Quantitative and qualitative description of building orientation

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Abstract
This paper deals with the automation of the cartographic generalisation and proposes a new measure of the orientation of a building. The description of this characteristic is a complex issue, as if the computing of orientation is relatively clear for a segment or a line, this is not the case for a polygon. Thus, existing measures of orientation are briefly reviewed. Our measure is inspired by the measure of building orientation of walls, modulo π. The proposed modification is an adaptation of this measure modulo π/2, associated with a confidence indicator on it, and is called *Wall statistical weighting*. We show that this new measure can be combined with existing ones to better describe and generalise buildings.

Keywords: building description, orientation measure, meaning of a measure.

1. Introduction

The automation of cartographic generalisation process is often divided into three parts [Agent 99]: (1) the description and the analysis of the spatial context of geographic features, (2) an algorithmic processing adapted to this context, and (3) an evaluation of the results of generalisation. The research presented here concerns the first step and focuses on the description of buildings. Generally a building is described by its position, shape, granularity, size and orientation. The studied characteristic in this paper is the orientation. This description can also be used for the evaluation step to compare the evolution of the building orientations before and after generalisation.

Describing the orientation of a building is important within the framework of an automatic process of generalisation. Actually, the computing of orientation is relatively clear for a segment or a line, but this is not the case for a polygon. This description is related to three main aims. The first aim concerns the preservation of this characteristic, e.g. a building must have the same orientation before and after generalisation. If decided, the orientation can slightly be changed according to the orientation of its neighbouring objects to improve the map clarity. The second aim is the constitution of a particular element structuring the space which will be used to guide generalisation, e.g. a group of buildings having the same orientation or the perpendicular orientations (an alignment) or a building parallel to a road. This has not been studied in this research. The third aim finally, consists in the description of the shape of the building by combination with other measurements. The interest is to classify the buildings into a typology of shape to better control their generalisation.

The definition of the orientation of a building depends on the required goal. But beforehand, just asking this simple question: does the notion of orientation have a sense for any buildings? For instance, let us discuss about the represented buildings in the following figure :

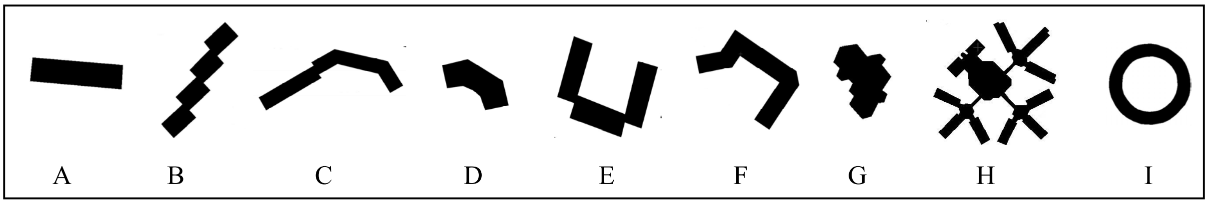


Figure 1. What is the orientation of a building?

A general orientation is perceived for building A, B, C, D and E. This orientation corresponds to the axis of elongation of the building. Nevertheless there are several possible local orientation for buildings B, C, D and E.

In those cases the general orientation is different from those local orientations. Buildings F, G and H are problematic because no main orientation exists, but if there is a rotation during generalisation, the orientation of the building is modified. In the case of building I, no orientation can be defined.

This example emphases the difficulty to give a common definition of the orientation of a building. As defined in [Regnauld 98], the orientation of a building corresponds to two needs of information: either a general orientation, used to characterise the elongation of a building, or an orientation of the walls, used to compare the orientation of two parallels walls for different buildings. The general orientation of a building is defined modulo π, thus it is represented by a segment (as a segment is invariant by a rotation of π). The orientation of walls is defined modulo π/2, thus it is represented by a cross (Figure 2), which is invariant by a rotation of π/2.

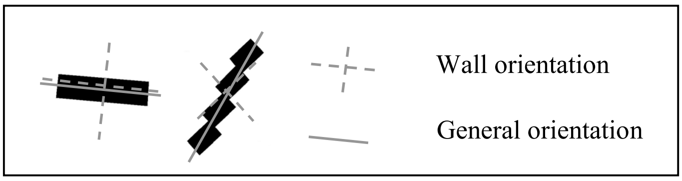


Figure 2. Representation of wall orientation and general orientation

In this paper we focus on the study of the absolute orientation of a building, i.e. its orientation (which encompasses wall and general orientations). The second part is devoted to a brief state of the art of existing measurements of absolute orientation. In the third part, we propose a new measure of orientation based on an improvement of one of existing measurements. Lastly, the fourth part presents the various possible contributions of the suggested measure.

