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Computerized method for quantity surveying

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The dimensions take-off of building elements is the most tedious and time-consuming stage in the quantity surveying procedure. A computerized comprehensive method of quantity surveying aimed at reducing work invested in this stage has been developed. The method is based on geometric representation of the structure elements of a building (columns, beams, slabs and walls) in a three-dimensional co-ordinate system. This enables the intersections and contact areas between elements to be defined by the computer program. Consequently, the dimensions take-off, to be carried out by the quantity surveyor, is significantly reduced and simplified. The method has been developed for quantity surveying of buildings with rectangular structure elements whose edges are parallel to the axes of the co-ordinate system. The general approach of this method may, however, be extended to other kinds of buildings. The approach is likely to be of value in the development of computer graphic systems.

Keywords: Buildings, computers, quantity surveying

Introduction

A bill of quantities is an essential part of the financial system of many construction projects. It is used as a basis for budget and cost estimates, and for the monetary part of the contract between owner and contractor. For certain projects a bill of quantities may be prepared even twice, first by the owner at the pre-tender stage, and later by the contractor during construction, according to production progress.

The preparation of a bill of quantities consists, in general, of the following operations:

(a) determination of the dimensions of each element of the building according to a given measurement code;
(b) computation of the quantity (volume, area, length, weight or number) of each element;
(c) grouping the various elements according to definite items, and summing up their quantities;
(d) printing the bill of quantities.

Operations b to d have been computerized by several companies, and a number of such computer programs, including commercial ones, are being used. Yet, operation a, which is the most tedious and time consuming, is still performed manually, even when all others are computerized (Alvey, 1976; Schlick, 1981).

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This paper presents a computerized method for quantity surveying, aimed at reducing the amount of work invested in the dimensions take-off. The method is based on a geometric representation of the structure elements (slabs, beams, columns and walls) in a three-dimensional co-ordinate system. This general approach was developed into a complete quantity surveying method for buildings with rectangular structure elements and edges parallel to the axes of the co-ordinate system. Since many of the reinforced concrete buildings fit into this category, the development of a specific method for this kind of building seemed justified. However, the general approach may be extended to other kinds of structures as well.

Fundamentals of the proposed method

From the aspect of quantity surveying, the building elements may be classified as follows:

(a) *Structure elements* including slabs, beams, columns, walls and partitions. The dimensions take-off for such an element requires a geometrical definition of all its intersections with others. For example, if the height of a column is to be determined, all beams located on top of or beneath it, and their relative positions, are to be defined. The dimensions take-off of a wall requires consideration of all its intersections with columns and walls (for determination of its length), beams located above and beneath it (for determination of its height) and beams perpendicular to its axis (subtractions from its area).

(b) *Finishes of structure elements* including interior and exterior wall finishes, floor finishes, skirting, insulating and waterproofing. The quantities of these elements cannot be computed directly from the dimensions of the structure elements, as the free surface area of these depends on their contact areas with others.

(c) *Attachments of structure elements* include a variety of elements, such as doors, windows, lintels, reinforcing steel, pipes, ducts and fittings of various service systems, furniture and many others. The quantities take-off of these elements is relatively simple, as their dimensions appear explicitly in the drawings without requiring any further elaboration.

The dimensions take-off for the structure elements and their finishes is the most time-consuming task in the preparation of a bill of quantities, since it requires the definition of all their intersections and contact areas. Geometric representation of the structure elements in a three-dimensional co-ordinate system enables these definitions to be performed by computer. Consequently, it is possible to obtain automatically the final dimensions of each element (through affiliation of those parts common to two or more elements) and their free surface area (by subtracting their contact area with others), according to a given code of measurement.

As to the third group mentioned above, attachments of structure elements, no special problem exists in their dimensions take-off and the proposed method has no specific contribution in this regard. Yet some of these elements, such as doors, windows, lintels, sanitary fittings and others, are involved in the computation of quantities of structure elements and their finishes. These elements will be referred to mainly in this connection.

