DETERMINATION OF FACADE ATTRIBUTES FOR FACADE RECONSTRUCTION

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ABSTRACT:

In the last years more and more applications make use of 3d building models. Automatic reconstruction is essential for the acquisition and updating of the huge amount of data. For many applications it is useful to be able to transform the object representation automatically in order to generalize the geometry. For this task a structurally rich description of the object is needed. We presented a reconstruction procedure which models the structure of facades. This method is based on a facade grammar and a reversible jump Markov Chain Monte Carlo process. For the stochastic process we need prior knowledge about facades. The distribution of facade elements can influence the proposal of rules. Until now we made general assumptions about these distributions. In this paper we analyze facades from a set of facade images and derive prior facade information which support the modelling process.

1 INTRODUCTION

1.1 Motivation

Many approaches for the extraction of man-made objects from sensor data have been published. An overview is given in (Baltsavias, 2004). Especially for the modelling of 3D buildings, numerous approaches have been reported, based on monoscopic, stereoscopic, multi-image, and laser scan techniques. While most of the effort has gone into sensor-specific extraction procedures, very little work has been done on the structural description of objects.

Modelling structure though is very important for downstream usability of the data, especially for the automatic derivation of coarser levels of detail from detailed models.

Representing structure is not only important for the later usability of the derived data, but also as a means to support the extraction process itself. A fixed set of structural patterns allows to span a certain subspace of all possible object patterns, thus forms the model required to interpret the scene. Patterns can also guide the measurement process.

Our aim is to extract facade elements from image and range data automatically. The model is a structural description of the facade. Therefore we use the reconstruction method described in (Ripperda and Brenner, 2006, 2007). It is a grammar based extraction approach which is guided by reversible jump Markov Chain Monte Carlo (rjMCMC). The stochastic process is composed of a proposal and an acceptance step. For the proposal of rules we need information about facades and the elements on it. We are interested in the distribution of windows and doors. The width and height of them as well as the number of rows and columns on a facade and the distances between them. In our previous work general assumptions were used in this step. This paper presents an analysis of facades to obtain information for the proposal step.

1.2 Related Work

Building reconstruction approaches can be subdivided in top-down and bottom-up methods. Modelling methods like (Becker and Haala, 2007) start with the data and build up a model where the following approaches design a model first and in some cases (see Wonka et al. (2003)) create building models completely without data. The model is often given by a grammar.

For modelling plants, Lindenmayer systems were developed by Prusinkiewicz and Lindenmayer (1990). They have also been used for modelling streets and buildings (Parish and Müller, 2001; Marvie et al., 2005). But Lindenmayer systems are not necessarily appropriate for modelling buildings. Buildings differ in structure from plants and streets, in that they don't grow in free space and modelling is more a partition of space than a growth-like process.

For this reason, other types of grammars have been proposed for architectural objects. Stiny and Gips (1972) introduced shape grammars which operate on shapes directly. The rules replace patterns at a point marked by a special symbol. Mitchell (1990) describes how grammars are used in architecture. The derivation is usually done manually, which is why the grammars are not readily applicable for automatic modelling tools.

Alegre and Dallaert (2004) use a stochastic context free attribute grammar to reconstruct facades from image data by applying horizontal and vertical cuts. van Gool et al. (2007) discuss different facade reconstruction algorithms and show the use of repetitions in the structure for the reconstruction with shape grammars.

Wonka et al. (2003) developed a method for automatic modelling which allows reconstructing different kinds of buildings using one rule set. The approach is composed of a split grammar, a large set of rules, which divide the building into parts, and a control grammar, which guides the propagation and distribution of attributes. During construction, a stochastic process selects among all applicable rules.

Dick et al. (2004) introduce a method which generates building models from measured data, i.e. several images. This approach is also based on the rjMCMC method. In a stochastic process, 3D models with semantic information are built. In addition to implicit shape models Reznik and Mayer (2007) also use a MCMC method for the interpretation of facade from images.