2. Existing measures of building orientation

We work on the GIS LAMPS2 (from Laser-Scan). On this GIS, five measures of orientation of a building have been implemented during the European project AGENT [Barrault et al. 2001]. Three of these measures have been selected among the literature as the more significant ones, the last two ones have been added to complete the existing ones. The first step of our work was to understand how each measure works, and to test and compare them on a selection of buildings extracted from real topographic data.
Figure 3 shows the results of the five measures on a subset of buildings extracted from the topographic database BD Topo® of IGN. The first four measures are supposed to characterise the general orientation of the building, i.e. an orientation modulo π, thus their result is represented by a segment. The fifth one is supposed to characterise the orientation of the walls modulo π/2, thus its result is represented by a cross.

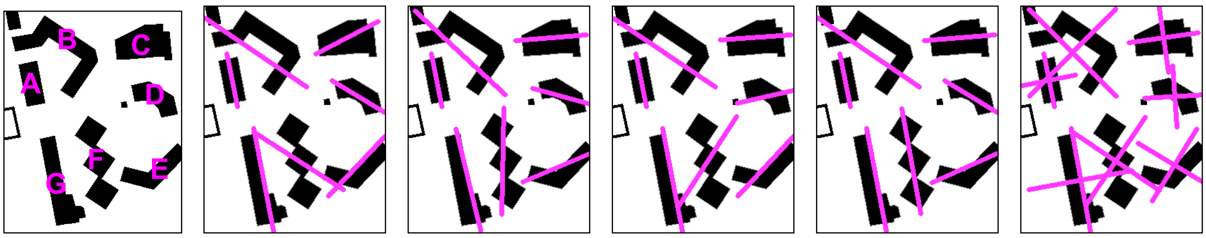
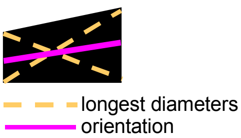


Figure 3. Existing measures of orientation

The principles of computation of these measures are briefly described hereafter:

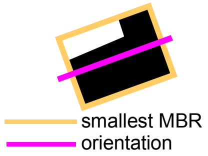
Longest edge
This measure has first been proposed in [Ruas 88]. It measures the orientation of the longest edge of the building after having removed the aligned points of the building.

Weighted bissector



This measure has been proposed by [Regnauld 98, p.72]. The general principle is to consider the two longest diameters of the building (lines joining any pair of points of the contour – one point can only be used in one diameter). Then an average of the two directions (modulo π) is computed, each direction being weighted by the length of the line.

Smallest Minimum Bounding Rectangle : SMBR



This measure has been proposed by Mats Bader during the AGENT project. Usually a MBR (Minimum Bounding Rectangle) of an object is computed parallel to the x and y axes to have an idea of the extension of the object. Here the principle of the measure is to find the smallest rectangle containing the building (not necessarily parallel to the x and y axes), hence the name "Smallest MBR". Then the orientation of the longest size of this rectangle is kept. This measure is also used in [Rainsford and Mackaness 02] to support the matching of a building to a set of predefined template shapes.

Wall average

This measure has been proposed by [Hangouët 98, p.213-221]. It computes an indicator of the orientation of the walls (edges) of a building. As buildings are often square-angled (as man-made features), the orientation of the walls is considered modulo $\pi/2$. The general principle of the measure is to consider the orientation of each edge modulo $\pi/2$ (thus between 0 and $\pi/2$), and to compute an average of these directions, weighted by the lengths of the edges. Some precautions are taken since the values around 0 and around $\pi/2$ correspond to the same direction, thus several edges around 0 or $\pi/2$ have to result in an average around 0 or $\pi/2$, not around $\pi/4$.

Statistical weighting

This measure has been proposed by Mats Bader during the AGENT project. The aim is to compute the general orientation on the building, thus the orientations of the walls are considered modulo π and so is the resulting orientation. The philosophy is to compute an orientation that is the most frequent among the orientations of the walls with a small tolerance. For that, a series of candidate orientations between 0 and π, with a fixed step, are tested (the step corresponds to the required precision of the result, 1 degree for instance). For each candidate orientation, a weight is computed and the candidate orientation of greatest weight is finally kept. The weight of a candidate orientation is computed as follows: for each edge of the building, a contribution to the candidate orientation is computed. The weight of the candidate orientation is the sum of the edges contributions. The contribution of an edge is computed as described in Figure 4. The edge only contributes if its orientation is within a maximum deviation δ from the candidate direction (δ is a parameter, empirically fixed to $\pi/12$). If the direction of the edge is equal to the candidate direction, the contribution is the length of the edge. Otherwise, the contribution linearly decreases until 0 at the maximum deviation.

