Calculation of areas for facility management from measured model of a building

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Summary

In the measured model structures are described by their surfaces because usually only visible parts of buildings can be measured. There is a method that can generate wall elements between measured surfaces. This publication describes a method that automatically calculates the facility management areas of a building. Input data are obtained by measurements. The facility management areas treated here are gross floor area, area of structures, useful floor area and floor area. The results of the test calculations of four real buildings have been presented.

Keywords: facility management, measuring of building, geometric modeling of building

1. Measured model

Measurement of buildings

Measurement is a useful way to obtain reliable information from existing buildings. With advanced methods, the space and material information could also be included in the stored model. The main measurement methods for the inside of a building use distance meters or tacheometers. Both methods need a special measurement program to store the model as the equipment observes only one point at a time. The model should be stored in a form that includes building parts and their attribute data. These kinds of methods are described in publications [3.] and [5.]. Photogrammetric methods are suitable for measuring the exterior of buildings. The laborious part of measurement is the orientation of different photographs taken from different angles into the same coordinate system. Inside buildings several rooms should be measured in the same coordinate system, which usually renders photogrammetry impractical.

Measuring methods only allow measuring visible parts. In the measured model the building parts are described by their surfaces. Instead of one wall element the measured model contains its two surfaces; one surface for both rooms adjoining the wall. When the walls are measured, their structural information can be stored to attribute data. Load-bearing capacity can be estimated by the measurer on the basis of experience and visual inspection.

Visible columns can be measured and stored in the database so that their plane area can be output in the form of polygons. No conversion is needed to utilize data of columns in the calculation of facility management areas. However, when walls are generated independently of columns the intersections between walls and columns should be checked.

Generation of wall elements from a surface model

A method that generates wall elements based on the measured surface model is described in publication [4.]. The geometric model generated by the method is feature-based as it includes construction information. The solution is based on the author’s definition of wall geometry. In the model the walls generated by the method are described by a four-node polygon. The advantage of the method is that the wall elements can be described in very simple form. Height information can be added to every node so that linearly changing three-dimensional wall structures can also be described. To describe the joints between wall elements a special intersection element is defined. An intersection is also a polygon but there the number of nodes is not limited.

If the model is converted to a CAD file, the intersection areas should be removed. This is possible by extending the walls to the intersection area and editing the overlapping areas. In facility management intersection areas can be treated in the same way as wall areas.

In the generation of a model, the load-bearing capacity of intersection areas cannot be determined with certainty. To make the treatment easier, the intersection area is determined as load-bearing if any of the adjoining walls are load-bearing. Figure 1. shows an example of wall and intersection areas.

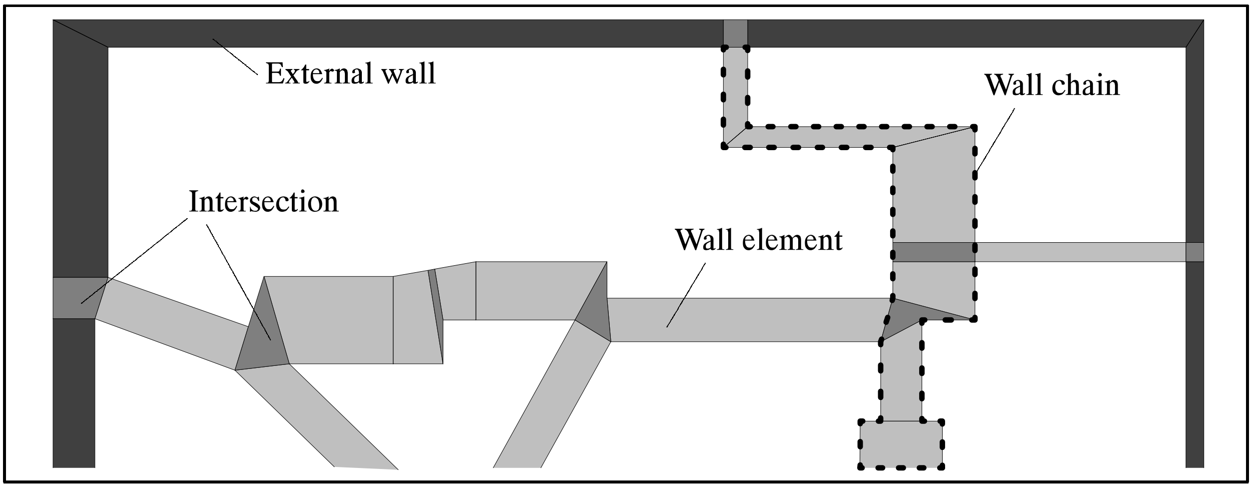

Figure 1. Example of wall areas generated between spaces.