The rjMCMC algorithm is used for other applications e.g. detection of road marks (Tournaire and Lafarge, 2007) as well. In general rjMCMC is a top-down-approach, but Tu et al. (2005) integrated generative and discriminative methods and used a data driven MCMC (DDMCMC) for image parsing. In (Ripperda and Brenner, 2007) a data driven extension of an rjMCMC based facade reconstruction method is shown.

2 FACADE RECONSTRUCTION BASED ON A FORMAL GRAMMAR AND RJMCMC

In this section the reconstruction method is shortly presented. First the facade grammar which defines the facade model is introduced and then the reconstruction by rjMCMC is shown.

2.1 Facade Grammar

For facade reconstruction we define a grammar which gives possible models of the facade whereat the model describes the structure of the facade. The modelling process based on this grammar corresponds to the derivation of a word of the grammar.

In each step the model of the facade should be developed further. Therefore each grammar rule splits the left side symbol in a variable number of symbols. So the derivation process is a partitioning process of the facade. The start symbol S is a blank facade which is subdivided in further derivation steps.

In this partitioning process a split can be caused by different reasons. The first reason is a difference in the facade structure. If a facade contains different structural parts it is split into part facades according to the structure and each part is modelled individually in further derivation steps. This change in structure often occurs in ground floor and upper floors, e.g. if shop windows are located in the ground floor.

The other reason for a split is similarity or repetition. If a facade is symmetric or contains repetitions, the repeated pattern needs to be stored only once. Additional information like number of repetitions complete the model.

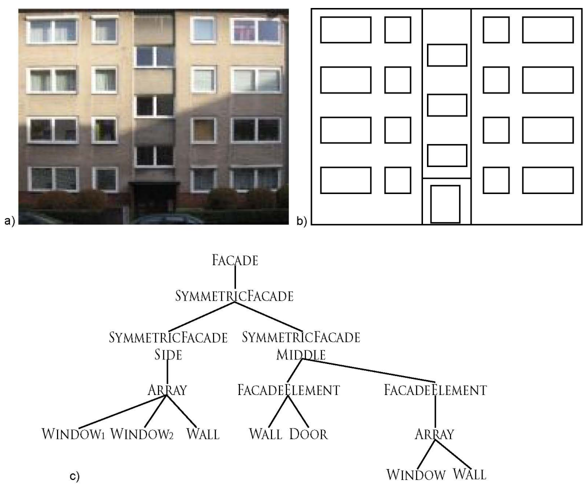

Figure 1: Derivation example: a) Image of the sample facade, b) partitioning of the facade according to the grammar rules, c) resulting derivation tree.

As an example fig.1 shows an image of a facade (a) and an outlined subdivision (b) according to the rules of the facade grammar. The corresponding derivation tree is given in (c). The example facade is first declared as symmetric, so only the middle part and one of the outer parts need to be modelled in the following steps. The outer part SYMMETRICFACADESIDE is modelled as an ARRAY with two kind of WINDOWs. The middle part SYMMETRICFACADEMIDDLE is partitioned further in two FACADEELEMENTs, the lower one contains a DOOR and the upper one consists of an IDENTICALARRAY which means that the attached elements (in this case WINDOWs) are all of the same kind.

The facade grammar consists of different kinds of symbols. The start symbol is the bare facade which knows only about the outline of the facade. Other nonterminal symbols comprise structural information like symmetries, repetitions and so on. These symbols can be divided in other nonterminals or in terminal symbols like WINDOW or DOOR.

During the derivation process the facade model is developed. It is defined by a parameter vector θ which contains the derivation tree and the attributes of the symbols.

2.2 Facade Reconstruction using rjMCMC

The grammar provides many different models unrelated to the scan and image data. But in the reconstruction process we search for the best matching model for that data. Therefore we use a stochastic process. Markov Chain Monte Carlo Methods help to find the model (given by parameter vector θ) with the highest probability $p(\theta|D_S D_I)$ under given scan (D_S) and image data (D_I).