Geometric representation of structure elements

The co-ordinate system

A three-dimensional cartesian co-ordinate system is used for the geometric representation of the structure elements. The two horizontal axes will be denoted by x and y, and the vertical one by z. Although the origin of the system may be located at any point relative to the building, it will be more convenient if it coincides with the origin of the axes appearing in the plans.

General representation of an element

Any element with the shape of a rectangular box, whose edges are parallel to the axes x, y and z can be represented geometrically by the co-ordinates x_1, x_2, y_1, y_2, z_1 and z_2, shown in Fig. 1. These values define the location of the element in the co-ordinate system and all its dimensions. For a certain element E these co-ordinates will be denoted by $x_1(E)$, $x_2(E)$, $y_1(E)$ etc.

In order to simplify the determination of these co-ordinates, they may be expressed not only in direct relation to the origin, but also relative to the co-ordinates of any adjacent element which has already been defined. Usually, it will be convenient to express the x and y co-ordinates

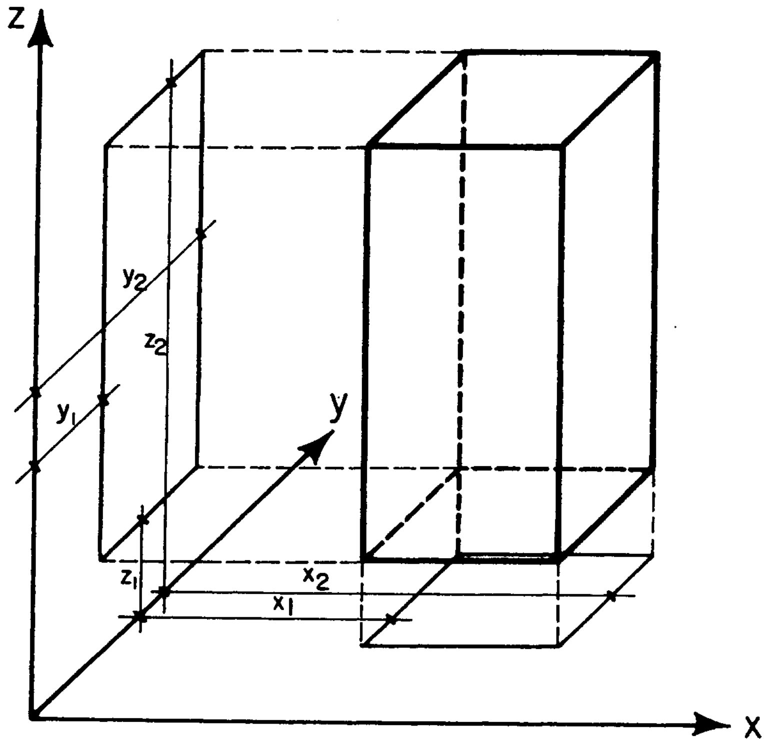

Fig. 1. Parameters of geometric representation of a rectangular element.

of elements relative to those of columns, and the z co-ordinates relative to those of slabs. Thus, for instance, beam B3 in Fig. 2 may be represented as follows (co-ordinates expressed in cm):

$$x_1(\mathrm{B3}) = x_1(\mathrm{C32})$$
$$x_2(\mathrm{B3}) = x_2(\mathrm{C37})$$
$$y_1(\mathrm{B3}) = y_1(\mathrm{C32})$$
$$y_2(\mathrm{B3}) = y_1(\mathrm{B3}) + 20$$
$$z_1(\mathrm{B3}) = z_2(\mathrm{S2}) - 40$$
$$z_2(\mathrm{B3}) = z_2(\mathrm{S2}).$$

Some of the co-ordinates of an element may be expressed relative to others of the same element.

