A web dashboard to support early design decisions to meet energy goals

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Abstract
This work demonstrates the achievements of a dashboard, in development, devised to support energy performance design decisions during pre-design and sketch design phases of office buildings in tropical climates. The interface is structured on principles of energetics in design to meet goals, adapted to systemic and collaborative design processes. It is compatible with design timing during early design phases, enabling browsing a vast thermal zone characteristic combinations and instantaneously quantifying cooling loads using Brazilian labeling metamodel. The dashboard has been tested in academic architectural design studios. The dashboard outputs help show design spaces for different restrictions and find specific solutions.

Highlights
- The energy tool quantifies architectural decisions' impact on thermal loads and energy performance for a specific climate.
- The dashboard design is envisioned to attend systemic and collaborative design processes during the pre-design and sketch design phases.
- The design space accessed by the dashboard is countless and uses a metamodel based on 2.5 x 1013 cases.
- The outputs are generated immediately with the input modifications, without significant delay between the raised questions and the feedback.
- The use of the dashboard improves the role of the consultants in the collaborative design process.

Introduction
A design process aiming to achieve environmental performance goals is not linear or follows steps, as usual (Lawson, 2011), however, an integrated design process with quantitative tools is necessary to support the design decisions from the early phases and defining solution spaces (Athienitis and O’Brien, 2015; Szokolay, 1984; Yudelson, 2013). Beginning at the pre-design stage, digesting problems based on bioclimatic analysis and precedents and defining a goal can help determine a solution space. In the sketch phase, generating ideas and formulating and testing design hypotheses are expected until getting a design proposal. Specifying dimensions and material properties is essential in the detailing phase to assert the goals.

Energy tools based on computer simulation have been developed for the last five decades to predict building thermal and energy performances (Kusuda, 2001). Despite the advances, their limitations difficult the application in the early design phases. A building model simulation requires details compatible with an executive project, such as accurate dimensions, thermal construction properties, and building services definitions. Meanwhile, most of the inputs are unknown or not decided yet. The dozens or hundreds of inputs have different impacts on the building's performance; however, the tools do not discriminate them sufficiently to optimize the modelling process without compromising the results. The outputs are suitable for HVAC engineers, but thermal loads, radiant temperature, air changes, and many other terms may be new for the designers (Al-Sa'dan and Blei de Souza, 2018; Wilde, 2004). Modeling, simulation, and analysis require more time than most design process timing (Hensen and Lamberts, 2011; Kheiri, 2018; Wilde, 2004): 'If the procedure takes more than 10 or 15 minutes, then it simply won't be used' (Balcomb et al., 1980). The 15-minute mark remains challenging even for experienced consultants, and the design process has not slowed since then. Designing to match environmental goals demands performance quantification, which is not a common way of thinking for architects, and interaction with experts in a collaborative and systemic design process. The collaborative process depends on a team of experts differentiated by cultural and professional backgrounds. Each expert finds a solution from their point of view and shares it with the others in a way that the team can understand. This group should judge the effect of that proposal in their areas, excluding inconsistencies and/or making suggestions to make the system work as a whole (Carrara, 2012). The success of collaboration depends on defining the team and their interdependencies, identifying the expected products, and clarifying the objective of cooperation (Kvan, 2000). High levels of collaboration and learning between disciplines indicates a fruitful interaction between the team (Charnley et al., 2011; Figueiredo and Silva, 2012; Löhner et al., 2003; Sanders, 2009).

A systemic approach assumes the design as a system influenced by the context and affected by emergent properties, which came from mutual interactions and the
organization between parts and the whole, not just as a sum of parts (Boundon et al., 2000; Charnley et al., 2011; Marx, 2011; Mascaro, 2013; Morin, 1992). One of the biggest challenges is obtaining the best of the experts and the interaction simultaneously. Therefore, the eco-charrette mode is an alternative to improve collaboration between the team and emphasize engagement from the early design phases (Smith, 2012; Yudelson, 2013). The eco-charrette is a workshop with a multidisciplinary team interacting for a few days. The design and collaboration are highlighted, and the creativity is intensified. Promoting some different ways of participation is essential, where anyone can expose their thoughts (Athienitis and O’Brien, 2015; Ineichen, 2016; Kim et al., 2011; Smith, 2012; Yudelson, 2013).

