# A NEW APPROACH TO INTER-ZONAL ADJACENCIES ANALYSIS FOR BUILDING ENERGY SIMULATION PROGRAMS

Piotr Narowski[1]
[1]Warsaw University of Technology, Faculty of Environmental Engineering, Warsaw, Poland
[1]e-mail: piotr.narowski@is.pw.edu.pl

## ABSTRACT

One of the main goals of sustainable development is the reduction of fossil fuel consumption. It can be done by applying a range of principles that help practitioners to move their projects toward the goal of natural energy resources conservation. The American Institute of Architects in their program 50»50 listed the fifty principles which when embraced individually or collectively will help to reduce the fuel consumption to 50%. One of these principles is «Energy modelling». There is a lot of building energy simulation software available on the market, one of them free of charge other commercial, but they are not commonly used in everyday designing because of their complicated interface for building geometry defining. Geometric information input required for the building energy modelling sometimes is so big that designers resign to use such tools. Every improvement in the process of geometric data input will help to disseminate using energy modelling. This paper presents a new approach to inter-zonal adjacencies analysis in building geometry. One can easy imagine two plans of adjacent building floors drawn on the same plane with two colours. Such sketch will show the elementary parts of floor adjacent to rooms or zones separated by this floor. In most energy simulation programs user has to input data about these elementary parts of walls, floors or partitions. The new approach uses the computational geometry and its topological maps and simplifies process of geometric data input.

## INTRODUCTION

Searching of elementary fragments of floors or walls separating adjacent zones or spaces in building seems to be a simply job. It is actually easy to find these elements of building in case of simply construction with small number of rooms or spaces in building. The matter fast complicates in buildings with many adjacent spaces. Sometimes it is difficult to define precisely parts of floors or walls separating spaces using plans or sections of building drawn on paper. It is helpful to use stock of transparent drawings in such cases. Some time there is problem to get complete technical documentation of building on such materials with proper scale. The energy management engineers and energy auditors need information about elementary fragments of partitions of adjacent spaces in buildings to calculate heat transfer between the rooms or to prepare data in building energy simulation applications. The building geometry data input into energy simulation programs is probably the most laborious part of data preparing. Users have to work with paper technical documentation frequently making calculation of area of elementary fragments of partitions. This work is sometimes easier when the available documentation is in electronic form as CAD drawings. There are energy simulation programs, which helps users to calculate inter-zonal adjacencies for example *"Ecotect"* [Marsh]. This one uses probability methods to calculate the area of overlapping surfaces of well-defined thermal zones. This great method is very efficient with small number of adjacencies as it uses huge number of probe points. The computational geometry with its topological maps, planar maps and arrangements of simply geometric elements may be helpful to prepare efficient methods for semi-automatic recognition of elementary floors and walls fragments adjacency in building construction.

## IDEA

The main energy simulation programs such as ESP-r ,EnergyPlus, DOE-2 etc. make the general assumption that the building is divided into thermal zones. It is clear that without thermal zones and its' surfaces, the building cannot be simulated. The user of energy simulation system always decides about the number and shape of the thermal zones, which are always a group of internal spaces of building. There are many guidelines about combining spaces into thermal zones in building, taking in consideration thermostat or operational characteristics of rooms or heating/cooling systems. This all leads to simplification of building geometry and the user has to input small number of surfaces surrounding the thermal zones. The surfaces are in most cases defined as ordered lists of planar vertices in the world or relative coordinate system. As the result of such calculation, user gets the energy consumption of the thermal spaces of building but heat/cool loads for single space in thermal zone stays unknown.

The designers of the heating/cooling systems or energy auditors issuing building energy certifications want to know the heat/cool loads of every single space in a building (including heat transfer through elementary partitions enclosing single space) and energy consumption for group of spaces. There is difference between the knowledge of energy consumption of the whole block of dwellings and the energy consumption of every dwelling in the building.

Developing software tools, which help engineers to design building heating/cooling systems and allow calculation of annual building energy consumption in the same software, require simplification in definition of building geometry.

Finding elementary fragments of partitions, which enclose single spaces in building, allows grouping them in thermal spaces used in the annual energy calculations and allows determining the heat loads for single spaces. It is very simple to decide that the user has to define every single surface element of building construction but if we find the method of simplifying this task, it will increase the productivity of software and its users. This paper presents one of the methods of finding elementary partitions taking as the input the sketches of adjacent floors using computational geometry arrangements.