To construct a Markov Chain that simulates a random walk in the space of θ we have to define a transition kernel $J(\theta_t|\theta_{t-1})$ which assigns a probability to each change from one state θ_{t-1} to another one θ_t. For the reconstruction these changes are given by the rules of the facade grammar. With this kernel changes are proposed and after that an acceptance probability decides if the change is accepted. The acceptance probability is defined in a way that the system converges to the target distribution $p(\theta|D_S D_I)$.

In our case the dimension of θ changes during the process. This is not possible in the basic MCMC method. Therefore we use rjMCMC which contains dimension changes of θ (jumps). The probability of a dimension change is added to the transition kernel. For the rjMCMC process with target distribution $p(\theta|D_S D_I)$ we have to define a transition kernel $J(\theta_t|\theta_{t-1})$ and the acceptance probability α.

$$\alpha = min\{1, \frac{p(\theta_t|D_S D_I) \cdot J(\theta_{t-1}|\theta_t)}{p(\theta_{t-1}|D_S D_I) \cdot J(\theta_t|\theta_{t-1})}\}$$

This depends on the unknown distribution $p(\theta_t|D_S D_I)$. Using Bayes' law, this is proportional to $p(D_S D_I|\theta_t) \cdot p(\theta_t)$, a product of likelihood and prior of the facade. To obtain the likelihood scoring functions based on depth and image data are used. The prior is influenced by the alignment and extend of the elements on the facade.

Results of the reconstruction are shown in fig. 2. The left facade is subdivided in upper and lower part (green line) and the upper part is modelled by an array of windows. The windows is the right facade are modelled as a regular grid of pairs of windows.

3 FACADE ANALYSIS

In this section the analysis of facade images is described. First the dataset is presented. Then the grammar rules which need the information about facade properties are described and the required distributions are mentioned. After that the calculated distributions are presented and their influence on the reconstruction process is examined.

Figure 2: Results of the reconstruction process.

3.1 Data presentation

To get the information about facades we acquired about 400 photographs of facades in a residential area. The dwelling houses have between two and six floors. Fig. 3 shows some examples.

Figure 3: Example facade photographs.

In a first step the photos are rectified and then the properties are labelled using ArcMAP. The facades outline and facade elements like windows, doors or balconies are modelled. Fig. 4 shows two manually labelled facades. If the facade has different colours or projections like oriels these are modelled as well.

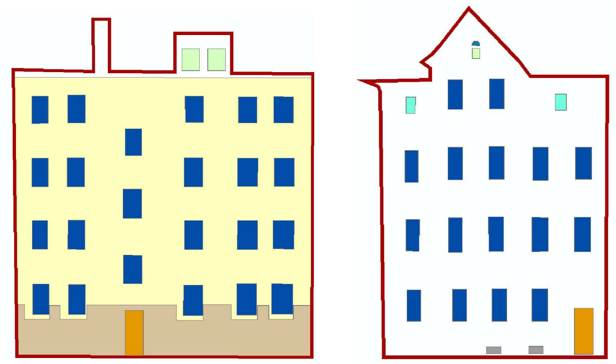

Figure 4: Manually labelled facade models.

3.2 Facade properties

In the reconstruction process one rule of the grammar is chosen and subsequently the parameters of the rule have to be proposed. Therefore we need to know about the distribution of facade elements, the width and height of windows and doors, the number of rows and columns on a facade and their average distance. The information we need depends on the grammar rules. In the following different rules are presented and the required parameters are enumerated. Fig. 5 shows the four discussed grammar rules.

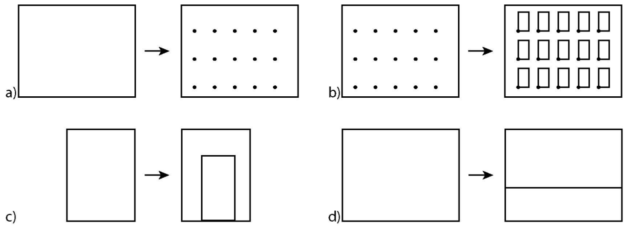

Figure 5: Different grammar rules which need information about facade parameters.

The grammar rule Facade → IdenticalArray subdivides the facade in a regular grid of cells which are supposed to contain the same element (see fig. 5 a); in general windows. The IdenticalArray possesses the parameters number of rows and columns, distance between the rows and columns and position of the array.