In the Brazilian context, a reliable and accurate method for assessing the energy efficiency of building design is the Inmetro Normative Instruction for commercial, public, and service buildings (INI-C) (Eletrobras/CB3E, 2021). The INI-C utilizes a metamodel for the classification of building efficiency from ‘A’ (most efficient) to ‘E’ (least efficient) (Eletrobras/CB3E, 2021). The metamodel was developed through artificial neural networks, offering a more efficient method for handling complex and non-linear models (Melo et al., 2016), such as building performance simulation. The INI-C metamodel was created with the building properties significantly impacting commercial buildings’ annual energy demand. Each range of properties was defined accurately to represent the variations found in commercial buildings, resulting in 2.5 quadrillion cases of possible combinations (Melo et al., 2016). The computational burden was reduced with the Latin Hypercube sampling method, lowering the representative sample to 1 million cases without reducing data quality (Melo et al., 2016), which was simulated in Energy Plus software. The metamodel was trained using R Language and the Caret library, maintaining the 21 building properties as independent variables and the annual energy demand as dependent. The current INI-C metamodel web interface (PBE Edifica, 2023) reduced the inputs to a minimum necessary to generate the results instantaneously. However, it requires each thermal zone’s characterization of every independent variable to test any case. This paper demonstrates the accomplishments of a dashboard in development devised to support architectural design decisions in the early stages of the design process to achieve a specific energy performance, based on the INI-C metamodel.

Methods

The dashboard assessment occurred in a design charrette, in an academic environment, with undergraduate and master’s degree architecture students representing the designers and the current researchers representing the consultants. The charrette focused on bioclimatic and energy efficiency decisions and took three hours. Two teams’ design processes were mapped to evaluate the tool application. The teams already had a schematic design at the charrette began. Due to time constraints, the teams continued the analysis independently after the charrette.

The design approaches were classified into four stages:

1. Digest brief elaboration by the consultants.
2. Share the digest brief with designers graphically.
3. Definition of the solution space.
4. Test of ideas, both in cooperation among designers and consultants.

The designers analyzed their projects on the dashboard supported by consultants, exploring solutions and testing the resources.

The dashboard

The dashboard prototype in development has a conceptual design based on Østergård et al. (2017), and the classic recommendations to integrate energetics in design from the 70s and 80s (Balcomb et al., 1980; Szokolay, 1984). The dashboard runs in Microsoft Power BI (Microsoft Corporation, 2022), and the development requires R language (R Core, 2020) and the RStudio platform (RStudio Team, 2020). Power BI has been the primary tool for designing and developing the interface. The dashboard contains 1 million simulated cases from 16 different types of thermal zones, each of which is influenced by the building envelope. A dataset for different types of thermal zones, differentiated by orientation (north, south, east, west) and pavement (floor, intermediate, roof, single floor) was prepared with an R language script (Silva, 2016), combining the possible ranges of the envelope properties (Table 1).

