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INDEXING SYSTEM FOR TRADITIONAL WOODEN FRAME STRUCTURE RECOGNITION

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ABSTRACT

Broadly speaking, wood has been used as a structural material for a long time all over the world and construction techniques have evolved considerably over time to express architectural adaptations to economic and sociological contexts. A lot of traditional wooden buildings are still visible in our cities, towns and villages. This heritage is rarely protected in villages and serious renovations made by successive owners may have diminished the authenticity of the wooden structures. In addition, if we look at the wooden structures of the gables, it is surprising to note that the structural arrangement of the beams may change over time and differ from one geographical region to another. However, the morphological analysis of the structure is not straightforward if the structure has been transformed by the addition or removal of beams. Therefore, it becomes difficult to identify a particular typology or even to imagine what the original structure may have looked like.
In order to assist architects, archaeologists and historians, we propose an innovative indexing system for traditional wooden frame structures making it possible to identify similarities between structures. This semi-automatic approach is based on the calculation of statistical descriptors between pairs of pictures. The fractal dimension, the Hausdorff distance and the geometrical ratio are evaluated and combined as a single original parameter. As a result, the typology of an unknown structure can be recognised and matched to other similar examples in a database even if the wooden frame structure to be identified has been renovated several times.

Keywords: *Timber, Structure, Recognition, Indexing system, Heritage*

1. INTRODUCTION

Compared to urban heritage, rural architecture remains often disregarded. However, it is a matter of fact that rural regions constitute a wealth of knowledge. A lot of traditional construction techniques, transmitted informally, have been forgotten and have remained petrified through picturesque villages. Structural analysis of historical constructions implies a series of questions. Documentation and exchange of experience are therefore compulsory to learn and understand the genesis of a building. Recording the state of a building also implies comprehending the structure as a result of successive adaptations to sociological and economic change. From this point of view, parts of a building may have been replaced, transformed, added or simply removed [1]. Consequently, the authenticity of the building may have been affected. Identifying the visible transformations is never straightforward and often time consuming. Interdisciplinary studies are therefore necessary to record, understand and share information. Research, publications and awareness-raising activities provide precious information on special issues and help to better understand the values of this particular heritage. Gathering this information is never easy, though it helps to have a wider overview on particular topics through cross-regional influences for example. Subsequently, the availability of these resources is variable according to the building significance. Ample precious information, such as survey drawings stemming from restoration of unprotected buildings, remains not spread and inaccessible for documentation.

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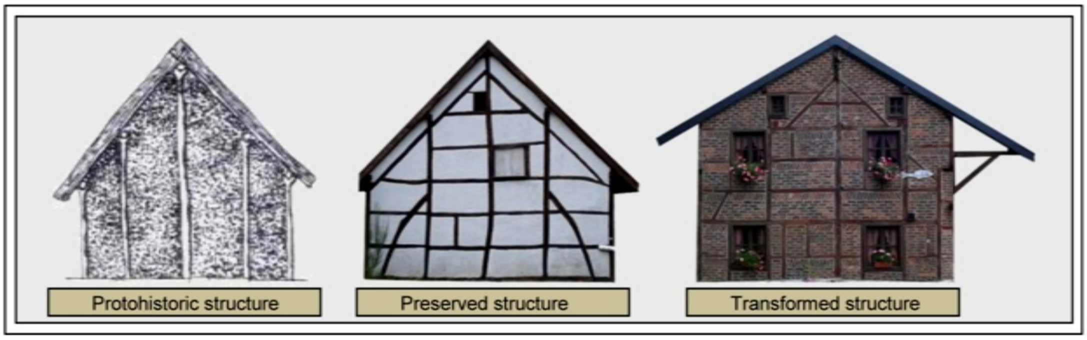


Fig. 1 Examples of rural wooden structures expression through time

Rural wooden structures are a perfect illustration of this issue. In a restricted rural area, wooden frame structures often show similarities to each other due to construction habits of their local creators who have reproduced a particular existing canvas based on their experience and culture [2]. For a variety of reasons, it can be demonstrated that the arrangement of the beams within the structure has undergone little change since primitive huts (Fig. 1).

