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Layout modeling and construction procedure for the arrangement of exhibition spaces in a fair

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Abstract

This paper tackles a subset of layout problems that is not a subject of the scientific research to date: the arrangement of the exhibition spaces in a fair. A fair is a large-scale exhibition for goods and services; for example a trade fair or a regional fair. The layout problem of fairs consists in finding an acceptable layout for both the exhibitors, the visitors, and the organizer of the fair. A model for representing the layout of fairs is presented: the adjacency model. Based on the adjacency model, a construction procedure is developed that leads to the generation of alternative layout solutions. Numerical results for the layout of a real fair are reported.

Keywords: Layout design, modeling, facility layout, optimization, heuristics

1 Introduction

Making locational decisions corresponds to the choice of locations within a spatial context. Examples of such choices include locating factories, warehouses, schools, hospitals, and emergency services. In contrast to locational decisions, the facility layout problem is concerned with finding the most efficient arrangement of departments or machines with area requirements within a facility. By most efficient, it is meant the optimal for a given criterion, such as material handling costs, space utilization, flexibility of layout, safety, and work conditions (Domschke and Krispin, 1997).

For years, this problem has received considerable attention from firms engaged in manufacturing activities. As far as manufacturing is considered, researchers usually reduce the cost function to the material handling cost, which is the most important cost factor (Meller and Bozer, 1996). The material handling cost function is based on the interaction between the departments or machines (i.e. material flow) and on the inter-department respective inter-machine distances. The facility layout problem has been first mathematically formulated as a quadratic assignment problem (Koopmans and Beckmann, 1957). Since this initial work, a variety of contributions has been published (see the surveys (Domschke and Krispin, 1997; Heragu and Kusiak, 1987; Francis, McGinnis and White, 1992)).

The topic of this paper is another, less known, case that is also subject to layout considerations: the design of fair layouts. The term fair refers to a large-scale exhibition of goods and services like a trade fair, a regional fair, or a sample fair. As in the facility layout problem, the layout designer (the person responsible for the layout of the fair) needs to place the exhibition spaces in a non-overlapping manner on the fairground. Usually, he has to consider area requirements for the different stands. Apart from the exhibition space, it is necessary to provide space for the visitor corridor. It is obvious that an acceptable fair layout must arrange the visitor space in such a way that each stand can be reached by the visitors.

The layout designer has to deal with many constraints that can affect the fairground plan. Building geometry can serve as a restriction on the layout because the arrangement of the exhibition spaces has to fit in the shape of the building. When there exists a building within which the layout has to be designed, it can impose a large number of restrictions on the solution. For example, the layout solution will be affected by the present location of walls and columns, windows, lights, ventilation equipment, power lines, and emergency exits.

A given layout solution of a fair can have a dramatic impact on many issues such as visitor convenience, space utilization, attraction of the location of an exhibition space, shape of an exhibition space, safety, and heating/cooling requirements. Very often, tradeoffs have to be made between conflicting factors to produce an acceptable layout. For example, the higher the space utilization, the lower the ground cost for the fair organization. However, the allotment of only a small amount of space to the exhibitors and the visitors is unfavorable to both the exhibitors and the visitors. Also, if the layout designer dedicates more space to the visitor corridor, then the visitor's safety is higher in case of an emergency. In opposition, the organizer of the fair will be faced with increasing ground costs.

As seen above, the design process of a fair layout is difficult and time-consuming, and many open-ended questions arise in the field of layout design:

- Can the layout problem of a fair be solved with an analytical approach?
- How is an acceptable and efficient layout of a fair characterized?
- How can the design task be performed faster and more efficiently?

To answer these questions, the adjacency model to represent the layout of a fair was developed and three quantitative criteria were selected to measure if a layout solution is efficient. In the next section, a more precise description of the layout problem of a real fair is given. Section 3 introduces the adjacency model to represent the layout. In Section 4, a construction procedure is developed based on the adjacency model. This construction procedure permits the generation of alternative layout solutions. Numerical results are reported in Section 5. Section 6 concludes the paper with a discussion of the model's limitations, extensions, and potential for future work.

2 Problem description

The first part of this section describes the layout problem more precisely according to a real exhibition: the regional fair in Romont. The second part looks at three determinants which are

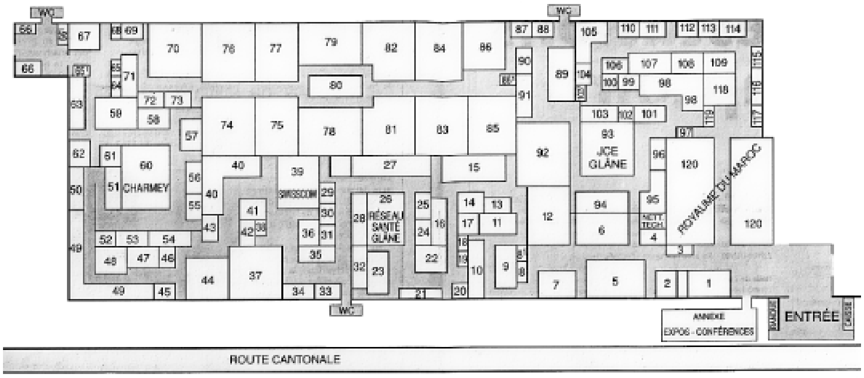


Fig. 1. The arrangement of the exhibition spaces of the fair in Romont (1998).

important for judging the efficiency of a given fair layout from the point of view of the fair organizer.

2.1. The regional fair in Romont

The exhibition examined in this paper is a regional fair which takes place every two years in the small town of Romont (Switzerland). About 100 exhibitors expose theirs goods and services for 8 days on a fairground of 5200 square meters that is roofed over by a tent. The fairground is 100 meters long and 52 meters wide. Figure 1 shows an example of the arrangement of the exhibition spaces. About 50,000 visitors attended this edition of the fair in the year 1998.

The layout designer of the fair in Romont has basically two approaches to accomplish his task. One approach is to start from the list of exhibitors and their space requests and to construct the layout by placing one exhibition space at a time. Another approach is to start from a predefined layout and then assign each exhibitor a surface that fulfills the area requirements. In Romont, the layout is typically constructed using the first approach.

The layout design process consists of two major steps. First, the layout designer has to allocate space for the stands in such a way that the exhibitor spaces do not overlap. Second, he has to allocate space for the visitor corridor.

2.1.1. Exhibition spaces

An important property of the fair in Romont is that the set of the exhibitors changes strongly from one year to the next. For this reason, the layout designer has to redraw the layout from scratch for each new edition. Consequently, the layouts of two successive editions never look alike. In a first phase of the design process, the layout designer collects the area requirements of the stands, see Fig. 2:

- *shape of the stand*: rectangular or angular (angular stands are favorably placed in a corner, see area 49 in Fig. 2);
- *size of the stand*: length and width in meters;

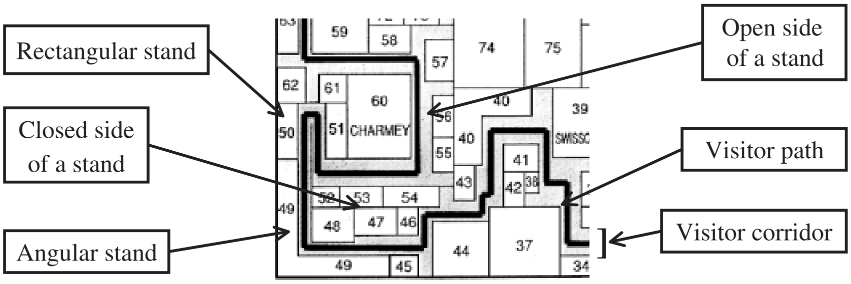


Fig. 2. Exhibition and visitor space in the layout of a fair.

- *open sides of the stand*: because each stand is organized differently, the layout designer has to know which sides of the stand are accessible to the visitors. These sides are called the open sides of the stand. The remaining sides are closed with walls by the organizer of the fair.

The facility where the exhibition spaces have to fit introduces additional restrictions. The stands have to be placed in a tent of rectangular shape. Inside the tent, attention has to be paid to fix walls, columns, aisle space to access the toilets, and corridors for emergency exits. Some exhibition spaces are grouped together, see all the car sellers (stands 70 to 86) in Fig. 1. In contrast, stands where similar services or goods are presented should not be placed side by side.

2.1.2. Visitor space

The fair layout designer needs to allocate space to the visitor corridor. In the case of the fair in Romont, a one-way visitor path is imposed. It is a round tour with an entrance and an exit. That way, the organizer of the fair achieves that each visitor has to walk through the whole fair and that each exhibition space is accessible to the visitors, see Fig. 2. Throughout the layout, the visitor corridor is generally 3 meters wide. The minimum width is 2 meters.

The fair in Romont features typically a so-called closed visitor path. In contrast, there exist also fairs with an open visitor path where the visitor path is not imposed and the visitors have to find their own way through the space.

