mentioned above will be processed. Every rectangle ascertained a suitability value is assigned corresponding to the valuation of the rule's value. A rule is evaluated within the interval (-1,1). These values have no influence on the process itself. In every grid element fulfilling the rule the valuation of the processed rule will occur in the graphics.

A) 1. rule evaluation

"storage area should be between site road and building" (valuation: 0.5)

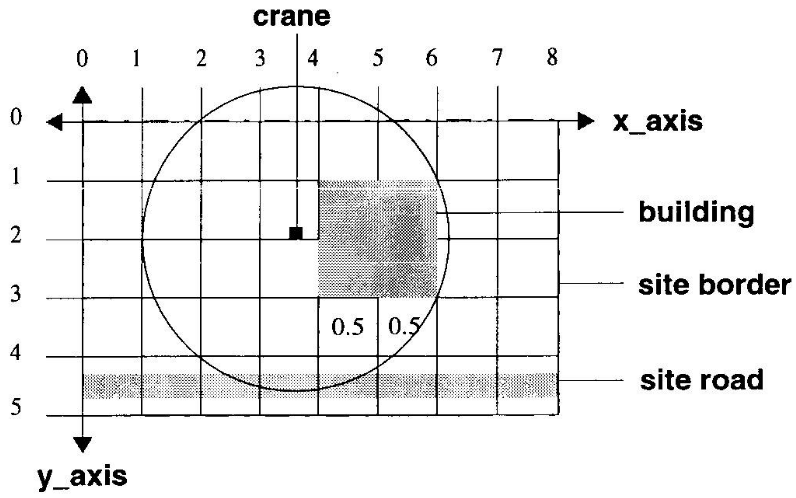


Fig. 2: Grid method 1. rule

According to this rule, the grid elements r(4,3) and r(5,3) are suitable rectangles with the value 0.5. The grid elements r(4,4) and r(5,4) are not appropriate because a part of the site road crosses them.

B) 2. rule evaluation

"storage area should be within the crane's jib range" (valuation: 0.7)

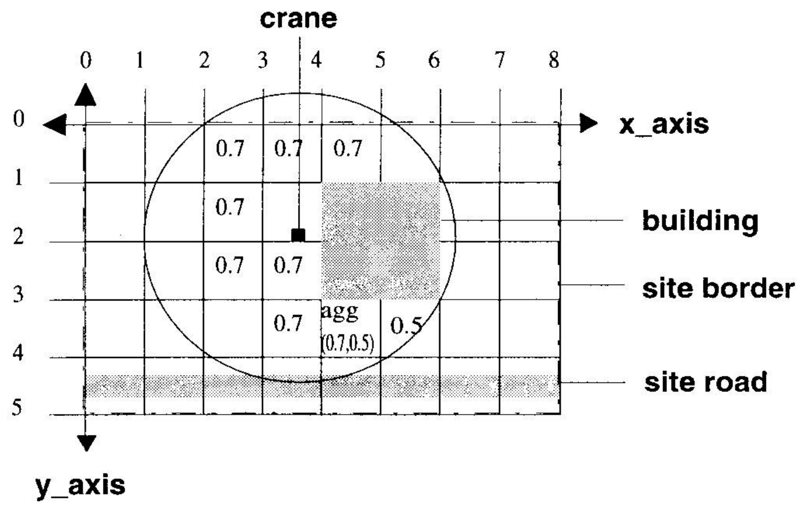


Fig. 3: Grid method 1. and 2. rule

All grid elements that are located completely inside the circle are assigned the rule valuation 0.7. Grid elements that cannot be covered completely by the crane's jib range do not obtain a suitability value. Further the abbreviation "agg" will be used for the aggregation of the suitable values (see r(4,3)). If a rectangle is ascertained by more than one rule and therefore more than one suitability value is assigned, the aggregation function derives one decisive suitability value out of the different ones. This is necessary, because the mathematical optimization algorithm can only take into account one suitability value for every grid element. Looking at Fig. 3, it can be observed that the grid element r(2,3) is not located completely within the crane's jib range and therefore it is not assigned the suitability value 0.7. On the other hand, the grid element r(4,3) which obtained the valuation 0.5 in the first step is assigned the value 0.7 by the second rule. Here the aggregation function has to derive a single suitability value from these two valuations.

