Automatic recognition and reconstruction of traditional wooden frame structures in view of their conservation and/or restoration

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ABSTRACT
The research aims to provide a tool able to help architects and historians to conserve timber-framed house. Recognition and reconstitution of traditional rural timber walling which have been structurally transformed are the two major functions of our research. This paper will present the recognition approach. Past studies show that vernacular wooden-framed structures and more particularly the gables can be distinguished into several typologies embodied by the architectural and structural characteristics.

The study has two aims. Generate an automatic tool which firstly, record the available examples of gables and identify their typologies. Secondly, formulate transformations hypothesis of a given wooden structure through time. The recording procedure is made by analyzing pictures with image processing in order to extract the wooden structures from colored pictures. The recognition of wooden structures is based on the statistical and structural approaches. Structure recording and typology recognition will be presented in this paper.

INTRODUCTION
Studies and researches are more and more focused on reconstruction of ancient or vernacular architecture in a digital environment. This interest may be certainly explained by the progressive loss of our built heritage. For several authors [1, 2], timber walling can be seen as part of a world we have definitely lost. If this postulate can be verified in lots of our old cities, it is not always true in the European countryside where several examples of old wooden constructions are still present in rather good condition. The reasons are varied and can be resumed in three main points. Firstly, in the past, rural buildings were less assigned to respect town-planning laws which, for example, prescribed fireproof materials for the roofs and façades. Secondly, we can assume that the city buildings have been much more transformed over ages. Finally, buildings localized in the countryside benefit from their geographical isolation. All these facts helped to preserve some vernacular buildings from disappearance until now. Nevertheless, this kind of architecture is fragile and hardly resists to carelessness. In a located region, vernacular constructions often seem very similar to each others due to the construction habits of their creators who reproduce a particular existing canvas based on their experience and culture. However, despite a global visual homogeneity, each house has something particular in its construction which explains the adjustment of the traditional way of building applied to a particular context.

In several countries such as Belgium, theoretical studies have been published on traditional wooden architecture [3, 4, 5, 6, 7]. Since the researches carried out in the 90’s, it is assumed that timber-framed gables are particularly expressive and distinguishable into typologies according to the architecture and design characteristics of their structures. In Belgium, five typologies have been roughly localized taking into account that an exact division of regions is impossible due to intercultural influence between neighbouring regions (figure 2). This research has been used as a reference in order to classify pictures of remaining examples.
Five main typologies of gable structures have been identified in the French-speaking part of Belgium. Type a: king post and posts rising from a timber sill to the edge, type b: posts rising from a timber sill to the edge with a rail in the upper part of the gable, type c: wall plate supporting two posts with a rail in between, type d: tie-beam and collar-beam supported by braces, type e: king post rising from a timber sill to the ridge (figure 2).

Some are influenced by the French or German architectural way of building [4, 5]. The richness, the variety but also the fragility of these structures justifies to provide to the architects and historians a way to evaluate their quality. This observation implies to have a clearer view of their locations to avoid a complete destruction of the remaining examples. It also implies to identify the possible structural modifications of their structures through time in order to propose an additional tool for conservation projects. A tool able to make timber walling reconstructions based on case studies is considered. It uses different approaches linked to architectural knowledge, image processing and pattern recognition. The scope of the study is currently limited to the Belgian architecture.

**EXPERIMENTAL**

**Image processing**

A representation of the gable we want to study is first required for the processing. Pictures and scanned drawings are used at same scale data’s. The timber frames constituting the gable structures have to be segmented from the rest of the pictures using noise reduction and thresholding operations.

When we look at a picture representing a building in its surroundings, our mind can immediately isolate the different details of the façade from the rest of the photography. This is due to our ability to visually isolate the different areas or textures of an image by using our knowledge of materials, perception of colors [8]. Textures can be described as the structural arrangement of a surface and the relationship that one arrangement has with others surrounding it [9]. As a result, we are able to distinguish regions of an image by identifying common properties or differences between delimited regions. For decades, algorithms of segmentation have been developed in order to separate an image into different regions or contours corresponding to particular objects. However, it is accepted that no segmentation algorithm can be systemically applied. Each case is independent and particular. Taking into account that each wooden structure differs from its form, wood color and surroundings, one of the difficulties is to express and extract the representations of the wooden structures from the pictures. Thresholding techniques have been applied. Basically,
thresholding methods turn all pixels below some threshold to zero and all pixels about that threshold to one. As a result, we get binary images from the grey-level ones (figure 3).