Extensions, enlargements and raised structures affect the interpretation of the original frame. However, as it has been stated in the Charter on Built Vernacular Heritage [3], *changes over time should be appreciated and understood as important aspects of vernacular architecture. Conformity of all parts of a building to a single period, will not normally be the goal of work on vernacular structures.* Interdisciplinary studies must, among other things, emphasise these transformations in order to be understood and taken into consideration for subsequent investigations.

In the scope of structural analysis, our aim is to record, recognise and compare particular types of rural timber frame houses through an automatic process.

The organisation of this paper is as follows. Section 2 explains the utility of an indexing system dedicated to the recognition of building typologies. Section 3 describes the methodology we have developed. Section 4 illustrates our results and section 5 presents our conclusions

2. INDEXING SYSTEM FOR ARCHITECTURE

Documentation of cultural heritage status is fundamental for scientific studies carried out during the conservation process. Recognition has been developed in several disciplines, trying to match forms or patterns together. However, little research makes the link between traditional architecture and building similarities. In contrast, more work concerns the automation of surveys and representation techniques able to facilitate the acquisition of buildings.

In architecture, the physiognomy of a building is commonly depicted by using a variety of words belonging to a particular vocabulary and being able to express its shapes and arrangements. This semantic categorisation helps to classify a construction according to a particular style or period. However, this approach is deeply influenced by the personal skills or experience of the observant and can therefore lead to misunderstandings. Concurrently, public access to heritage documentations is developed more and more through online databases but the structural analysis of the constructions are seldom highlighted. In addition, these databases do not allow any search based on architectural styles. Shalunts and Al. [4] have proposed a methodology to fill the gap. It is an innovative approach but leaves no room for expert interpretation during the decision making process.

Our approach is based on the fact that architectural styles have undergone a progressive evolution to formal complexity. As a consequence, an architectural style has various expressions depending on the considered period, location or building techniques. Beyond that, architectural styles refer more to urban architecture with a particular codification which is hardly applicable in the rural areas. Typology embraces a wider scope of descriptors such as materials or structures. For these reasons, the term typology is preferred rather than architectural style.

Computer visualisation has proved to be an effective tool to study the visual properties of the built environment [5]. However, to the best of our knowledge, there is no indexing system for typological recognition of buildings. We believe that such approach can provide an additional benefit over automatic systems for classification.

As a consequence, we believe that generating a documentation tool, comparable to a search engine and dedicated to built heritage, is worthwhile research. In particular, the objective of this paper is to

illustrate an innovative way to automate the recognition of a building typology by content-based image retrieval. To that end, images are assessed through the degree of similarity expressed by their architectures and structures in order to study and better understand the physiognomy of buildings.
The method will be illustrated by studying vernacular wooden gables. These constructions have the particularity to show different structures depending on the geographical origins and possible transformations they have faced.

3. METHOD

Scanned survey drawings and photographs are used as data. We assimilate an image of a gable to a vector of representative characteristics. This statistical approach means that each pattern is represented in terms of d measurements and is viewed as a point in a d-dimensional space [6]. From a mathematical point of view, the analogy between two vectors is calculated by measuring the distance between them. Comparability is evaluated for the entire facade, taking into account the different scales of the architecture. The measured distance between a pair of vectors is a help in the decision making process in the sense that short distances between vectors mean high shape correlation.
The method is intended to be transposable to different kind of architectures and styles. Therefore, the selection of parameters is decisive for the accuracy of the results but is not focused on architectural particularities. The recognition of structures is a semi-automatic approach. Applying the *k*-means theory, a structure to be acknowledged is associated with similar examples from our database. This selection identifies the most comparable examples of the *k*-means theory with regard to the statistical descriptors.
We call S_i the "*global distance*" calculated between two images of facades (Fig. 2). The global distance is calculated by adding three statistical descriptors: (I) the Hausdorff distance which indicates the degree of similarity between two point sets, (II) the difference of fractal dimension which expresses a variation between the visual complexity of the facades and (III) the difference between the geometrical ratios.