When walls are generated the joining of two wall surfaces is based on their perpendicular projections. The limit to how near two projections are allowed to lie can be entered into the program as input data. Where a complete solution is required, a very small limit should be allowed. Then the wall elements generated by the method can also be very small.

2. Space-oriented facility management

Today, facility management is space-oriented. In theory, one space could be defined as part of a room. One space usually has only one occupancy. Especially in the case of big halls, the possibility of dividing the room is useful. Most often, however, walls provide a natural boundary for one space. In computer-based facility management spaces are not often such small units. It is usual that one space is part of a storey. Spaces are limited according to the area rented to one tenant, not according to rooms.

One important reason why a more accurate division of spaces is not generally used is the cost of the modeling of a building. A lot of work is needed to model every room as a space. The problem is that not only rooms but also the structures between them should be modelled. The structural behaviour should also be stored when walls are modelled. In Finland non-bearing walls are included in the rentable area. A non-bearing wall between two rooms should be divided along its middle axis. In Finland, not all commonly used architectural software packages can output the areas of spaces of facility management. Modelling them point by point with CAD software requires a lot of human resources.

In effective rental business, buildings should be controlled more accurately than only by tenants. Below is a list of a few examples of the benefits of such space-oriented management of buildings:

- Harmonizing the areal information of different buildings. If the rentable, non-rentable and structural areas of buildings are modelled in the same way, different buildings can be compared. Many indicators used in reviewing the real estate business are based on areal information.
- Setting rents of spaces based on occupancy. For example, storage space is usually rated cheaper than actual commercial space. The exact areas of spaces divided by occupancies are valuable information to the owner of the building.
- Renting of common spaces such as corridors. The maintenance costs of common spaces should be known and included in the rents of other spaces. When common spaces are separated from other spaces, the costs can be shared in proportion to rented areas. A tenant may be informed of

the part of common spaces shared by him to justify the related cost. A uniform method for treating common spaces also helps harmonize areal information from different buildings.

- Developing the effectiveness of the use of spaces. The effectiveness of renting a building can be estimated by the area of different spaces. For example, a large amount of common space reduces effectiveness. It could also be profitable to minimize the amount of cheap storage space.
- Individual pricing of spaces. All spaces in buildings are not of the same type even if they have the same occupancy. There could be differences, for example, in technical properties, in customer appeal, and even in the view afforded by the window. Individual pricing is not governed by the inflexible fixed prices based on the location of a building. Less appealing spaces can be rented at an economical rate. Then, the occupancy rate and the profits from the building can be maximized simultaneously.

3. The generation of areas of facility management

Calculation of the areas of facility management

The following areas of facility management are discussed in this publication. Their exact determination is described in publication [6.].

<u>Gross floor area</u> is limited by the outer surfaces of external walls.

<u>Useful floor area</u> is limited by the inner surfaces of surrounding walls. In Finnish practice, frame structures are not included in useful floor area. However, the areas of non–bearing structures are included. This means that if there are non–bearing walls between two apartments, their area is calculated up to the centre line of the wall.

<u>Area of structures</u> is divided into two groups: non–bearing structures and frame structures. External walls are not included in useful floor area. They can be included in the same group as frame structures. Another possibility is to form a third group of external walls.

<u>Floor area</u> is limited by the inner surfaces of its walls.

The selected method for modelling areas is to use two–dimensional polygons. A polygon is stored as a set of points and their drawing order. Two points are connected by a straight line. The two most important properties pertaining to the determination of a polygon concern the boundary. Its tracing direction should be constant and it should not intersect itself. The accurate determination of polygons is presented in publication [2.].

The gross floor area can usually be modelled by one polygon. If there is a courtyard completely enclosed by a building, the final result is the difference between the outer and inner polygons.

The most accurate level in the modelling of buildings also separates the areas of structures. That is the only way to get exact and comparable information from buildings. The effective area of a building can then be calculated. Areas of structures are simple polygons. In calculations, it is supposed that two structural polygons may not overlap, except for columns and walls.

Floors can be modelled by the same principle as structures. In some cases one space can be completely inside another. To avoid recalculation, the surrounding space should be modelled in two parts. The occupancy of a space is very useful information to be included in the model because it allows, for example, distinguishing rentable areas from technical spaces.

In raw modeling, apartments can be modeled by polygons. The method of modeling an apartment by one polygon is limited because the areas should be connected. No room located on another floor can belong to the apartment. Modeled apartments can still be called “spaces“, but the model does not include any room information.

Another possibility is to model an apartment as a group of spaces. Then the apartments cannot be modeled with physical polygons but with a data structure listing the spaces of one apartment. Apartments can be formed dynamically. A space can be moved to another apartment without new graphical modeling. To save modeling costs, several rooms of the same type can be joined to one space.

