3-D GEOMETRICAL MODELLING AND SOLAR RADIATION AT URBAN SCALE - MORPHOLOGICAL OR TYPOLOGICAL DIGITAL MOCK-UPS?

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ABSTRACT

Studies regarding solar energy at the neighbourhood scale always have to deal with the size and the complex geometry of a real built context. Three-dimensional modelling techniques allow visual reproduction of formal features and solar performance of a city portion. Nevertheless, the definition of the right level of detail (LOD) is always a crucial point when creating digital mock-ups.

On the one hand, currently available computational resources are not totally able to support the exact representation of a building cluster and the simulation of environmental phenomena is often based on parametrical analyses. On the other hand, a drastic geometrical abstraction could discard important information and affect the reliability of solar predictions.

This study aims to identify the most suitable LOD to simulate the solar performance at the *mesoscale* of the city. To do this, the direct radiation access within a building cluster is assessed by employing virtual models with different approximation degrees.

This comparison allows assessing the margin of error between different levels of detail and discussing about benefits and inconveniences of the two approaches. The results might be elaborated to define a rank of *deviation factors*, useful to evaluate the margin of error provided by generic models with regard to solar predictions.

Keywords: geometrical 3-D modelling, mesoscale, morphological and typological mock-ups, LOD, solar potential predictions, roughness

INTRODUCTION

The development and application of three-dimensional virtual models in the field of environmental studies offer great facilities to the research regarding solar access at the scale of the city district [1]. Traditional graphical methods [2] impose, in fact, a high degree of abstraction and provide information that is often limited to a schematic or two-dimensional representation of the urban context. Digital tools permit, instead, to handle large amounts of data and reproduce the complexity of a real urban structure considered as a whole system.

The employment of digital mock-ups for solar simulation allows for simultaneous evaluation of energy gains on different surfaces and ensures more accurate results. However, currently available hardware and software resources still have some limitations in exactly reproducing the complex interaction between the solar phenomenon and the extremely heterogeneous geometry of an urban portion. Therefore, a certain approximation degree is necessarily required by *mesoscale* modelling.

At the same time, applying drastic simplifications and assimilating the irregular urban fabric structure to a continuous array of identical blocks might cause the loss of relevant information and seriously affect the reliability of final outputs.

What is, therefore, the correct level of detail (LOD) for 3-D digital mock-ups at the neighbourhood scale? What is the relevant geometrical information to enclose, in order to get the right balance among calculating time, processing power and confidence of solar results?

Previous research was developed about the effectiveness of generic models for environmental analyses [3, 4] and about techniques for a simplified spatial representation of complex urban scenes [5, 6]. Outcomes of those studies commonly demonstrate the significant influence of morphological specificities on the amount and distribution of solar energy collected. Nevertheless, the possibility to exploit simple and synthetic models is not rejected at all, but it asks for some specifications.

The definition of a correct LOD for virtual models is firstly related to the final purpose of the solar analysis. Furthermore, it should be considered that the effects of any simplification action might differently affect solar predictions, depending on the *uniformity* of the original configuration and on the position of the exposed surfaces.

This paper deals with the assessment of solar potential on building façades and roofs by means of digital mock-ups with different levels of detail. The main purpose is to establish the most suitable LOD of 3-D models for solar simulation at the district scale. More specifically, it aims to evaluate the extent to which an identical simplification process might affect the solar potential of horizontal and vertical surfaces with regard to different degrees of *morphological roughness*. This kind of approach shall permit to identify the variable *deviation factor* associated to the application of generic models to different urban contexts.

METHOD

This study is based on the comparative analysis of solar predictions provided by the use of *morphological* and *typological* models. The former class keeps relevant geometrical specificities of the real urban form; the latter consists of a homogeneous simplified pattern, shaped according to the general and average spatial features deduced from experimental data.