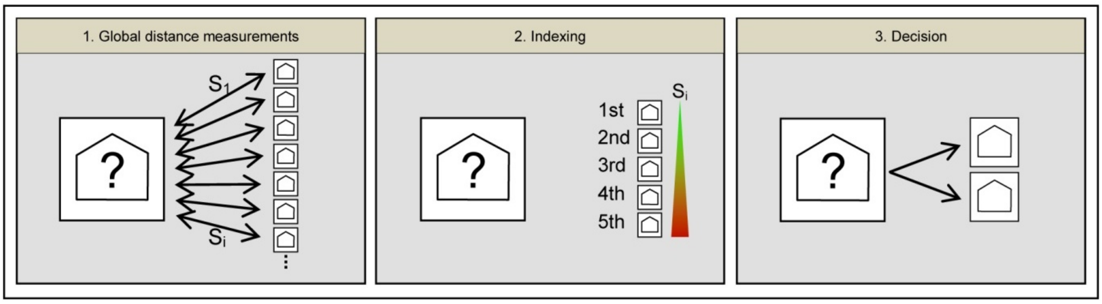


Fig. 2 Illustration of the decision making process

3.1. Measuring similarities

In our approach, the measure of the Hausdorff distance is based on the assumption that a binary image [mxn] is a set of black and white pixels which can be turned into a histogram that will show the number of black pixels present in each column of the image (Fig. 3). These histograms allow expressing the images in a normative way whereby complex structures are turned into simpler shapes. Thereafter, each histogram can be converted into a matrix. As a result, a histogram or its associated matrix can be assimilated to the structural signature of a sample and can be used for image retrieval [7]. This entire process has been implemented into Matlab. The Hausdorff distance H(A,B), between two shapes A and B, is given by

$$H(A,B)= \max(h(A,B), h(B,A)) \tag{1}$$

with

$$h(A,B)= \max_{a\in A}(\min_{b\in B}(d(a,b))) \tag{2}$$

$$h(B,A)= \max_{b\in B}(\min_{a\in A}(d(b,a))) \tag{3}$$

where d(a,b) = the Euclidian distance between the set of points a and b of the shapes A and B.

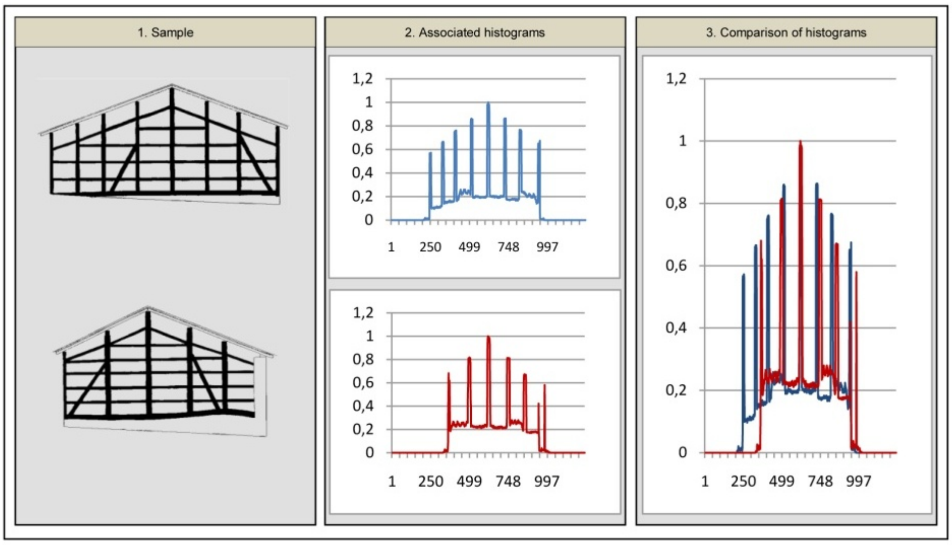
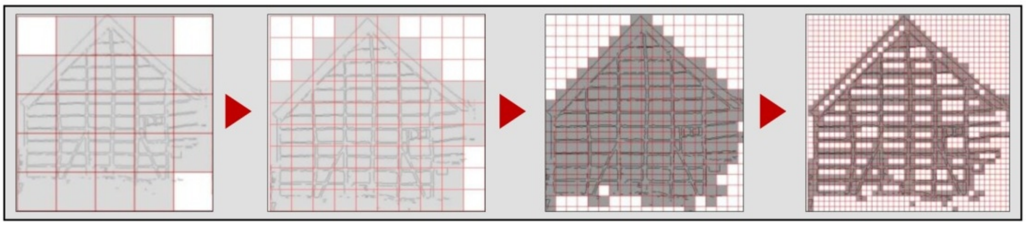