C) 3. rule evaluation

"storage area should be located at the site road" (valuation: 0.3)

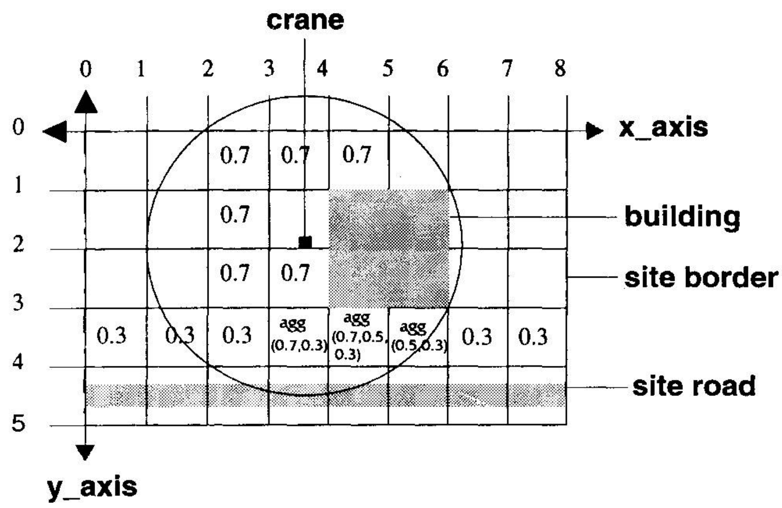


Fig. 4: Grid method 1., 2. and 3 rule

All rectangles located at the site road obtain the valuation 0.3, thus the rectangles r(3,3) and r(5,3) have two values, and r(4,3) even has three, which have to be aggregated to one suitability value. After processing all rules the positively valued grid elements are passed on to the mathematical optimization algorithm.

Concerning the exact location of a construction site facility within a grid element, the optimization algorithm examines all possible locations. The various possible locations are determined systematically by defined interval steps (Fig. 5). The site facility has to be located completely inside the grid element. In case of identical dimensions of the construction site facility and the grid element, the step above will be dropped due to the fact that the site facility fits exactly into one grid element.

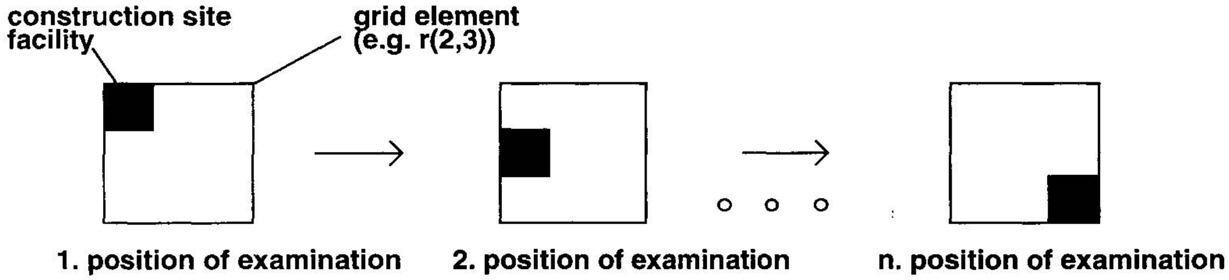
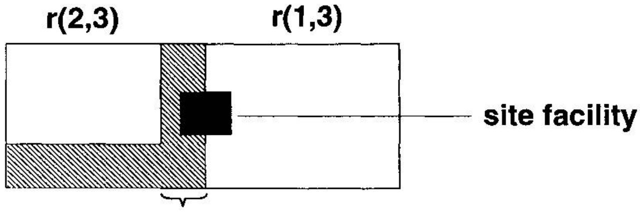


Fig. 5: Procedure of positioning a site facility inside a grid element

However, the mathematical optimization algorithm is not able to take into consideration locations for a site facility covering more than one grid element, even if the valuations of both grid elements were identical (e.g. r(1,3) and r(2,3): valuation 0.3). The layout algorithm does not examine the whole grid, but a given single grid element (rectangle). Therefore it is not able to split the base of the site facility and distribute it over different grid elements. Thus possibly appropriate areas for locating the facility element cannot be examined. For example the following Fig. 6 shows the hatched area of r(2,3) in which the site facility cannot be located due to the reasons described above. The size of the hatched area results from the length of the side of both the site facility and the grid element.



(length of a side of a site facility - ε, with ε → 0)

Fig. 6: Problem of two overlapping grid elements

The sum of all hatched areas grows with the grid elements getting smaller as well as with the base of the site facility getting bigger. In case of identical sizes of the site facility and the grid element base, the hatched area amounts to the entire grid element minus its top left corner.

