Complementary Approach for Vernacular Wooden Frame Structures Reconstruction

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Abstract. The research is focused on traditional timber frame structures (TFS) situated in rural areas. Often neglected, remaining examples embody our build Heritage. However, architects have few tools to manage a conservation project in respect to the structural authenticity of these constructions. Therefore, providing a complementary tool able to automatically recognize and reconstruct traditional rural timber walling which have been structurally transformed is the major function of our research. The tool should automate as much as possible the procedure in two steps. 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 typology recognition is based on a statistical approach where' as structural approach will help to achieve reconstruction hypothesis. Structure recording and typology recognition will be presented in this paper.

Keywords: Timber framed structures, Conservation, Image processing, Features extraction, Reconstruction.

1 Introduction

1.1 Motivation

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 rural built heritage. For several authors (Pesez, 1983; Laslett, 2004), timber walling can be seen as part of a world we have definitely lost. However, if we pay more attention to our build environment, it can be argued that European countryside's still present several examples of vernacular wooden constructions. The reasons are various and can be resumed in three main points. Firstly, rural buildings were seldom assigned to respect town-planning laws which, for example, prescribed fireproof materials for the roofs and façades. Secondly, compared to rural areas, we can assume that the city houses have been much more transformed over ages. Finally, constructions 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

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resists to carelessness of the owners. In a restricted area, vernacular constructions often show similarities to each others due to construction habits of their creators who reproduced a particular existing canvas based on their experience and culture. However, if the constructions still exist, structures may have been strongly transformed to respond to social and economical needs. As a result, despite a global homogeneity of their architecture, each house has something particular in its construction which explains the adjustment of the traditional way of building applied to a particular context. From our concern, we assume that the particularities also reflect more structural transformations/adaptations rather than ornamentations of the façades. 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 regions where wood is easily available, 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, using shorter span. 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.

In several countries such as Belgium, theoretical studies have been published on traditional wooden architecture (Genicot, 1989; Genicot & Butil, 1996; Hoffsummer, 2002; Houbrechts, 2008). Past studies identified that these transformations are more visible in the gable structures. 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 the French-speaking part of 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 (fig. 1).

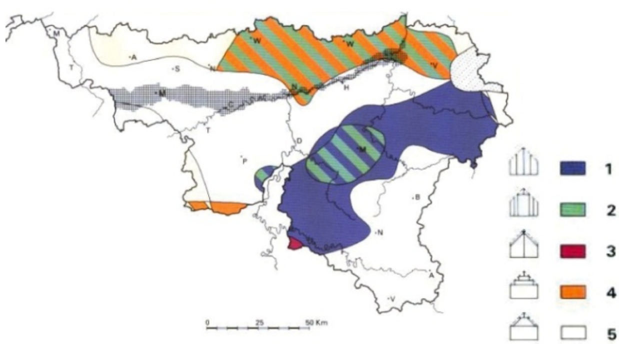


Fig. 1. Localisation of (TFS) in south Belgium by Genicot

This mapping has been used as a reference in order to classify pictures of remaining examples. Type 1: king post and posts rising from a timber sill to the edge, type 2: posts rising from a timber sill to the edge with a rail in the upper part of the gable, type 3: wall plate supporting two posts with a rail in between, type 4: tie-beam and collar-beam supported by braces, type 5: king post rising from a timber sill to the ridge (fig. 2). The richness, the variety but also the fragility of these structures justify to provide to the architects and historians a way to evaluate their quality.

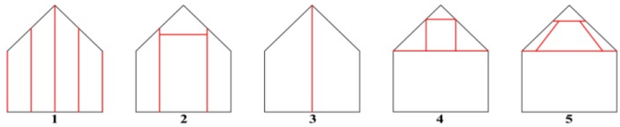


Fig. 2. Referenced gable structures from fig. 1

1.2 Aims

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 pictures. The typology recognition of the structures is based on a statistical approach. Reconstruction hypothesis are based on shape grammar analysis.

2 Methodology

2.1 Wooden Structure Extraction

The acquisition of data has to be straightforward, avoiding special computing knowledge of the user. An orthophoto of a gable is required for the processing. In order to record, compare and reconstruct the hypothetical structures, we first need to extract the relevant information from the photography. The ability we have to visually isolate the different parts of the image is due to our knowledge of materials and perception of colors (Tucker & Ostwald, 2007). In our context, everyone is able to easily distinguish the wooden parts of the structures at first glance because we all know how wood looks like. The major difficulty in an automatic feature extraction process is to characterize the wooden material to be extracted. Thresholding techniques have been applied. Basically, thresholding methods turn all pixels below some threshold to zero and all pixels over that threshold to one. As a result, we get binary images from the grey-level ones (figure 3).

