# Remote facade surveying

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**Abstract**

Unfortunately for those studying topics ranging from the history of architecture to the potential for cites to improve their energy efficiency, there is no worldwide inventory of our built environment. This paper helps to solve this problem by showing how by using publicly available satellite and street level views it is possible to remotely and accurately measure the dimensions of buildings and their main components such as width-height ratios or the fraction of a facade that is glazed.
This novel approach is applied to the question of fenestration by remotely completing a survey of 124 randomly selected buildings in 6 cities. The accuracy of the method is verified using a subset of buildings for which the dimensions are known. The results provide the first estimate of how glazing ratios vary with location.
The approach is transformative and shows that with a combination of publicly available images and the use of crowdsourcing it is now possible to accurately and remotely survey complete cites and obtain the dimensions of major retrofit elements, or make studies of the evolution in time of various architectural elements

*Keywords:* Buildigns; windows; surveying; stock; remote.

## 1. Introduction

Buildings are responsible for a large proportion of the carbon emissions in developed countries (around 40% according to [1]). This makes the sector a natural target for reducing energy use in buildings, particularly as it is known that this is a sector that could reduce its energy use substantially [2]. A major missing element in our understanding unfortunately is that very little is known about the current building stock in most countries.

The focus of this paper is made what we know is one of the most important elements of the building envelope: windows. Windows are related with almost every aspect of the behaviour and physics of a building, for example: energy use, air quality, wellbeing, etc.

Xiao et al. created a fully automated tool to identify building blocks and building elements [3]. In their work the windows and other features are considered to provide an aesthetically realistic result than an informative model. Rundle et al. also used Google Street View to audit neighborhood environments [4]. Although in this case the authors looked for informative models, little attention was put into the exact features of the buildings as they concentrated on the characteristics of the neighbourhood with respect to health concerns. The work of Haugeard et al. [5] could be considered as more focused on finding window geometry in buildings. In their work, they present an algorithm that they claim finds the windows of a given façade. Their algorithm is tested with 300 images in which 70 of them have real windows. The algorithm seems to find windows automatically but does not investigate glazed or openable areas and it was not used to perform any kind of window survey on a variety of buildings.

In the work presented in this paper a novel surveying tool is introduced to identify window geometry and characteristics. However this approach is a general one with applicability to many other aspects characterising the world's building stock. The result is an application with a graphical interface that allows pictures of buildings from any location to be analysed to generate the area that can be opened, and the area that is glazed. With this tool, more than 100 facades were analysed to perform a survey of facades and windows in six major cities across the globe. This preliminary survey was used to analyse important parameters such as window to façade ratios or frame to window ratios; in addition a new parameter was introduced that relates opening area to glass area ratio. The authors believe that this ratio is important as it gives an indication of the balance that will exist between solar gains and potential ventilation.

The paper comprises methodology, results and conclusions, followed by further work, acknowledgments and references.

# 1 Nomenclature

| | |
|---|---|
| *lat* | latitude |
| *long* | longitude |
| d | distance from the camera to the façade in the direction of the focal axis |
| α | angle of the façade with respect to the focal axis |
| r | scale factor for google maps |
| fov | field of view |
| f | focal length |
| H | dimension of the sensor in the vertical axis |
| W | dimension of the sensor in the horizontal axis |

**2. Methodology**

The methodology used is in essence the resolution of a series of problems. For example, street view images do not include dimensions, so the size of a facade that is being viewed is unknown. This means it is impossible to discover the size of any building element. We show in the following how these problems were solved.

*2.1. Connexion with Google Maps and Google Street View*

For each location in the globe that is going to be surveyed, the user is located in the closest Google Street View point. After that, the user can adjust orientation, pitch and field of view of the camera to frame the façade to be studied. Once this is done, the tool needs to obtain the location of the camera; this is not necessarily the same as the input location. To get the exact point the command in Code 1 was used.

http://cbk0.googleapis.com/cbk?output=xml&ll=*Lat*,%%20*Long*&cb_client=apiv3 Code (1)

where *Lat* and *Long* are latitude and longitude respectively of the input. This command produces an XML file that provides the location (latitude and longitude) of the closest point in which Street View images are available. This set of coordinates are used for all the following calculations.