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof thermal capacity</td>
<td>kJ/m²K</td>
<td>0.22</td>
<td>4.50</td>
</tr>
<tr>
<td>Roof transmittance</td>
<td>W/m²K</td>
<td>0.51</td>
<td>5.07</td>
</tr>
<tr>
<td>Roof solar absorptance</td>
<td></td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Wall thermal capacity</td>
<td>kJ/m²K</td>
<td>0.22</td>
<td>4.50</td>
</tr>
<tr>
<td>Wall transmittance</td>
<td>W/m²K</td>
<td>0.51</td>
<td>5.07</td>
</tr>
<tr>
<td>Vertical shading angle</td>
<td>°</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Horizontal shading angle</td>
<td>°</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Surroundings Obstruction Angle</td>
<td>°</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Window wall ratio</td>
<td>%</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Solar factor</td>
<td></td>
<td>0.21</td>
<td>0.87</td>
</tr>
<tr>
<td>Glass transmittance</td>
<td>W/m²K</td>
<td>1.9</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Latin Hypercube sampling was used to produce combinations within the defined ranges. The number of samples for each thermal zone type was based on the number of building envelope properties. Zones with more properties have more samples, i.e.: roof zone, which has three additional properties. The constant values for other thermal zone properties, necessary to simulate via the INI-C metamodel, were obtained from reference building values provided in the INI-C manual application (Eletrobras/CB3E, 2021). Each case was simulated after incorporating these fixed values. All
cases from the 16 types of thermal zones were merged into a single dataset that contained a column with the orientation and type of floor of the thermal zone. The dataset was uploaded to the Power BI environment and the resulting dashboard was designed to systematically explore building envelope properties according to the various phases of the design process. The dashboard includes filter windows that enable users to refine and explore all cases, using slider selectors for envelope properties and annual energy demand, as well as a checkbox for thermal zone type, such as orientation and pavement type. The dashboard supports tasks associated with the initial design stages, as described in the RIBA plan of work (RIBA, 2020) and Energetics in Design (Szokolay, 1984): briefing, feasibility analysis, defining solution field, and elaborate and test design hypothesis.

The dashboard first page (Figure 1) provides an overview of the design space, using histograms to visualize envelope properties and annual energy demand. The application of filters to the design space enables identification of ranges with a higher probability of achieving the design goal in the property distribution.

![Figure 1: Dashboard first page.](image1)

In order to define the solution field and elaborate and test design hypothesis, the utilization of Parallel coordinate plots has been implemented. These plots are designed to analyze the interaction between properties for each thermal zone (Figure 4). Nonetheless, due to the large quantity of cases, which surpasses 50,000 cases per type, the interpretability of the charts can become challenging. To counter this issue, a set of five distinct chart types were developed for each thermal zone, comprising 1%, 5%, 25%, and 50% of the cases with the most favorable annual energy demand results, alongside a chart that displays all cases.

![Figure 4: Parallel coordinate plot.](image2)

Overall, the resulting dashboard provides an intuitive and user-friendly interface for exploring building envelope properties, allowing professionals to optimize building design and construction. The approach presented in this study offers an innovative tool for architects and engineers, providing insight into the behavior of different types of thermal zones under varying conditions.

**Evaluation of tool application**

The evaluation of tool application observes the design process and the product. The analysis sources are reports of students (containing their analyses, conclusions, and project decisions), the design panels resulting from the whole process and the charrette observation notes. The design process mapped shows how the dashboard supports energetics design decisions during the bioclimatic charrette. Also, it indicates if the tool improves collaboration of the multidisciplinary team.

The bioclimatic charrette process was systematically mapped in the Diagram of Representation for Course of Actions in the Design Process (DICA), proposed by Dutra (2010), and adapted for multidisciplinary teams (DICA-M, in Figure 5) by Rodrigues et al. (2019).
The DICA-M is structured based on measures for the bioclimatic design process: gathering of information, design decisions, conceptual synthesis (goals and targets, as a design intention), analysis, design synthesis (formal design solution), conjecture and Environmental Design Support Tools (EDST). The categories are arranged in individual lines, in which an action is represented by a point. (Dutra, 2010). Those points are colored according to the professional background of multidisciplinary team members (Rodrigues et al., 2019). The line between each point represents the design process chronologically.

**Results and discussion**

The consultants first presented the teams with an overview of climate analysis and bioclimatic strategies. Next, the consultants approached the dashboard to illustrate a briefing about the influence of the variables on thermal loads and energy classification, relating the occurrence distribution of each one to demonstrate tendencies of the design space. Then, filters were introduced to restrict the design space, defining the already decided or known parameters and the range of performance (25% besties) to evidence the open parameter combinations.