\[
g(x, y) = \begin{cases} 
1 & \text{if } f(x, y) \geq T \\
0 & \text{otherwise}
\end{cases}
\]

**Figure 3:** \(G(x, y)\) is the thresholded version of \(f(x, y)\), \(T\) is the thresholding value.

Some existing algorithms have been tested in order to threshold the pictures. Histogram shape-based method has been first tried to separate light and dark regions of the pictures. Each picture can be analyzed using its histogram which is a graph, counting how many pixels are at each level between black and white. A suitable threshold can be determined by founding each of the local maxima (peaks) and minima (valleys) of the histograms. Nevertheless, it can be easily understood that using grey levels pictures occurs a loss of chromatic data since different colored objects can be turned into more or less similar grey levels ones. As a consequence, there is no guarantee that the selected pixels by the thresholding technique are contiguous. Therefore, it is necessary to get a balance between losing too many pixels of a desired region and getting too many extraneous background pixels of the picture. The different textures represented in the picture, the changes in illumination make each representation particular and make the automatic thresholding difficult. As a result, in our research, the automatic thresholding algorithms didn’t give satisfying results and was abandoned. Boundary-finding methods have been also tested unsuccessfully. We finally decided to use colored pictures thresholded by an algorithm similar to the magic wand of Adobe Photoshop. The algorithm allows the operator to remove a selected color from a picture.

Afterward, the extracted structure is turned into a set of idealized lines which are called a skeleton or medial axis representation. Drawings which are already lines drawn with a particular thickness are thinned and turned into skeletons. Skeletonisation gives the thinnest representation of an input pattern and represents a powerful tool for qualitative shape matching because Skeletons resume, synthesize and help the understanding both of the object shape and its topology. Working on wire frame representations makes comparisons with drawings possible. In addition, refining the representations also suppress the undesired details such as siding.

**Pattern recognition**

Watanabe [10] defines a pattern « as opposite of a chaos; it is an entity, vaguely defined, that could be given a name ».

We decided to do supervised classification. That means that the input patterns are assigned to predefined clusters. These groups have been identified in past researches. The best known approaches for pattern recognition are statistical classification, structural matching, template matching and neural network. The first two methods are used in our work.

*a) Statistical approach*

In the statistical approach, each pattern is represented in terms of \(d\) features or measurements and is viewed as a point in a \(d\)-dimensional space. The goal is to choose those features that allow pattern vectors belonging to different categories to occupy compact and disjoint regions in a \(d\)-dimensional feature space [11].
We know that the different typologies are distinguishable by their geometrical particularities. In addition, computer visualization has proved to be an effective tool to study the visual properties of the built environment [12]. However, one of the difficulties was to express these particularities from a statistical point of view.

Lots of researchers such as Brolin, Bently, Tugnutt or Robertson support the hypothesis that details, expressed by materials, colors or patterning’s, play an important part in architectural quality [13]. For others, ornaments help us to automatically establish a scaling hierarchy of the structure. In cases where the scales are ambiguous, our perception of structure is frustrated [14].

Therefore, from our point of view, it was interesting to express the different typologies by means of the visual complexity of their wooden structure. This matter has been exposed in the 80’s by Benoit Mandelbroot and its fractal theory [15]. Literally, the word fractal, coming from Latin fractus means “broken”. Therefore, a fractal form is fragmented, geometrically torn, divided into parts from which each is approximately a smaller copy of the whole. In 1996, Carl Bovill applied the concept to architecture and proved it was possible to express the visual complexity of an architectural conception by calculating a number called its fractal dimension which measures the mix between order and surprise. Fractal geometry in architectural composition is related to the formal study of the progression of interesting forms, from the distant view of the façade to intimate details [16]. As Bovill mentioned rural architecture shows natural detail progression from a large to a small scale. In order to calculate the fractal dimension of objects, Bovill proposed the box-counting method. The higher the fractal dimension, the more surprise is mixed into the underlying order. As it has been proved in Lorenz and Zarnowiecka’s researches, box-counting method can be used to measure the visual complexity of a façade and consequently confirm an architectural transformation. However, the fractal dimension of an object cannot be easily related to its esthetical value.

