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P-BALANCE: A DATA-DRIVEN TOOL FOR VISUAL AND INTEGRATED FAÇADE PERFORMANCE ASSESSMENT

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Abstract: In consultancy processes for the integrated performance assessment of building façades, challenges include handling multiple performance metrics related to environmental comfort and energy efficiency, tight project deadlines, complex analyses, and difficulties in communicating results to non-specialist decision-makers. To simplify this type of assessment and make it more objective, agile, accessible, and scientifically grounded, the P-Balance methodological tool was developed. It provides graphical outputs and an evaluation method that supports integrated design approaches. Aligned with the Design Science Research (DSR) methodology, its development involved the careful application of Data Visualization Techniques (DVT) to condense large volumes of data obtained through simulation. Applying P-Balance prototypes led to the conclusion that the tool effectively simplifies multi-objective assessment processes and shortens the time required for evaluations and consultancy work. It accelerates analyses and decision-making, fosters effective communication and integration, and enhances the technical maturity of design teams.
Keywords: Integrated Building Assessment. Building Performance Simulation. Data Visualization Techniques. Project Decision Making. Multi-Objective Optimization.

INTRODUCTION

Technologies that support the implementation of a Performance-Oriented Design (POD) approach are available and constantly evolving. These include computer simulation tools, multi-criteria decision-making methods [1], optimization algorithms using artificial intelligence and machine learning [2][3][4], parametric and generative design approaches [5][6], and BIM tools that support Integrated Design (ID) practices.

In a non-integrated design context— referred to hereafter as a Conventional Project (CP)—consultancies for evaluating façade performance, particularly regarding environmental comfort and energy efficiency in high-end office buildings, are typically required at advanced design stages [7].

In this context, several obstacles still pose significant challenges to effectively implementing these technologies in design and consultancy practices:

- Inadequate application of data visualization techniques [8].
- Poor interoperability between components and limitations in automation, parametrization, documentation, and scripting tools [9].
- Limited interpretability of optimization tool outputs, low architect participation in decision-making, and insufficient programming skills for workflow customization [10].
- The need to account for the subjective nature of design decision-making [11][12][13], especially considering how stakeholder behavior influences project outcomes [14][15].
- Technical, regulatory, and software constraints limiting the availability of performance metrics to represent integrated performance adequately.

Developing tools and assessment methods that can be implemented in the short term offers a promising pathway for transitioning to POD and ID approaches. These tools should enable:

1. Multi-objective analysis of design alternatives with greater objectivity and speed, aiming to reduce evaluation time and better align with project deadlines.
2. Fast, intuitive, and effective communication with project decision-makers.
3. The integration of performance assessments into the design process—not me-

rely as tools for verifying compliance with standards or certification criteria after design decisions have already been made.

PURPOSE OF THE STUDY

Therefore, the objective is to develop a methodological tool for integrated performance evaluation that enables simultaneous analysis of thermal comfort, daylighting, and energy efficiency metrics — while addressing the demands outlined above.

METHOD

The development process followed the Design Science Research (DSR) methodology, which focuses on creating and evaluating artifacts to address problems and improve current practices. The P-Balance tool was developed through the stages of problem identification, literature review, design and development, artifact demonstration, evaluation, and communication.

This article focuses on the development stage, which was carried out in four steps, as illustrated in Figure 1.

To support the tool's development, application, and testing, a database of performance metrics for alternative façade design solutions was required. This, along with other outputs and related processes, is illustrated in the flowchart in Figure 2.