Fig. 3 Measuring similarities. Comparison between two histograms

Intuitively, h(A,B) finds points a from set A that is furthest from any point in B and measures the distance from a to its nearest neighbour in B.

3.2. Measuring visual complexity

The study of the visual complexity of objects has been exposed by the mathematician Benoit Mandelbrot in his publication *The Fractal Geometry of Nature* [8]. He observed that natural shapes, such as coastlines or galaxies, are fractal forms because they present self-similarities at particular scales of observations. In other words, each part is approximately a smaller copy of the whole.
Since Carl Bovill's research [9] was carried out in the nineties, the concept of fractal geometry has been extended to the study of various architectural compositions and artefacts where fractal geometry is related to the formal study of the progression of interesting forms, from a distant view to intimates details. It has been proven that ornament and decoration subdivide building facades on many different scales and that the most effective hierarchical scaling creates fractal geometry [10].



Itérations	N(1/s_i)	log N(1/s_i)	N(s_i)	log(N(s_i))	dimension
1	5	0,698	22	1,342	
2	10	1	72	1,857	D(s1-s2)=**1,705**
3	20	1,301	248	2,394	D(s2-s3)=**1,784**
4	40	1,602	684	2,835	D(s3-s4)=**1,465**

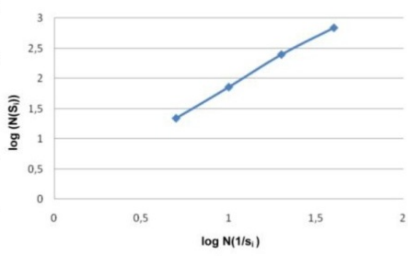


Fig. 4 Box-Counting method

The visual complexity of a facade is expressed by its fractal dimension D_b and calculated with the box-counting method. The higher the D_b, the more visually complex the object. The growth of the fractal dimension is associated with the concentration of lines in the image. Thus, a preliminary step imposes to extract and thin the boundaries of the wooden structure in order to suppress irrelevant information in the image. The box-counting method implies laying a series of grids of decreasing calibre over the image. For each grid, the number of boxes which superimpose the details in the image has to be counted (Fig 4). The software FracLac has been used to automate the process.

The fractal dimension D_b of a facade is given by

$$D_{\mathrm{b}} = \frac{[\log(N(s_2)) - \log(N(s_1))]}{\left[\log\left(N(\frac{1}{s_2})\right) - \log\left(N(\frac{1}{s_1})\right)\right]} \tag{4}$$

where D_b = the slope of the plot, $N(s_i)$ = the number of boxes needed to completely cover the structure, $N(1/s_i)$ = the number of boxes which divide the width of the grid.

3.3. Measuring the geometrical proportions

Comparing the proportions of the facade dimensions is straight forward. It is probably the first indicator that everybody would think about because it figures the size of a sample. This can easily be achieved by measuring the bounding box of the facade (Fig. 5). The geometrical proportion of a gable is given by the ratio width on height of the facade. The difference between the sizes of two facades is inappropriate to distinguish intact and transformed structures of a same typology. However, we know that traditional wooden buildings have evolved from rather squat facades to slender structures. As a result, the latest constructions show a lower ratio compared to earliest ones.