2.2. Three determinants

A given fair layout solution can have a dramatic impact on many issues. The main determinants from the point of view of the organizer of the fair in Romont are described below.

Space utilization

The organizer of the fair strives for an optimal utilization of the fairground. He tries to minimize the dead space that is not allocated as exhibition spaces. This objective has naturally an economic aspect. In fact, the fairground rent is proportional to the surface required to arrange the exhibition spaces. For this, the organizer of the fair tends to cut down the dead space.

The space costs to rent the fairground have to be compared with the revenues that the exhibitors have to pay to rent the exhibition spaces.

Attraction value of an exhibition space
The attraction value of an exhibition space does not only depend on marketing and promotion capabilities of the exhibitor to draw the visitors' attention. Indeed the location of an exhibition space in regard to the visitor corridor has already an attraction value. For this reason, the term 'potential attraction' is used when talking about the attraction value of an exhibition space. For example, the exhibition space 60 in Fig. 2 has a very promising location because the visitor path passes along the three open sides of the stand.

The organizer of the fair is naturally interested in giving each exhibitor the same initial conditions. In other words, each stand should have a location that is as attractive as possible. In the ideal case, all the open sides of the stands border the visitor path. Since this goal is hard to reach, the organizer tries to find a layout which optimizes the attraction value of all locations of the stands in such a way that no exhibitor feels disadvantaged.

Visitor convenience
Naturally, the organizer of the fair wants to offer an exhibition which is as pleasant and as comfortable as possible to the visitors. In order to reach this goal, the organizer can act on the following elements regarding the layout:

- the number of direction changes of the visitor path;
- the length of the sections of the visitor path which goes along the closed sides of the stands;
- the space dedicated to the visitors;
- the width of the visitor corridor;
- …

It is obvious that the three presented determinants are conflicting and that it is not possible to fulfill all determinants entirely. This makes the layout problem of the fair in Romont difficult to solve. A tradeoff between the three determinants has to be found so that the layout is acceptable for the organizer, the exhibitors, and the visitors. Usually, it is the experience and capacities of the layout designer that influence the design process.

3 Adjacency model

The adjacency model permits the representation of the layout of a fair (Schneuwly and Widmer, 2001). It measures the adjacency of the visitor path to the open sides of the exhibition stands.

3.1. Modeling

The adjacency model uses a discrete representation of the layout. This means, that the surface available and the space requirements for each activity of the fair are expressed as an integer multiple of the unit area square. In contrast, the model introduced in (Schneuwly and Widmer, 2000) uses a continuous representation that is based on the slicing structure (Tam, 1992).

Fairground
In the adjacency model, the fairground corresponds to a rectangular area that consists of a certain number of unit area squares, see Fig. 3. The fairground is L unit area squares long and B unit area

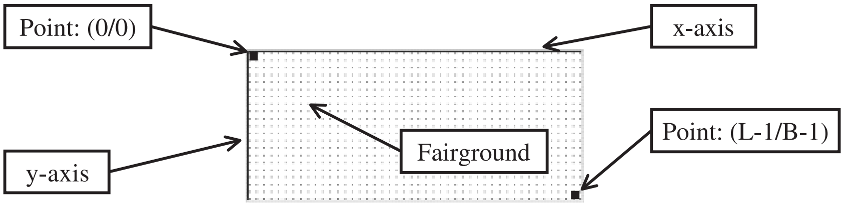


Fig. 3. Fairground.

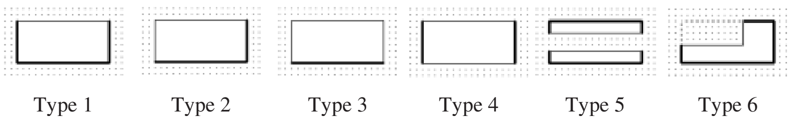


Fig. 4. Six types of exhibition spaces.

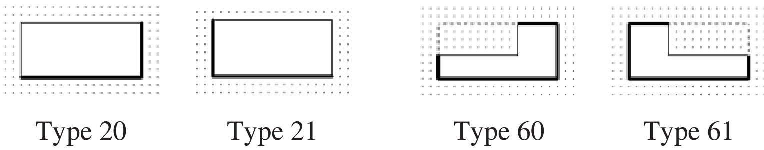


Fig. 5. Asymmetry of the exhibition space of Type 2 and 6.

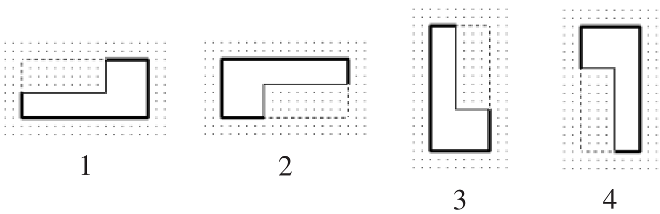
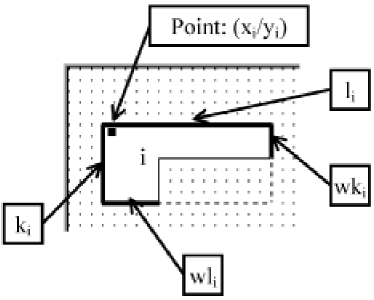


Fig. 6. Orientation of an exhibition space.

squares wide. Each unit area square inside the fairground can be referenced like in a coordinate system with x- and y-axes.

Exhibition spaces
The stands of the fair are either represented as rectangular or as angular areas, which are composed of unit area squares. Six types of exhibition spaces can be distinguished which are illustrated in Fig. 4. The open sides of the stands are marked with a thin line while the thick lines correspond to the closed sides.

The exhibition space of Type 2 includes two types of exhibition spaces, depending on how the open and closed sides are arranged. The same asymmetry holds for the angular exhibition space of Type 6. The new type labels of these asymmetrical exhibition areas are indicated in Fig. 5. The

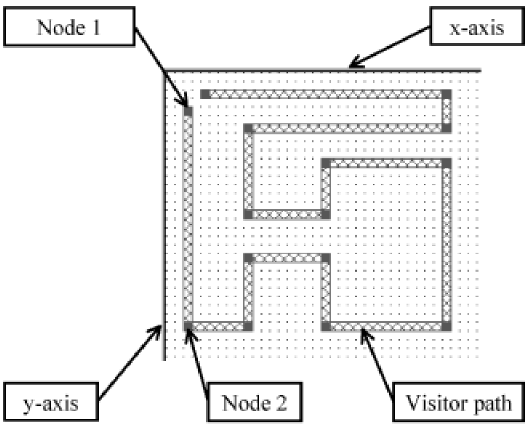


Dimension	Variable	Value
Type	typ_i	60
Longer side	l_i	15
Shorter side	k_i	7
Margin of the longer side+	wl_i	5
Margin of the shorter side+	wk_i	3

+$wl_i = l_i$ and $wk_i = k_i$ if the exhibition space is rectangular

Placement	Variable	Value
x-coordinate	x_i	3
y-coordinate	y_i	5
Orientation	o_i	2

Fig. 7. Placement of exhibition space *i* on the fairground.



Node j	x_j	y_j
1	2	4
2	2	29
3	9	29
4	9	21
5	18	21
6	18	29
7	32	29
8	32	10
9	18	10
10	18	16
11	9	16
12	9	6
13	32	6
14	32	2
15	4	2

Fig. 8. Visitor path and coordinates of the nodes.

other types of exhibition spaces are non-ambiguous if the open sides are arranged with respect to the longer and shorter side of the stand, see Fig. 4.

The exhibition spaces are either placed vertical or horizontally regarding the x- and y-axis. Considering the open sides, there are four possible orientations result for an exhibition space, see Fig. 6. The different orientations can be obtained by rotations through an angle of 90 degrees.

Figure 7 shows the placement of an angular exhibition space on the fairground and lists the values of the corresponding dimension and placement variables.

Visitor path

The visitor path of the fair is a rectilinear path which is exactly one unit area square wide. In Fig. 8, the visitor path corresponds to the hatched stripe. The term rectilinear means that the visitor path is composed of horizontal and vertical path sections which lie parallel to the x- or y-axis. The solid node at the end of a path section indicates a direction change of the visitor path. Each node can be referenced because a node corresponds exactly to one unit area square. This way, the visitor path can be expressed as a sequence of nodes.

3.2. Three quantitative criteria

The adjacency model allows the formulation of three quantitative criteria to measure the quality of a given layout of the fair. The criteria are derived from the three determinants described in Section 2.

Space utilization
The sum of the surfaces of the exhibition spaces are related to the surface of the fairground to measure the space utilization. The coefficient r expresses exactly this ratio:

$$r = \frac{\sum_{i=1}^{N}((k_i \times l_i) - ((k_i - wk_i) \times (l_i - wl_i)))}{L \times B}$$

where
N = the number of exhibition spaces,
L = the length of the fairground,
B = the width of the fairground.
For the exhibition spaces with a rectangular shape $(k_i = wk_i) \times (l_i - wl_i) = 0$ applies and the surface of the latter is calculated correctly by $k_i \times l_i$.

