Urban Rules and Morphology Analysis as Support to Solar Performance in Passo Fundo/RS, Brazil

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Abstract. The expansion and densification of cities should be planned to ensure minimum health conditions for buildings. In this sense, this study is interested in the right to solar access for buildings using the analysis of solar envelope to propose urban forms that guarantee this right. The study is in the exploratory phase, and it is applied to the city of Passo Fundo, Brazil. The study started from an analysis of the pre-existing morphological structure, and the solar envelope was generated using the Ladybug tool plugins for Grasshopper and Diva applications in Rhinoceros software. The results showed that the pre-existing urban form has low solar performance, evidencing the need to review construction rules according to the pattern and positioning of lots. Thus, it is expected to be counterbalanced by the revision of urban rules, proposing subsidies for the reformulation and adequacy, or creation of new legislation.

1. Introduction

Decisions on urban design are crucial to establishing rules that determine the performance of urban environments and should be incorporated by local urban rules. The urban form spatially defines relationships between human activities over time. As a result of all these relationships in the city, there is considerable variation in the levels of exposure to the negative consequences of urban transformations. Moreover, the prioritisation of real estate market conditions has produced urban areas that present themselves as quickly built clusters of buildings and low levels of natural lighting and ventilation (1).

Several studies have been discussing which urban design model is most appropriate for sustainable and healthy development in cities (1) (2) (3). The results point to a more compact city, with better use of existing infrastructure, reduction of displacements in cities and dependence on air conditioning and artificial lighting (1) (4). In this context, the right to the sun is considered a relevant aspect, because regardless of location, the sun is necessary for adequate conditions of health in salubrious indoor environments.

The Brazilian standard regarding thermal performance of buildings provides general constructive guidelines according to the Brazilian bioclimatic zoning (5). However, solar access is essential for climate zones 1, 2 and 3 (13.7% of the territory), where it is essential for comfort and health in built environments (6) (7) (8) regardless of the use of complementary heating systems.

According to the Climatological Normals of Brazil, for the historical series 1981-2010 (Figure 01), the average annual temperature for Passo Fundo ranges from 18 to 20 °C (9).
Even in the hottest month of the summer period (February), the average temperature is not more than 25 °C, ranging from 10 to 12 °C in the coldest month (July). This characteristic makes evident the need for heating, including in warmer periods, and justifies the concern regarding solar access, discussed in this study.

In the Brazilian context, the urban construction rules that result in the urban morphology are specified by the Municipal Master Plan - MMP. Nevertheless, (10) we argue that the MMP does not address the topic of solar insolation adequately. In this sense, access to the sun is little considered in the internal and external spatial composition of the built environment, resulting in buildings that have higher energy consumption to ensure comfortable conditions to occupants (6).

Thus, this study aims to propose a methodological analysis able to improve the urban rules and guarantee solar access to the building. Therefore, the work uses solar envelope analysis techniques as a tool to verify the geometry of buildings more suited to pre-existing urban design in the city of Passo Fundo-RS, Brazil. The following study should open discussion about the urban performance of the current building rules. The rules defined by the urbanism instruments using solar envelope analysis can help to review the future Brazilian Master Plans.

2. Definition of analysis methods

The solar envelope has become a concept of urban planning related to building availability for solar access in a certain period, to get the maximum benefits of solar energy and to make built environments more comfortable and sustainable (11). However, its applicability in the urban design requires a systematization of the urban form that allows its translation into different rules and zoning. Therefore, it is necessary to analyze the pre-existing, reconciling morphology and access to the sun.

Thus, the first methodology addresses morphological analysis, based on the identification and systematization of zones with uniform urban parameters (12). The second one presents how solar envelope analysis was approached in the experiment, using Rhinoceros/Grasshopper software and Ladybug plug-in to generate the solar envelope geometry. However, if envelope analysis could be supported by free tools and software, it would be widely used for better planning propositions according to specifics features of each city. In the case of Passo Fundo/RS, it was possible to analyze and systematize information related to the urban form necessary to find other planning strategies that guarantee solar access.

2.1. Morphology Analysis

The design and orientation of the roads and blocks are crucial to orientation of the lots and, consequently, in the positioning of the main façade of the buildings (6) (10). These features
limit the implementation of projects and the choice of the best solar orientation for long-stay environments. In the case of buildings with more than four floors, solar access guidelines are even more necessary as they may impair the insolation of neighboring buildings.

The morphological elements articulate among themselves and create unique urban spaces, defined by the morphology of each articulation. Thus, the concept of urban morphology is associated with the presence of different urban tissues.

