Diagrammatic information and environmental parameters: decision making in the early design phases

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ABSTRACT
In the last decades, the initial phase of the design process has been discussed from the point of view of the construction process economy contribution. In this sense, several authors highlight the decisions made at this stage as an impacting point of influence on the direct cost of the building. This concern is repeated in the cases investigated by the ZEMCH (Zero Energy Mass Custom Homes) group in Brazil, which is focused on social housing, consequently, cost becomes a fundamental factor that must be considered on these buildings’ life cycle. Furthermore, ZEMCH’s workshops in Brazil have characterized the initial phase of the design process as a process that requires speed and simultaneous control of a large amount of data by the designers. Over these perspectives, the objective of this work in progress is to verify the potential of a diagrammatic artifact as an intuitive tool of visualizing information and supporting decision making in the initial phase of the urban land subdivision design process, to obtain energy efficiency during the building’s life cycle. Therefore, diagramming information of the environmental conditions into a visualization tool, helps designers to deal with requirements of this phase and cause impact on the operational cost of the building. This research was conducted over the Design Science Research method, and concludes that although visualizing information with the aid of an artifact can play an important role
for the practical requirements of the early design phases, the solution can be potentially expanded to other purposes such as teaching, and even for users self-awareness on the operational impact.

Keywords: design process, energy efficiency, diagram, social housing, land subdivision plan.

1 INTRODUCTION

This inquiry is carried out within the ZEMCH research group in Brazil, with approximately 20 years of research experience on Social Housing in this country. This group is dedicated to a wide spectrum of fields that aims at Mass Customization and Sustainability of Social Housing Projects, from the urban land subdivision to the constructive modulation of horizontal single-family buildings, predominantly in Brazil [1]. Within this spectrum, this investigation deals with the launch of the land subdivision plan, an action that defines aspects that will influence the entire building life cycle and the cost of the social housing developments. This research connects a recent Brazilian investigation [2], which developed artifacts of automated associative design with parametric tools to be used as a tool of visualization, supporting the design decisions in the initial stages of the design process. The general question is concerned with thinking about how it is possible to encourage designers of urban land subdivision for social housing development to reflect on aspects related to environmental impacts since the very first early stages.

Every decision made on the design process has a consequence and a cost, this means that every wrong decision undertaken, lead to a higher difficulty in correcting it, and so does the cost of it. This relation is commonly known as the MacLeamy curve. This curve was revisited by Bragança, Vieira, and Andrade [3] and by the American Institute of Architects [4], where they highlight the importance of decisions in the early stages in relation to the environmental impacts and life cycle costs of a building. This Institute also notes that the energy performance is very little thought of as an initial goal, forcing changes later in the process [4]. In a similar direction, Bogenstätter [5] states that decisions taken in the early stages can influence 80% of the environmental impact ratios and building's operational cost.

In the case of social interest housing projects, the concern about the costs of decision-making in the initial phases becomes more important due to the need to optimize the investment. One of the initial steps in these projects is to define the land and urban design, which in Brazil can impact up to 65% of the total cost of the subdivision (not even considering the costs of buildings) [6]. As a consequence, it is common for the designer to be concerned with the items that most interfere in the immediate cost, such as paving services, guides, gutters, and rainwater drainage that can reach between 48% and 62% of the cost [7]. In this sense, concerns about the environmental impact and costs in the building's life cycle end up not having much attention. However, still in Brazil [8], through the survey of Index of General
Significance (IGS), it was possible to identify the users’ requirements that are most valued in these types of Projects. In this IGS, the environment and green areas are in second place and, in third place, savings in electricity and water expenses.