## TOPOLOGICAL MAPS

A topological map [de Berg] is a graph built of vertices, edges, faces and an incidence relation on them. Each edge is represented by two halfedges with opposite orientations. A face of the topological map is defined by the ordered circular inner and outer sequences of halfedges along its boundary.

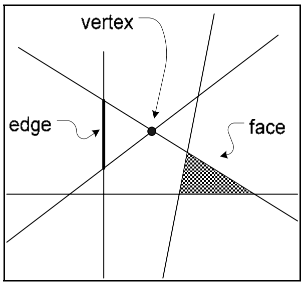



*Figure 1 Topological map objects*

Each edge of topological map is considered to be two-sided and is represented by two directed halfedges. A halfedge is an ordered pair ($u$, $v$) of its endpoints called vertexes, and it is directed from the source $u$, to the target $v$, and the twin halfedge is directed from vertex $v$ to vertex $u$. Each halfedge lie on the boundary of a single face and that means that each connected component of the boundary of a face is defined by a circular list of halfedges. This list called connected component of the boundary (CCB). A bounded face has a unique CCB that is defined to be its outer-CCB and it means that the outer edge of a face is a chain of directed vectors defined as pairs of source and target vertices. An unbounded face does not have any outer boundary and there is only one unbounded face in any topological map. It means that the plane with any bounded face on it has no CCB.

Structures defining topological maps are used to describe many geometrical problems. These structures are not limited only to lines on plane. The graphs representing topological maps can be used to describe any kind of facets bordered with any curve lines in three-dimensional space. The simples and most popular application of topological maps is defining sets of plane facets in 2D or 3D space – for example – surface modelling in 3D space. This method is efficient way of modelling complicated surfaces as set of small plane facets that creates polyhedron or polyhedral surface approximate the real surface. It is important in description of surfaces to have possibility of defining holes in the surface. The definition of the edge as pair of twin halfedges with opposite direction makes possible to describe the absence of any facet in the polyhedron or in plane. Counter clockwise halfedge chain defines positive area of face and the clockwise chain of halfedges describes negative area of face. The sign of area is useful to distinguish between the hole and the face in the surface or polyhedron. The negative number means hole and the positive number the existence of face.

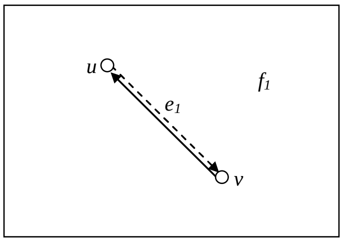



*Figure 2 The simplest topological map – two vertices u and v of one edge $e_1$ and one unbounded face $f_1$.*

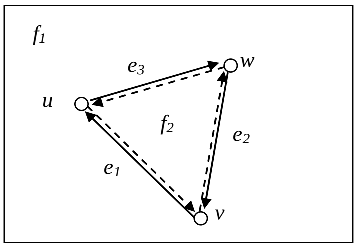



*Figure 3 Topological map of triangle on plane – three vertices u, v, and w, three edges $e_1$, $e_2$, $e_3$ and two faces $f_1$ – outer unbounded and $f_2$ – triangle.*

The simplest topological map is line segment between two vertexes $u$ and $v$ as shown on fig. 2. This map consist of one unbounded face $f_1$ and one edge $e_1$ assembled with two halfedges ($u$,v) and ($v$,$u$). It represents the infinitesimal thin cut in the plane. Another simply case of topological map is the triangle on the plane shown on fig. 3. In this case the topological map consist of two faces $f_1$ and $f_2$, three vertices $u$, $v$, $w$ and three edges $e_1$, $e_2$, $e_3$ with six halfedges. The unbounded face $f_1$ represents the whole plane with triangle cutout. The triangle hole in the plane is defined by the chain of three halfedges (CCB) drawn with clockwise continuous arrows. The face $f_2$ is the triangle and its CCB is drawn with counterclockwise dashed arrows. Every bounded face has only one outer CCB and may contain many inner CCB that represents holes in that face.