To instantiate windows in the array the grammar rule IdenticalArray → Window Wall is used (see fig. 5 b). Here the distribution of width and height of windows is needed. Additionally the ratio of width and height is used. For creating a Door besides the distribution of with, height and the ratio of them, the position relative to the facade is needed. FacadeElement → Door Wall is the corresponding grammar rule (see fig. 5 c). Furthermore the grammar symbols Shop and Doorway can be used.

Another kind of rule is the split rule Facade → PartFacade PartFacade where the split is based on the difference in the colour of the ground floor and the upper floors (see fig. 5 d). The idea of this rule is not to split by reason of the change in colour but because of a change in the facade structure which often come along with the colour change. Examples for the coincident change in colour and structure are given in fig. 6. For this rule we use the distribution of the position of colour changes in facades.

Figure 6: Example facades with different colours and different structures in the ground floor and the upper floors.

3.3 Facade analysis

Here the results of the facade analysis are presented. To get the distribution of the facade parameters we calculate the histogram of the values. Figs. 7 and 8 show the distribution of the width and height of windows. The width of windows in the test area lies between 0.3m and 1.9m and the majority of the height values between 0.5m and 2.4m. In the reconstruction the ratio of both attributes is important as well. This distribution is shown in fig. 9. The ratio ranges from 0.2 to 0.7 with its mode at 0.48.

The analysis also provides the different kinds of windows. Fig. 10 lists all occurring window types of the test data set. Window

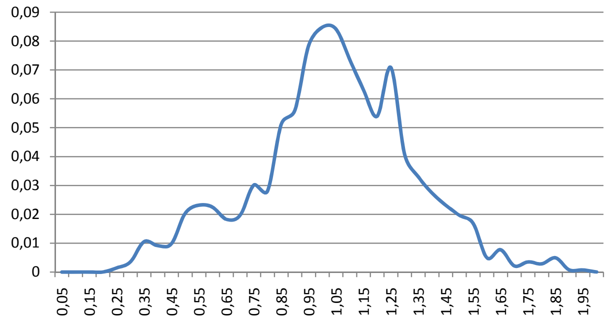

Figure 7: Distribution of window width.

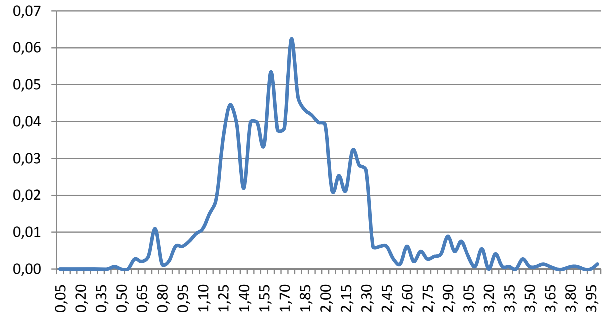

Figure 8: Distribution of window height.

type 17 is a bricked window. Fig. 11 shows how frequent each window type occours. The most frequent windows are windows of type 1, 3 and 7. Window types 10 and 11 are very rare with 1,36%.

For the reconstruction of window grids the number of rows and columns in a facade is important. Fig. 12 shows the distribution of these values. The facades in the test dataset have between two and eight rows where five is the most frequent number of rows. The number of columns lies between three and ten with a mode at six.

After the number of rows and columns is defined in the reconstruction process the distance between them was determined. Therefore the distribution of the distance of rows and columns is used (see figs. 13 and 14). The distances between rows range from 0.2m to 3.8m with a mode at 1.6m. For columns the distances lie between 1m and 5m with a mode at 3.3m.