More recent approaches define the morphological uniformity by the set of “islands” or identical blocks that form an urban fabric (12).

The different blocks organized in a repetitive way (the fabric) result in urban space with different characteristics and dimensions that influence the economic and functional use of these spaces. (Figure 02) (12).

2.2. Use of the solar envelope in urban planning
The Solar Envelope concept defines the building's total floor area for a given lot, which does not create unwanted shadows in the immediate surroundings, ensuring adjacent lots access to the sun (13).

Conceptually, the solar envelope is the synthesis of a temporal and a spatial component, the sun's cyclical paths define that according to the latitude and the physical characteristics of a place (Figure 03). As such, the shape and size of the solar envelope can vary concerning the location, lot orientation, latitude, desired period for sunlight and the shading limit allowed for the immediate surroundings (14) (15).

However, these aspects condition buildings at low densities to current urban standards, considered optimal from the point of view of environmental quality, but inefficient for land use and urban mobility (4).

In this sense, (16) a simple descriptive method was created that regulates solar rights to buildings, as well as their surroundings, such as streets and public spaces (Figure 04). This method, based on the SustArc computer tool, establishes the blocking angles and maximum heights that guarantee sunlight for all facades in specific periods. In this way, the method allows
to analyze and compare different design solutions in order to determine which configuration provides the optimal built density (16). Thus, the application of the solar envelope provides greater diversity in the urban landscape due to the different geometries, heights and setbacks generated in each lot (6) (10) (14).

Figure 4. The maximum height of buildings in Tel Aviv to guarantee solar rights on facades (above) and streets (below), according to different orientations (16).

Currently, with the growing demands to reach the performance standards of architectural projects, the use of environmental analysis tools has been increasing among construction professionals.

In this context, Rhinoceros/Grasshopper software has been one of the most used platforms by designers today, as it has functional versatility with several environmental analysis plug-ins, such as the Ladybug plug-in (17). The plug-in performs parametric environment simulation from interfaces with other validated software, such as EnergyPlus, Radiance and Daysim. Besides, users can customize the tool based on their needs and contribute to the source code (17).

In this study, the solar envelope programming routine was conducted following the steps:
1) location setting according to latitude,
2) import .dwg files into Rhinoceros,
3) creation of polygons in the chosen lots, and
4) creation of building volumes through programming in Grasshopper.

The period chosen for the analyses was the winter solstice, which according to the Brazilian standard that defines the building guidelines for each bioclimatic zone, is the period that most requires strategies for thermal conditioning of indoor heating (5). The analysis time was from 9 a.m. to 3 p.m. at 1-hour intervals.

3. Results and discussion
The exercise was performed by the master’s degree students of the Post-Graduate Program Stricto Sensu in Architecture and Urbanism during the Disciplines of Urban Morphology and Special Topics in Urban Climatology, in the second semester of 2017, under the supervision of the authors. The results seek to test and validate the proposed methodological structure.

3.1. Morphological analysis
The morphologic-type analysis identified six predominant block models in the city of Passo Fundo. Their shape organized them by proportion and dimension, totaling 15 typologies, as shown in Figure 5.

The Quadricular tracing is formed by blocks with a ratio of up to one and a half times one side over the other (a = 1b-1, 5b). This tracing is found preponderantly in average size, mainly in the central region of the city. According to its area, the square blocks were classified in:
• Small grid: up to 10,000 m² (dark grey),
• Average grid: between 10,000 m² and 20,000 m² (medium grey),
• Large grid: above 20,000 m² (light gray).

The Rectangular format is diverse in shape and size, and they were previously classified into three types according to their proportion and dimension (Table 1):

| PROPORTION OF THE BLOCK                        | DIMENSION                        |
|-----------------------------------------------|----------------------------------|
| Rectangular type A where 1.5 b < a > 2.5 b    | Small rectangle: up to 8,000 m²  |
| Rectangular type B, where 2.5 b < a < 4 b     | Medium Rectangle: Between 8,000 m² and 15,000 m² |
| Rectangular type C, where a > 4 b             | Large rectangle: Above 15,000 m²  |

Thus, the analysis resulted in nine types of rectangles, which are found mainly, though not exclusively in the peripheral subdivisions.

It is noteworthy that there was flexibility in the classification of block types, incorporating those that were predominantly rectangular or quadrangular, also those that presented slightly angular or curved shapes, due to their adaptation to the pre-existing urban grid or some geographical condition. Such flexibility was necessary as most of the rectangular blocks in the city of Passo Fundo are not presented as a perfect polygon. Lack of flexibility would mean excluding more than 50% of the blocks from performance analysis.