The separate modeling of spaces means that a space has two areas: floor area and so-called rentable area. If the structures delimiting a space are non-bearing, the rentable area is bounded by the centre line of walls and extends through the centre of intersection areas. If all walls delimiting a space are bearing, the rentable area is the same as the floor area. The rentable area can be determined based on these rules because in the generated wall model wall and floor elements are connected through common nodes. The useful floor area is the sum of the rentable areas of spaces.

Irrespective of the modeling method, the calculation of useful floor areas is always complicated. Frame structures overlapping floors partly or completely should be subtracted from the area. The intersections between every floor and frame structure polygon should be checked.

A polygon located inside other polygon can be calculated by the method documented in publication [1.]. All points of a polygon must lay inside the other polygon. To determine if a point is inside a polygon, a line is drawn from the point to a point beyond the minimum or maximum coordinates of the polygon. The point is inside the polygon if the line intersects the polygon's boundary an odd number of times. If all points of the examined polygon (number one) lie on the boundary of another polygon (number two), it should be checked if the polygons bound the same area. This can be done by calculating if the points of polygon number two lie on the boundary of polygon number one.

If two polygons intersect, their common area must be calculated. The calculation method is also documented in publication [1.]. The method first calculates the intersection points between polygons. If an intersection point falls in the middle of a side, the side is divided in two. Secondly, all loops formed by the sides of polygons are traced starting from the intersection point. The tracing starts and ends at the same point. The loop that has sides belonging to both polygons forms the common area.

However, the calculation accuracy of computers poses some problems to the programming of the method. When one loop is traced the tracing direction must not be changed. At intersection points there are several possibilities for continuing the tracing. The right direction to continue is the first line in the selected tracing direction. The angles between the previous line and all possible continuing lines must be calculated. Since programs use radians as units of angles, comparisons between floating-point values cannot be avoided. The problem lies, for example, in distinguishing the zero and 2π angles from each other when there is a slight difference between the calculated and exact values due to calculation accuracy. An example of rotation is presented in Figure 2.

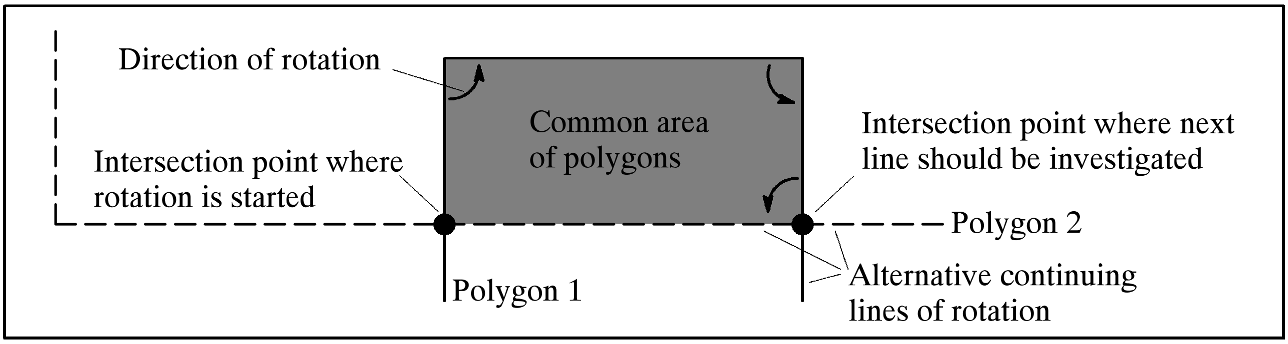

Figure 2. The rotation of common area of two polygons.

The use of floating-point values can be avoided by using only integer values and by saving figures in longer form. In multi-precision accuracy, figures are represented by 64-byte integers. When normal 32-byte floating point values are used, calculation errors may occur. The presented examples are calculated by such a program.

Joining of wall areas

The more polygons the model contains, the more computing resources are needed. The wall generation method may produce more wall elements than it is reasonable to use. The solution to this problem is to join walls into large polygons depicting the structural areas of facility management.

The main components of a program for generating joined wall areas are:

- Joining of walls between two intersection areas. The result of joining is one polygon called a wall chain. Walls of zero thickness are not accepted into chains. Figure 1. presents an example of a chain.
- To replace intersection areas two walls adjoining one intersection are marked as forming a continuous structure. The chains that include the continuous walls are joined over the intersection. The intersection is also incorporated into the chain.
- If one chain forms an endless loop, it must be divided into two parts.
- It is possible that the other end of a chain adjoins an intersection in the middle of the chain. Such a polygon intersects itself and cannot be accepted. Parts that form loops must be divided.
- Chains are divided into parts at points where the load–bearing capacity changes.
- Those wall areas that are not included in any chain are used to generate separate chains.
- The nodes forming the chain polygon are examined after the generation of chains. First, the drawing order of successive original wall elements should be investigated. The nodes of wall elements are divided between the left and right sides. Intersection areas where the number of nodes is not limited constitute special cases. Each wall always adjoins successive nodes of an intersection. It must be checked which nodes the next wall adjoins. The drawing order of an intersection can be examined by calculating which node belonging to the next wall is the nearest to the left and right side nodes of the previous wall. Here “the nearest“ does not mean the distance but the number of nodes between the nodes joined to the previous and next walls. If an intersection area is at the end of a chain, its nodes are joined to the right side nodes.
- The remaining generated triangular wall areas are removed by replacing the node belonging to the triangle and square wall by the apex node of the triangle.
- Outputting of joined wall polygons. First, the right side nodes are output in ascending order followed by the left side nodes in descending order.