Attraction value of an exhibition space
The attraction value of an exhibition space and its location is measured by the adjacency index a_i

$$a_i = \frac{b_i}{q_i}$$

where
b_i = the adjacency length of the exhibition space i,
q_i = the length of the open sides of the exhibition space i.
The adjacency index relates the adjacency length of an exhibition space to the length of the open sides of the exhibition space. The adjacency length corresponds to the vertical and horizontal projection of the visitor path to the open sides of an exhibition space.
The calculation of the adjacency index is shown in Fig. 9. Two exhibition spaces of Type 3 with different surface dimensions and two alternative visitor paths are considered. The adjacency index is calculated for each of the four combinations. The surface of exhibition space 1 is quadratic (each side is 4 units long), whereas the surface of exhibition space 2 is rectangular (8 units long and 2 units wide). The examined exhibition space has three open sides because it is of Type 3. One of the longer sides is closed to visitors. The visitor path 1 is adjacent to one of the longer sides of the exhibition space whereas the visitor path 2 is adjacent to three sides of the exhibition space. Figure 10 gives an example for the calculation of the adjacency index of angular exhibition spaces. The adjacency index gives a lower bound for the attraction value of an angular exhibition space.

Independently of whether the exhibition space is rectangular or angular, the adjacency index takes values between 0 and 1. It indicates in percent how much of the length of the open side is

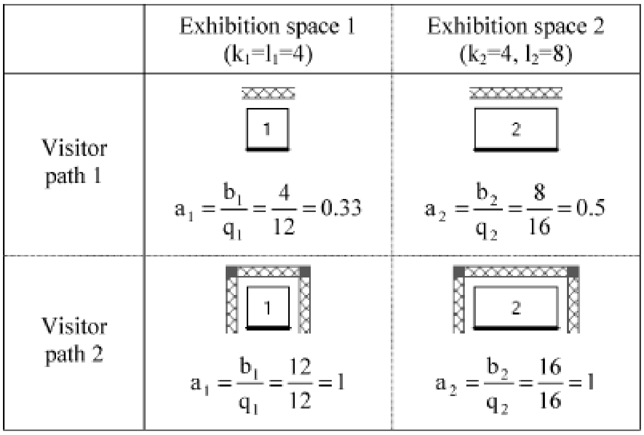


Fig. 9. Adjacency indexes.

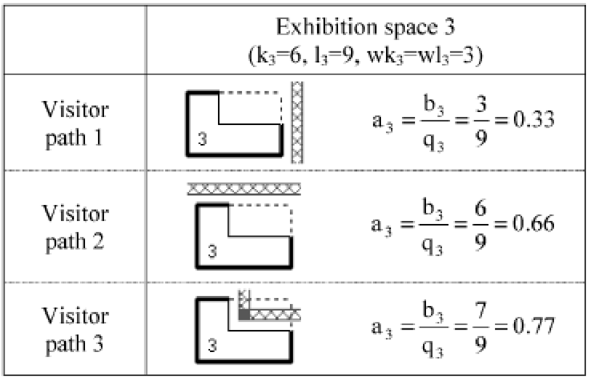


Fig. 10. Adjacency indexes for angular exhibition spaces.

adjacent to the visitor path. The potential attraction of an exhibition space becomes more important if the adjacency index is higher. This is explained by the fact that the visitor is faced with more opportunities to enter the exhibition space if the the adjacency index is higher.

Visitor convenience

The visitor convenience in a fair is rather difficult to quantify. Therefore, a criterion is adopted that can be easily calculated. This criterion relates the sum of the adjacency lengths of the exhibition spaces to double the length of the visitor path. The double length of the visitor path must be considered because each unit area square of the visitor path can be adjacent to two opposite exhibition spaces.

The coefficient f is defined as:

$$f = \frac{s}{2 \times g}$$

where

$s = \sum_{i=1}^{N} b_i =$ the sum of the adjacency lengths,

$g =$ the length of the visitor path.

The smaller the value of the coefficient f in a given layout the shorter the sections of the visitor path leading along a closed side or along the side limitations of the fairground. For this reason, a high value of the coefficient f is preferred by the visitors.

3.3. Illustration of the three criteria

An existing arrangement of the exhibition spaces in Romont has been examined to evaluate the relevance of the formulated criteria. The year 2000 edition of the fair in Romont served as an example. The arrangement of the exhibition spaces is showed in Fig. 11.

The choice of an adequate unit of measurement (corresponding to a unit area square) is important because it determines the resolution of the layout in the adjacency model. The unit of measurement is set to one meter for the fair in Romont. The transfer of the data of the actual arrangement into the adjacency model is achieved without problems, see Fig. 12.

If possible, the path sections of the visitor path were designed exactly in the middle of the visitor corridor. In some cases, the modeling of the visitor path is ambiguous. If the visitor corridor is two units wide, one must decide between one of the two unit area squares. No unique rule was adopted because the deviation by one unit does not substantially influence the length of the visitor path and the adjacency lengths.

The obtained layout enables the calculation of the values of the three criteria. These values and further indicators are listed in Table 1. The coefficient f reveals that 80% of the visitor path

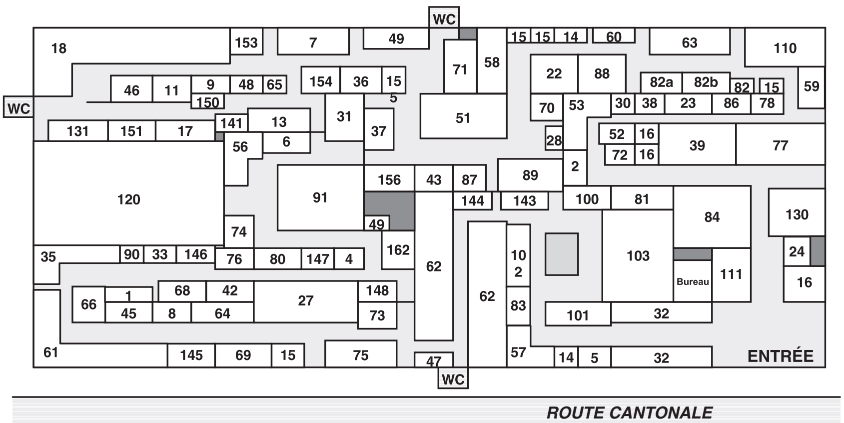


Fig. 11. The arrangement of the exhibition spaces of the fair in Romont (2000).

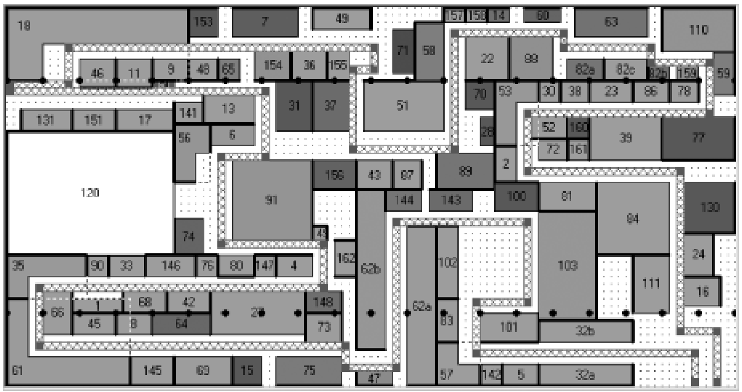


Fig. 12. The adjacency model of the fair in Romont (2000).

Table 1
Indicators of the adjacency model (2000)

Criterion or indicator	Value
number of exhibitors	106
dimension of the fairground ($L \times B$)	100×52
space utilization (coefficient r)	0.64
averaged adjacency index ($\bar{a}$)	0.84
sum of the adjacency lengths (s)	821 m
length of the visitor path (g)	515 m
coefficient f	0.80

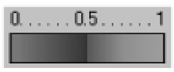


Fig. 13. Color scale.

borders the open sides of the exhibition spaces, whereas on average 84% of the open sides of an exhibition space are adjacent to the visitor path. A color scale was introduced in order to be able to visualize the information about the adjacency index of each individual exhibition space, see Fig. 13. The brighter the color, the closer the value of the adjacency index to a boundary. The color green designates good adjacency indexes (1) whereas the color red designates bad adjacency indexes (0).

How does the adjacency index behave for the exhibition spaces of the fair in Romont? Figure 12 gives an overall picture thanks to the introduced color scale. The adjacency index was not calculated for the exhibition space 120 (guest of honor) as this space is composed of several small stands and has its own visitor path inside. Altogether, the adjacency index proves to be adequate to judge the attractiveness of an exhibition space. Only in a few exceptions such as exhibition spaces 7, 15, and 71, does the adjacency index not reflect the reality, because it does not account for the fact that the visitors can also enter an exhibition space through the lateral corridors between the stands.

Interval of acceptance

For each of the three criteria, what are the lower and upper limits for the values such that an acceptable layout exists for both the exhibitors, the visitors, and the organizer of the fair? The term interval of acceptance is used when speaking about these limits.