It is necessary, therefore, to look for techniques that the land subdivision designer can consider during the decision-making steps, that relates to energy efficiency and impacts on the life cycle. However, there is a notable absence of more intuitive tools for this purpose. The tools are usually aimed at simulation after decision-making [9], often marked by more specialized and inaccessible knowledge. In this sense, the construction of an artifact to solve this practical problem uses the Design Science Research strategy, the objective is to transform more hermetic and specific information, into definitions (visual information-diagrams) that are easier to be accessed, while still being generically accurate and understandable to designers and stakeholders. The research is based on a basic model of social housing and the Technical Regulation of Quality of Residential Buildings (Regulamento Técnico da Qualidade para o nível de eficiência energética de edificações residenciais - RTQ-R). The purpose is to make it possible for the designer to pedagogically understand the main thermal performance impact factors generated by the building plot orientation and plan of land division, anticipating requirements not normally considered in these initial land development stages. This step was evaluated by a set of experts, technically pointing out the positive and negative aspects of prescriptive definitions in a diagrammatic tool. In short, in the face of so many items to be thought about, how can we transform aspects that are inaccessible to the urban land subdivision designer into ways of making decisions more intuitively?

2 METHOD

For the development of this research, it was adopted the method of Design Science Research (DSR), a research strategy derived from the so-called “science of the artificial” [10]. This type of knowledge production comes from the design of artifacts that fulfill clear objectives, trying to point out the best solutions to the existing problems [11]. In this way, DSR is more specifically concerned with the valid and reliable knowledge produced in the design of solutions [12,13]. The DSR focuses on the development and performance of a designed artifact, with the explicit intention to better understand the function of the solutions and how they operate in the practical world [14]. This research is based on the framework proposed by Vaishnavi and Kuechler [12], with the following steps: (1) Awareness of Problem; (2) Suggestion and development of prescriptive definitions; (3) Artifact Development; and (4) Evaluation.

This article presents with more depth details the steps 1, 2, and some aspects of step 3. Vaishnavi and Kuechler [12] call this part of the research as abduction. After identifying the research problem, this
part is about understanding how to approach it. To do so, we seek to detail the chosen approach and, in addition to just reviewing the literature, an exploratory study was done to understand how experts can use their experiences in a similar context. At this moment, prescriptive definitions are reached to develop the artifact, as well as suggestions collected from experts. Thus, this part of the research was subdivided into four stages, three for prescriptive definitions, and one last of suggestions and evaluations made by experts, leveraging the awareness of the problem and the potentialities of the proposed solution. The four sub-sections are (2.1) Definition of a basic social housing unity (standard floor plan); (2.2) Characterization of basic parameters: envelope and location; (2.3) Variables score: envelope, natural ventilation, and solar radiation; and (2.4) Expert panels.

2.1 DEFINITION OF A BASIC SOCIAL HOUSING UNITY (STANDARD FLOOR PLAN)

The first step is the definition of a basic diagrammatic drawing of a standard single-storey house in Brazil. For the construction of this diagrammatic floor plan, we adopted as a reference the research made from 2012 to 2014 by Montes [1]. This author proposes a basic floor plan that is the result of a study using approximately 50,000 units, in different regions of Brazil.

The standard floor plan used this study, shown on Figure 1 (a), was adapted from Montes [1], and consists of two bedrooms, an integrated kitchen, one living, and circulation, these are considered long permanence areas (LPA). The total area is approximately 58.00 m². The study was carried out with 16 different possibilities of orientation and positioning of windows.

Figure 1. (a) modular adaptation of Montes (2016) floor plan; (b) Gypsum (1), OSB (2), pine wood + air gap (3), OSB (4), cement board (5). U= thermal transmittance (W/m²); C = Thermal Capacity (Kj/m²K)
2.2 CHARACTERIZATION OF BASIC PARAMETERS: ENVELOPE AND LOCATION

The second step seeks to define the materials of the envelope and the location according to its climatic conditions.

For the envelope characterization, this work follows the discussions held by the ZEMCH group in Brazil, using the industrialized light wood frame system [15]. A modular adaptation of Montes’ floor plan [1] is proposed to the constructive characteristics of this constructive system. The wall panel has the following configuration, Figure 01 (b). The floor is made of ceramic tile on concrete slab foundation (slab-on-ground – “radier”), the ceiling is made of ceramic tile, air gap and PVC panels, the windows present simple glass (3mm) and in the bedrooms, there are shutters. Table 1 exposes the thermal properties of the entire envelope.