2.2. GENERATING METHOD

In this case every rectangle is generated by the rules. The size of the rectangle is determined by the minimum and maximum distance between site facility and its reference object given by the rule. The location of the rectangle results from the reference object's position and the rule's assignment instruction. Then a suitability value for the rectangle is deduced from the rule's valuation.

The generating method will be explained using the same rules as already done in the grid method. To compare both methods under equal conditions no overlapping of the rectangles generated by the same rule is allowed at this stage. A discussion of possible modifications concerning the overlapping of the generated rectangles will follow in the chapter dealing with the method's modification.

A) 1. rule evaluation

"storage area should be between site road and building" (valuation: 0.5)

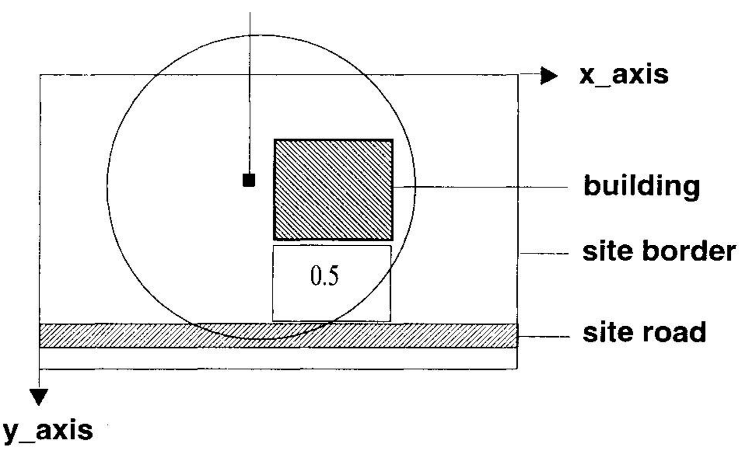


Fig. 7: Generating Method 1. rule

The generated rectangle is indicated by its suitability value 0.5. It is bounded by the site road and the building.

B) 2. rule evaluation

"storage area should be within the crane's jib range" (valuation: 0.7)

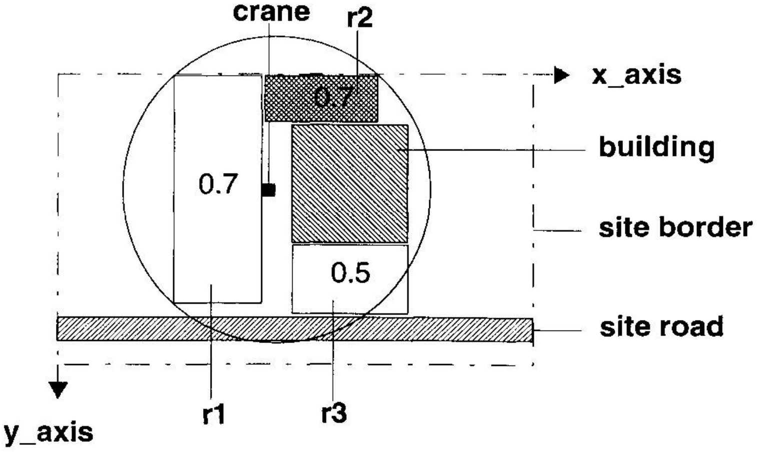


Fig. 8: Generating Method 1. and 2. rule

The two rectangles r1 and r2 are bounded by the building, the crane's jib range and the site border. Because of the equal conditions at this stage it is not allowed that the rectangles intersect with each other in order to prevent the ascertained rectangles from overlapping (like appearing in the grid method).

3. rule evaluation

"storage area should be located at the site road" (valuation: 0.3)