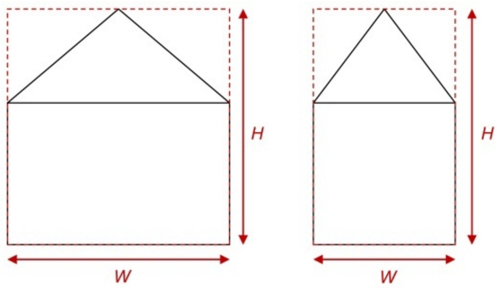


Fig. 5 Bounding boxes for two different proportions of facades

3.4. Measuring the global distance

The global distance calculated between a pair of images, A and B, is given by

$$S = \sqrt{\left(\frac{W(A)}{H(A)} - \frac{W(B)}{H(B)}\right)^2} + \sqrt{(\mathbf{Db}(\mathbf{A}) - \mathbf{Db}(\mathbf{B}))^2} + \mathbf{H}(\mathbf{A}, \mathbf{B}) \tag{5}$$

where $\sqrt{\left(\frac{W(A)}{H(A)} - \frac{W(B)}{H(B)}\right)^2}$ = the difference between the geometrical proportions of the facades,

$\sqrt{(\mathbf{Db}(\mathbf{A}) - \mathbf{Db}(\mathbf{B}))^2}$ = the difference of fractal dimensions, H(A,B) = the Hausdorff distance calculated between the associated shapes.

It can be considered that a potentially recognized facade will present a high level of similarity with a sample if both structures show equal proportions, comparable levels of complexity and similar histograms. In this case, the measured global distance is expected to be minimal, in comparison with the rest of the database.

4. EXPERIMENTAL RESULTS

In this section, we describe the database we used and then present the indexing system results based on statistical descriptors calculated between pairs of images. The approach is semi-automatic in order to make the optimum use of the knowledge and skills of the experts.

Rectified photos and some existing survey drawings have been collected to constitute a sample of fifty three structures of gables. Each photo has been processed to extract the wooden structure, the openings and the general shape of the facade from the background. Survey drawings have been cleaned and all the data has been transformed at a 1:200 scale representation. The study area is situated in southern

Belgium where different typologies of wooden structures are still present in the countryside [11]. This region has been subdivided into three zones where two distinctive typologies are observed simultaneously.
The database is divided into three typologies. The first one is characterised by long gable studs which link the sill plate to the rafters. The second typology is defined by a tie beam situated in the upper part of the gable while the third typology presents two tie beams that horizontally divide the gable in two parts (Fig. 6). By way of illustration, the first typology makes a distinction between intact and transformed structures. The two other typologies only contain structures which have not been transformed.

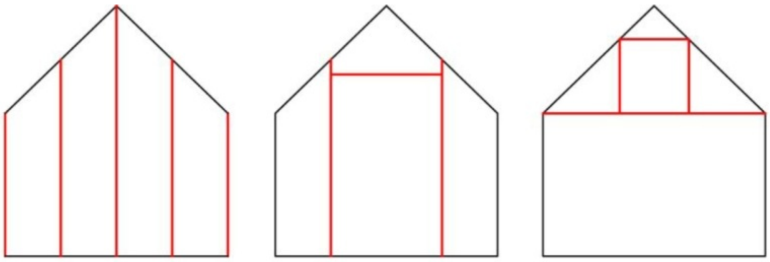


Fig. 6 Typologies of wooden structures under focus

The calculation of the geometrical ratios and fractal dimensions leads to extracting the contour of the resulting black and white pattern and thinning it as feasible. This method is called skeletonisation. The contour extraction of a pattern is unnecessary for the Hausdorff distance calculation. In the case in question, the wooden structure is expressed as a bi-dimensional collection of black pixels in rectangular coordinates and is finally turned into a matrix.
Leave-one-out cross-validation is the method we used for estimating the performance of the approach. Each observation from the original sample will be used as validation data where remaining observations are employed as training data. The procedure is repeated so that each observation in the sample is used once as validation data. Then, the tested image is associated with the k images of the training data which present the lowest S value (Fig. 7).