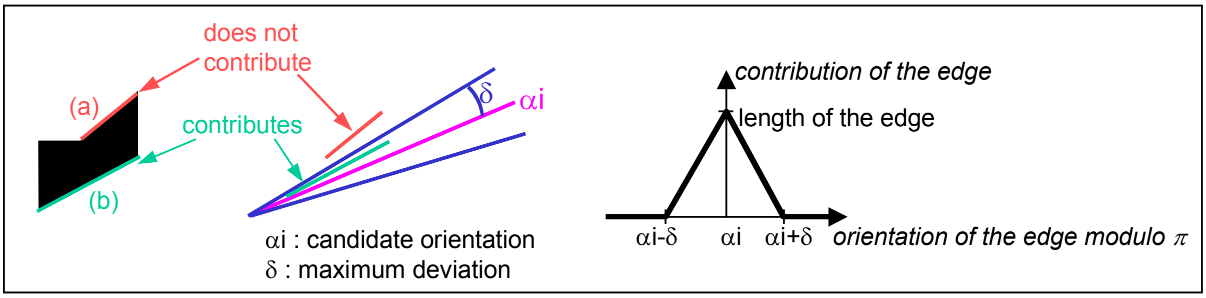


Figure 4. Contribution of an edge of the building to a candidate orientation αi

Critical analysis of these measures

By testing the measures on a large set of buildings extracted from real topographic data, we conclude that the *SMBR* is the most appropriate to describe the general orientation of a building. The *Longest edge*, as well as the *Statistical weighting*, rely on wall orientations, and the "general orientation of a building" is precisely not necessarily linked to the orientation of its walls (cf. Figure 3 building F). Moreover, *Longest edge* is sensible to intermediate points on a long wall or small changes of direction inside a long wall (building C). And *Statistical weighting* favours orientations which are the most frequently represented (building D). *Weighted bissector* is too sensible to intermediate points and configurations where one longest diameter exists and then two or more "second longest" (Figure 3 buildings C and D).

Thus we keep the *SMBR* as an indicator of the general orientation of a building.

In what concerns the orientation of walls, we think it is very important to have such a measure, but we are not very satisfied with the *Wall average*. Actually, we feel it does not give an orientation that is really *representative* of the orientation of the walls. This is because when two distinct orientations of walls exist within a building, performing an average of these orientations results in an orientation which is different from every wall orientation, thus which is not representative of them (Figure 3, buildings B and E). Instead, we would expect a resulting orientation that is very close to at least a part of the orientation of the walls, i.e. rather based on frequencies than on an average.

3. Combination of previous research: a new measure of the orientation of the walls and its internal confidence indicator

Based on the analysis presented in previous paragraph, we think that the principle of computation of *Statistical weighting* would be very adapted to compute an orientation of the walls. Thus we propose a new measure *Wall statistical weighting* orientation, which is an adaptation of the *Statistical weighting*, considering the orientations modulo $\pi/2$ instead of modulo π.

3.1. Principle of computation

As in Statistical weighting, the principle is to test a series of candidate orientations, now between 0 and $\pi/2$, with a step depending on the required precision of the result (in our case, 1 degree has been chosen i.e. $\pi/180$). For each candidate orientation, a contribution is computed for each edge of the building, on the same principle as the one described in Figure 4 except that, now, the angles and differences between angles are all considered modulo $\pi/2$. Thus, an edge contributes to the candidate orientations that are almost parallel to it, but also to the orientations that are almost perpendicular to it (Figure 5: edge (c) of the building also contributes to orientation αi).

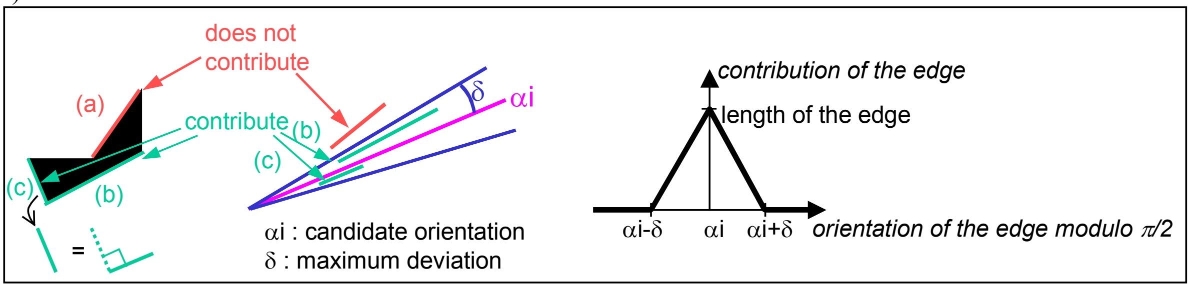


Figure 5. Contribution of an edge of the building to a candidate orientation αi, modulo $\pi/2$

The results of this measure on the set of buildings used as example are shown in Figure 6 by a thin, dark blue cross. The thick, light orange cross represents the orientation of the walls as it was computed by *Wall average*. Note that the sizes of the crosses have no special meaning, they only depend on the size of the building.
As foreseen, with the statistical weighting method, the computed orientation is the orientation to which most of the edges of the building are close ("most" in terms of total length, not in terms of number of edges). For the buildings that have only squared angles, the result is the same as with *Wall average* (buildings A, F and G). In the cases where there are several distinct orientations of walls inside a building, the *Wall statistical weighting* "chooses" the most important orientation (buildings B, C, D and E).