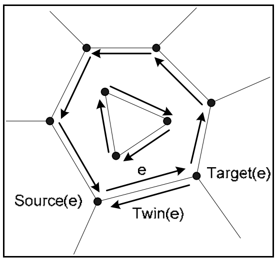



*Figure 4 Face with marked outer CCB and one inner CCB creating hole.*

Graphs describing topological maps are used to search geometrical information. One can search for all CCBs for chosen vertex to find all faces it belongs. There are many ways to record information about topological maps. One of most popular is doubly connected edge list. This structure contains records for each face, edge and vertex. Except basic geometric and topological information, the doubly connected edge list can store other useful data about the elements.

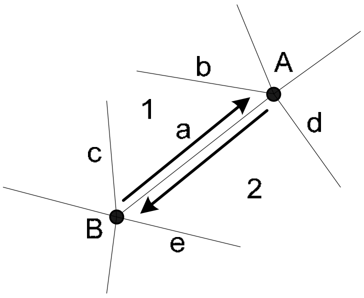



*Figure 5 Doubly-connected edge list - one of many ways to record information about topological maps.*

*Table 1 Example doubly connected edge list for edge **a** on figure 5.*

| Edge | Source vertex | Target vertex | Left face | Right face | Previous left edge | Next left edge | Previous left edge | Next right edge |
|---|---|---|---|---|---|---|---|---|
| a | B | A | 1 | 2 | c | b | d | e |

## PLANAR MAPS AND ARRANGEMENTS

Topological maps are general concept of computational geometry and as written above they describe dependence between vertices, edges and faces without detailed geometric information about these elements. There is no geometric limitation concerning components of topological maps. One popular implementation of topological map is planar map. Planar map is embedding of topological map into the plane. A planar map subdivides the plane into vertices, edges, and faces. The vertices, edges, and faces of a subdivision are the embeddings of their topological map counterparts into the plane. Each vertex is embedded as a planar point, each edge is embedded as a bounded monotone curve, and does not contain vertices in its interior, and each face is a maximal connected region of the plane that does not contain edges and vertices in its interior.

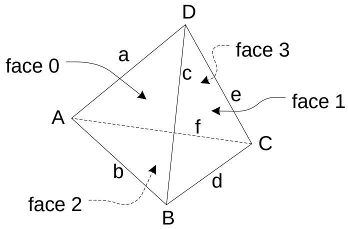



*Figure 6 Topological map of tetrahedron.*

*Table 2 Doubly connected edge list of tetrahedron on figure 6*

| Edge | Source vertex | Target vertex | Left face | Right face | Previous left edge | Next left edge | Previous left edge | Next right |
|---|---|---|---|---|---|---|---|---|
| a | A | D | 3 | 0 | f | e | c | b |
| b | A | B | 0 | 2 | a | c | d | f |
| c | B | D | 0 | 1 | b | a | e | d |
| d | B | C | 1 | 2 | c | e | f | b |
| e | C | D | 1 | 3 | d | c | a | f |
| f | C | A | 3 | 2 | e | a | b | d |

The planar maps can use as edges any planar curves. In the simplest case (Fig. 7a) edges are segments of straight lines and in more complicated are arcs (Fig. 7b). The planar maps presented on fig. 7 are formed as arrangements of lines and circles.

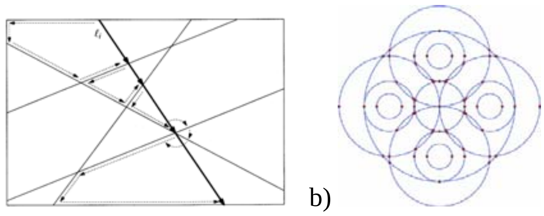
a)  b)

*Figure 7 Examples of planar maps created from arrangements of (a) straight lines– [de Berg] (b) circles – [CGAL Reference Manua]l.*

In geometry, an arrangement of curves is the partition of the plane formed by a collection of curves. Bounds on the complexity of arrangements have been studied in discrete geometry, and computational geometers have found algorithms for the efficient construction of arrangements. The arrangement $A(C)$ for a given a set $C$ of planar curves, is the subdivision of the plane into zero-dimensional, one-dimensional and two-dimensional cells, called vertices, edges and faces, respectively induced by the curves in the set $C$. Arrangements are popular in the computational-geometry literature and have many applications. The curves in $C$ can intersect each other and are not necessarily cross monotone. Decomposition of each curve into subcurves and possibly isolated points generates collection of vertices, edges and faces that are then embedded into planar map.