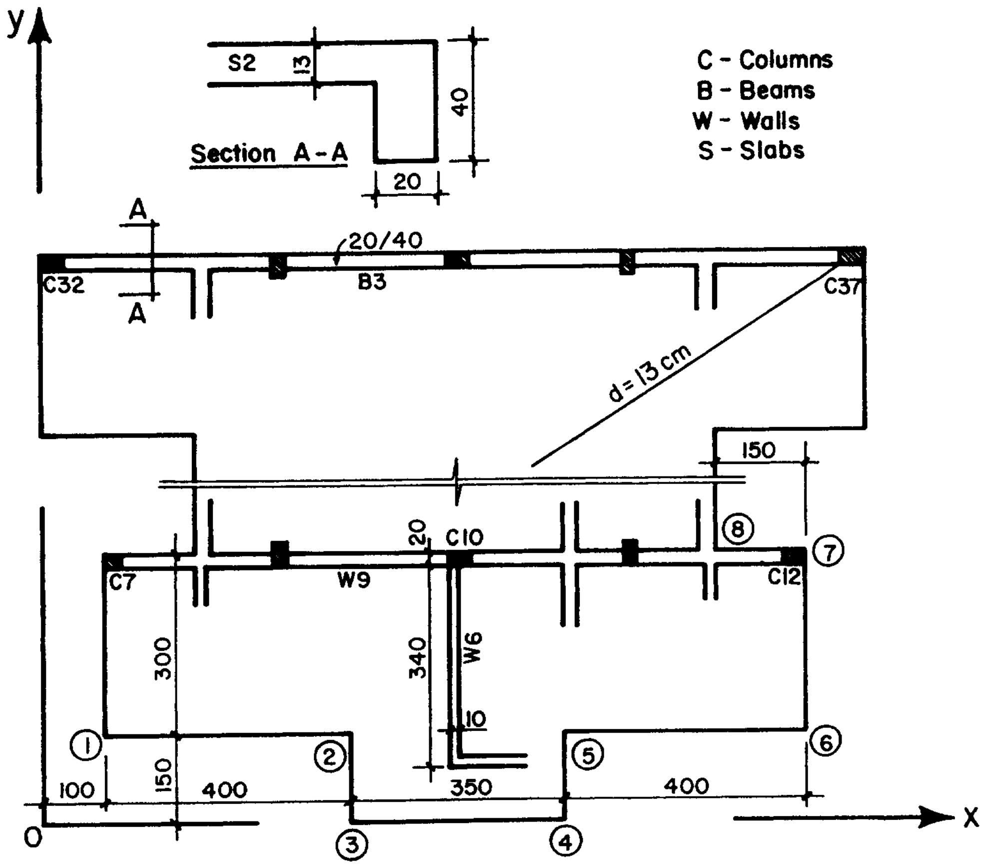

Fig. 2. Schematic partial plan to demonstrate the geometric representation of structure elements.

The order of their insertion is insignificant, i.e. x_2, y_2, z_2 may precede x_1, y_1, z_1. For example, the x and y co-ordinates of wall W6 in Fig. 2 may be expressed by:

$$x_1(\mathrm{W6}) = x_1(\mathrm{C10})$$

$$x_2(\mathrm{W6}) = x_1(\mathrm{W6}) + 10$$

$$y_2(\mathrm{W6}) = y_1(\mathrm{C10})$$

$$y_1(\mathrm{W6}) = y_2(\mathrm{W6}) - 340.$$

Simplifications in geometric representation of elements

Some simplifications in the geometric representation of certain structure elements can be made as follows:

1. Columns and most walls are stretching to the full free height of a storey between its upper and lower slabs or their beams. The definition of the z-co-ordinates of such elements does not require determination of their accurate height, but merely an indication of the number of slabs between which they are located. The initial height of these columns and walls will be the difference between z_1 of the upper slab and z_2 of the lower one. The final height will be obtained by the computer program, considering their intersections with upper and lower beams of the same storey.