*2.2. Geometric calculations*

To obtain the location of the plane that contains the façade google Maps was used. For this, all facades are considered planar. Having planar vertical facades allowed us to define the plane of the façade with the parameters ‘d’ and ‘α’ shown in Figure 1(a). Parameter ‘d’ is calculated in pixels. Ten distances were measured using Google maps’ measuring tool to obtain the factor that turns ‘d’ in meters. (see Figure 1 (A) and (b)):

The parameters that are left to calculate the projection are ‘H’ and ‘W’ that were calculated by empirical correlation.

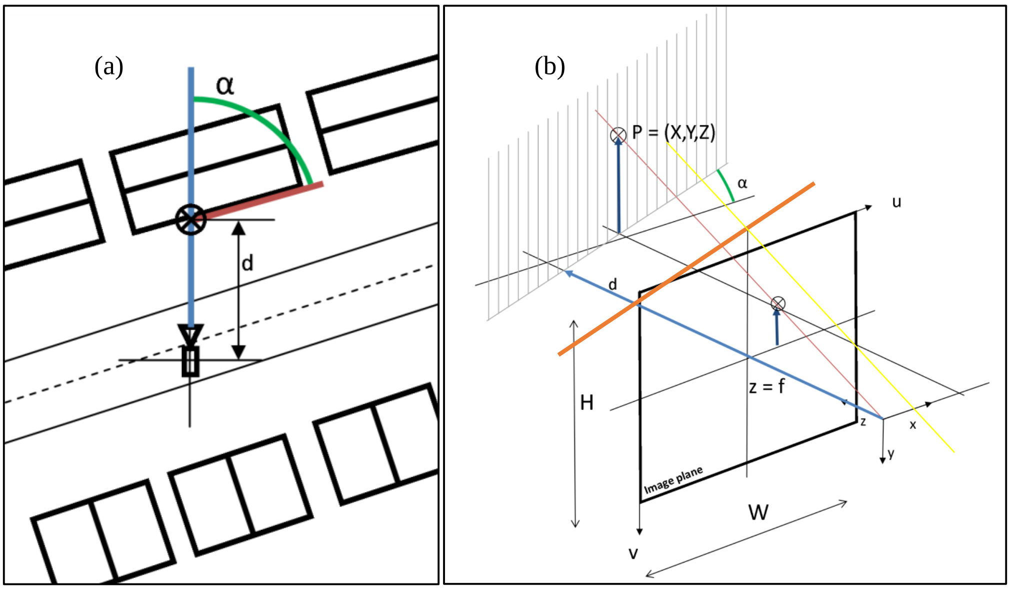


Figure 1 - Diagrammatic view of the map image of Figure 1 and main measurements (a) and representation of the projection in 3D (b). The blue line is the z axis and the focal line of the camera, the red line is given by the user by clicking the map and it defines the angle of the plane of the facade α (green).

### *2.3. Description of the survey*

In this work, a window survey was performed, but the approach could be used with many other building elements. Six major cities were selected, and a cloud of random points within those created as sampling locations. The cities were selected in different continents to ensure that the study was as broad as possible. The cities were: London, New York, Lima, Johannesburg, Sydney and Tokyo and Exeter for calibration purposes. The cloud of points of each city was created by sampling two uniform random variables representing the radius and the angle of the point with respect to the centre of the city and the parallel passing through it. It should be noted that this kind of sampling generates more points as one get closer to the centre of the city.

As previously said, for every location in the city, the tool provides with the closest location where Street View is available. At that point, the interface allows changing the orientation of the camera, the pitch and the zoom, to select the view that will fit best the façade that wants to be study.