Table 1. Thermal properties of the envelope.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (m)</th>
<th>Thermal conductivity (W/(m.K))</th>
<th>Specific Heat (kJ/(kg.K))</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gypsum Wallboard</td>
<td>0.0125</td>
<td>0.35</td>
<td>0.84</td>
<td>750</td>
</tr>
<tr>
<td>2 Oriented Strand Board(OSB)</td>
<td>0.0095</td>
<td>0.17</td>
<td>2.30</td>
<td>681</td>
</tr>
<tr>
<td>3 Air gap + wood structure</td>
<td>0.05</td>
<td>0.045</td>
<td>0.70</td>
<td>10.53</td>
</tr>
<tr>
<td>4 Cement board</td>
<td>0.008</td>
<td>1.75</td>
<td>1.00</td>
<td>1700</td>
</tr>
<tr>
<td>Roof tile</td>
<td>0.02</td>
<td>1.05</td>
<td>0.92</td>
<td>2000</td>
</tr>
<tr>
<td>Roof air gap</td>
<td>Variable</td>
<td>Thermal Resistance = 0.21 m².K/W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceiling PVC panels</td>
<td>0.01</td>
<td>0.20</td>
<td>0.96</td>
<td>1300</td>
</tr>
<tr>
<td>Slab-on-ground + ceramic floor</td>
<td>0.15</td>
<td>1.75</td>
<td>1.00</td>
<td>2200</td>
</tr>
</tbody>
</table>

1 The numbers indicated on the material entry are demonstrated in Figure 1 (b). Elaborated by the authors.

For the local climate characterization, this research inserted the social housing unity into a specific Brazilian bioclimatic zoning. According to governmental guidelines [16], the city of Londrina, Paraná is located in Bioclimatic Zone 03, a climate with hot and humid summers and mild winters.

The survey of data for the analysis of natural ventilation was carried out based on data from the Brazilian Institute of Metrology, Standards, and Industrial Quality [17], and climate archives [16]. The predominance of the city's winds is east and the average speed is 2.6 m/s. Solar radiation was measured using the Formit© software, where the latitude (23°17'34" south) and longitude (51°10'24" west) coordinates for the location of the city of Londrina are inserted and the incident values of Wh/m² radiation on each façade were measured.

2.3 VARIABLES SCORE: ENVELOPE, NATURAL VENTILATION, AND SOLAR RADIATION

To carry out the energy analysis of the envelope and to produce this variables score, the research is based on the prescriptive method for labeling buildings, using the Technical Quality Regulation for Residential buildings – RTQ-R [17]. This method evaluates the thermal performance of the envelope
(walls, roof and, openings) of the building, considering the bioclimatic zone. This assessment can be performed using the prescriptive simulation method. We opted to use the prescriptive method because it is more didactic and simpler to insert the building's characteristics. In this method, first a spreadsheet is filled with thermal characteristics of the building, then the calculation method is applied, after the application results returns as indicators of energy efficiency in long-stay environments, at levels ranging from A (most efficient) to E (less efficient). This research only evaluated the performance of the envelope of the building.

The spreadsheet of the method also results in indicators such as the indicator of Cooling Degree Hours – CDH\(^1\) –used in this research as a basis for the valuation. The more degrees the environment presents, the less comfortable the environment is.

Even though the envelope analysis is based on the application of the RTQ-R method, which already considers ventilation and insolation factors, based on the openings, for the performance calculations on the long permanence areas (LPA), this work points out as an important factor the in-depth analysis of the cross ventilation and the incident solar radiation results. Together these two variables play a significant role in the didactics of the diagram.

The natural ventilation design must promote airflow conditions between the openings located in at least two different facades (opposite or adjacent) of the building, allowing the necessary airflow to meet comfort and hygiene conditions. The characterization of cross ventilation is given by the presence of one or two openings necessarily oriented to the east façade (considering the city of Londrina) and the possibility of air to flow due to the presence of openings on opposite or adjacent facades. This analysis was performed on the different floor plan options.