Only walls that do not reach the lower level of a slab or beam, require definition of their accurate z_2-co-ordinates (z_1 remains, in any case, as mentioned above).

2. Longitudinal elements, such as walls and beams, may be considered continuous, regardless of other elements interrupting or intercepting them. For example, the x-co-ordinates of wall W9 in Fig. 2 may be expressed by $x_1(\mathrm{W9}) = x_1(\mathrm{C7})$ and $x_2(\mathrm{W9}) = x_2(\mathrm{C12})$. The initial length of this wall will be $x_2(\mathrm{C12}) - x_1(\mathrm{C7})$. The final length, to be used for its quantity computation, will be obtained by the computer program after definition of its intersections with other walls and columns, and after subtraction of the corresponding dimensions. The x-co-ordinates of beam B3, described earlier, are also expressed in a similar way.

Geometric representation of slabs

Slabs are usually of a special shape whose projection on the xy-plane is an irregular polygon, like the one presented in Fig. 2. The geometric representation of such an element entails definition of the co-ordinates of all its vertices, in a definite order. Starting with any vertex of the polygon (e.g. vertex 1 in Fig. 2), its x- and y-co-ordinates are specified. Proceeding from this point along the perimeter of the polygon, in a counterclockwise direction, all other vertices are defined. This definition may be made either by the x- and y-co-ordinates of the vertex or by its signed distances from the preceding vertex along the x- and y-axes. For example, the first eight vertices of the slab in Fig. 2 (indicated by circled numbers) may be defined as shown in Table 1. The z-co-ordinates of a slab are defined in the usual way, i.e. z_1 is the level of its lower face and z_2 the level of its upper one.

Table 1.

Number of vertex	Co-ordinates		Distance from preceding vertex along	
	x	y	x-axis	y-axis
1	100	150	—	—
2	—	—	400	0
3	—	—	0	–150
4	—	—	350	0
5	—	—	0	150
6	—	—	400	0
7	—	—	0	300
8	—	—	–150	0

Input

In the proposed method, the geometric data of the structure elements, as described earlier, is the main constituent of the input. Also required are data describing the elements and the materials of which they consist (for all kinds of elements: structure elements, finishes and attachments), and dimensions of the attachments. Following is a complete list of the required input data, in order of their insertion.

Descriptive and geometric data of structure elements

For each structure element (slabs, columns, beams, walls and partitions) the following data is required:

1. identification number of element;
2. kind of element (slab, column etc.);
3. material (concrete B-200, concrete B-300, concrete blocks, bricks etc.);
4. geometric data, as described in previous sections.

For convenience of expressing the co-ordinates of these elements, as explained earlier, the data of slabs and columns will be inserted first. The order of inserting the data of the remaining elements is insignificant.

Description and dimensions of attachments

For each structure element (mainly walls, partitions and slabs), all elements attached and affecting its quantity computation are to be defined. This includes elements like doors, windows, lintels and the like. Deductible holes and openings in walls and slabs will also be regarded as attachments and defined in a similar way. Also small parts of walls and slabs, with dimensions or materials differing from those of their main part, will be treated as attachments rather than as structure elements.

For each attachment the following data is required:

1. identification number of structure element to which the attachment belongs;
2. identification number of attachment (optional);
3. kind of attachment (door, window, hole etc.);
4. material (required for certain elements only);
5. dimensions;
6. number of such attachments belonging to the corresponding structure element (if more than one exist).

For repetitive attachments, such as doors and windows, a basic table, defining types, materials and dimensions, may be given. The detailed data input will then include only items 1, 2 and 6.

Description of finishes

For the quantities computation of finishes, only their type description is required, as the area of the free surface of each structure element is obtained by the computer program, as explained earlier. The accurate dimensions are to be specified only for parts of elements in which the finish type differs from the main one.