The interval of acceptance for the adjacency index is the simplest one to determine. The upper limit is the maximum value (1) of the adjacency index. What can be said about the lower limit? In a first step, it is assumed that an adjacency index of 0.5 is regarded as sufficient because in this case at least half of the length of the open sides of the exhibition spaces are adjacent to the visitor path. The exhibition spaces which do not fulfill this condition were examined, see Table 2. One exhibition space (71) has an adjacency index that lies in the interval $0.25 \leqslant a_i < 0.5$. Nevertheless, this exhibition space has an acceptable location because the visitors can enter the stand through the lateral corridors. Therefore, the interval of acceptance is expanded in such a way that also values of the adjacency index are accepted that lie in the interval $0.25 \leqslant a_i < 0.5$ if there exist lateral corridors to enter the stand. The location of exhibition space 156 is not acceptable ($a_{156} = 0.16$) as can be seen in Fig. 12.

With an arbitrary long visitor path, it is theoretically possible to obtain the highest value of the adjacency index ($a_i = 1$) for all the exhibition spaces (except if the open side of an exhibition space is masked by the closed side of another stand). On such an overlong visitor path, the visitors would have to perform unnecessary loops and run along numerous path sections that are adjacent to closed sides of stands. This leads to a low value of the coefficient f (visitor convenience) because the length of the round tour is much longer than the sum of the adjacency lengths. Unfortunately, it is not possible to define precisely a lower bound for the coefficient f. What can be said for sure is that a coefficient f of 0.80 lies in the interval of acceptance for the examined layout of the fair in Romont. Nothing argues against a very high coefficient f so that the upper limit of the coefficient f is defined by the maximal value 1.

The coefficient r (space utilization) takes the value 0.65 for the examined layout. The determination of the interval of acceptance for this coefficient is as difficult as for the coefficient f. However, if the coefficient r deviates more than 0.15 from the above-mentioned reference value, a disproportion between the exhibition spaces and the space dedicated to the visitors is observed.

Table 2
Interval of the adjacency index

Interval of the adjacency indes	Exhibition space	
	i^+	a_i
$0 \leqslant a_i < 0.25$	156	0.16
$0.25 \leqslant a_i < 0.5$	71	0.33
$0.5 \leqslant a_i \leqslant 1$	remaining	

$^+$identifier of the exhibition space

More layouts of the fair in Romont and other fairs have to be evaluated to make further and more precise statements about the interval of acceptance for the three criteria.

4 A construction procedure

In this section a construction procedure is developed based on the introduced adjacency model. The method constructs a layout solution starting from an initial layout by placing successively exhibition spaces next to the visitor path. The visitor path and the placement of the exhibition spaces of special types are given in the initial layout. Three algorithms are formulated that are built up on each other. The algorithms are applied to the data of the examined fair in Romont.

Three algorithms

The input data of the construction procedure is composed of the data concerning the dimension of the exhibition spaces (l_i, k_i, wl_i, wk_i, typ_i) and the initial layout. The data of the initial layout include:

- the dimension of the fairground ($L \times B$);
- the coordinates of the nodes of the visitor path (x_j, y_j);
- the placement data of the angular exhibition spaces (o_i, x_i, y_i);
- the placement data of the exhibition spaces of Type 4 (o_i, x_i, y_i).

Figure 14 shows graphically a possible initial layout for the fair in Romont. The visitor path and the hatched exhibition spaces (of Type 4, 60 and 61) are given. The exhibition spaces that have to be placed by the algorithm are grouped together on the left side of the initial layout.

The rectangular exhibition spaces are selected one after another and placed by the algorithm into the layout until a layout solution is reached. The output data of the construction procedure are:

- the placement data of the placed exhibition spaces (o_i, x_i, y_i);
- the number of not placed exhibition spaces.

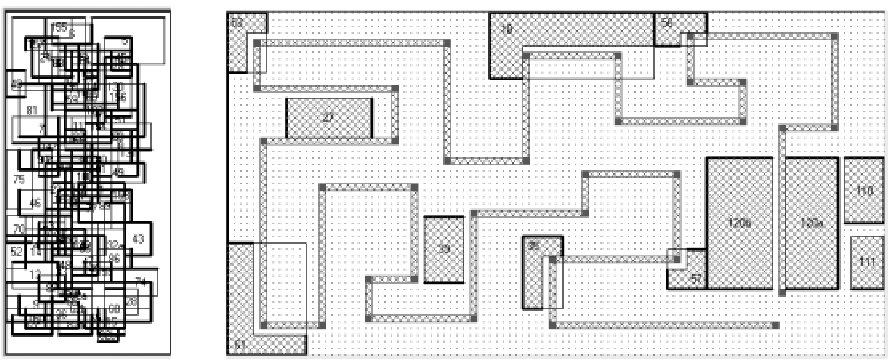
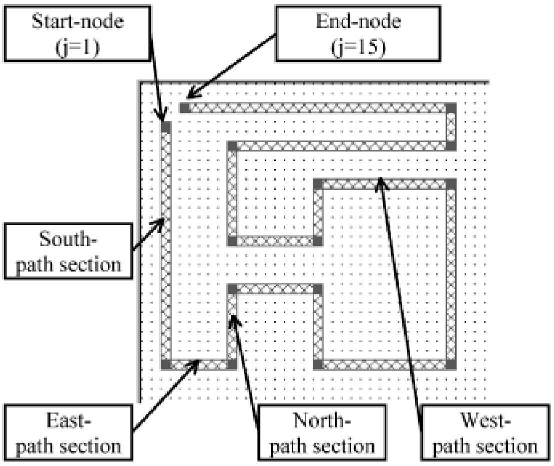


Fig. 14. A possible initial layout for the fair in Romont.



Node j	x_j	y_j	d_j
1	2	4	-
2	2	29	L
3	9	29	L
4	9	21	R
5	18	21	R
6	18	29	L
7	32	29	L
8	32	10	L
9	18	10	L
10	18	16	R
11	9	16	R
12	9	6	R
13	32	6	L
14	32	2	L
15	4	2	-

Fig. 15. Path sections and direction changes of the visitor path.

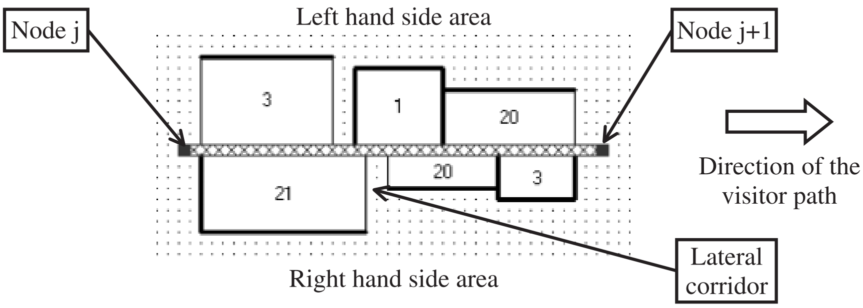


Fig. 16. East-path section.

Let us look at the path sections of the visitor path before the construction procedure is presented in detail.

Path section of the visitor path

The sequence of the nodes of the visitor path defines the direction in which the visitors walk on the path. Figure 15 shows a visitor path and the corresponding start- and end-nodes of the visitor path. A path section is defined as a horizontal or a vertical section of the visitor path. A vertical path section that is walked in a southward direction is called a south-path section. In the case of the northward direction, it is called a north-path section. Analogically, the horizontal path sections can be subdivided into west- and east-path sections.

A direction change of the visitor path occurs at the start and at the end of each path section. If the visitor path turns off to the right, then $d_j = R$ is in node j. In the same way, $d_j = L$ designates a

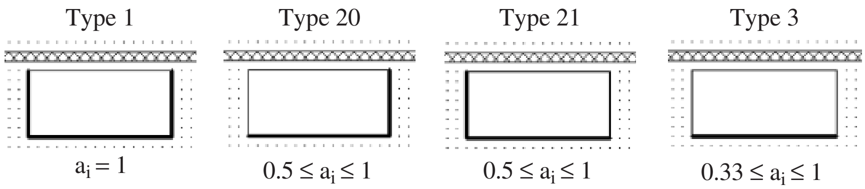


Fig. 17. Orientation of the long and open side to the visitor path.

direction change of the visitor path to the left. d_j is defined in a given visitor path for all nodes except for the start- and end-node.

Optimal placement with respect to a single path section

Let us look at a single path section and find out how an individual rectangular exhibition space is oriented optimally in respect to the vistor path. Figure 16 shows an east-path section. The visitor path goes from node j to node $j+1$. For each path section, there exists a left- and a right-hand side area for the placement of an exhibition space regarding the direction of the visitor path.