Fig. 3. Thresholded picture. Type 1 example. (RGB/gray/level/BW).

However, using gray levels pictures never provided satisfactory results for the wooden beams extractions. Therefore, in our research, features extractions of the wooden structures have been based on chromatic peculiarities. For this reason, RGB colored pictures has been used for the thresholding. Because we want to compare some existing drawings from past surveys, we decided to extract the edges of the beams from the thresholded image. As a result, these representations can be compared with drawings of existing or even disappeared buildings.

2.2 Typology Recognition

The statistical approach aims to express the different structures examples by means of numerical parameters coming from their Euclidian (length, width) dimensions. In addition, the concept of fractal geometry is used to express the visual complexity of the gable structures in order to calculate for each example, a number called its fractal dimension. Fractal geometry has been exposed in the 80's by Benoit Mandelbrot (Mandelbrot, 1983). 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 architecture, when we look closer and closer to a building façade, this never ending progression of self similar parts is never infinitely refineable. However, some forms and details can be reproduced from large to small scales. In 1995, Carl Bovill developed these concepts 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 (Bovill, 1995). 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. As Bovill mentioned rural architecture shows natural detail progression from a large to a small scale. These details can be expressed by ornaments or complexity resulting from the structures. Therefore, from this point of view, all architecture is fractal at certain scales. However, if the fractal dimension of an object refers to the visual complexity of its structure it cannot be related to its esthetical value. In order to calculate the fractal dimension of objects, Bovill proposed the box-counting method.

The method applies an iterative procedure:

- Superimpose a range of different scale grids (*s1, s2)* over the picture you want to study (*s1* is the first grid size).
- Count the number of boxes *N(s1)* that overlay parts of the image.
- Repeat the procedure, changing *s1* to *s2* with *s1*<*s2*. The number of boxes containing details of the picture will change with the grid size (fig. 4).

As a result it is possible to obtain a log-log linear correlation between the number of boxes counted and the associated size of the grid. The slope of the regression line is an estimation of the fractal dimension D_b of the picture (fig. 5). N(s) is the number of boxes in each box grid which contains part of the structure and 1/s is the number of boxes across the bottom of the grid.

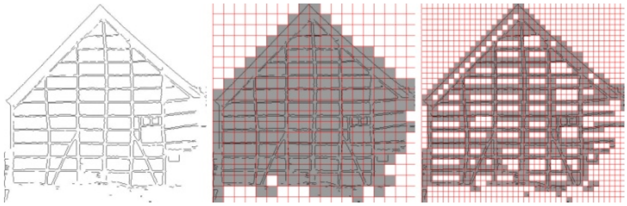


Fig. 4. Applying box-counting method to gable structures

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

Fig. 5. Box-counting dimension D_b formula

High fractal dimensions (D_b >1,5) mean high visual complexity. As it has been illustrated (Lorenz, 2002; Zarnowiecka, 1998), box-counting method can be used to measure the visual complexity of a vernacular features. Consequently we believe it can highlight an architectural transformation of its structure. Studies proved that box-counting method is also an effective way to evaluate the complexity of our environment (Tucker, Ostwald, Chalup, Marshall, 2005) or artifacts (Elizondo, 2001). It has been proved that ornament subdivides building facades on many different scales and the most effective hierarchical scaling creates a fractal geometry (Moughtin, Tanner, Tiesdell, 1999; Salingaros, 1999).

2.3 Structural Reconstruction

The structural approach is often used when the patterns have a definite structure which can be expressed in terms of composition rules of the form A→B (Stiny, 1980), where A and B are shapes made up of solids, planes, lines or points. The patterns are viewed as being composed of simpler subpatterns which are themselves composed of simplest elements. As a consequence, if a set of rules is able to express the generation of a kind of form, then it is possible generate new forms based on the language which has been created (Colakoglu, 2005; Cagdas, 1996; Flemming, 1987). Therefore, each typology has been expressed through several rules of construction. The combination of these rules allows generating existing examples of wooden frame structures as well as disappeared or still unrecorded structures. The rules parametrization is compulsory in order to avoid absurd reconstruction. A decision tree based on statistical observation is used to guide the user. For each region, width and height of the façades as well as the ratio (W/H), the slope of the roofs, the dimensions of the panels, height of the bases are parameters which help to restrict and improve the reconstruction. As a matter of fact, the panel dimensions are related to the gable dimensions which are themselves linked to the geographical area.