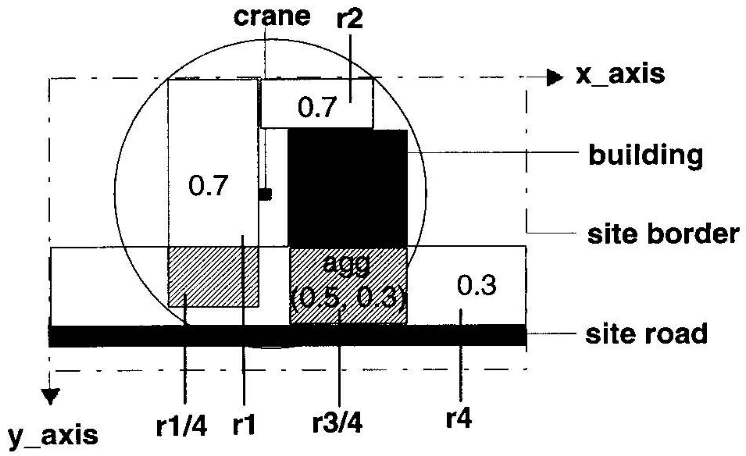


Fig. 9: Generating Method 1., 2. and 3. rule

The rectangle r4 with the valuation 0.3 is bounded by the building, the site road and the site borders. The hatched rectangles r1/4 and r3/4 represent the overlapping areas of the rectangles r1 and r4, and r3 and r4 respectively. They result from the combination of the 3rd rule with the 1st and 2nd one.

Now possible modifications of both methods are evaluated.

2.3 MODIFICATION OF THE GRID METHOD

The following faults occur when the grid method is realized as described in chapter 2.1.

A) 1. fault

If there are reference objects already located within a grid element, the remaining area cannot be considered as a suitable rectangle.

B) 2. fault

There are some grid elements partly covered resulting from the intersection of the crane's jib range with the grid elements, e.g. r(1,3) in Fig. 3. By not taking into consideration these grid elements the covered part of the rectangle gets lost as a possible storage area.

C) 3. fault

It is difficult to assign a valuation when only a part of a grid element obtains an additional valuation, as for example grid element r(5,3) in Fig. 3. For the complete grid element a valuation was already assigned and would have been passed on to the mathematical optimization algorithm, thus it is not clear if and how this additional value can be taken into account.

There are two kinds of modifications for the grid method: the first one retains the chosen grid and has no influence on the size of the rectangles whereas with the second the grid or single elements can be changed.

Modification concerning the first fault:

- with the size of the construction site facility in regard being chosen as the size of one grid element this fault cannot appear, but other disadvantages can.
- a rectangle is drawn into the remaining part of the grid element and is regarded as a suitable rectangle in case of sufficient size for locating the site facility inside.

Modification concerning the second fault:

- given a partly covered grid element, the whole grid element is regarded as a suitable area. Hereby it must be accepted that areas possibly not suitable will be considered as suitable.
- for the partly covered areas of a rectangle, that may not be rectangular any more, this suitable area will be approximated by one or several greatest possible rectangles.

Modification concerning the third fault:

- the valuation of the complete grid element will be changed in relation to the size of the affected area.
- the additional valuation will be aggregated with the old valuation and assigned to one or several rectangles approximating the suitable area.

2.4 MODIFICATION OF THE GENERATING METHOD

Apart from the first fault of the grid method, which can not occur using the generating method, the other faults of the generating method are identical to those of the grid method. This is why these faults are now called second and third fault, again.

B) 2. fault

Approximating the area covered by the crane's jib range with a rectangle means that possible suitable areas for locating the site facility get lost.

C) 3. fault

If only a part of a rectangle is assigned an additional valuation (see Fig. 9), it is uncertain if and how this valuation could be taken into consideration, because the complete rectangle has already got a valuation and would be passed on to the layout algorithm as a suitable area.

Modification concerning the second fault:

- the section resulting from the intersection of the crane's jib range with the rectangle will be approximated by a chosen number of rectangles.

Modification concerning the third fault:

- one possibility is to approximate the section by one or several rectangles. The new rectangle(s) is(are) assigned a new valuation resulting from the old one and the additional new one.
- another possibility is to assign the additional valuation to the complete rectangle in relation to the size of its covered area.

2.5 EVALUATION OF THE MODIFICATIONS OF THE GRID AND THE GENERATING METHODS

Both methods show some advantages compared to each other.

The advantages of the grid method are:

- neither the size nor the position of the rectangle has to be calculated.
- a calculation of the rectangle is not necessary, because there are no overlapping grid elements, given that the modification concerning the second fault has not been carried out.

- choosing the grid element very small, the resulting space is restricted in fact, but the mathematical optimization algorithm does not need to examine so many positions and, hence, a result can be achieved earlier.

The advantages of the generating method are:

- there is no first fault occurring because obstacles are considered, when the rectangles are generated.
- the generally bigger rectangles than in the grid method enable the mathematical optimization algorithm to examine more locations than in the grid method. Actually, the running time of the program can increase, but more locations can be examined, especially using the approximation of the crane's jib range with overlapping rectangles.