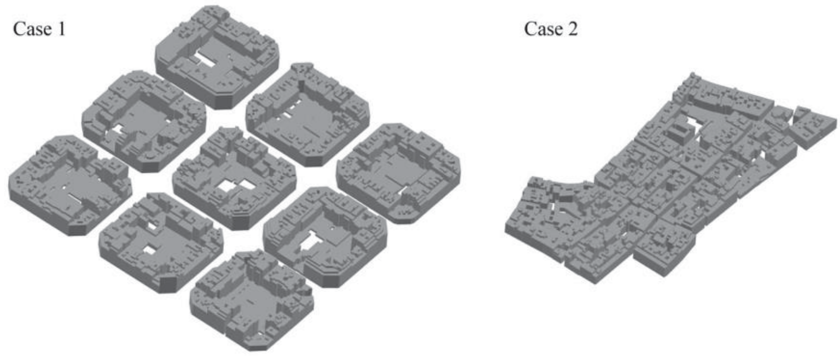
Two urban fabric samples with very dissimilar formal structures were selected in the metropolitan area of Barcelona (Spain): the *Eixample* district (Case 1) is the result of a specific design and stands out for its ordered network; the *Barri Gotic* area (Case 2) keeps the typical features of an old city centre with narrow streets and irregular blocks (Figure 1).

Figure 1: Aerial view of the selected urban fabrics: Eixample (left) and Barri Gotic (right). Source: https://maps.google.es/

Morphological modelling

The *morphological* models (class A) were built on the basis of the cadastral plans which contain data about the number of floors, *patios*, courtyards and staircases of every block. Direct observation and photographical surveys were employed to complete and validate the available information. By assigning a height of 3m to each floor and extruding the plot footprint by computer-aided design techniques (software *AutoCad*), a 3-D reproduction of the existing buildings was therefore obtained.

The level of detail of these models is similar to level LOD2 of the CityGML official OGC Standard [7]. This means that the positional and height accuracy is about 2m and objects with a footprint of at least 4m x 4m are included (Figure 2).



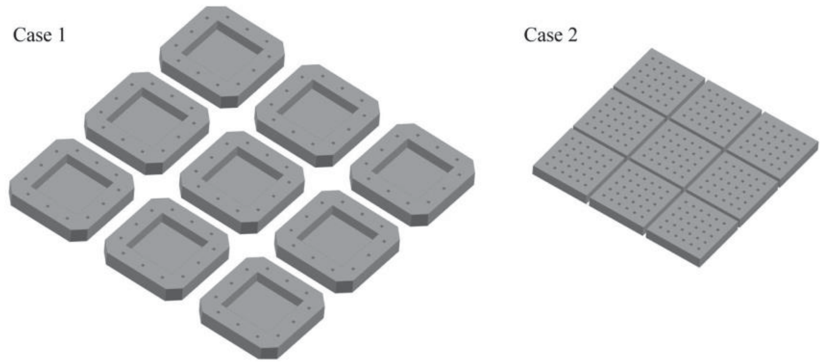
	Case 1	Case 2
Block volume	174.839	74.134 m³
Porosity	0,77	0,33

Figure 2: Morphological models of the Eixample (left) and Barri Gotic samples (right)

Typological shaping

The construction of the two *typological* models (class B) was based on the average dimensions determined by means of the *SpaceCalculator* method [8]. This tool allows calculating a series of indicators which express the abstract spatial properties of an urban area by mutually relating empirical data through mathematical functions (Fig. 3).

In order to reproduce the right proportion of full and empty spaces, the overall volume and the coefficient of *porosity* [9] were set equivalent to those of the *morphological* mock-ups (with a margin of error of about 2-3,5%); the proportions and distribution of voids were arranged according to the prevailing distinctive characteristics of the real urban fabric. The level of detail of typological models can be assimilated to LOD1 (see [7]), where the accuracy is about 5m and only major-scale objects are represented (Figure 3).