3 Results

3.1 Image Processing

Images processing has been mainly achieved with Matlab. In a picture, a construction is never isolated from its backgrounds. Often, vegetation, artifacts or other constructions have to be removed from the photography. As shown in fig.3, segmentation using grayscale pictures did not give satisfactory results. We decided to work on RGB pictures by using the algorithm "find_color" developed by Ikaro Silva on Matlab. Several other steps have been also added to this algorithm in order to be more adapted to the contexts. 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 can be extracted (figure 6).

Fig. 6. Segmented picture (RGB/segmentation/edges)

3.2 Pattern Recognition

12 pictures and 34 drawings founded in the literature have been analyzed. All are 1:200 scale representations. Keeping the same scale representation is compulsory if we want to compare the fractal dimensions of the various gables analyzed within a same range of different scale grids. Two typologies are presented in this paper (type 1 & type 4). Both are divided in two groups: intact and transformed structures. Each typology has been distinguished in two groups in order to identify the original structures ($1_{original}$ and $4_{original}$) and the structures which have been transformed through time ($1_{transformed}$ and $4_{transformed}$). The results conclude that original structures are rather represented by extreme values of the ratio (width/height). Structures of type 1 have rather high ratio expressing their squatness. At the opposite, structures of type 4 are rather slender. On the order hand, transformed structures can be identified by an extreme value of their fractal dimension (D), expressing that structures of the type $1_{transformed}$ are mainly more complex than type $4_{transformed}$ (figure 7).

The number of studied examples is of course relevant if we want to achieve statistical recognition. That is the reason why the data base must be enlarged. However, lots of gables have been hidden under a cladding or even included in new constructions. In some cases, artifacts do not allow access. In order to quickly enlarge our data base, we also 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.

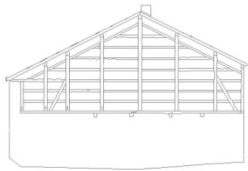
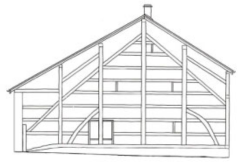
Type 1	
Intact structures ($1_{original}$)	Modified structures ($1_{transformed}$)
	
Mean val (W/H) for the group =1.58 Mean val (W/H) overall =1.38	Mean val D for the group =1.42 Mean val D overall =1.38

Fig. 7. Statistical results for type 1

3.3 Reconstruction Hypothesis

The parametric rules aim to create idealized two-dimensional representations of typologies structures. 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.

The language of the timber-framed houses is defined by the beam layouts inscribed within the gable geometries. The vocabulary elements in the shape grammar are an initial shape with constrained parameters. Five simplistic typologies are used to characterize each gable structures. At first, the gable envelope and its base are generated. Then, the façade is transformed by successive rules which (re)construct the intact wooden structure (figure 8). Depending on statistics coming from case studies, several reconstruction possibilities are proposed to the user (figure 9).

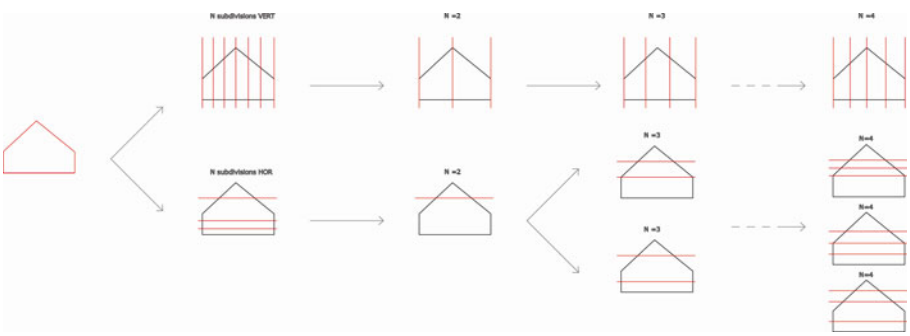


Fig. 8. Iterative rules for type 1 and type 4 reconstruction

Fig. 9. Incorrect (left) and correct (right) reconstruction of a gable

4 Conclusions

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

In this paper, a method able to make architectural recognition of wooden frame structures has 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. These first conclusions must be considered with caution due to the little amount of examples. Nevertheless, fractal dimension and geometrical proportions (W/H) have proved to be relevant for vernacular wooden structures distinction. 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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