The optimal placements of the exhibition spaces of Type 1, 20, 21, and 3 are illustrated in Fig. 17. The optimal placement corresponds to a placement producing the highest adjacency to the visitor path. Exactly one long side is an open side for each type of the exhibition spaces. The highest adjacency is obtained if the long open side of the exhibition space is oriented toward the path section. Figure 17 lists for each type the minimal and the maximal values of the adjacency index that result from such a placement. The exact value of the adjacency index depends on the ratio of the long to the short side of the exhibition space. The higher this ratio, the closer the value of the adjacency index to the upper limit which is 1. In an optimal placement, the value of the adjacency index is at least 0.5 except for the exhibition space of Type 3.

Lateral corridors

The lateral corridors play an important role for the placement of an exhibition space. A lateral corridor is orthogonal to a path section, see Fig. 16. The lateral corridors are necessary in order to guarantee that a stand is also accessible through the open sides that are not directly oriented toward the visitor path. If the exhibition spaces are placed optimally as discussed above, the lateral corridors have to be considered only for the short open sides of the exhibition spaces. The minimum width of the lateral corridors is expressed by the variable *zwb*.

Candidate points

Basically, each point (x, y) in the left- and right-hand side area of a path section represents a candidate point (x_i, y_i) for the placement of the exhibition space i. However, the candidate points are limited by the optimal placement of an exhibition space and by the direction changes in the nodes of the visitor path.

Figure 18 gives an example of the calculation of the candidate points in the left side area of an east-path section. Depending on whether a direction change to the left or to the right takes place

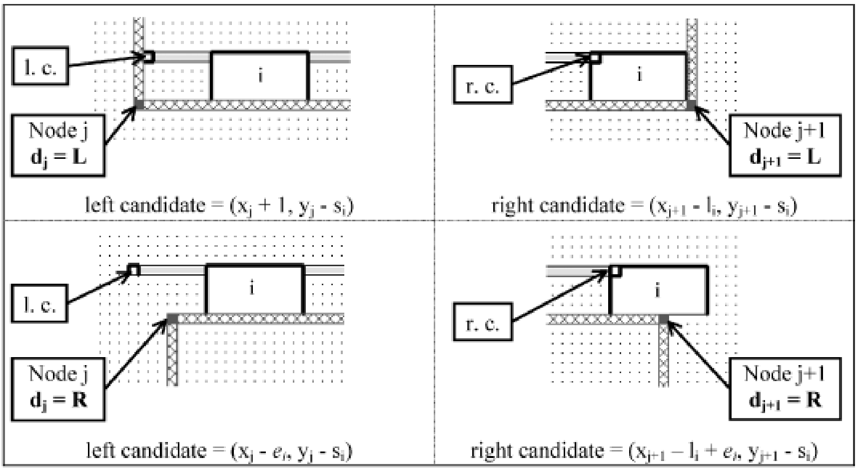


Fig. 18. Candidate points in the left-hand side area of an east-path section.

in the node j and in the node $j+1$, the area of the feasible candidate points is reduced or enlarged. In this example, the placement of an exhibition space of Type 1 is examined. The long open side is turned toward the visitor path in the optimal orientation ($o_i = 2$). The left candidate point limits the possible placements of the exhibition space to the left. If the visitor walks southward to the start node of the east-path section ($d_j = L$), then the positions of placement of the exhibition space are bounded to the left by the placement at the inner side of the direction change in node j. If the visitor path encounters the east-path section from the south ($d_j = R$), then the left candidate point is moved forward by e_i unit area squares. A high value of variable e_i leads to a smaller adjacency of the exhibition space if it is placed at the leftmost position. Consequently, it make sense to express e in relation to the long side of the exhibition space i, e.g. $e_i = 0.33\ l_i$.

The right candidate point bounds the positions of placement of the exhibition space to the right. Analogically to the left candidate point, two cases can be distinguished depending on the direction change in the node $j+1$. If the visitor path turns to the left ($d_{j+1} = L$), then the rightmost position of the exhibition space is defined by the placement in the inner side of the direction change in node $j+1$. If the visitor path turns to the right in node $j+1$ ($d_{j+1} = R$), then the path section after the direction change is no longer the limiting factor. Again, the variable e_i controls to what extent the exhibition space i can be placed beyond the end-node of the path section.

All points that lie on a straight line between the left and the right candidate point are also potential candidate points for the placement of the exhibition space i.

The left-hand side area of an east-path section is examined in this example. The same considerations hold also for the placement areas of all the other path sections.

First algorithm

The introduction of the candidate points for the placement of an exhibition space enables the formulation of a first algorithm:

Algorithm 1:

	Read the input data.
	Define e_i and zwb.
	Let UP be the set of exhibition spaces that have to be placed, and $E = \emptyset$.
Step 1:	Select at random an exhibition space i in UP.
Step 2:	Examine the candidate points for the exhibition space i in the left- and right-hand side areas of the path sections (in regard to the direction of the visitor path): If there exist a feasible placement of the exhibition space i, then place i and set $UP = UP - \{i\}$, else set $E = E \bigcup \{i\}$.
Step 3:	If $UP \neq \emptyset$, then go to Step 1.
Step 4:	The obtained layout solution is feasible if $E = \emptyset$.

The set E contains the exhibition spaces which could not be placed during and after the execution of the algorithm.

The placement of an exhibition space is tested for feasibility in Step 2 of the algorithm. The placement of an exhibition space is feasible, if

- the exhibition space i does not overlap with an already placed exhibition space;
- the exhibition space i does not intersect with the path sections of the visitor path;
- the exhibition space i lies inside the fairground;
- the short open sides of the exhibition space i provide a lateral corridor that is at least zwb unit area squares wide.

The algorithm was applied to the data of the fair in Romont. The layout pictured in Fig. 14 served as initial layout. Exhibition spaces 110, 111, and 120 were given fixed locations near the entrance and the exit of the fair. Exhibition space 120 (guest of honor) is crossed by the visitor path. With this arrangement, the problem of modeling the entrance and the exit of exhibition space 120 does not occur.

Figure 19 shows the layout solution after applying the algorithm 1 with $e_i = 0.33\ l_i$ and $zwb = 1$. The algorithm is not able to place all exhibition spaces: $E = \{101, 103\}$, therefore the obtained layout solution is infeasible. Furthermore, there are the following drawbacks:

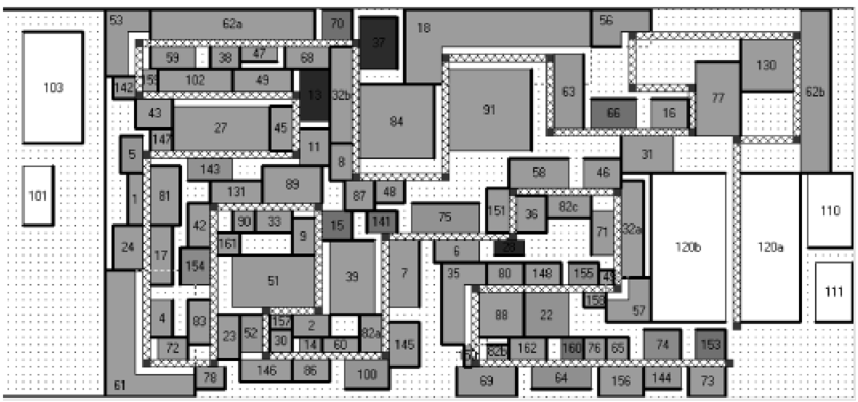


Fig. 19. Layout solution of algorithm 1.

- In some locations, one of the open sides of the exhibition spaces of Type 20, 21, and 3 is not adjacent to the visitor path. The exhibition spaces 13, 37, 51, 66, 75, and 77 typically have such locations in the obtained layout solution.
- Nearly throughout the whole layout, the visitor corridor is exactly as large as the visitor path (exactly one unit area square) because the algorithm places the exhibition spaces without any regard to the visitor path. However, a visitor corridor should be provided that is at least two unit area squares wide.
- In the case of the two exhibition spaces of Type 5 (32 respectively 62), it is not considered that the constituting exhibition spaces of Type 1 (32a and 32b respectively 62a and 62b) have to be arranged opposite. A more restrictive approach would consist in placing these exhibition spaces already in the initial layout.

The expansion of the possibilities to place an exhibition space next to the visitor path permits the formulation of a second improved algorithm.

Optimal placement with respect to two or three consecutive path sections

The algorithm 1 considers optimal placements regarding to only a single path section. Figure 20 gives the optimal placements of an exhibition space with respect to two or three consecutive path sections. An exhibition space of Type 3 is preferably placed within a U-shape that is formed by three path sections. Such a U-shape appears if the visitor path turns twice to the left or twice to the right. The exhibition spaces of Type 20 and 21 find an optimal placement in the corner of a direction change. The adjacency index takes the maximal value 1 in these three cases.

Figure 21 shows the calculation of the candidate points. The left-hand side area of an east-path section serves again as an example to show the conditions that must hold to place an exhibition space of Type 3 or 21.