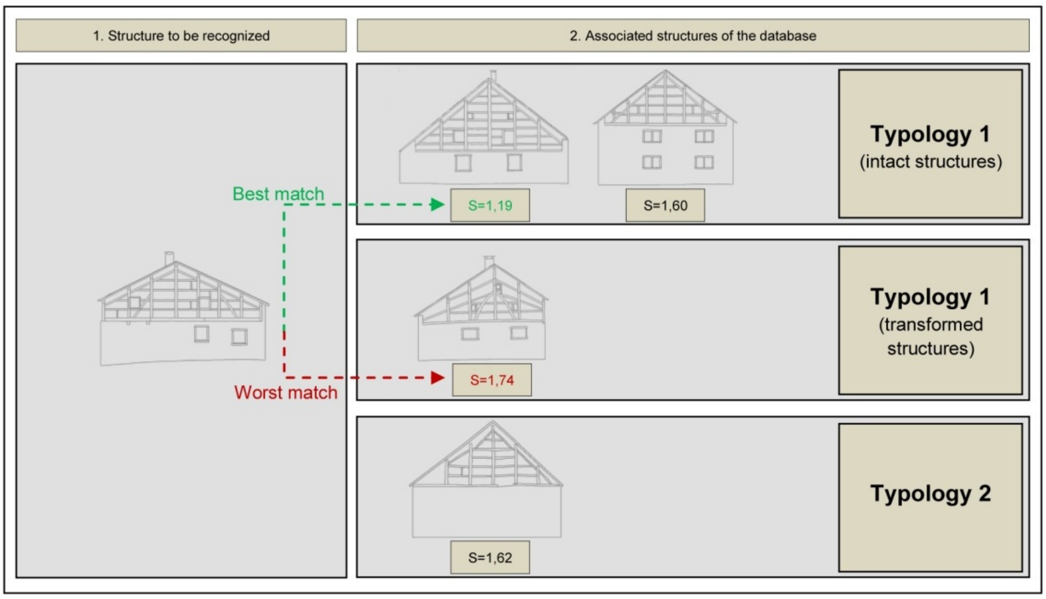


Fig. 7 Illustration of the indexing procedure

We consider that the typology of an unknown structure is correctly recognised, only if at least one example belonging to the right typology to be recognised is present among the k proposals. Running the classification yields at an average recognition rate of 89% with 3 clusters and 95% with 5 clusters gives encouraging results despite the small size of the database. Helped by the measurement of the global distance *S,* the indexing system we propose not only suggests the correct typology to be recognised but also gives similar examples of the tested picture.

5. CONCLUSION

We have presented an innovative approach for typology identification of building facades where best matches are associated with a new indicator as an aid for the decision making. This indicator takes into account the difference between statistical descriptors between representations of facades. Our study has been focused on rural timber frame structures which differ depending on their geographical regions and possible transformations.

The combination of statistical descriptors gives promising results for the search of complex images of structures that correspond to reference templates. Discrimination based on the association of descriptors provides complementary information about the clear similarities of the facades.

The recognition process is semi-automatic and based on the assumption that the user has sufficient knowledge of the subject which is compulsory when intervening in a conservation process. Therefore, the tool that we propose is comparable to a search engine dedicated to built heritage.

We believe that our methodology is transferable to various architectural typologies because the descriptors that we use are not strictly dedicated to the study of traditional wooden frame structures.

In addition, by working on past survey drawings and recent photographs, the proposed indexing system, allows the comparison between existing structures and buildings which may have been destroyed or seriously altered over time.

Future developments will be devoted to enlarging the database and testing the approach on other typologies. A computer interface allowing consultation of related information on the buildings will be also achieved.

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