The analysis of the distance between rows and columns gives additional information for the reconstruction. The plot of the histograms of the standard deviations of the distances between rows and columns of one facade in fig. 15 shows that the distances of

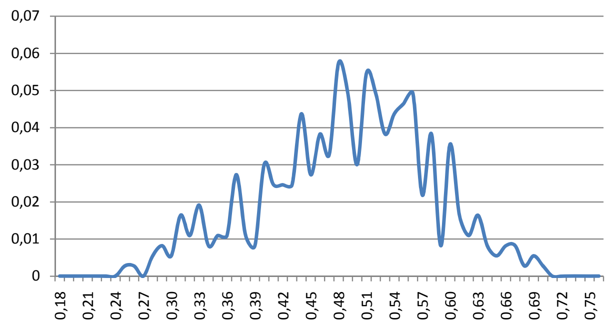

Figure 9: Distribution of the ratio of window width to window height.

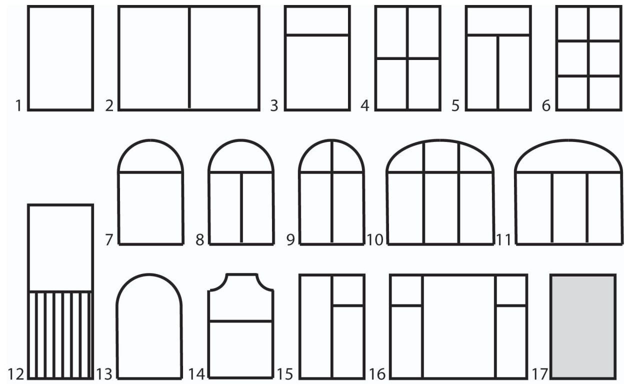

Figure 10: Different types of windows that occur in the test data set.

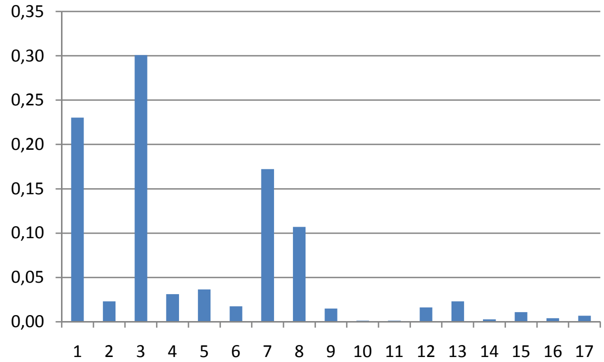

Figure 11: Histogram of different window types in the test data set.

columns vary much more per facade than the distances of rows. The blue line for the rows has a peak at zero and the maximal value is 0.48m where the highest deviation for the columns (red line) is 1.0m. Fig. 16 shows a histogram of the deviation of window height and width within a row or column. It shows that most deviations are below 5cm.

For the placement of facade elements like DOOR, SHOP and DOORWAY or the split line between ground floor and upper floors fig. 17 shows the ratio of facades containing zero to three elements of each type. We also analyse the distributions of the parameter or these elements. The following three figures (figs. 18, 19 and 20) show histograms of the width, height and the ratio of width and height of doors.

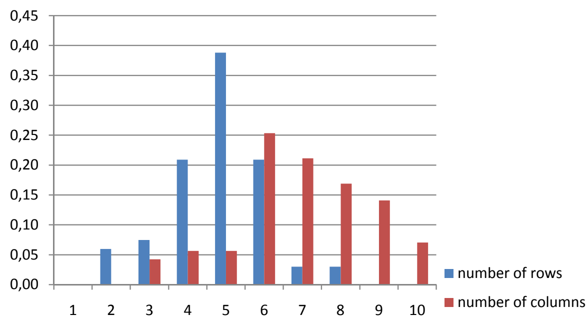

Figure 12: Distribution of the number of rows (blue) and columns (red).

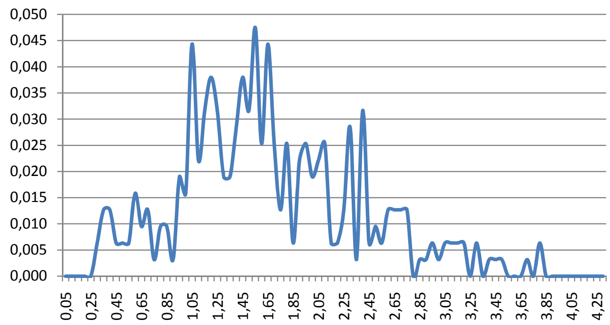

Figure 13: Distribution of the distance of rows.