### *2.4. Validation*

The Exeter City Council provided plans of a selection of fifteen properties in the city of Exeter to allow the system to be validated. This required knowing at least one dimension of the façade and the windows dimensions of the properties. The plans were provided on paper of A5 size with a scale of 1:100. This means that the error when measuring dimensions in these plans by a caliper was of the order of 100 x 0.2mm = 20cm.

The measurements carried out gave an error in absolute dimensions of -0.87 m in façade width with a standard deviation of 0.62 m. The absolute error for the width of windows had an average of -0.20 m and standard deviation of 0.19 m.

With respect to the perceptual errors in the ratios, it was seen an average error of -1.67% with a standard deviation of 6.39%. It should be noted that the authors found it difficult to find the termination of the façade in terraces and semidetached houses, thereby introducing another source of error.

## **3. Results**

The six cities mentioned in the previous section were surveyed at random points.

Johannesburg seemed to have many *villa* style houses what means that the façade is away from the road and in most cases hidden behind a fence, wall or bushes. This made it very difficult to sample the city and resulted in only two façades being surveyed although many locations were evaluated. Due to the small dataset, the results for this city should be ignored.

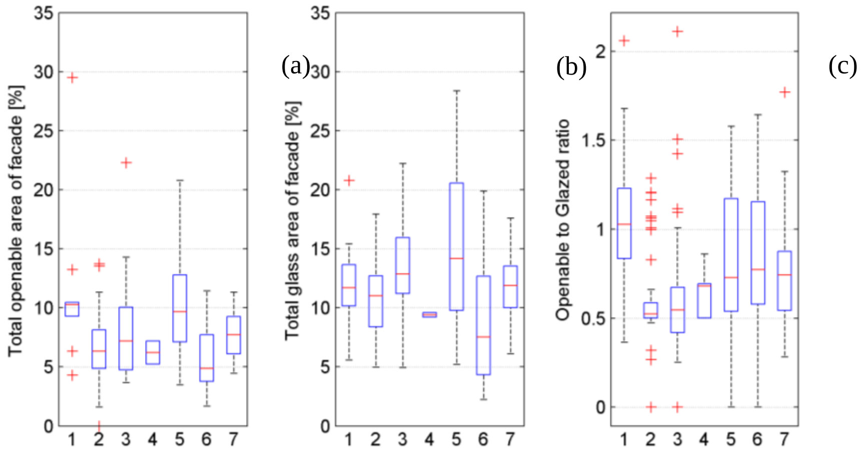


Figure 2 - Graphs showing percentage of openable area of façade (a), percentage of glazed areas of façade (b) and openable to glazed ratio per façade (c).

A total of 124 domestic facades were surveyed with a total of 837 windows. In London, 20 facades were surveyed with 42 windows; New York had 27 facades with 351 windows, Lima 20 facades with 93 windows, Johannesburg 2 facades with 18 windows, Sydney 20 facades with 166 windows and Exeter 15 facades with 52 windows.

The first factors studied were the percentage of façade that is openable and the percentage of façade that is glazed this is shown in Figure 2 (a) and (b). In addition to these common representations of fenestration, the openable to glazed ratio for the whole façade was also calculated (Figure 2(c)). This was considered as an important indicator as it relates two crucial parameters in building physics: potential ventilation and solar gains.

Figure 2 (a) shows that the ranges of openable areas in New York(#2) and Tokyo(#6) are the lowest, but this can also be seen in glazed areas, particularly for Tokyo(#6), this suggests either small fenestration percentages or large frames.

Sydney (#5) and Tokyo (#6) present a very large variability of the openable to glazed ratio and therefore no clear conclusion can be extracted from it but that the situation will be highly case dependent in each building. It was seen that the range of openable to glazed ratio in Exeter is significantly lower.

The boxplot graph of the frame percentage in Figure 3 (a) shows how the frame ratios in windows are rather substantial. Although one may think that frames are only a small percentage of a window, they actually account substantially to the total area. It can be seen in this figure how London (#1) and Exeter (#7) show the highest range of frame percentage of all the cities (Johannesburg [#4] should be ignored, as the small was too small). This could well be because more double glazed windows were surveyed in these cities, it was seen that this type of windows have larger frame percentages. Lima (#3) however, had fewer double glazed windows and more poor quality ones. These windows have smaller frame ratios as it can be seen in the figure. New York (#2), Sydney (#5) and Tokyo (#6) show a larger average range (from 10% to 50%). These large frame percentages were seen in double glazed small windows (with areas of around 0.25 $m^2$).