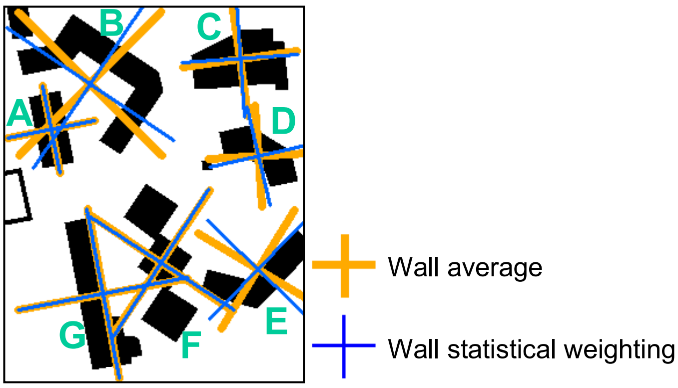


Figure 6. Results of the wall orientation measure *Wall statistical weighting*

3.2. Confidence indicators

Because of its mode of computation, our measure always finds an orientation. However, this orientation is more or less meaningful depending on the shape of the building. This is why we want to add two confidence indicators to it.
The basic idea to compute a confidence indicator is to consider the weights computed for each candidate orientation that has been tested, not only the one that has been kept. The weight of one candidate orientation can

be represented by a line of this orientation with a length equal to the weight. When considering the set of candidate orientations, it results in a set of spokes of different lengths, covering an angle of π/2 (Figure 7). The longest line corresponds to the retained orientation. We can also see one or several groups of spokes, that we call "leaves", around privileged orientations. The maximum (longest spoke) inside each "leaf" corresponds to one orientation which one or several walls of the building are close to.

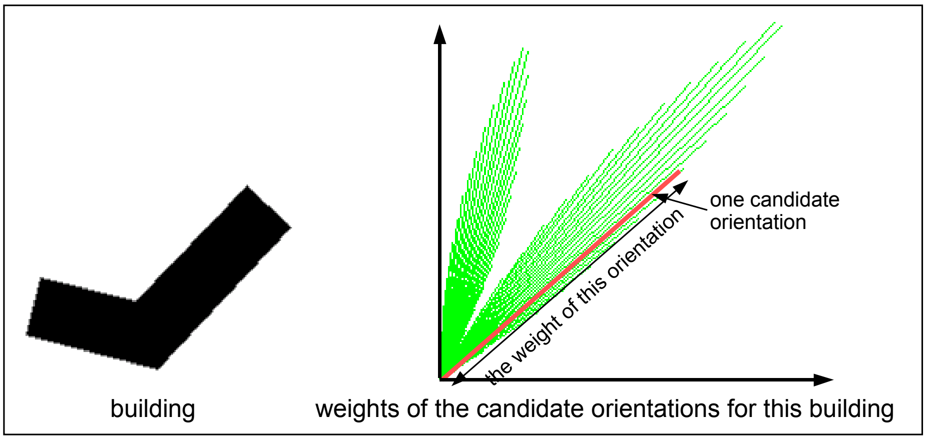


Figure 7. Representing the weights of the candidate orientations

Two indicators are interesting considering this representation:
- the number of leaves
- the length of the longest leaf (i.e. the weigh of the retained orientation).

Actually, for one given building we can define a "maximum theoretic weight". This is the weight of the computed orientation in the case where all the angles of the building are perfectly squared. In this case, each edge would contribute to the returned orientation of the maximum, i.e. of its length. Thus the weight of the returned orientation would be the sum of lengths of the edges, i.e. the perimeter of the building.
Thus, we define a confidence indicator that is the length of the longest leaf (weight of the returned orientation), divided by the maximum theoretic weight (expressed in percents). This enables to compare the confidence indicator from one building to another.

$$\text{Confidence indicator} = \frac{\text{Weight of returned orientation}}{\text{Maximum theoretic weight}}$$

We can visualise this indicator by adding on the "leaves schema", a quarter of circle with the maximum theoretic weight as radius. This way, we visualise the confidence indicator as the ratio between the longest leaf and the radius of the circle.
Additionally, we can automatically detect the different leaves by an analysis of the minima and maxima of the length values. We also add slight filtering to remove the leaves with a very small weight (parameter: minimum weight), and to aggregate leaves that are not well detached from each other (parameter: minimum angle between two maxima of leaves). Figure 8 represents the results for our 7 test buildings. The principal orientations (maxima of leaves) have been highlighted in dark blue, and the number displayed close to each one is the confidence indicator ([A (α1, **97.83**)] ; [B (α1, 24.36) (α2, **74.39**)] , etc.). The quarter of circle represents the maximum theoretic weight for the building. Let us notice that a leaf appears split into two parts if it corresponds to an orientation close to 0 or π/2, since orientations are considered cyclic modulo π/2 (Figure 8 buildings A and C): this needs a bit precautions when detecting the leaves.