The finishes are divided into six groups: exterior finishes, interior finishes, floor finishes, skirting, waterproofing and insulating. The finishes of each group are described in a hierarchical form of four ranks, each one of them overruling its predecessors, as follows:

1. general finish;
2. finishes of certain kinds of elements (walls, columns etc.);
3. finishes of definite elements;
4. finishes of parts of elements or of groups of elements defined in ranks 1 to 3. The elements or groups to which these parts belong, and their dimensions, are to be specified.

For example, the description of the interior finishes may be of the following form:

1. general finish – plaster and paint;
2. columns – exposed concrete;
3. wall numbers Ww_1, Ww_2 – plaster and wallpaper; wall numbers Ww_3, Ww_4, Ww_5 – exposed concrete; column numbers Cc_1, Cc_2 – plaster and paint;
4. 12.82 m^2 of general finish – ceramic wall tiles; 2.54 m^2 of wall Ww_4 – ceramic wall tiles; 4.80 m^2 of general finish – no finish (bathtubs attached to walls).

Obviously, not all four ranks are necessarily used in describing a certain group. Thus, the description of floor finishes may be as follows:

1. general finish – terazzo tiles 20/20 cm;
2. —;
3. —;
4. 6.80 m^2 – cast *in situ* terazzo (bathrooms); 4.25 m^2 – no finish (beneath bathtubs).

Waterproofing is usually described by rank 3 only, as it is applied on certain elements of the building.

Besides these three groups of input data required for the quantity surveying of every building, a basic library is necessary, defining codes and standard descriptions of materials and items of bill of quantities. It is advantageous that such a library be based on a national or international coding system as suggested by *The BSAB System* (1972), *An Introductory Guide to the Use of SfB* (1977) or the *Library of Items for Building Works* (1978).

Algorithms

Many of the elements' dimensions, included in the input of the proposed method, are not the final dimensions to be used in quantities computation. Thus, the heights of columns and walls were inserted as the full height of the storey in which they are located, without considering the beams located above or beneath them. The lengths of beams and walls were initially determined without consideration of other beams, columns and walls intersecting them. The dimensions of the various finishes were not specified at all in the framework of the input data, except for small areas of exceptional ones, as demonstrated earlier. Consequently, the main task of the computational algorithms is to define all intersections and contact areas between structure elements, in order to derive their final dimensions and free surface area.

A series of algorithms is required for defining the intersections between elements, determining their final dimensions and free surface area, computing their quantities and printing the bill of quantities. Only the basic general algorithms will be presented in detail, while those dealing with the quantities computation of specific elements will be described in general terms only.

Definition of intersections between elements

The definition of the relative position of any two structure elements may be divided into two stages: (a) definition of the relative position of their projection on the xy-plane; and (b) definition of their relative position along the z-axis.

In order to perform stage a for two structure elements I and J whose projections on the xy-plane are rectangles, we shall compute the values of the four following expressions:

$$d_1 = x_2(I) - x_1(J) \tag{1}$$

$$d_2 = x_2(J) - x_1(I) \tag{2}$$

$$d_3 = y_2(I) - y_1(J) \tag{3}$$

$$d_4 = y_2(J) - y_1(I). \tag{4}$$

Four feasible results of these expressions may be interesting from the quantity surveying viewpoint, as follows:

1. *Negative value of one of the expressions.* If one of the expressions $d_1 \ldots d_4$ has a negative value, then, regardless of the values of the remaining expressions, no intersection or contact between elements I and J exists. For example, if $d_1 < 0$, the relative position of the two elements is as described in Fig. 3a.