	Case 1	Case 2
Height	19,80	13,80 m
Side lenght	114,90	76,00 m
Street width	25,40	4,40 m
Block volume	179.539	76.716 m³
Porosity	0,78	0,34

Figure 3: Typological models of the Eixample (left) and Barri Gotic samples (right)

Assessment of solar potential and deviation factor

The **solar potential** is defined as the ratio of solar gains to exposure surface area of roofs and façades, independently. Horizontal (**SP_h**) and vertical solar potential (**SP_v**) were assessed in samples 1 and 2 with regard to the classes of model A and B, during the months with the highest and lowest level of irradiation: July and December, respectively. The solar simulation was implemented by means of the software *Heliodon 2* [10].

The **deviation factor** (**d_f**) is computed as the percentage variation between solar potential values provided by the typological approach and solar potential values referred to the corresponding morphological method.

RESULTS AND DISCUSSION

Roofs

As a general tendency, the employment of *typological* mock-ups enhances the assessment of horizontal solar gains (Table 1). In fact, the flattening of height variations and the elimination of any protruding volumes considerably reduces the presence of obstructions on the roofs and improves their exposition to solar rays. The only surfaces that nearly do not receive any direct radiation are the covers of the minor *patios* located at a very lower level, but they do not affect the overall results, tahnks to their very limited extension.

In both case studies, the deviation factor between A and B in the month of December is more than double with respect to July (59% vs 23% in *Eixample* and 48% vs 21% in *Barri Gotic*), due to the greater impact of obstructions and of their cast shadows during the winter months.

Comparing the performances of the two urban patterns, it is observed that the values of d_f are slightly lower in Case 2 than in Case 1 (48% vs 59% in December and 21% vs 23% in July). This means that, when dealing with morphological models, the weight of shadowing on SP_h is more notable in the *Eixample* than in the *Gotic* district. This performance is attributable to the major presence of vertical projections on the roofs, that is to say to the higher level of *roughness* in the former case with respect to the latter.

Finally, it has to be noticed that the utter amounts of SP_h, are always higher in Case 2 than in Case 1. In other words, the simplification process does not modify the general tendency of behaviour: both morphological and typological models, in fact, evidence that covers in the *Barri Gotic* area have a bigger solar potential with respect to those in the *Eixample* district.

Case studies	Model A	Model B	**d_f** (%)
1_Eixample	17,40	27,61	**59**
2_Gotic	23,25	34,42	**48**

Case studies	Model A	Model B	**d_f** (%)
1_Eixample	155,00	191,07	**23**
2_Gotic	165,09	199,82	**21**

Table 1: Horizontal solar potential (SP_h) in kWh/m^2: December (left) and July (right)

Façades

Vertical surfaces show a more complex functioning with regard to the use of different LOD models, but some points in common with the performance of roofs can be found. The results confirm that the influence of actual geometry on solar potential is more important during the cold season: in absolute values, d_f decreases from 72% to 51% in Case 1 and from 34% to 4% in Case 2, in December and July, respectively (Table 2).

Once more, the deviation factor is more elevated in the *Eixample* than in the *Barri Gotic* neighbourhood and the difference between the two cases is more considerable than before: d_f is 72% vs -34% in the cold period and 51% vs -4% in the warm one. These data verify the tendency that was previously identified, that is to say the greater impact produced by the simplification process on SP_v in the sample 1 with respect to the sample 2.

However, while in the case of roofs the divergence was entirely attributed to the height variations, the performance of vertical surfaces is also affected by the *horizontal roughness*, that is understood as the presence of folds, protrusions and indentations with respect to the hypothetical “straight line” of a façade. Looking at the spatial distribution of the SP_v, the main differences between models A and B are effectively detected on internal fronts of the block, which show a very fragmented geometrical structure.

The most remarkable and probably unforeseen result is that the employment of typological models leads to an under-estimation of the solar potential on *Barri Gotic* façades, namely: -34% in winter and -4% in summer. This one constitutes the only case, among those which were studied, where the homogenization of irregularities (i.e. the inner outline and cavities of the block) improves possibilities for solar access.

Despite the contrasting results obtained in cases 1 and 2, it is important to point out again that the overall qualitative trend is not altered by the application of simplified models: in both A and B, in fact, the results display that the *Eixample* configuration supplies a higher vertical solar potential than the one provided by the *Barri Gotic* domain.