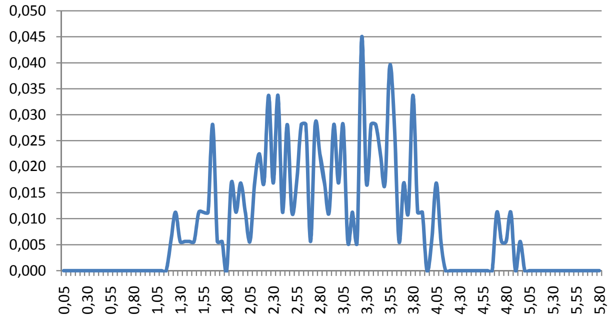

Figure 14: Distribution of the distance of columns.

3.4 Test of the distributions

The derived distributions of facade parameters are integrated in the grammar rules. Here the influence of the distribution of window width and height and the ratio between them is examined. In the test one part of a facade with a single window is used. The width and the height of the modelled window are changed by the grammar rule. These changes are proposed in three different ways.

The first test propose one of the values for width and height randomly from the previous value. Here a normal distribution is used. The other value is calculated by a randomly proposed ratio. This is assumed uniformly distributed from 0.5 to 2.0.

The second test uses the determined distribution of the ratio of width and height. By random one of the parameters width and height is chosen and the value is changed by sampling from the normal distribution with the previous value as mean. Then the ratio is sampled from the distribution of the ratio of width and height and the missing parameter is calculated.

In the last test width or height are sampled from the derived distributions as well. Again randomly width or height are chosen

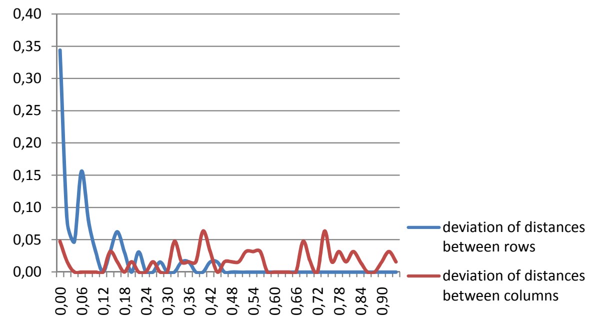

Figure 15: Histogram of the standard deviations of the distances between columns and rows per facade.

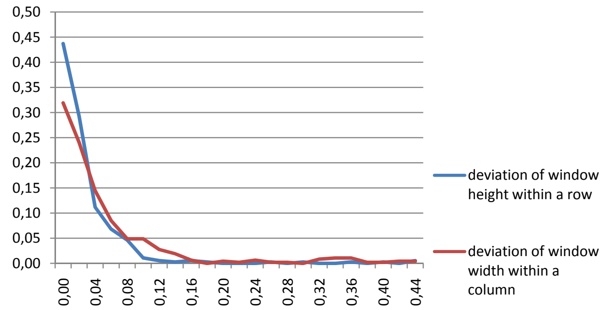

Figure 16: Histogram of the deviation of window hight (blue) or width (red) within a row or column.

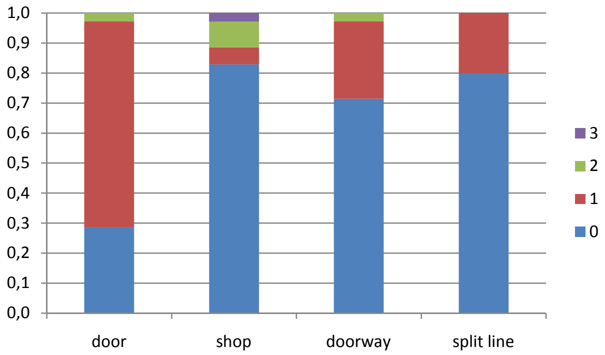

Figure 17: Relative number of facades containing 0, 1, 2 or 3 elements of a facade element or split line.

and the missing parameter is calculated with a randomly sampled ratio value.