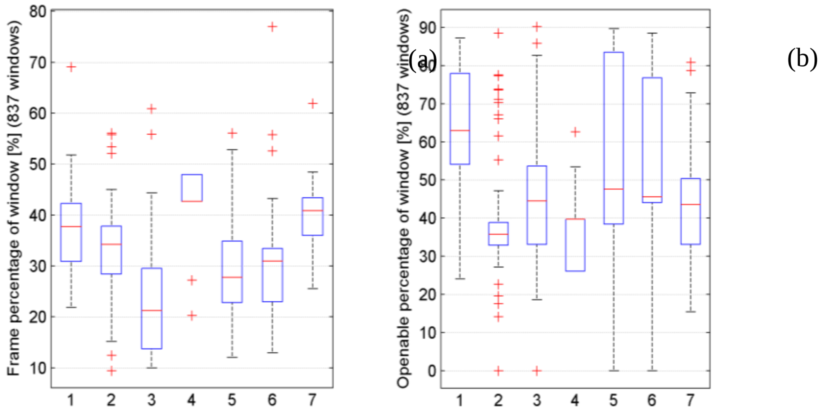


Figure 3 - Graphs showing frame percentage per window (a) and openable percentage per window (b).

Interesting findings can be obtained from Figure 3(b). Small opening areas are seen in New York (#2), however many outliers can be seen that have larger openable percentages. This tells that depending on the case house one find different window opening sizes; but also, that the majority have small openable areas which go in accordance with the overheating problems seen in New York.

The openable percentages in Lima (#3), Sydney (#5) and Tokyo (#6) seem to be the best in terms of available openable areas in windows although this parameter varies across the three cities. The last two seem to have the largest openable percentages, but also the lowest.

## 4. Conclusions

The surveying tool here presented has shown to have a great potential. Although there are errors in the measurements, a post-processing correction could be done to improve the quality of the results. The correction using homography could give a robust and accurate method for calculating ratios such as fenestration percentage, frame ratios and other parameters of interest and it is suggested for further work.

From the data gathered here, and contrary to popular belief, the frame percentage of windows is rather substantial, being close to 35%. This finding alone is of great value to the community of building modellers as this parameter can have a substantial impact on the energy and daylighting simulations. It is hence suggested that larger frame ratios are considered in future research.

The openable to glazed ratio for windows was introduced in this paper it is believed that this factor will be of great importance with a changing climate where extreme weather events are going to be more common and buildings will need to be more versatile and adaptable. Providing good ventilation will be key in fighting overheating. It has been seen that windows in New York have in most cases a smaller openable area than glazed area; this could lead to greater problems of overheating. In the case of London, it has been seen that the variability of this factor is large and in general larger than the other cities. However, there are still a substantial number of buildings in which this factor is small and may be prone to overheating.

Although somewhat anecdotal, it was seen that in Exeter window refurbishment aimed at reducing winter heating costs has led to windows with a radically small openable areas which means less resilient buildings with respect to summertime overheating. If this was a general observation, then this indicates a disconnect between strategies designed to mitigate against climate change and those to do with adaptation.

In general, it is believe that this tool has great potential and opens the door of crowdsourcing surveying for buildings, an inexpensive global way of learning about the key features of buildings.

## Further work

It is believed that the set generated in this study can be used to educate a computer vision tool able to recognise automatically building features. This being possible one could survey windows and other building elements in thousands of buildings automatically with almost no human effort.

## Acknowledgments

The authors would like to thank Dr Thomas Lovett his contribution to this study. This research has been performed in the project ENLITEN (Energy literacy through an intelligent home energy advisor) funded by the EPSRC (EP/K002724/1).

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