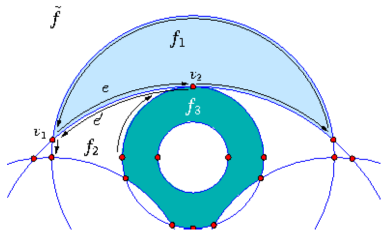


*Figure 8 Fragment of planar map generated by arrangement of 14 circles – [CGAL Reference Manual].*

Planar map presented on fig. 7b was generated from arrangement of 14 circles and consists of 53 faces (with one unbounded), 106 edges and 59 vertices. The blown up fragment of this planar map can bee seen in fig. 8. Arrangements with the computational geometry algorithms are very useful tools for geometrical analysis. Binary trees are commonly used to describe the collection of geometrical objects generated by arrangements. These data structures can be used to find intersection points forming vertices, monotone fragments of lines or curves – the edges and elementary faces on the plane generated by the arrangement. This property of arrangements is used to solve the problem of finding elementary elements of floors in a building.

## APPLICATION

Described above planar maps and arrangements were used to build the semi-automatic system which recognizes elementary fragments of partitions of adjacent spaces in building. The experimental system was build as dynamic load library (DLL) written with C++ programming language using the *CGAL library*. To find the elementary fragments of partitions plans of adjacent floors or sections in building raster or vector drawings are used in graphic interface of building energy simulation programs to sketch contours of rooms on adjacent floors. The scheme of spaces in building can be in different scale as the raster or vector drawings can be easily stretched to the same scale using image processors in a graphic interface of computer programs. Sample of technical plans on fig.9 present the first floor and the basement of small one-family building. These 1:1 scale plans were used to sketch (fig.10) the contours of rooms and spaces in the basement and first floor. It is important that the user does not have to draw these sketches very precisely and connect ends of segment lines.

The DLL library takes as the input data list of pair points for each floor. Each pair of 2D points describes single segment of floor contour drawn by the user. More precisely the input data is internally collected as the array of structures containing the integer floor handle and quadruple of double floating numbers representing coordinates of segment ends. The internal DLL function of space recognition uses sets of crossing lines with floor information (fig.11) to build separate arrangements to identify single spaces (fig.12). The result of this process is a list of storey spaces (faces of planar maps) with list of boundary segments. For example, spaces numbered from 1 to 6 are recognized in the basement and 7 to 14 on the first floor. Each of the identified space has its list of boundary segments. Ends coordinates of these segments are equal to the coordinates of intersection points of sketch lines drawn by user. The joined set of sketch lines for adjacent floors (basement+first floor – fig.13) is used to create the arrangement identifying all intersection points, edges and faces of elementary floor fragments separating two storeys. Letters from A to J on fig.13 mark the founded elementary fragments of floor separating the basement and the first floor. After the process of two storeys space recognition and finding the elementary floor fragments, an internal function assigning numbers of spaces to each floor fragment is called. This function utilizes the natural property of planar maps that allows finding face by point belonging to it. Internal points of elementary floor fragment are used to search two planar maps of adjacent storeys to find separated spaces. The result of the spatial search is the list of floor elements and spaces separated by them shown in table 3.

*Table 3 List of floor fragments dividing adjacent basement and first floor building spaces.*

| |
|---|
| (A, 1, 7); (B, 2, 8); (C, 3, 7); (D, 4, 9); (E, 2, 10); (F, 5, 11); (G, 6, 7); (H, 2, 14); (I, 6, 12); (J, 6, 13) |

The space recognition DLL returns three lists of structures. Two of them describe spaces on the adjacent storeys. The third list describes elementary floor fragments with space identifiers that they divide. Grouping of single building spaces allows to describe building zones and the zone surfaces are sums of the elementary fragments of partition.

Described spatial recognition DLL was experimentally developed for one of the most popular in Poland software used for calculation of heat/cool loads and designing of heating/cooling systems in buildings. Development of this application will allow HVAC engineers and energy auditors to calculate the heat/cool loads and annual energy consumption with multi-zone 6R1C model in compliance with standards PN EN 12831 and PN EN ISO 13790. The software allows users to describe building geometry with single spaces, group of spaces, dwellings and thermal zones once and use it for several purposes.

The DLL can be used in any graphic building energy simulation application that allows users to sketch lines on the background technical documentation.