Case studies	Model A	Model B	$\mathbf{d_f}$ (%)
1_Eixample	11,42	19,65	**72**
2_Gotic	7,07	4,64	**-34**

Case studies	Model A	Model B	$\mathbf{d_f}$ (%)
1_Eixample	32,67	49,45	**51**
2_Gotic	24,65	23,67	**-4**

Table 2: Vertical solar potential (SP_v) in kWh/m^2: December (left) and July (right)

CONCLUSIONS AND FUTURE DEVELOPMENTS

This paper examines and compares the application of variable level-of-detail digital mock-ups with regard to the assessment of solar potential within different urban patterns.

In general terms, the results of the analysis demonstrate that the same LOD might produce changeable margins of error in evaluating possible solar gains, depending on the roughness and on the spatial characteristics of the urban pattern, on the period of the year and on the relative position of surfaces which are considered. It is, therefore, not possible to define an optimal LOD for solar simulation at urban scale nor identify a univocal deviation factor to be indistinctly applied to all classes of typological models. Nevertheless, some general considerations can be done:

- The simplification process mostly affects the three-dimensional virtual models of those urban fabrics which display a high degree of geometrical roughness.

In the present analysis, the highest deviation factor is detected in the case of the *Eixample*. The apparent morphological homogeneity that characterizes this pattern is actually limited to the street network and the external perimeter of the blocks, but the effective distribution of volumes is jagged. In fact, both the *compactness* and the *porosity* coefficients (see [9]) confirm that the *Eixample* sample has a lower level of mass concentration and a denser distribution of empty spaces with respect to the *Barri Gotic* one, which exhibits, instead, a smoother envelope.

- The employment of typological digital mock-ups might have dissimilar effects on quantitative predictions of solar potential, according to the vertical or horizontal position and to the *openness* of a surface.

In the case of roofs, the flattening of vertical projections generally produces an over-estimation of the energy collected. In the case of façades, the influence of roughness enhances or reduces the SP_v according to the greater or lesser *spaciousness* of the block internal surfaces. In fact, the deviation factor assumes positive values in wide and unobstructed spatial surroundings (i.e. the central courtyard in the *Eixample* block), but becomes negative when close and narrow spaces are considered (i.e. the resulting room within the *Barri Gotic* block). From the historical point of view, this performance might be related to the fact that the unplanned growth of the *Gotic* district probably allowed for an "instinctive" and spontaneous exploitation of available space, in order to get optimal solar exposure conditions.

- For both horizontal and vertical surfaces, the incorporation of specific details within the morphological 3-D modelling is definitely more impacting during the cold season because of the lower altitude of the sun in the sky vault and the greater impact of cast shadows.

In summary, it must be recognized that, in all the cases that have been studied, a lower approximation degree (from LOD2 to LOD1) does not modify the tendential relative solar performance of roofs and façades within a particular layout. Therefore, the employment of simplified models appears particularly suitable and helpful in comparative analyses aimed at evaluating the qualitative solar potential of different urban fabric archetypes. This kind of approach might be useful during the early decision steps of the design process, in order to fit urban design solutions and predicted daylight and thermal requirements.

However, specific attention should be paid to the simplification process, particularly to the definition of proper criterions and tools to regulate and implement the transition from a morphological reproduction to a typological representation of the city at the mesoscale. The manual method applied in this study proves to be valid and reliable, but displays some restrictions in the simultaneous handling of several dimensional and formal parameters. For this reason, the typological modelling necessarily requires a certain approximation degree.

A *parametrical* approach, supported by appropriate computational and modelling software, is strongly recommendable for further investigation about 3-D digital mock-ups and solar potential assessment. This kind of method would ensure a greater rigorousness with regard to the consistency between different level-of-detail models and to the assumption of generally applicable results. Furthermore, it would enable systematic processing of digital mock-ups and solar comparative analyses extended to a wider series of urban cases.

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