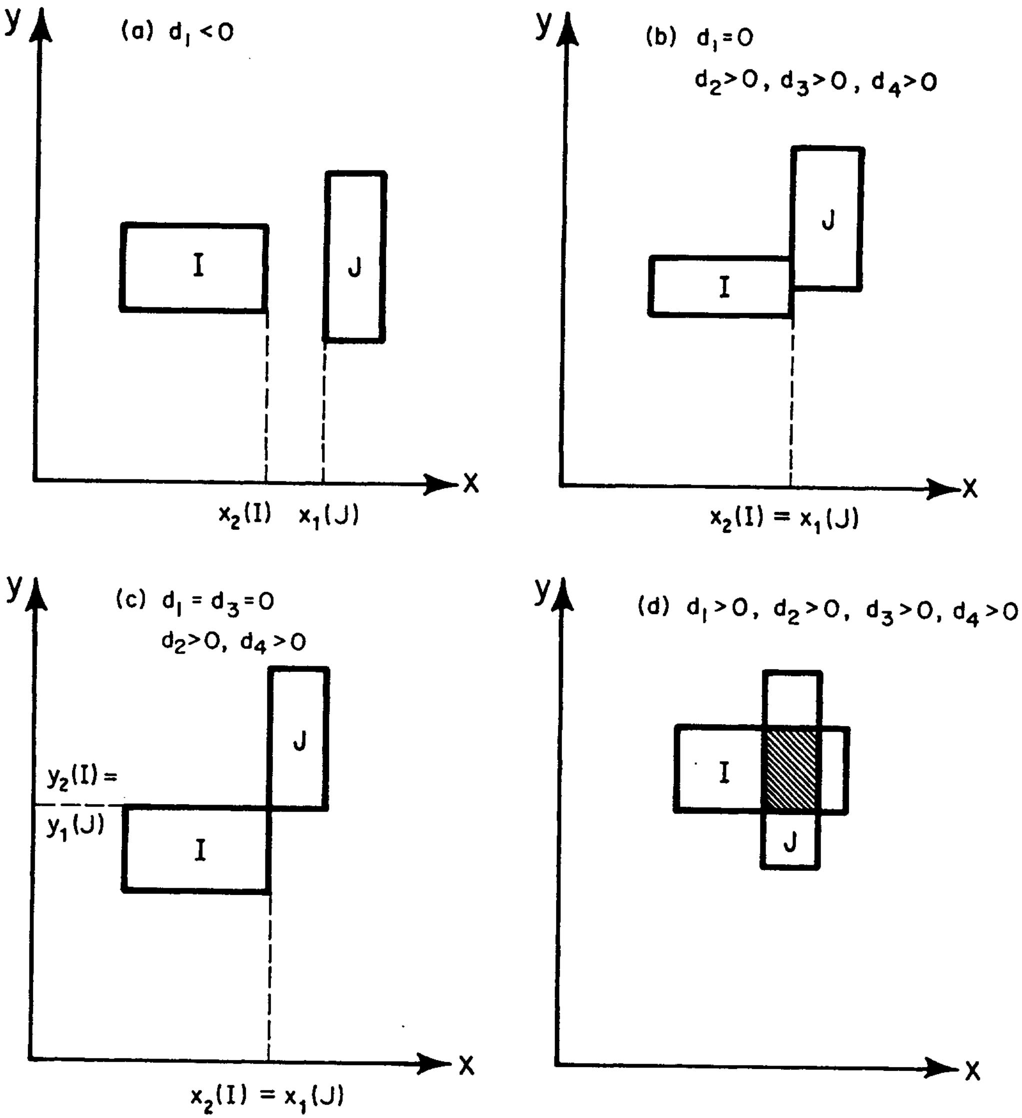

Fig. 3. Feasible relative locations of the projections of two elements on the xy-plane.

2. *Zero value of one expression.* In case one of the expressions is equal to zero, and the remaining three have positive values, the two rectangles are touching each other along one of their sides, as shown in Fig. 3b for $d_1 = 0$ and $d_2 > 0$, $d_3 > 0$, $d_4 > 0$.

3. *Zero values of two expressions.* If two of the expressions have zero values and the other two are positive, the rectangles are touching each other at one of their vertices as in Fig. 3c describing the case $d_1 = d_3 = 0$ and $d_2 > 0$, $d_4 > 0$.