The calculation of the candidate point for the placement of an exhibition space of Type 3 in a U-shape is pictured in Fig. 21. The visitor path takes the form of a U-shape only if there is a direction change to the left in both of the nodes of the east-path section ($d_j = L$ and $d_{j+1} = L$). The U-shape must be large enough to hold the exhibition space, i.e. $x_{j+1} - x_j > l_i$. The U-shape should not be too wide otherwise there would be more exhibition spaces placed in the same U-shape and it is not guaranteed that the adjacency index takes the value 1. If the variable h designates the margin expressed in unit area squares, then the maximal allowable width of the U-shape is defined by $x_{j+1} - x_j \leqslant l_i + h$.

The optimal placement of an exhibition space of Type 21 demands that the visitor approaches southward to the start-node of the east-path section ($d_j = L$). This way, a corner is formed in

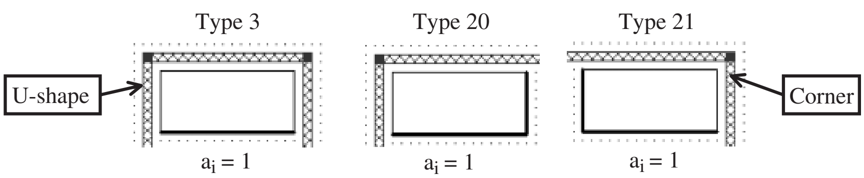


Fig. 20. Optimal placements of the exhibition spaces of Type 20, 21, and 3.

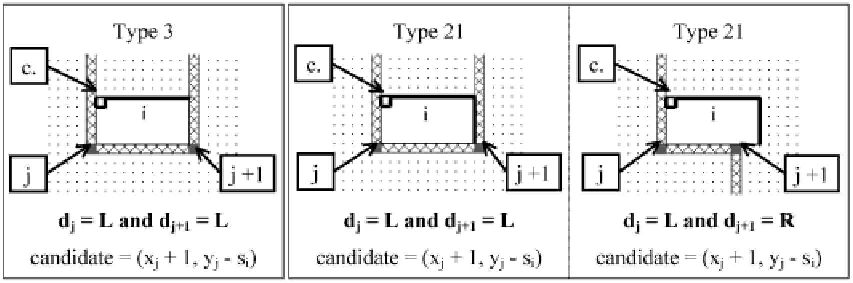


Fig. 21. Candidate points in the left-hand side area of an east-path section.

which the exhibition space will be placed. Two cases can be distinguished depending on whether a direction change to the left or to the right takes place in node $j+1$. In the first case ($d_{j+1} = L$) it has to be examined whether the exhibition space can be placed in the U-shape, as illustrated in the middle section of Fig. 21. The candidate point corresponds to the one presented before and the test of the minimal allowable width of the U-shape is performed by $x_{j+1}–x_j > l_i$. In the second case ($d_j+1 = R$) the visitor path turns to the right and describes a sort of a stairway (as illustrated in the third section of Fig. 21). The placement at the candidate point is only accepted if $x_{j+1}–x_j+e \leqslant l_i$. As before, this condition controls to what extent the exhibition space i can be placed beyond the end-node of the path section.

Width of the visitor corridor

The model can be extended to consider the width of the visitor corridor. Let *mb* be the desired width of the visitor corridor in unit area squares. The variables dbL_j and dbR_j indicate how many unit area squares are dedicated to the visitor corridor to the left and to the right of the visitor path. For all path sections (j, $j+1$) the condition $dbL_j+dbR_j+1 = mb$ must hold. Figure 22 gives an example for three alternative widths of *mb* for the visitor corridor, and shows the values of dbL_j and dbR_j for the east-path section (j, $j+1$).

The values of dbL_j and dbR_j have consequences on the calculation of the candidate points in the placement areas of the path sections. The inner width of the U-shape for example is shorter in the example $mb = 2$ than in the example $mb = 1$.

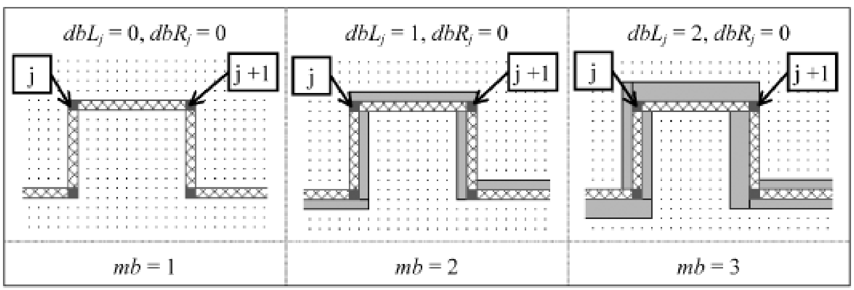


Fig. 22. Width of the visitor corridor.

Second algorithm

The second algorithm considers the presented extensions:

Algorithm 2:

	Read the input data.
	Define e_i and zwb.
	Define h, mb, dbL_j and dbR_j for all path sections $(j, j+1)$.
	Let UP be the set of exhibition spaces that have to be placed, and $E = \emptyset$.
Step 1:	Select in UP the exhibition space i of Type 3 that has the largest surface.
	Examine the candidate points in the U-shapes of the visitor path for the exhibition space i:
	If there exist a feasible placement of the exhibition space i, then place i, else set $E = E \bigcup \{i\}$.
	Set $UP = UP - \{i\}$.
	If UP contains exhibition spaces of Type 3, then go to Step 1,
	else set $UP = UP \bigcup E$ and $E = \emptyset$.
Step 2:	Select in UP the exhibition space i of Type 20 or 21 that has the largest surface.
	Examine the candidate points in the corners of the visitor path for the exhibition space i:
	If there exist a feasible placement of the exhibition space i, then place i,
	else set $E = E \bigcup \{i\}$.
	Set $UP = UP - \{i\}$.
	If UP contains exhibition spaces of Type 20 or 21, then go to Step 2,
	else set $UP = UP \bigcup E$ and $E = \emptyset$.
Step 3:	Go to Step 1 of Algorithm 1.

Algorithm 2 was applied to the initial layout of the fair in Romont with $e_i = 0.33\ l_i$, $zwb = 1$, $h = 1$ and $mb = 2$. The variables dbL_j and dbR_j were initialized at random except if the visitor path is adjacent to an already-placed exhibition space. In this case, the value of dbL_j or dbR_j is determined by the distance between the path section and the boundary of the exhibition space.

Figure 23 shows the layout solution obtained with Algorithm 2. The preferable conditioning of the exhibition spaces of Type 3, 20, and 21 is immediatly apparent in the layout solution. The exhibition spaces 22, 64, 66, 77, and 130 for example are placed optimally. Furthermore, the placements of the larger exhibition spaces like 51, 84, and 91 are also near optimal because they are selected in a descending order. In addition to the improved locations, the layout solution features a visitor corridor that is at least two unit area squares wide.

As for Algorithm 1, Algorithm 2 is not able to place all the exhibition spaces: $E = \{62b\}$. It is not by accident that an exhibition space of Type 1 remains. The algorithm places the exhibition spaces of Type 1 late during the execution of the algorithm and therefore, the favorable locations are already occupied by other exhibition spaces.

The obtained layout solution reveals that some placement areas of the path sections are not used in full depth. As examples can be mentioned the arrangements of the exhibition spaces 4, 56, and 153, as well as 32b and 83. Furthermore, the placement areas at the beginning of the visitor path are more occupied than those at the end. This is because Algorithm 2 evaluates the placements starting from the start-node of the visitor path. In the example, the visitor path is evaluated counterclockwise.

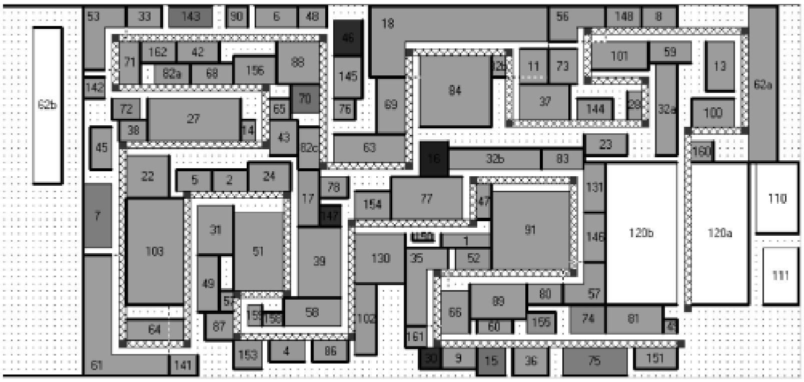


Fig. 23. Layout solution of Algorithm 2.