The team members needed help understanding the envelope properties despite the academic environment. Catalogs with thermal properties of walls, roofs, and glasses commonly utilized in construction were introduced, and the consultants assisted the teams in their initial analyses. Team 1 began defining the favorable and unfavorable parameters ranges based on the project restrictions and conditions. The team opted for the parallel coordinate plot with filters and a definition of energy criteria to assess the concentration and dispersion of cases on the other variables (Figure 6). The favorable intervals identified became criteria for designers to select materials from the catalog. The team followed this method of analysis for each façade (Figure 7).

Team 02 opted for the parallel coordinate plots to test their previously established ideas. The approach consisted of creating filters on the graph that reflected the team’s choices for the façade (Figure 9). After applying the filters, the team observed cases with high energy consumption on the axis corresponding to energy performance. Then, they searched for other properties that would positively impact the building’s energy consumption and identified viable ranges to reduce it. Like team 01, team 02 applied the same methodology for the four facades, as seen in their design process map in Figure 8.
In practice, the designers' actions concerned proposing conceptions, testing, and adapting them to all disciplines regarding restrictions, conditioning, and energetic goals. The consultants' activities involved introducing the use of the dashboard and explaining its relation with envelope properties, building systems and design strategies, assisting the teams in conducting and interpreting the initial analyses, and providing precedents of design solutions. The collaboration between architects and consultants was partially fulfilled, emphasizing the test of concepts rather than selecting different solutions spaces to come up with solutions.

- The highlights are:
  - the assessment of conceptual sketches barely developed provided feedback to evolve in direction to the solution space defined by the performance goal;
  - the overcoming of the infamous lack of timing between designers and consultants, whose answers became faster than the formulation of the question;
  - the process was very didactic and increased designers' autonomy and reduce designers' dependence on the consultants.

There were significant findings to improve the dashboard development:
- unfriendly interface regarding the thermal properties and other parameters, with users' suggestions to insert inserting illustrations, graphical schemes, and examples to elucidate them;
- only parallel coordinates plot was helpful (Figure 7 and Figure 8);
- partially justified by the design development stage, where concepts were already pre-defined, and partly due to the more intuitive and interactive readings, also directed to the task;
- designers' reports did not mention the use of sensitivity indices, histograms, violin, and correlation graphs due to the lack of understanding;
- the assessments occurred for each thermal zone without weighing the impact of the parts on the whole building's performance.

**Conclusion**

The dashboard passed the first operational test once it assisted in design decisions to reach energy targets and evidenced several aspects. Performance definition precedes any action because it restricts the solution space, which the team can browse to find combinations or test the assumptions, as demonstrated.

On the other hand, the dashboard operation may be cumbersome for designers, as confirmed in the pilot. Improving the interface and the Help support will not replace the need for the designer's learning and training commitments. Technical knowledge and understanding of the thermal properties and their impact on the design of buildings are necessary to operate a tool such as this dashboard autonomously. The pilot participants struggled with the terms U-value, shading angle, and similar, as reported in other studies by Wilde (2004) and Al-Saadani and Blei de Souza (2018).

On the other hand, the dashboard supported the consultants satisfactorily in introducing the subject, demonstrating the sensibility and relationships among the variables on the thermal zone performance, and exploring solutions space. During the eco-charrette, the dashboard was effectively utilized for several purposes, including digest brief elaboration by the consultants, sharing the digest brief with designers graphically, helping to define the solution space, and testing ideas. Therefore, the dashboard is potentially suitable for a collaborative process due to the complementarity of skills and competence and the systemic approach because it makes easily sharing and testing different points of view in accordance, attending the design process timing.
Further work

The first pilot justifies the following dashboard development:

- insertion of illustration, schemes, catalogs and help support;
- improvement of the interface design, such as charts reorganization and building performance baseline introduction.

The next design studios will introduce the dashboard early in the process, and the architectural program will be more restrictive to deepen the investigation.

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