Figure 5. classification of the Passo Fundo blocks, based on the digitized aero photogrammetric survey on CAD platform (18).
The triangular trace is found in the urban mesh as a projected block and a residual block at the junction of angled roads. The irregular layout was also recurring. Because triangular and irregular blocks have varied angles and asymmetric shapes, which results in entirely different lots from each other, these types were disregarded from this exercise.

In total, analyses were performed for four lots in 6 blocks, distributed to the nine students involved in the experiment, which should result in 216 study lots. In the study, erroneous or mistaken analyses were also discarded. Thus, this study worked with the selection of 107 integral lots of 29 blocks, which were differentiated by the solar orientation of the front lot division lines. These lots were analyzed by the solar envelope methodology, which explored two approaches:

a) The solar envelope analysis for different urban areas (where the lot and block were inserted), with volume, built following all current MMP rules: Occupancy Rates - OR; Coefficient of Use - CU; Minimum Frontal, Side and Rear Yard setbacks.

b) In this case, we tried to exhaust the utilization coefficient in options that prioritize the maximum occupancy rates over height, or that maximize the height over the occupancy rate exhaustion. In this option, it was considered as the minimum constructive dimension of 7 meters for frontal yard setback. In both cases, the minimum setbacks provided for in the MMP were respected.

c) Creation of the maximum volume built in compliance with the existing OR and CU rules but using the solar envelope to propose variations on the frontal, side and rear yard setbacks, in order to verify if these changes would allow better solar access.

The results served as a comparison regarding the densification and occupation rules and the constructive positioning rules in the lot.

3.2. Solar analysis
The results of the first analysis are presented by examples for Extensive Occupation Zone (ZE), Intensive Occupation Zone 1 (ZOI 1) and Transition Zone (Table 2).

From the chosen examples one can see that the results showed a wide range of situations, in which some lots simulated according to the MMP intensity rules did not exceed the solar envelope (extensive occupation zone), others exceeded quite intensively (intensive occupation zone 1). In the transitional occupation zone, analysis of the solar envelope showed that current building rules also exceed the solar envelope, but less intensely.
Table 2. Synthesis of urban regulations and solar envelope analysis

| MUNICIPAL MASTER PLAN | SOLAR ENVELOPE ANALYSES |
|------------------------|--------------------------|
| **EXTENSIVE OCCUPATION ZONE** |  |
| URBAN BLOCK | URBAN LOTS |
| Occupancy rate (%) | Coefficient of use | Block Typology | Identification | A1 | A2 | A3 | A4 |
| 60 | 1.2 | Foursquare | Solar orientations | NW | NE | SW | SE |
| | | | Surplus built volume | 1.2 % | 2% | 2.3% | 1.5% |

| MUNICIPAL MASTER PLAN | SOLAR ENVELOPE ANALYSES |
|------------------------|--------------------------|
| **INTENSIVE OCCUPATION ZONE 1** |  |
| URBAN BLOCK | URBAN LOTS |
| Occupancy rate (%) | Coefficient of use | Block Typology | Identification | C1 | C2 | C3 |
| 60 – 80 | 4 | Foursquare | Solar orientations | NW | SW | SW |
| | | | Surplus built volume | 75% | 72% | 65% |
The second analysis of the study sought to verify the influence of variations in setbacks within the plot so that the building had the best solar utilization. In this step, different setbacks for the different study zones were analyzed. Here we present by sample, six different conditions for an irregular block in Controlled Occupation Zone 1 (Table 3 to 7).

| TRANSITIONAL OCCUPATION ZONE | MUNICIPAL MASTER PLAN | SOLAR ENVELOPE ANALYSES |
|-------------------------------|-----------------------|-------------------------|
| URBAN BLOCK | Identification | L1 | L2 | L3 |
| Occupancy rate (%) | Coefficient of use | Block Typology | Solar orientations | Surplus built volume |
| 60 | 2.8 | Foursquare | NE | SE | SW |
| 73% | 63% | 75% |

| CONTROLLED OCCUPATION ZONE | MUNICIPAL MASTER PLAN | SOLAR ENVELOPE ANALYSES |
|-------------------------------|-----------------------|-------------------------|
| URBAN BLOCK | Identification | A1 | A2 | A3 | A4 |
| Occupancy rate (%) | Coefficient of use | Block Typology | Solar orientations | Surplus built volume |
| 40 | 1.2 | Irregular | N | W | E | S |
| 7.5% | 52% | 52% | 10% |

Table 3. Case 1 – Solar envelope analysis according to MMP
For the situation configured by the MMP, with 4 meters frontal yard setback, the built volumes were placed in the middle of the lot. North-South oriented lots had a smaller percentage of excess volume compared to East-West lots.