The analysis of incident solar radiation aims to point out an optimal orientation according to the solar incidence for summer and winter, that is, to minimize solar radiation in summer and potentiate radiation during the winter. In this way, the Formit © software is applied to calculate the amount of incident radiation (Wh/m\(^2\)) on each facade, on these two critical periods. With these values, it is possible to make a detailed analysis of the orientation influence compared to solar heat gain.

2.4 EXPERT PANELS

Expert panels are recommended at different stages of the development process, they commonly seek to understand the meeting of different fields or approaches with uncertain issues. Melbourne's

\(^1\) It is the indicator of the thermal performance of the naturally ventilated building envelope and it is based on the degree-hour method, which uses a base temperature, independent of comfort temperatures, consisting of a reference temperature for comparisons. On the RTQ-R, the indicator represents the annual sum of degrees-hours, calculated for the base temperature of 26° C for cooling.
Department of Sustainability and Environment [18], suggests that using expert panels on environmental issues because results based on experience are needed. Although this methodology is discussed in this book for the involvement of citizens, the same recommendation was made in this research, analyzing a variety of informed points of view from which was able to undertake recommendations or courses of action that could enhance the problem’s solution.

This activity was carried out with the presentation of prescriptive definitions, and its intended use in the development of the artifact, for debate between two professionals with different specialties, seeking to resolve the conflict based on greater credibility. In this moment, we consulted specialists in building fields, because the final evaluation (step 5) is planned to treat with experts in planning land subdivision. Expert 1 is a Ph.D. architect and specialist in social housing and construction technology and Expert 2 is a Ph.D architect and specialist in sustainability and in design based on thermal performance. Both experts have over 20 years of experience and work in these fields for more than 10 years.

3 ANALYSIS AND RESULTS

3.1 CONSTRUCTION OF THE PRESCRIPTIVE DEFINITIONS

The application of the RTQ-R spreadsheet was carried out in 16 different situations, as shown in Table 2 below. The first column of this table presents four dispositions with different accesses (north, south, east, and west). The other columns show variations in the windows’ positioning as well as the mirroring of the floor plan. These 16 configurations deal with all plant variations to be used in the artifact, which in the next step, together with ventilation and incidence of solar radiation, receive specific scores.

Table 2. Simulation results for efficiency levels of each LPA according to the orientation of the building and openings.

<table>
<thead>
<tr>
<th>Entry Orientation</th>
<th>Plan 1</th>
<th>Plan 2</th>
<th>Plan 3</th>
<th>Plan 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Entry</td>
<td>B C C C</td>
<td>C C C C</td>
<td>C B C C</td>
<td>C C C C</td>
</tr>
<tr>
<td>South Entry</td>
<td>C D B C</td>
<td>C D B C</td>
<td>C B D C</td>
<td>C D B C</td>
</tr>
<tr>
<td>East Entry</td>
<td>C C D C</td>
<td>C B D C</td>
<td>C B C C</td>
<td>C C C C</td>
</tr>
<tr>
<td>West Entry</td>
<td>C B C C</td>
<td>C B C C</td>
<td>C C D C</td>
<td>E B C D</td>
</tr>
</tbody>
</table>

1 The letters A B C D E (A,B,C,D,E) indicates A for best score, and E for worst score, north orientation is set to the upper position ↑ as indicated beside each floor plan, elaborated by the authors.
3.2 NATURAL VENTILATION SCORES

To analyze cross ventilation in long permanence areas, the 16 configurations were presented in relation to the direction of the dominant east wind (Table 3 - analysis). Based on this analysis, scores from 0 (no rooms with cross ventilation) and up to 3 (three rooms with cross ventilation) are given. A combination of numbers and colors is used to illustrate the variation in the amount of cross-ventilation flow in the studied environments. Color grading defines dark blue as (most efficient) to white (least efficient).