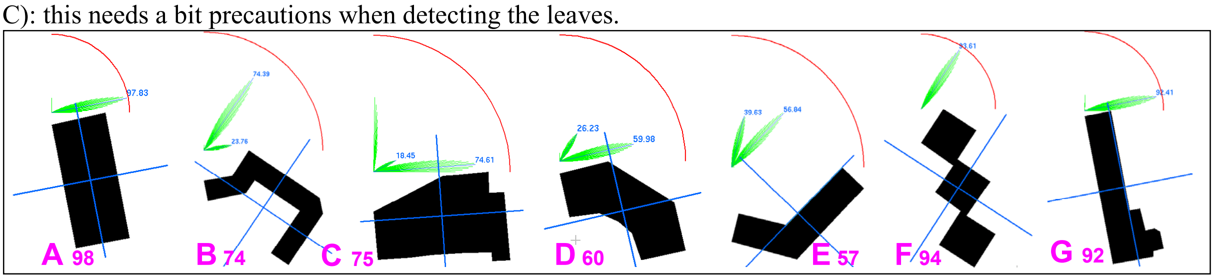


Figure 8. Detection of the principal orientations of walls and their relative weights

The confidence indicator is all the greater as there is only one leaf and this leaf is "thin" (i.e. the walls are perfectly parallel or perpendicular to its direction - Figure 8 buildings A, F and G). When there are several leaves, the confidence indicator decreases (Figure 8 buildings B, C, D and E). It also decreases when a leaf is "thick", i.e. walls are not exactly parallel or perpendicular to its direction, as illustrated by Figure 9a. When there are walls of any orientation, the confidence indicator becomes very low. In this case, either we cannot really distinguish leaves any more (Figure 9c), or any candidate orientation has a non-zero weight, even if some leaves are noticed (especially in the case of partially round buildings, Figure 9b).

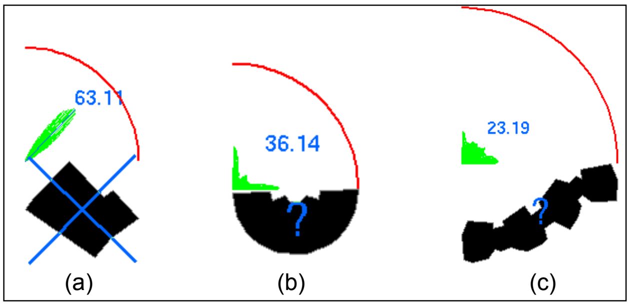


Figure 9. Some remarkable cases.

Empirically, we manage to detect cases where no representative wall orientation exists (because there are walls of any orientations): a building is considered having "no wall orientation" if no candidate orientation has a weight of zero and if the difference between the greatest and smallest weight is inferior to 30.0.

After performing some tests on the possible values of the confidence indicator and the number of leaves, we came to a qualitative confidence indicator associated to the *Wall statistical weighting* orientation. This qualitative confidence indicator (classification of buildings) is presented in Figure 10.

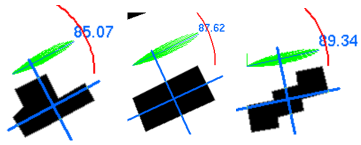
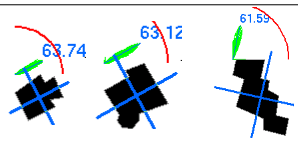
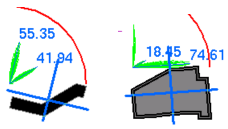
Confidence indicator	Number of leaves	Qualitative confidence indicator: caracterisation of buildings	
≥ 80%		straight walls	
< 80%	1	not very straight walls	
	≥ 2	several different orientations of walls	

Figure 10. Qualitative confidence indicator

As a synthesis, we define the following first rules :

- if no orientation has a weight of zero and if the difference between the greatest and the smallest weight is inferior to 30 then the <u>building has no wall orientation,</u>
- else a filtering is done to remove the smallest leaves, and
  - if the confidence indicator is bigger than 80, the <u>building has a main orientation and is nearly square-angled,</u>
  - else
    - if there is one single orientation, the <u>building is not really square-angled,</u>
    - else : <u>the building has several wall orientations</u>.

According to the final needs, it seems that more information could be extracted from the weighted orientation. The measures we have chosen (*SMBR* and *Wall statistical weighting*) seem to be sufficient for our needs in the generalisation process.

4. Combining orientation measures to better describe buildings

The aim of this section is to propose a process to describe orientation of buildings. As seen before, orientation can be computed according to two types of methods for: first the computation of the orientation of the longest edge of the smallest minimum bounding rectangle (SMBR), and secondly the computation of the orientation of the walls: the first one is called *general orientation* and the second one, *wall orientation*. However, none of them is sufficient to fully describe the orientation of a polygon ; each of them may be suitable for some kind of particular buildings, but not adapted to the other ones.