4. Testing of method

The method has been tested by calculating facility management areas of four buildings at Tampere University of Technology. The buildings are shown in Figure 3.

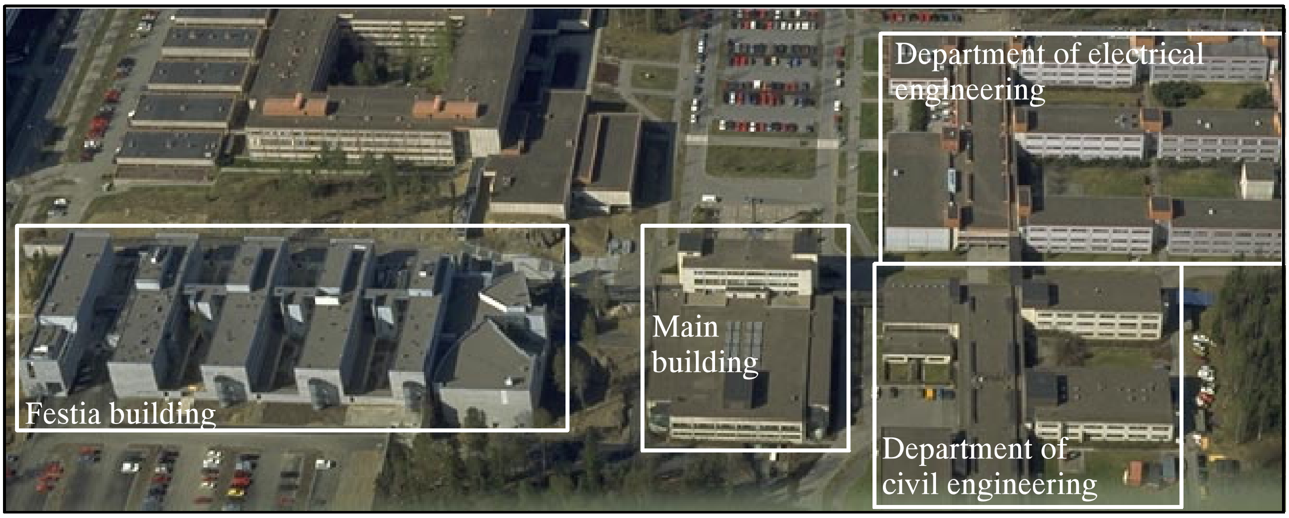

Figure 3. Tampere University of Technology.

The scope of data is described in Table 1. The “Difference“ is the area calculated by subtracting the sum of floor, shaft, column and wall structure areas from gross floor area. The closer the value is to zero, the more accurate the solution. Comparisons can be done when the polygon depicting the gross floor area has not been used in the calculation of other areas.

Building	No. of storey	Gross floor area	Number of spaces	Floor area of spaces	No. of wall elements	Area of walls	Area of shafts and columns	Difference
Festia	6	11193.636	431	9770.370	740	1299.125	123.699	0.442
Main build.	6	7300.999	205	6707.518	275	477.442	115.698	0.341
Civil Eng.	5	12542.659	361	11463.874	549	940.761	144.034	-6.010
Electr. Eng.	6	24509.539	850	22520.820	1154	1739.784	251.096	-2.161
Total		55546.832	1847	50462.582	2718	4457.112	634.527	

Table 1. Test data for calculation of areas [m^2].

5. Conclusions

In the testing, drawings of every storey could be calculated. If the calculation of intersecting polygons was first halted by an error, the geometry of intersecting polygons was corrected to make it more rectangular. The magnitude of corrections was less than one millimetre so it had no influence on calculated areas. Almost every drawing had a few corrected points. The number of corrected cases was not calculated exactly, but it was small. The automation level of the method can be considered remarkable compared to working with the graphic editor of a CAD program.

Table 1. shows that the calculated difference is small. It can be concluded that the method is usable in the calculation of areas.

The method is intended only for processing of input data corresponding to the definition. Input data have not been checked or revised by a separate program. Because of the small magnitude of errors the input data can be supposed to be highly reliable.

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