<table>
<thead>
<tr>
<th>Entry Orientation</th>
<th>Plan 1</th>
<th>Plan 2</th>
<th>Plan 3</th>
<th>Plan 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Entry</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>South Entry</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>East Entry</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>West Entry</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Elaborated by the authors.

3.3 SOLAR RADIATION SCORE

From the analysis of the solar radiation incidence peak in each month for all 16 situations, a graph was constructed to illustrate the maximum and minimum values for the summer and winter peaks. This graph helps to understand the optimal orientation characterized by the direction of the largest faces oriented towards the minimum summer and maximum winter radiation (Figure 2).
Thus, building plots with smaller edges facing east and west will be identified in the diagram as guidelines for optimal orientation purposes and earned a score bonus.

4 CONSTRUCTION OF THE DIAGRAMMATIC ARTIFACT

For the development of the artifact, it was considered aspects of the envelope, natural ventilation, and solar radiation; general scores were established to guide the designer in the initial stages of launching the land subdivision and generate the building plots. It is noteworthy that, based on the different approaches taken to the analysis of these variables, the numerical scoring parameters adopted for the construction of the artifact have only the function of guiding the visual reading, creating a numerical scale. It is observed that the values referring to the envelope have greater weight, considering that it has a greater impact. However, the artifact adopts extra scores, even though it has less weight on the generic overall score, these scores are based on the results of cross ventilation and optimum solar orientation, this was made due the need of raising a didactic awareness to the importance of these two variables considering this specific climatic high-low peaks.

4.1. ENVELOPE

The result of the Cooling Degree Hours (CDH) performance, were evaluated for each room separately. However, to favor the synthesis of the information, a joint final score was defined, referring to the performance of the entire building.
In order to facilitate the numerical reading, and the subsequent construction of the artifact, multiple values of 5 for each letter referring to the performance of the rooms were established as scoring criteria, starting at 5 (worst performance - letter E) up to 25 (best performance - letter A).

The sum of the envelope values resulting from the three rooms generates a new final classification also divided into 5 scoring levels. In this case, the range of values ranges from 0 to 75 (15 points for letter E to 75 for letter A).

Table 4 shows the summation reasoning of the score established for the joint classification of the rooms in the 16 situations evaluated.

### 4.2 NATURAL VENTILATION

For the ventilation results, the number of rooms with the possibility of cross-flow ventilation from openings on the opposite and/or adjacent faces were considered as a scoring factor based on the RTQ-R [17]. Five points were measured for each ventilated room as a numerical value for constructing the diagram. Therefore, as shown on Table 4, the variation ranges from 0 to 15, considering the possibilities of applying at least no room with ventilation crossings and at most 3.

Table 4. Score result of Energy Efficiency for the different plans and Score result for the natural ventilation on different plans.

<table>
<thead>
<tr>
<th>Entry Orientation</th>
<th>Plans</th>
<th>Sum Efficiency</th>
<th>Plans</th>
<th>Sum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Entry</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>South Entry</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td>East Entry</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
<tr>
<td>West Entry</td>
<td><img src="image13" alt="Image" /></td>
<td><img src="image14" alt="Image" /></td>
<td><img src="image15" alt="Image" /></td>
<td><img src="image16" alt="Image" /></td>
</tr>
</tbody>
</table>

Elaborated by the authors.
4.3 SOLAR RADIATION

For the measurement of the solar radiation quality, 10 points were credited, the lowest score of the items evaluated. It is understood that this score is complementary to the envelope analysis, which also considered factors related to solar radiation. However, it only occurs when its longitudinal position is oriented exactly to north and south. Consequently, the fronts of the building plots, which have smaller dimensions, must face east or west.

In this case, there are only 8 situations of plants divided into 4 for the west front and 4 for the east front, which receives the possibility of extra punctuation when they are oriented exactly on the East-West axis.