Table 4: Case 2 – Solar envelope for MMP limits in lots without front yard setback.

| URBAN BLOCK | URBAN LOTS |
|-------------|------------|
| Occupancy rate (%) | Coefficient of use | Block Typology | Identification | A1 | A2 | A3 | A4 |
| 40 | 1.2 | Irregular | Solar orientations | N | W | E | S |
| Surplus built volume | 1.2% | 50% | 50% | 24.5% |

With the removal of the frontal yard setback, the significant improvements regarding sun access went to the first lot (A1), north-facing, which now has only 1.2% of the volume outside the solar envelope.

Table 5. Case 3 – Solar envelope for volume of building without rear yard setback.
With the removal of the rear yard setback, the same situation was presented for the south-facing lot (A4) and resulted in only 2.2% of the volume outside the solar envelope.

Table 6. Case 4 – Solar envelope for volume of building in lots without left side yard setback.

| OCCUPATION ZONE | SOLAR ENVELOPE ANALYSES |
|----------------|-------------------------|
| MUNICIPAL MASTER PLAN | | |
| URBAN BLOCK | URBAN LOTS |
| Occupancy rate (%) | Coefficient of use | Block Typology | Identification | A1 | A2 | A3 | A4 |
| 40 | 1.2 | Irregular | Solar orientations | N | W | E | S |
| Surplus built volume | 8% | 30% | 50% | 9% |

In the case of the side yard setback removal, the influence was minimal in the north and south orientation lots. Removal of the left side yard setback reduced the excess volume in lot A2 by 20%, possibly due to the irregularity of the court compared to the original case.

Table 7: Case 5 – Solar envelope for volumes in lots without right side yard setback.

| OCCUPATION ZONE | SOLAR ENVELOPE ANALYSES |
|----------------|-------------------------|
| MUNICIPAL MASTER PLAN | | |
| URBAN BLOCK | URBAN LOTS |
| Occupancy rate (%) | Coefficient of use | Block Typology | Identification | A1 | A2 | A3 | A4 |
| 40 | 1.2 | Irregular | Solar orientations | N | W | E | S |
| Surplus built volume | 10% | 74% | 74% | 10% |
The removal of the right-side yard setback had a 20% increase in the excess volume of lots A2 and A3 compared to the original case.

From these samples one can see that the shape and solar orientation of the conditions of the lot different behaviors and performances require mishaps and better-adapted building rules.

4. Conclusions
The analyses presented, although derived from experimental study, allowed us to obtain some preliminary conclusions, which guide further research.

Firstly, the study highlights the inadequacy of the MMD rules to the characteristics of the lots that vary according to the shape of the blocks and their solar orientations. By disregarding the morphology, the MMP generalizes urban densification and setback rules, which although justified as sun access strategies, become inefficient or harmful in many cases. In this sense, the study concludes that the pathways were determinant for the conformation of blocks and lots. In the case of the city of Passo Fundo, the predominance of roads in the NORTH-SOUTH orientation is more suitable for the placement of the lots front yard setbacks on the block, as it allows greater access to the sun by the buildings. Such information may support rules for the construction of new subdivisions.

Secondly, the work was organized in such a way that the analyses sought to cover the multiplicity of situations: the proportion of lots, setback ratio and solar orientation of the selected lots, as well as their location within the different zoning. However, the plethora of exploratory study options made comparisons difficult. We realized that the rules of the plan are not suitable for all lots studied, but as each lot was specific and the rules of the Plan varied very little, we cannot get answers about the MMP rules that would allow densification without impeding the right to Sun.

The need was found to repeat the analysis using a fictional lot-type strategy, in order to compare the behavior of the solar envelope for different batch patterns (proportions and dimensions) in different positions on the blocks and according to different solar orientations. In this way, we can verify possibilities of occupancy rates, coefficient of uses, the minimum setbacks or even disregard them if applicable.

Third, we noticed that the blocks and their consequent lots are similarly grouped in large areas of the city because subdivisions built them. This situation allows a grouping, systematization and incorporation of these blocks as a basis for a new zoning proposal for the building rules. This result should not be used as the sole parameter for the definition of zoning, uses and building rules; however, it should not be ignored.

Finally, the analysis also points to the real possibility of restructuring these rules in order to guarantee solar rights, since two of the main areas defined by the PDM are currently under-densified, far below what the MMP predicts. The fact that it is not consolidated highlights the importance of further analyses and possible incorporation in future revisions of the Municipal Master Plan.

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