Third algorithm

The third algorithm has additional steps comparing to Algorithm 2. These steps ensure that the exhibition spaces are distributed more uniformly along the visitor path, and that the placement areas are better utilized in depth. The algorithm has the following scheme:

Algorithm 3:

	Read the input data. Define e_i and zwb, h, mb, dbL_j and dbR_j. Define pa, the number of repetitions of Steps 5 to 7. Let UP be the set of exhibition spaces that have to be placed, and $E = \emptyset$. Set $zpa = 1$.
Step 2:	Execute Step 1 of Algorithm 2.
Step 3:	Execute Step 2 of Algorithm 2.
Step 4:	Order the exhibition space in UP by the short side k_i in descending order, and let UPO be the ordered set. Select in UPO the first exhibition space i (maximal k_i).
Step 5:	Select at random a path section $(j, j+1)$ and choose a left- or right-hand side area at random.
Step 6:	Examine the placement of the exhibition space i in the selected placement area of the path section $(j, j+1)$: If there exist a feasible placement of the exhibition space i, then place i, set $UPO = UPO - \{i\}$, select in UPO the next exhibition space i and go to Step 6, else set $zpa = zpa + 1$.
Step 7:	If $zpa \leq pa$, then go to Step 5.
Step 8:	Select in UPO the first exhibition space i (maximal k_i).
Step 9:	Examine the candidate points for the placement of the exhibition space i in the left- and right-hand side area of the path section $(j, j+1)$ regarding to the direction of the visitor path and set $UPO = UPO - \{i\}$: If there exist a feasible placement of the exhibition space i, then place i, else set $E = E \bigcup \{i\}$.
Step 10:	If $UPO \neq \emptyset$, then go to Step 8.
Step 11:	The obtained layout solution is feasible if $E = \emptyset$.

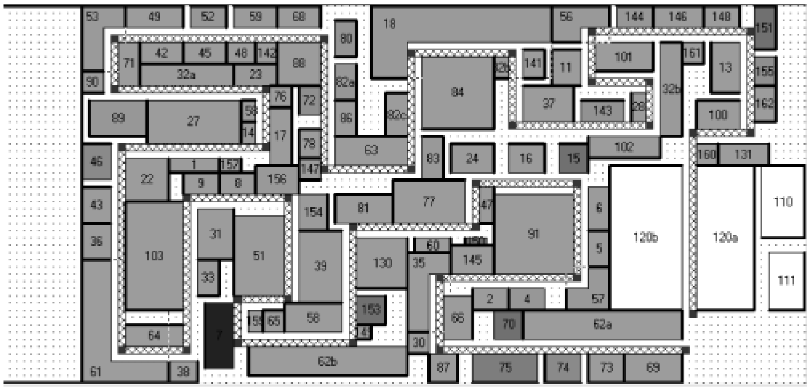


Fig. 24. Layout solution of Algorithm 3.

Steps 8 to 11 of Algorithm 3 correspond to Steps 1 to 4 of Algorithm 1, with the exception that the selection of the next to place exhibition space is not done at random but in descending order of the short side k_i.

Algorithm 3 was applied with $pa = 40$. Therefore, the algorithm selects 40 times a placement area of a path section at random and tries to place the next exhibition space in this area by evaluating the candidate points. Figure 24 shows the obtained feasible layout solution where all the exhibition spaces were placed by the algorithm: $E = \emptyset$. The placement areas were first evaluated in depth because Step 4 of the algorithm sorts the exhibition spaces in descending order by the short side.

It can be seen that the arrangement of the exhibition spaces is better distributed over the whole layout in the solution of Algorithm 3 than in the solution of Algorithm 2.

Figure 25 illustrates stepwise the construction of the layout solution of Algorithm 3. In Step 2 of the algorithm, 8 out of 11 exhibition spaces of Type 3 were placed in a U-shape of the visitor path. In Step 3, a placement in a corner of the visitor path was found for 15 out of 31 exhibition spaces of Type 20 and 21. In Steps 4 to 7, the algorithm places 9 exhibition spaces in randomly selected placement areas. Finally, the remaining 62 exhibition spaces were placed in Steps 8 to 10.

5 Numerical results

This section summarizes the numerical results that were obtained by applying the algorithms to the data of the fair in Romont. Three alternative initial layouts were used to evaluate the influence of the given visitor path on the final layout solution. Figure 26 shows graphically the three initial layouts. They differ in the length of the visitor path (g), in the number of nodes (M) and in the positions of the nodes. Furthermore, the five angular exhibition spaces and the exhibition spaces of Type 4 are placed at different positions.

Initial layout 1 was used in the preceding section to illustrate the algorithms. Initial layout 2 has a shorter visitor path with fewer nodes than initial layout 1, whereas the visitor path in initial layout 3 is much longer and has more direction changes.

(a) Initial layout (b) After Step 2

(c) After Step 3 (d) After Step 7

(e) After Step 11 (f) Coloring of the adjacency

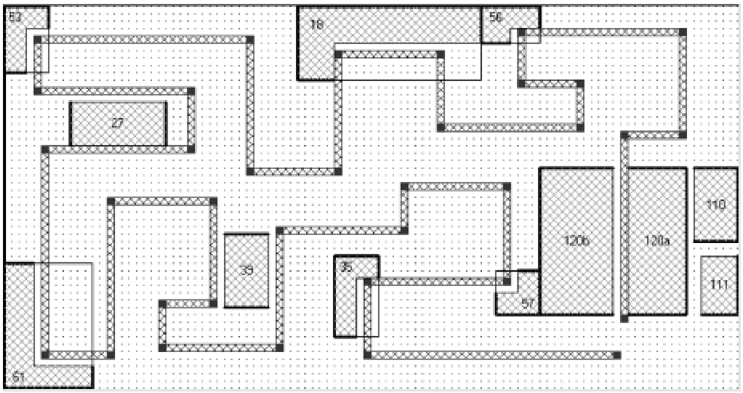
Fig. 25. Stepwise construction of the layout solution of Algorithm 3.

Only Algorithms 2 and 3 were applied to the three initial layouts. Algorithm 1 was omitted because it does not consider the width of the visitor corridor. The parameters of the algorithms take the same values as in the preceding section: $e_i = 0.33\ l_i$, $zwb = 1$, $h = 1$ and $pa = 40$. The width of the visitor corridor mb is set to 2 meters and as before, dbL_j and dbR_j were initialized with random values.

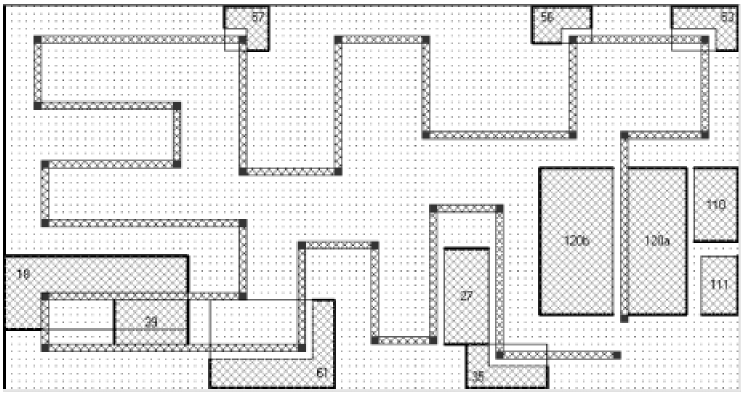
To evaluate the sensitivity of the layout solutions with respect to the values generated at random, both algorithms were started 50 times. In Algorithm 2, it is the order in which the exhibition spaces are introduced in the layout that is determined randomly. Algorithm 3 selects the left- and right-hand side areas of the path sections to place the exhibition spaces at random.

Tables 3 and 4 summarize the obtained results. The minimal, maximal and average value of the indicators are calculated for the 50 runs for each combination of the algorithm and the initial layout. The adjacency length (s) and the coefficient f take high values for all the considered combinations. Basically, it can be said that the locally optimal placement of the exhibition spaces leads to a good final layout regarding to the adjacency.

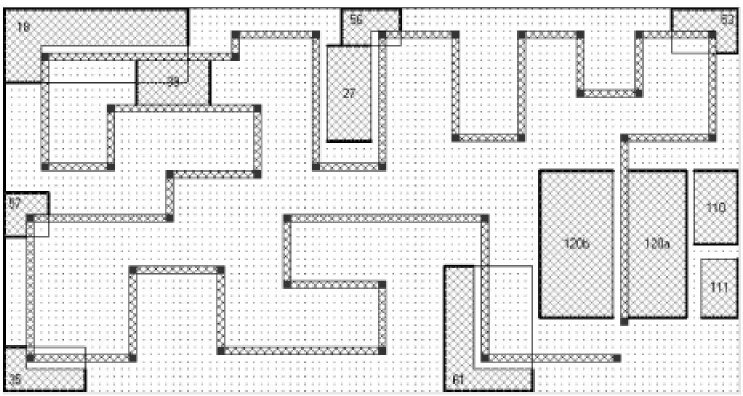
The algorithms differ strongly in the number of generated feasible layout solutions. For these solutions, the condition $|E| = 0$ holds. Algorithm 2 is able to construct a feasible layout solution only for initial layout 1. In Table 3, this information is given by the occurence of |E| whereby the



Initial layout 1: g = 508, M = 35



Initial layout 2: g = 478, M = 31



Initial layout 3: g = 508, M = 39

Fig. 26. Three initial layouts.