Fig. 10 shows the construction site after applying the three rules using the slightly modified generating method with overlapping rectangles of the same rule.

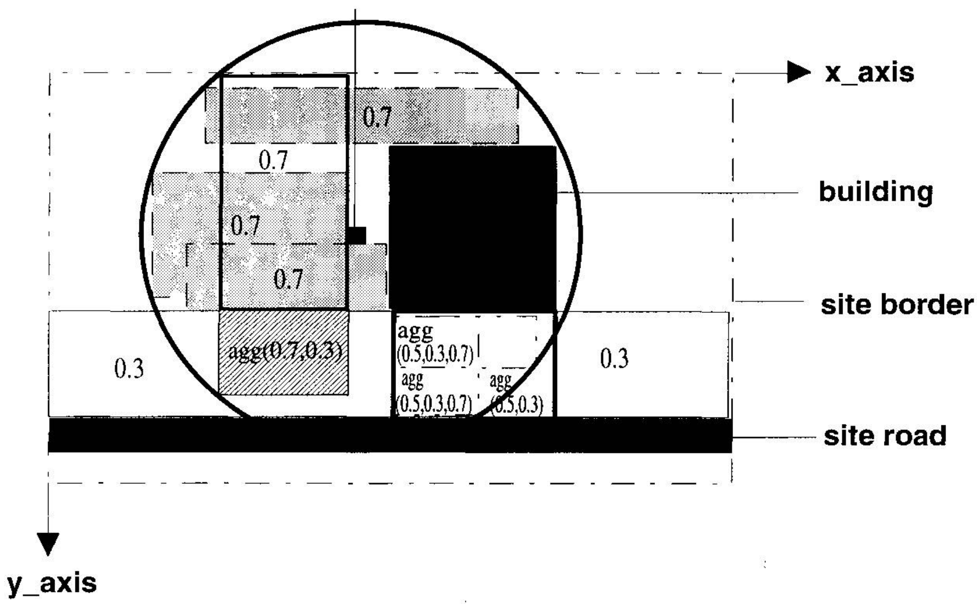


Fig. 10: Modified generating method rule 1.,2. and 3.

3. CONCLUSION

Even after the modifications concerning the faults in the grid method, the basic problem still exists, namely the disability to take areas at the borders of the grid elements into consideration even if the adjoining grid elements are identically valued. A further modification might be to unite identically valued grid elements to form the biggest possible rectangles. This results in rectangles similar to those obtained by the generating method. The definition of the grid and therefore the size of the single grid elements in the beginning of the procedure naturally still has influence on the size of the suitable rectangle. Here the grid method still differs from the generating method.

After evaluating the two methods a modified version of the generating method with the following modifications will be carried out by ESBE:

- several rectangles, which may overlap, are generated to approximate the crane's jib range.
- if the section of two suitable areas does not result in a rectangle, this section will be approximated by several rectangles (see the third fault of the generating method).

Fig. 11 shows the result of the expert system program using the modified generating method. Especially the approximation of the crane's jib range by overlapping rectangles can be seen very well.

The expert system has been realized using the object-oriented language Eiffel [4].

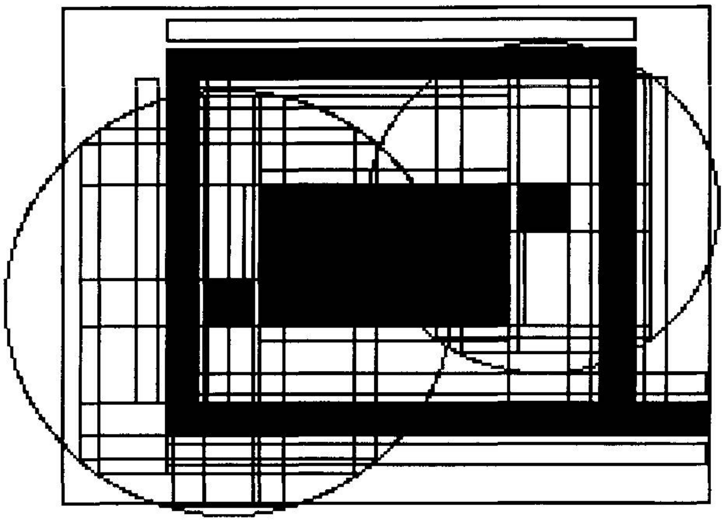


Fig. 11: Output of the expert system using the modified generating method

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