4. *Positive values of all expressions.* If all four expressions have positive values, the rectangles are intersecting each other as in Fig. 3d. The co-ordinates of the rectangle common to the projections of elements I and J are:

$$x_1(I \cap J) = \max[x_1(I), x_1(J)] \tag{5}$$

$$x_2(I \cap J) = \min[x_2(I), x_2(J)] \tag{6}$$

$$y_1(I \cap J) = \max[y_1(I), y_1(J)] \tag{7}$$

$$y_2(I \cap J) = \min[y_2(I), y_2(J)]. \tag{8}$$

After defining the relative position of the two elements in the xy-plane, the examination along the z-axis may be performed in a similar way. Obviously, if no intersection or contact between them exists in the xy-plane, no further examination is required. Otherwise, the two following additional expressions are computed:

$$d_5 = z_2(I) - z_1(J) \tag{9}$$

$$d_6 = z_2(J) - z_1(I) \tag{10}$$

and interpreted in a similar way to that of $d_1 \ldots d_4$.

Determination of the dimensions of structure elements

On the basis of the algorithm described above, it is possible to define the intersections and contact areas of each structure element with all others. Consequently, the final dimensions of an element to be used for its quantity computation, can be determined by combining the parts that are common to two or more elements with the proper one. This is done through a series of algorithms, each one of them dealing with the intersections of one or two kinds of structure elements, as follows:

1. Columns with beams; determination of final height of columns and partial length of beams.
2. Beams among themselves; final length of beams.
3. Walls (including partitions) with beams (with parallel axes only); final height of walls.
4. Columns with walls; partial length of walls.
5. Walls among themselves; final length of walls.
6. Walls with columns (perpendicular axes); subtractions from areas of walls.

The order of these algorithms is significant as the results obtained in each one may be used in the following ones.

A complete description of these algorithms is given by Selinger *et al.* (1980). Obviously, they must be based on a definite set of measurement rules, which, in this case, was the *Method of Measurement of Building Works* (1975). The adaptation of these algorithms to another measurement code is relatively simple.

Computation of quantities of structure elements

After obtaining the final dimensions of the structure elements, the calculation of their quantities is a rather simple task including mainly computation of rectangular boxes volume and rectangles area. Only slabs, having the shape of an irregular polygon, require a special algorithm for their quantity computation, as follows.

Let us take any irregular polygon in the first quadrant of the xy-plane, and enumerate its vertices consecutively, in a counterclockwise order, as in Fig. 4. The vertices were denoted by 1, $2 \ldots i \ldots n$, where 1 and n refer to the same vertex (i.e. the polygon is one of $n-1$ vertices). For the computation of the area of such a polygon, we shall use the well known fact that the area s_i of the trapezoid formed by the straight line section between points (x_i, y_i) and (x_{i+1}, y_{i+1}) and the x-axis (see Fig. 4), can be obtained by:

$$s_i = (x_{i+1} - x_i)\,(y_{i+1} + y_i)/2. \tag{11}$$

Let us indicate by $(-)$ all sides of the polygon bounding it from below, and by $(+)$ those bounding it from above, as in Fig. 4. Let $\Sigma_1 s_i$ be the sum of the areas of the trapezoids between the x-axis and the sides of the polygon indicated by $(+)$. Similarly, $\Sigma_2 s_i$ will be this sum for the sides indicated by $(-)$. Obviously the area of the polygon is equal to $\Sigma_1 s_i - \Sigma_2 s_i$. As the vertices of the polygon have been denoted in a counterclockwise order, its area (S) may be computed according to the formula:

$$S = \sum_{i=1}^{n-1} (x_i - x_{i+1})\,(y_i + y_{i+1})/2. \tag{12}$$

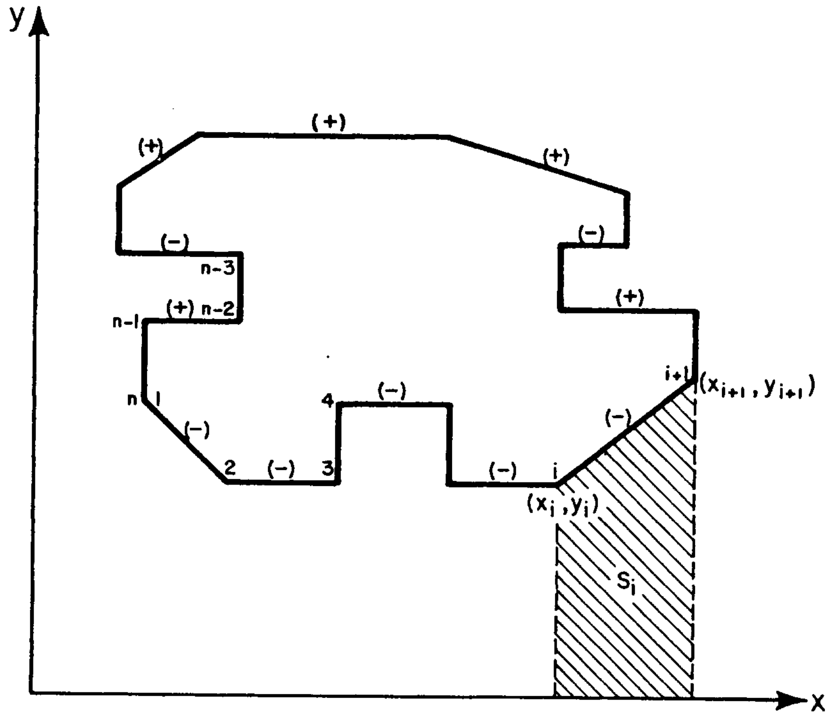

Fig. 4. Illustrations of procedure for computation of irregular polygon area.

Computation of quantities of finishes

As emphasized earlier, the contact area of every two structure elements is being computed within the process of defining their intersection. Accordingly, the free surface area of each structure element, or a definite part of its faces, can be obtained. Using the finishes' input data described earlier, their area is obtained through a series of algorithms, each one of them dealing with a certain kind of finish. These algorithms consist of basic data processing procedures described in detail by Selinger *et al.* (1980).

Output

The final output may be presented in several forms, as follows:

(a) regular form of bill of quantities, including items description and their quantities;
(b) detailed form, specifying the quantities for each storey or section of the building separately;
(c) partial form, specifying the quantities of definite prescribed elements only. This form is especially useful for the construction stage where the contractor's bills are based on produced quantities.

Summary and conclusions

The proposed method was aimed at reducing the amount of work invested in dimensions take-off for quantity surveying. The representation of the structure elements in a three-dimensional co-ordinate system enables the following simplifications and savings in dimensions take-off to be achieved:

(a) certain dimensions of structure elements, such as height of columns and walls, need not be determined;
(b) the length of walls and beams may be determined without considering their intersections with other elements;
(c) the co-ordinates of any structure element may be defined relative to those of an adjacent one. This simplifies the geometric definition of elements, especially of walls and beams;
(d) dimensions of the various finishes (plastering, painting, flooring, skirting etc.) are not required, but for small exceptional areas;
(e) the fact that intersections of structure elements are not to be considered, enables dealing with each drawing separately, instead of the simultaneous treatment required in the usual process.

Despite these advantages, simplifying and shortening the dimensions take-off procedure, it is not to be expected that the proposed method can be performed by non-professional staff. Further, a thorough understanding of the building and its plans remains an essential requirement for this task.

Although the method has been developed for a certain kind of building only, its principles may be extended for the quantity surveying of other kinds as well. The method might be of special importance when the usage of computer graphic displays, at the design stage, expands in the future.

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