4.1. Both measures are essential

We propose to compare the result given by these two measures.
Before that we state that :

- Wall orientation is inconsistent if no orientation exist (see previous section)
- General orientation is inconsistent if the SMBR is a square or nearly a square (e.g. Figure 11 d & e)

There are five possibilities:

1. both measures are consistent and give the same result (*cf.* Figure 11a).
2. both measures are consistent but do not give the same result (*cf.* Figure 11b).
3. only the general orientation is consistent (*cf.* Figure 11c).
4. only the wall orientation is consistent (*cf.* Figure 11d).
5. none of them is consistent (*cf.* Figure 11e): orientation is not defined for the building.

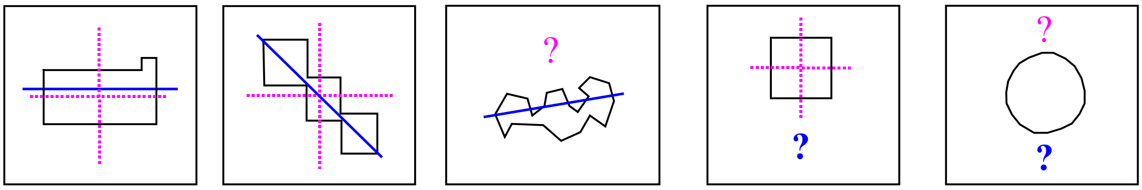


Figure 11. Comparison between wall orientation and general orientation

Let us examine in detail Figure 11c and Figure 11d; at a first level of analysis, both measures are sometimes complementary: one may happen to be inconsistent whereas the other one may be consistent. The Figure 11b shows moreover that these tools do not measure the same concept: in Figure 12, one can realise that, in the case of a 'scale' building for instance, a deviation of wall orientation or general orientation produces something unacceptable; in fact, the parallelism of the walls of A and C (see Figure 12a) should be kept (unless we decide to simplify C into a rectangle) and the parallelism of the general orientation of B and C (see Figure 12b) should also be kept. So it is fruitful and essential to use both of them.

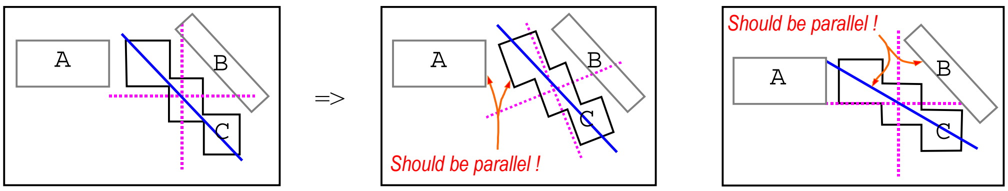


Figure 12. Wall and general orientation are both essential

The process proposed (see Figure 13.1) consists in considering first the wall orientation: according to section 3, four categories may be distinguished. The first category includes buildings which have only *one* wall orientation (the orientation of the walls is always the same modulo $\pi/2$). The second category comprises buildings whose wall orientation is not well-defined but is also unique. For buildings of this category, the fuzziness of wall orientation permits to activate a squaring operation: this is the first step of the process. Afterwards, the third category comprises buildings with several wall orientations and the fourth one, buildings with no preferred orientation.

At the end of the first step, i.e. after the squaring operation, we have three different categories:

- the one with one leaf concerning the vast majority of the buildings (approximately 80%).

- the one with at least two leaves.
- the one without leaf.

As a second step, wall orientation is compared with general orientation (see Figure 13.2). For instance, one leaf and non identity between wall and general orientation permits to detect a *stair-shaped* building.