The method applies an iterative procedure [17]:
- Superimpose a grid boxes over the image (s1 is the grid size).
- Count the number of boxes N(s1) that contain some (pixels) of the image.
- Repeat the procedure, changing s1 to s2 with s1<s2.
- Count the resulting number of boxes N(s2) that contain the image.
- Repeat the procedures changing s to smaller and smaller grid sizes.

\[ D_b = \frac{\log(N(s_2)) - \log(N(s_1))}{\log \left( \frac{1}{s_2} \right) - \log \left( \frac{1}{s_1} \right)} \]

**Figure 4:** Box-counting dimension \( D_b \) formula.

Existing researches have been focused on regional architecture by looking for the box-counting dimension of vernacular features [18, 19]. It has been proved that ornament and decoration subdivide building facades on many different scales and that the most effective hierarchical scaling creates a fractal geometry [20, 21].

Working on refined structures representations is essential if box-counting method is used if we consider that the growth of the fractal dimension is linked to the concentration of lines on the façade. Undesired ornamentations such as sashes must be erased. Only the structures constituted of panels which make various subdivisions have to be studied.
b) Structural approach

The second method which is used to recognize the patterns is the structural approach. The structural approach is used when complex patterns have to be recognized. The patterns are viewed as being composed of simpler subpatterns which are themselves composed of simplest elements.

Structural pattern recognition is divided in two types. Syntactic pattern recognition and graph-based pattern recognition. Both strategies are applied in the research. The syntactic pattern recognition describes a structure using a grammar whereas graph-based pattern recognition uses graphs to represent structural relationships between parts of the pattern [22].

The structural approach is often used when the patterns have a definite structure which can be expressed in terms of composition rules [23, 24, 25, 26, 27, 28].

Expressing architectural designs by means of composition rules has been done for a long time. The work of Jean L. Durand, “Précis des leçons d’architecture” should be mentioned (figure 5).

The syntactic approach uses a parametric shape grammar in order to generate the different typologies of the timber-framed houses. A shape grammar consists of rules of the form \( A \rightarrow B \), where \( A \) and \( B \) are shapes made up of solids, planes, lines or points [29]. The proposed grammar is based on a corpus of gables belonging to Belgian rural timber frame gables. The compositional principles of architecture reflect the various languages of their builders, naturally influenced by the surrounding they live in. As stated by Serageldin [30], in making any architectural statement, the designer calls upon a formal vocabulary drawn from his or her previous experience and from the background tradition or culture in which the design is being executed. These recurrent ways of building can be defined by a set of rules which compose the grammar of a language. An architectural language is characterized by a vocabulary of shapes and a grammar which define the spatial relationships between patterns. The morphological aspects such as symmetry, axes distribution, addition and subtraction of spatial organizations and forms transformations are taken into account in the shape grammar construction. Programming structural knowledge of architectural compositions using rule-based formalisms is illustrated in past studies such as Palladian villa plans (Stiny and Mitchel, 1978), the architecture of Guiseppe Terragni (Flemming, 1981), bungalows of Buffalo (Downing and Flemming, 1981), the prairie houses of frank Lloyd Wright (Koning and Eizenberg, 1981), traditional Turkish houses (Gülen çagdas). According to Agarwal and Cagan, shape grammars have been shown to be an effective design tool because of their ability to handle geometric reasoning and their ability to operate on parametric geometric representation [31]. Our study use shape grammar due to the fact that vernacular wooden construction can be easily described with some simple polygons and lines. Moreover, the interesting concept of shape grammar is its ability to generate new architectural designs based on languages. Based on compositional grammar principles, it is also possible to create transformed structures.

**Figure 5:** Durand neo-classical design rules. From [32].
and consequently recover original disappeared or destroyed structures. From this point of view, the approach of discovering new shapes based on existing examples is similar to Flemming’s [32] and Colakoglu’s work [27].

**Figure 6**: Flowchart illustrating the different stages for developing a generative system for wooden frame structures of the gables plan [33].

**RESULTS AND DISCUSSION**

**Image processing**

Images processing has been mainly achieved with Matlab. Due to the different surroundings to be segmented, no existing thresholding algorithm give a satisfactory result. The algorithm “find_color” developed by Ikarlo Silva has been as a basis. Several other steps have been also computed (figure 7). Working on colored pictures, the algorithm successively extracts the pixels which have the same color and turn them to black. Then, the boundaries of the structure are extracted, dilated and Skeletonised.

**Figure 7**: image processing steps.

**Pattern recognition**

12 pictures and 34 drawings founded in the literature have been analyzed as well. All are 1:200 scale representations. Statistical and structural pattern recognition has been tested.

Two typologies are presented in this paper. Both are divided in two groups: intact and transformed structures. In the statistical approach, fractal dimension and the fraction (width/height) have been selected as parameters.