Table 3
Results of Algorithm 2

		Algorithm 2													
		s	f	|E|	ns	CPU	Occurrence of |E|								
							0	1	2	3	4	5	6	7	8
Initial layout 1	Min	820	0.807	0	0	9.78	3	28	12	4	2	0	0	1	
	Max	867	0.853	7	208	11.92									
	Avg	847.12	0.833	1.58	116.7	10.68									
Initial layout 2	Min	807	0.844	1	15	10.34	0	20	19	9	1	1			
	Max	852	0.891	5	248	14.52									
	Avg	829.12	0.867	1.88	124.88	11.74									
Initial layout 3	Min	815	0.802	1	41	10.16	0	5	32	8	4	1			
	Max	865	0.851	5	296	14.72									
	Avg	843.20	0.829	2.28	175.84	11.85									

s = the sum of the adjacency lengths (m); |E| = the number of unplaced exhibition spaces;
ns = the sum of surfaces of unplaced exhibition spaces (m^2); CPU = the computation time (in seconds).

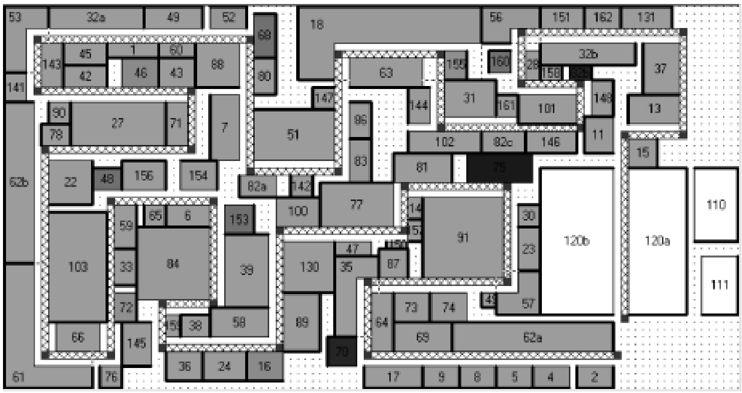
Table 4
Results of Algorithm 3

		Algorithm 3													
		s	f	|E|	ns	CPU	Occurrence of |E|								
							0	1	2	3	4	5	6	7	8
Initial layout 1	Min	844	0.830	0	0	10.67	26	20	4						
	Max	877	0.863	2	120	14.06									
	Avg	859.48	0.845	0.56	29.08	12.36									
Initial layout 2	Min	822	0.859	0	0	12.48	11	22	10	4	1	2			
	Max	858	0.897	5	94	15.42									
	Avg	841.22	0.879	1.36	36.88	13.67									
Initial layout 3	Min	844	0.830	0	0	11.47	12	32	4	0	2				
	Max	880	0.866	4	109	13.61									
	Avg	858.44	0.844	0.96	58.06	12.56									

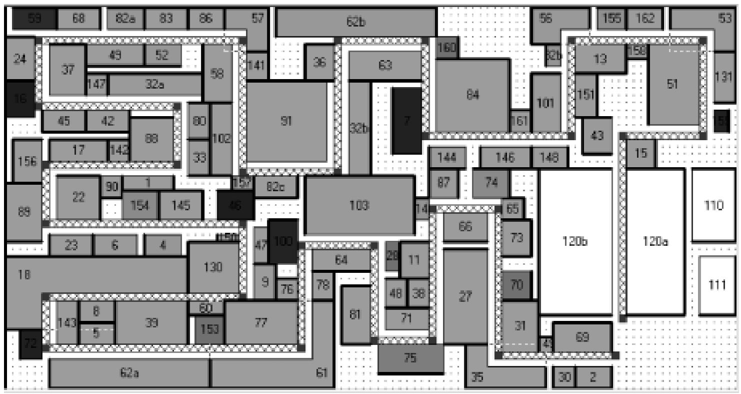
s = the sum of the adjacency lengths (m); |E| = the number of unplaced exhibition spaces;
ns = the sum of surfaces of unplaced exhibition spaces (m^2); CPU = the computation time (in seconds).

totality of the exhibition spaces have been placed in only 3 out of 50 runs. Algorithm 3 finds for all three initial layouts a feasible layout solution. In the case of initial layout 3, more than the half of the constructed layout solutions are feasible.

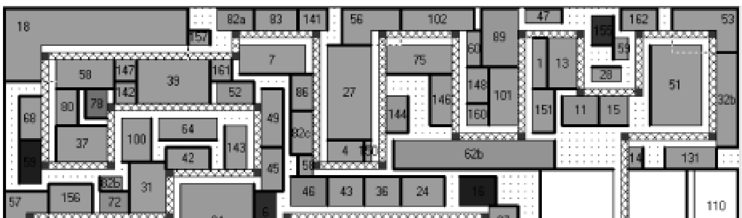
Not only the number of unplaced exhibition spaces but also the size of the unplaced exhibition spaces differs between the two algorithms. The remaining exhibition spaces for Algorithm 2 have generally larger surfaces than those for Algorithm 3. This can be explained by the fact that Algorithm 3 places the larger exhibition spaces first. If the exhibition spaces were selected at



Initial layout 1: s = 877, f = 0.863



Initial layout 2: s = 858, f = 0.897



Initial layout 3: s = 878, f = 0.864

Fig. 27. Feasible layout solutions with maximal *s* for the Algorithm 3.

random (like is done in Algorithm 2) then the feasible placements of the large exhibition spaces are occupied by small exhibition spaces early in the process of placement.

How does the given visitor path influence the final layout solution? The results concerning initial layout 3 with the long visitor path are comparable with those of initial layout 1. However, initial layout 3 tends to produce more infeasible layout solutions due to the strongly angled visitor path. In the case of initial layout 2, the absolute adjacency lengths are significantly shorter than in the case of initial layout 1 because of the shorter visitor path. The coefficient f of the solutions from initial layout 2 is in general higher than for those of the other initial layouts.

The results show that the construction procedure generates promising layout solutions in regard to the adjacency. The values of the three proposed criteria lie in the interval of acceptance. The values of the coefficient f are higher than those of the manually produced layout. The coefficient r to measure the space utilization takes the value 0.64 for all feasible layout solutions. Algorithm 3 generates the best results for all initial layouts. Figure 27 shows the feasible layout solution with the maximal sum of the adjacency lengths produced by Algorithm 3.

The calculations were performed on a Pentium PC 200 MHz and the algorithms were implemented using Visual Basic 6.0. The examined combinations of an initial layout with an algorithm are comparable in terms of computation time, see Tables 3 and 4. The construction of one final layout solution takes between 9.78 and 15.42 seconds. Algorithm 3 needs on average about one second more than Algorithm 2.

6 Conclusion

The arrangement of exhibition spaces in a fair has not been the subject of scientific research to date. However, this layout problem has some parallels to the classical layout problem in production systems. The layout problem differs at most in the formulated evaluation criteria. In the classical layout problem, usually one criterion is considered, namely the transfer costs that have to be minimized. In the case of the layout problem for the fair of Romont, several criteria have to be considered. Basically, the arrangement of the exhibition spaces has to fulfill the three criteria to a certain degree in order to obtain an acceptable layout solution.

The developed construction procedure places the exhibition spaces toward the given visitor path. The placement algorithm makes locally optimal decisions. These decisions have a positive impact on the final layout solution. The numerical results show that the adjacency of the exhibition spaces to the visitor path is very high for each of the three initial layouts. To find out more about the efficiency of the construction procedure other initial layouts and other problem data have to be analyzed. The different possibilities of parameterizing the algorithms do not limit furthergoing analyses.

The initial layout influences the finding of feasible layout solutions. The ease of finding a feasible layout solution depends on

- the dimension of the fairground;
- the length of the visitor path;
- the number of direction changes;

- the position of the nodes of the visitor path in the fairground (these positions define the placement areas of the path sections);
- the placement of the fix-placed exhibition spaces;

The problem of feasibility can be weakened by an extension of the construction procedure. Actually, the exhibition spaces are placed one after another. The placement areas could be occupied more efficiently using a packing-algorithm that places several exhibition spaces at a time.

The creation of the visitor path using a second construction procedure is another potential for expansion. Afterwards, the generated visitor path could serve as initial layout for the proposed algorithms. It is important to see that the creation of an ideal visitor path can be considered as a layout problem on its own. An ideal visitor path should facilitate the finding of feasible layout solutions.

Other extensions are the development of complementary methods such as

- a construction procedure which permits the placement of angular exhibition spaces and the exhibition spaces of Type 4 and 5 (this involves the definition of adequate candidate points in the placement areas of the visitor path sections);
- a construction procedure that places simultaneously the nodes of the visitor path and the exhibition spaces;
- a procedure that improves a given layout solution by changing the placements of individual exhibition spaces and by moving the nodes of the visitor path sections. This procedure could be implemented using one of the known meta-heuristics (Widmer, Hertz and Costa, 2001).

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