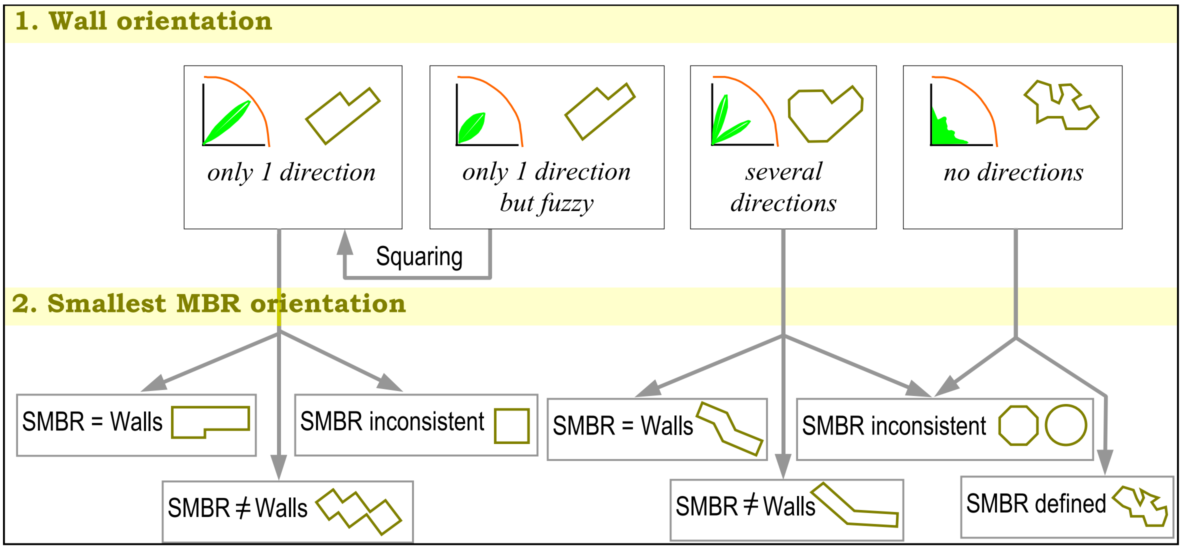


Figure 13. Combining wall orientation and general orientation

To sum up we will try to use the building characterisation for generalisation purposes. We name 'classical building algorithm' the one that simplifies the shape adapted to squared angles. The rules could be the following:

1. If the building has a single but fuzzy orientation, it should be squared and then analysed according to step 2
2. If the building has a single, well defined orientation
   - If SMRB ≠ Walls, it is probably a stair-shaped building, it should be generalised accordingly, by an algorithm that would remove one of the stairs. The building has two different significant orientations (general and wall).
   - Else : it is a classical building either square (if SMRB is not defined) or elongated, possibly concave (e.g. L-shaped or U-shaped). Classical algorithm can be used for such a case. Moreover the orientation is very significant in the process.
3. Else if the building has several wall orientations :
   - If SMRB = Wall, classical algorithm could be tried. The general orientation remains significant in the generalisation process.
   - If SMRB ≠ Walls, the general orientation may be lost by an algorithm. Moreover, the orientation used within generalisation process (for example to control self generalisation or to compare two close objects orientation) could be both orientations as they are both significant. None of them is enough to define the building orientation.
   - If SMRB is inconsistent, the shape is nearly round, a specific algorithm for round shapes should be used for that type of building. The orientation of the building is not very much significant. It should be used with caution.
4. Else if no wall orientation is defined
   - If SMRB is consistent, the shape is nearly round, a specific algorithm for round shapes should be used for that type of building. The orientation is meaningless in the process.
   - Else (SMRB is defined) the shape is complex. Maybe an algorithm for polygon generalisation (such as vegetation area) should be used for such a case. The general orientation is not very meaningful in the process.

This set of rules is an attempt to identify the cases where current algorithms are adapted and the cases where they are not. It appears that new algorithms such as 'stairs removal' and 'round improvement' could be developed to complete the current algorithm library for such specific cases.

4.2. To go further: taking shape into account to better characterise orientation

Although general orientation is not consistent for a square building (see Figure 11d), the fact that a rotation of $\pi/6$ induces something unacceptable for generalisation shows that square buildings do have an orientation, given by their walls. Actually, general orientation does not exist for buildings whose SMBR is a square or almost a square: the only information available with our measure is the orientation of its walls. But this is not sufficient because, as illustrated below, this information depends on the shape of the building: for a square, orientation is given modulo π/2 (see figure Figure 14a), whereas for a U-building, it is given modulo 2π (see figure Figure 14b).

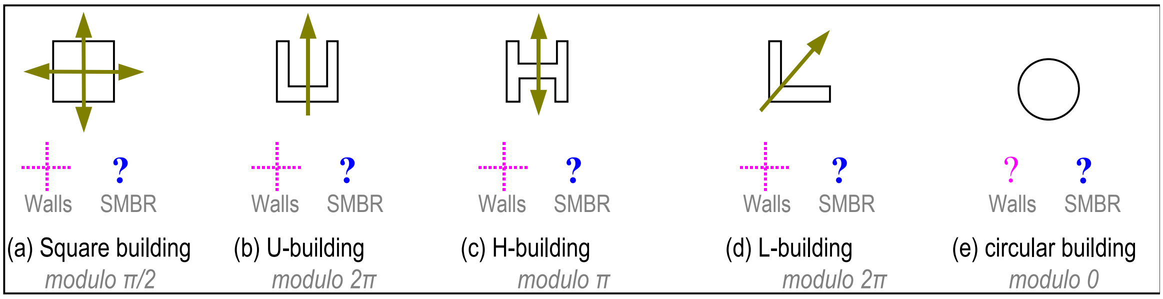


Figure 14. Importance of shape in the orientation

Note that the importance of shape is not reserved for buildings with square SMBR, but is possibly consistent with all buildings. So, a third type of orientation exists: it depends on the shape of the object and often merges with *one* orientation of the walls (but not always: see Figure 15b). In most cases, the direction of the line bearing the orientation is consistent: this information never exists in wall orientation (because it is defined modulo π/2), neither in general orientation (defined modulo π) as shown in Figure 15c and Figure 15d. Of course, *shape orientation* is only consistent in the case of buildings of remarkable shape: so this requires to define a typology of building shape.