First results prove that intact structures are characterized by extreme fractions \(W/H\). That means that intact gable structures can be distinguished by their geometrical proportions. The typology A (intact structure) is represented by structures which are wider than higher. Examples of typology B (intact structures) are higher than wider. On the other hand, transformed structures are represented by a higher or lower fractal dimension value (D). A higher fractal dimension value express higher visual complexity of its architecture which seems perfectly true if we compare an original structure to a modified one. However, the typology B corresponding to modified structures is represented by a lower fractal dimension. This fact would express that these transformed gables are visually less complex than some original ones (figure 8).
<table>
<thead>
<tr>
<th>Typology A</th>
<th>Typology B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact structure</td>
<td>Intact structure</td>
</tr>
<tr>
<td>Modified structure</td>
<td>Modified structure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean val (W/H) for the group</th>
<th>Mean val D for the group</th>
<th>Mean val (W/H) for the group</th>
<th>Mean val D overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.38</td>
<td>1.42</td>
<td>1.11</td>
<td>1.38</td>
</tr>
<tr>
<td>Mean val (W/H) overall</td>
<td>Mean val D overall</td>
<td>Mean val (W/H) overall</td>
<td>Mean val D overall</td>
</tr>
<tr>
<td>1.38</td>
<td>1.38</td>
<td>1.38</td>
<td>1.38</td>
</tr>
</tbody>
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**Figure 8:** clustering for two typologies.

These first conclusions must be considered with caution due to the little amount of examples. Nevertheless, fractal dimension and geometrical proportions \(\frac{W}{H}\) have proved to be relevant for vernacular wooden structures distinction.

The number of studied examples is of course relevant if we want to achieve statistical recognition. However, surveys are time consuming and difficult to complete on a large scale. In addition, lots of gables have been hidden under a cladding or even included in new constructions. In some cases, artefacts do not allow access (figure 9). Therefore, in order to quickly enlarge our data base, we propose to use a two-dimensional shape grammar able to generate existing but also unreferenced structures. This knowledge-based approach must help to design wooden constructions that satisfy formal and structural observations.

The parametric rules aim to create idealized two-dimensional representations of typologies structures. This research is a work in progress and steel need to be coded for computer implementation.

**Figure 9:** problems of structure accessibility.

At first, it is necessary to analyze the typologies particularities in order to generate a vocabulary able to explain the structural language of the wooden gables. Then, the language has to be transformed into a shape grammar capable of proposing existing or innovative designs.

We assume that socio and economical context, functional and dimensional requirements are main factors which influence the wooden frame structures design.

The influence of the socio and economical context is expressed in the various typologies expressions which reflect a regional belief, the construction style of a carpenter or a lack of particular building materials. In the forest regions, timber-framed houses are made of larger beams. At the opposite in the farming regions, constructions have been developed to spare wood as much as possible. As a consequence, structures are often more complicated. Often, constructions...
have been also transformed due to laws which have forbidden flammable materials such as thatch which obliged to modify the slope of the roof to be adapted to slate.

The language of the timber-framed houses is defined by the beam layouts of the gables. The vocabulary elements in the shape grammar are an initial shape and lines with constrained parameters. Past researches have identified five simplistic typologies which are distinguishable by their gable structures. These plans must be adapted to the sociological, economical and environmental conditions which make each example particular by its dimensions. Therefore, the generated parametric rules are made to generate not only the structure type but also the building envelope and the building base (figure 10 & 11).

Figure 10: Structure layouts of a part of the tree generated by the shape grammar.
Figure 11: Generation of the primary structure rules for type B.
CONCLUSIONS

Traditional timber frame structures embody particular ways of building. These particularities are illustrated by means of different structural typologies geographically localised.

In this paper, two methods able to make architectural recognition of wooden frame structures have been illustrated. It constitutes a work in progress. A statistical approach is based on geometric concerns as well as the evaluation of the visual complexity of wooden frame structures. First results proved that intact and transformed structures examples can be distinguished within the same typology. Despite few examples, the statistical approach shows encouraging results. An extended data base should confirm and refine the actual results. A shape grammar adapted to traditional timber framed structures is developed. Wooden constructions seem particularly adapted to this kind of analysis. The creation of existing and unknown structures based on generated rules is a way of studying architecture styles, particularly if the represented examples are difficult to survey. These two approaches will be used as a basis to develop a reconstruction methodology.

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