Table 1 list the percentage of the proposals with nearly correct width and height values. It is not important to hit the correct values exactly at the first try because change operations can move the values to the correct solution in further steps if the value is near the correct solution. The number of correct proposals in the tests 2 and 3 which are based on the distribution of facade parameters is clearly larger than the one in test 1 without the distributions. The numbers for test 3 including all distributions are a little better than the numbers for test 2 only including the ratio of width and height.

If we look at the acceptance rate of both tests (see tab. 2) test 2 shows a higher acceptance rate for both scoring methods. So we propose to use the distribution of window width and height and the ratio of them for the instantiation of a window and to use only the ratio for the changing of window size.

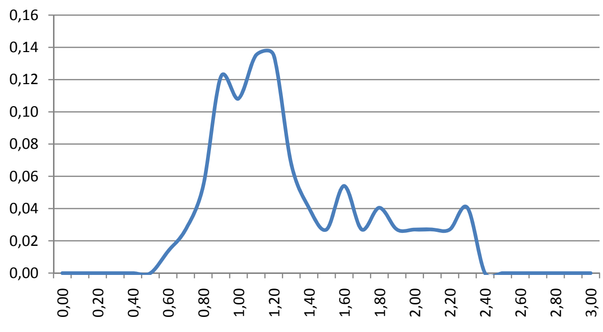

Figure 18: Histogram of width of doors.

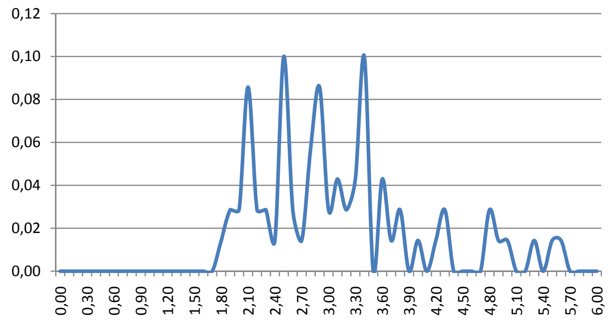

Figure 19: Histogram of door heights.

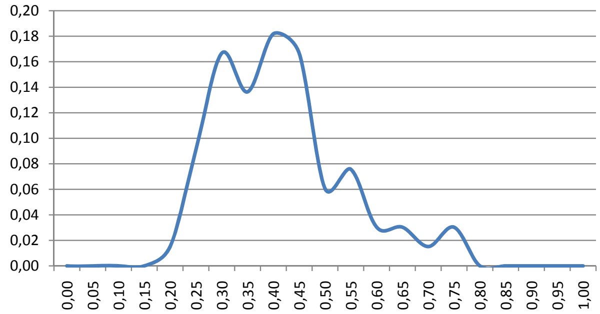

Figure 20: Histogram of the ratio of width and height of doors.

4 CONCLUSION AND OUTLOOK

In this paper, we have presented an analysis of facade data. We determine several facade parameter distributions which can be used in the grammar rules of the reconstruction framework. This framework combines the generation of artificial facade structures using grammars, and the reconstruction of facades using rjMCMC. Compared to existing grammar-based approaches, we gain the ability to reconstruct facades based on measurement data. Compared to existing rjMCMC approaches, by using a grammar, we obtain a hierarchical facade description and the ability to evaluate superstructures such as regularity and symmetry at an early stage, i.e., before terminal symbols such as WINDOW are instantiated.

One of the future tasks is to implement further facade elements like the different window types shown in fig. 10. Additionaly scoring functions for the rjMCMC process have to be defined for the different types.

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	Test 1	Test 2	Test 3
Colour Cluster	0.85 %	7.25 %	9.02 %
Depth Cluster	0.85 %	7.00 %	8.90 %

Table 1: Percentage of accepted proposals near the right solution.

	Test 2	Test 3
Colour Cluster	97.51 %	95.58 %
Depth Cluster	98.26 %	96.72 %

Table 2: Acceptance rate of test 2 and test 3.

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