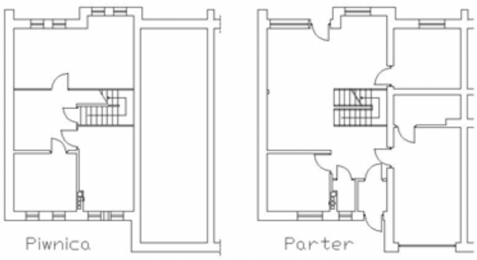



*Figure 9 Planes of basement and first floor in small building.*

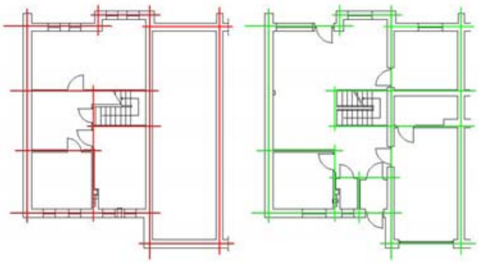


*Figure 10 Contour sketches of spaces in building.*

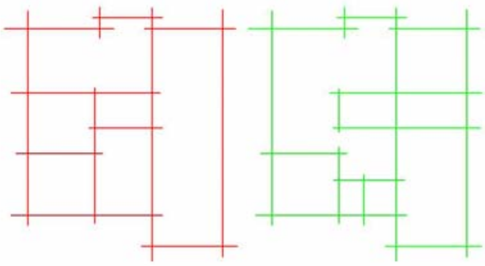


*Figure 11 Two set of contour lines creating two arrangements for basement and first floor.*

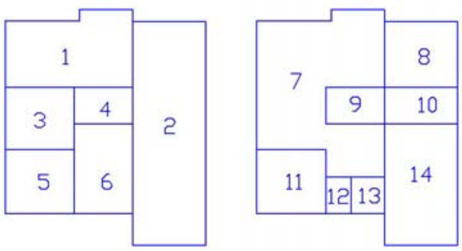



*Figure 12 Recognized faces of arrangements representing spaces in basement and first floor.*

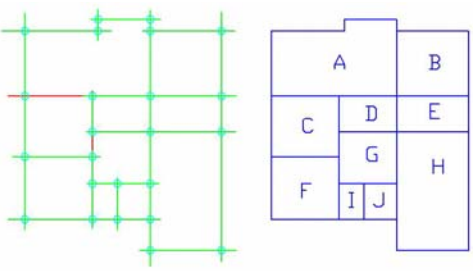



*Figure 13 Arrangement of segment lines formed from two sets of contour lines used for recognition of elementary fragments of floor separating adjacent spaces.*

## CONCLUSION

Presented in this paper recognition method of elementary fragments of floors or wall separating zones or spaces in building may be useful in elaborating new graphic interfaces for building simulation programs. Energy management engineers and energy auditors should commonly use this kind of software tools in everyday work. They need to calculate the energy consumption in buildings more precisely as there is necessity to conserve the energy in contemporary world. Experts who issue building energy certificates, which are required by Energy Performance Building Directive in European Community countries, should use building energy calculation software. Modern, advanced building simulation systems are equipped with complicated graphical 3D interfaces or even have no graphical interface at all. This situation discourage most users who are not experts in building simulations from using advanced tools in their work and they calculate energy consumption in buildings with simplified methods which does not need so many geometric data. Presented adjacency calculation of elementary fragments of floors and walls method may be helpful in new simply graphical interface of advanced energy simulation programs.

## ACKNOWLEDGEMENT

The article was written due to the support of STEP Project PL 0077 financed by a grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Norwegian Financial Mechanism.

## REFERENCES

de Berg M., van Kreveld M., Overmars M., Schwarzkopf O.: *Computational Geometry – Algorithms and Application*, 2nd Edition, Springer, 2000

Mehlhorn K., Näher St.: *The LEDA Platform of Combinatorial and Geometric Computing*, 1st Edition, Cambridge University Press, 1999

Marsh A, J.: *Ecotect v.5.2 – software help system,* 2003

O'Rourke J.: *Computational Geometry in C*, 2nd Edition, Cambridge University Press, 1998

Narowski P.: *Analiza geometryczna przegród budowlanych*, Sympozjum Budownictwo Ekologiczne, Nr 4, 2007, p. 97 (in Polish)

Collective work: *CGAL User and Reference Manual,* Release 3.1, www.cgal.org

Collective work: *The LEDA User Manual*, Release 6.2, www.algorithmic-solutions.info /leda_manual/MANUAL.html