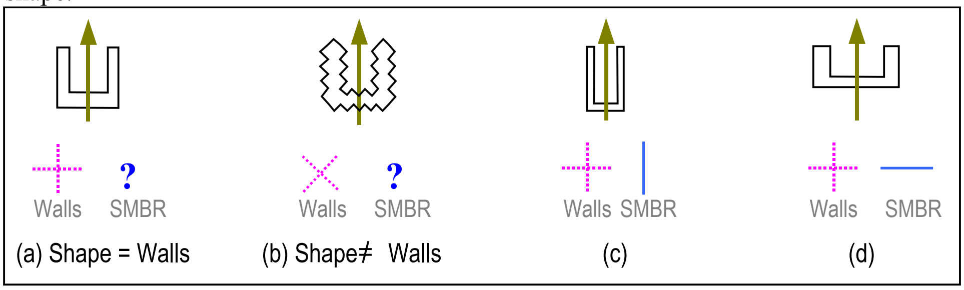


Figure 15. Comparison between shape orientation and wall or global ones

The following typical shapes should be kept: U, L, H, T and S/Z (see [Meyer 89]). Note that the characterisation of shape requires additional parameters like the angle of the L.

This typology may rely on the computation of the skeleton of the building but also, more simply, by comparing the SMBR with the polygon: the number of holes and their location with respect to the edges of the SMBR, is a relatively accurate indication of the shape. In particular, when there is only one hole, the polygon is a U or L-building: it is possible to discriminate them by considering the number of edges of the SMBR which are adjacent to the hole (see Figure 16 *b* and *c*). Afterwards, the shape of a two holes building is T, H or Z : by considering the number of adjacent edges to each hole, it is also possible to recognise these three shapes (see Figure 16 d, e and f). The drawback of this method is that there may be non consistent small holes: this problem could be solved by a previous filtering.

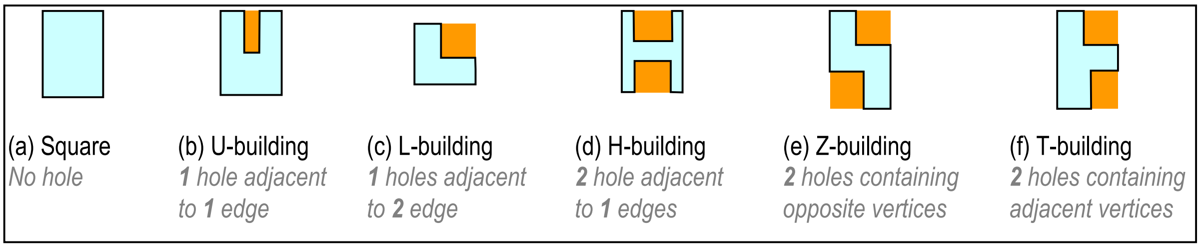


Figure 16. Detecting typical shapes of buildings

This first analysis of building shapes and orientations could be appropriate for specific methods of generalisation, either by detecting the type of shape and replacing it by the closest one in a library of templates, or by applying very specific algorithms that would preserved as well as possible each building main shape and orientation characteristics during its generalisation as suggested by [Rainsford and Mackaness 02].

5. Conclusion and perspectives

We have proposed an analysis of the existing measures dedicated to the absolute orientation of a building. Two kinds of orientation are measured within a building: its general orientation and the orientation of its walls. Among the existing measures, *Smallest Minimum Bounding Rectangle* has been identified as the most appropriate to describe the general orientation.

As no existing measure was really satisfying to compute the orientation of the walls, an additional measure was introduced, called *Wall statistical weighting*, together with a confidence indicator.

A process to describe the orientation of a building has been proposed, using both the wall orientation and the general orientation. The result of our investigations is that orientation and shape are deeply bound together: *most shapes are oriented*. Three different orientations can be defined for polygons (even if they are not consistent for all buildings): *general orientation*, *wall orientation* and *shape orientation*.

This common work done at the COGIT laboratory in summer 2002 shows one of the complexity of spatial analysis. We all conceive measures to characterise the objects we have to manipulate (for generalisation or other purposes) but these measures are not always significant. We can consider that they are 'generally' significant, for classical and common cases. While using these measures within a process, we implicitly make the hypothesis that they will be significant, even though we know that they are not always significant. At the end of the European project AGENT, an accurate analysis of results on specific cases [AGENT Consortium 2000] showed that some objects were badly generalised, not because of the algorithm but because of their characterisation that either generates a bad choice of algorithm or rejects a good solution. It means that adding a confidence indicator on each complex measure (such as shape, orientation, granularity) would certainly improve not only the decision but also the validation step of the process. Of course, this statement induces some more work to do, but that is our collective duty.

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