4.4 THE SCORES IN THE ARTIFACT DIAGRAM

The design of the diagram was carried out in order to make it clear to the designers that different orientations of the land subdivision result in buildings that can be more or less efficient. The Diagram places the score information side by side (Figure 3a). In the centre is located the building plot, that rotates varying the orientation. Then the different plant options (grey) are placed. The next concentric circles are related to the energy efficiency of the envelope (green and yellow) and next to the natural ventilation scores (blue). The dashed line (purple) refers to the optimal orientation of the building. As the designer rotates the plan, it is possible to visualize the potential efficiencies of the buildings and consequently the land subdivision’s (Figure 3b).

Figure 3. (a) Prototype of the diagram (b) Designer working with the diagram on an urban land subdivision.
5 EXPERT PANEL ASSESSMENT

After presenting the construction of the prescriptive definitions, and its expected application of a diagram, the expert panel discussion raised a few alerts and confirmations.

(a) The conflict between the necessary generalization of the information for the early stages of the project and the transmission of wrong information could induct designers to error. Expert 2 highlighted that certain assumptions which were adopted, such as that the building will have cross ventilation, can generate misunderstandings. Likewise, the orientation of windows can be positive for ventilation, but negative for solar radiation. The resulting recommendation was that, even if such a guideline is generalized, it has traceability paths for the designers’ awareness of such regulation on these prescriptive definitions.

(b) Expert 2 still positively pointed out that the facilitated way on how the method RTQ-R was deployed, because RTQ-R is considered a hermetic process for the non-specialists. However, it was observed the need of thinking of ways to make simulation software more accessible to users. The experts did not express any recommendation.

(c) Expert 1 observed that, although the artifact is aimed at the urban land subdivision designer, we must find ways to clarify, in a practical way, the impact of the building materials choices in the assessment of the subdivision designs. He highlighted the characteristics of the envelopes and of the stilt houses. The recommendation was to reinforce in the usage procedure the definition of the characteristics of the surroundings as a first step of the procedure, paying attention to situations where there is the possibility of more than one type of wrapping, taking into account more customized processes.

(d) Expert 1 draw attention to the impact of these prescriptive definitions as a knowledge that could change not only designers’ habits but also on users. It has the power to produce awareness about the maintenance and cost of the object in its life cycle for various agents in the social housing production chain. The recommendation was to reinforce an accessible language that everyone can understand.

(e) Both experts highlighted that the pedagogical potential of such prescriptive definitions can achieve in an artifact. They emphasized that its usefulness goes beyond its use by designers of urban land subdivision and stakeholders, it could also be used in the teaching process in architecture and urbanism.

In summary, the two experts considered that such prescriptive definitions are compatible with the culture of horizontal and single-family housing projects of social interest in Brazil.

6 DISCUSSION AND FINAL REMARKS

This research presented a more intuitive way of considering prescriptive environmental definitions in the early design stages of land subdivision plan. The assessment of the Expert Panel makes it possible
to discuss aspects directly related to the need pointed out by Attia [9], which lies on the need of producing tools that reveal more specialized and inaccessible knowledge in sustainability into eased and comprehensive ways for designers. We must emphasize that the inclusion of information in these phases need to be more generalized, considering that there are still not many details of the future building. Therefore, it is necessary to transform regulatory instruments such as RTQ-R, normally employed in final stages of the project, into more generic instructions.

The experts’ assessment drew attention to the fact that such generalization implies on losses that designers must be aware of. In other words, although the experts considered the anticipation of such information to be valid, it must be carried out with the support of auxiliary material that allows a greater pedagogical understanding of the instructions. In this way, we can speculate that this artifact could be further applied to other purposes like on teaching for example, in which a generalized knowledge gets to be useful meanwhile students still don’t have an in-depth understanding, or even to get users’ awareness over to the whole operational impact that the early decisions taken can have over the whole building’s life cycle.

Further research can aid the deployment of such generalization guidelines, where the analogic artifact can be transposed into digital interfaces like on software plugins or mobile apps. Henceforth the next step in the research is building the artifact digitally and evaluating with land subdivision practitioners and stakeholders.

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