Three key aspects of the base study are highlighted as essential for understanding the structure of the P-Balance tool:

1. Features of the case study: a 20-story office building (Figure 3) (Table 1).

2. Configurations of the parametric study adopted to test the tool, including variations in WWR and shading devices (Figure 4), glazing types (Table 2), and internal blinds (Table 3)

3. Performance metrics used to evaluate each parametric design alternative (Table 4).

Data	Unit	Parameters / Characteristics
Weather file	—	São Paulo / BRA_SP_Sao.Paulo-Congonhas.AP.837800_TMYx.2004–2018
Total internal load density – people + lighting + equipment	(W/m²)	40.3
Air conditioning – system typology	—	Central system – Water-cooled screw chiller – Pumping system: constant primary / variable secondary (ASHRAE 90.1-2010)
Air conditioning – heating / cooling setpoint	(°C)	20 / 24
Lighting control	—	Dimming of general lighting in perimeter zones (dimming fraction: 0.78) – LPD: 5.5 W/m², setpoint: 300 lux. Non-dimmed task lighting (1.5 W/m²)

Table 1. Summary of fixed input data for the simulated models

Source: The author. Adapted from [18].

Glass ID	Description	U-Factor (W/m²·K) - Winter	Solar Factor (SCGH) [%]	Visible Transmittance (Tvis) [%]
V27	Insulated (28mm)	1.758	27	33
V44	Laminated (14mm)	5.484	44	37
V61	Laminated (14mm)	5.486	61	67

Table 2. Simplified characterization of glazing types

Source: The author. Adapted from [18].

As a key part of the development stage, the use of Data Visualization Techniques (DVT) was adopted as a central strategy to address the following challenges:

(a) Improving agility in multi-objective assessments.

(b) Enhancing the efficiency of result communication to decision-makers.

(c) Supporting the adoption of Performance-Oriented Design (POD) and Integrated Design (ID) practices.

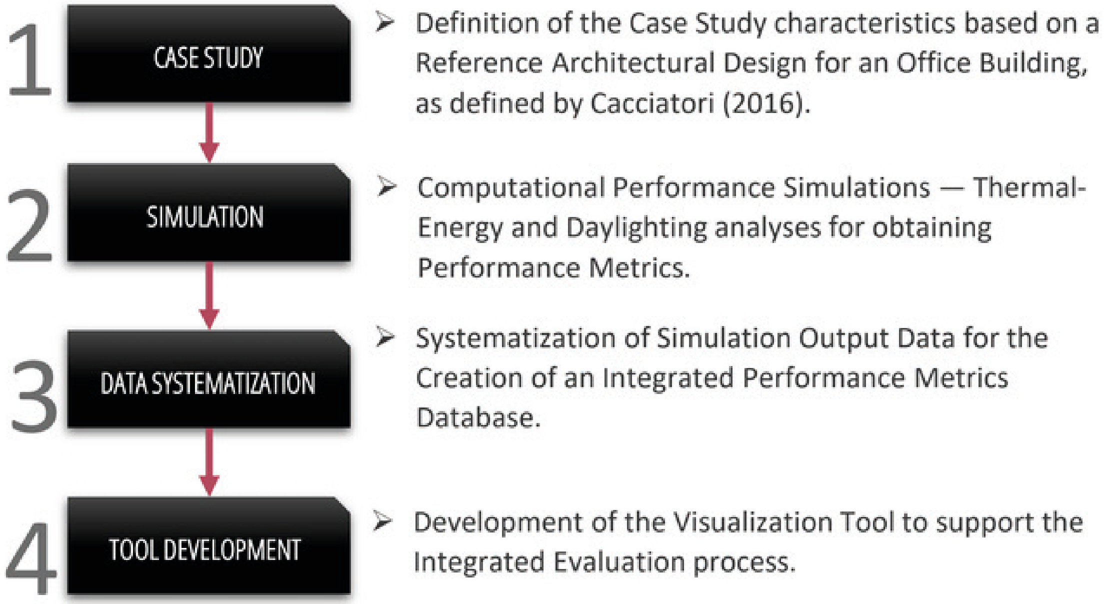

Figure 1. Development stage summary diagram of the P-Balance tool
Source: The author.

The ability to identify useful information is essential for effectively leveraging building performance data generation processes, such as computational simulations and other data--intensive approaches, as emphasized by Stephen Few:

> *"The ability to find what is useful in the mountains of data that surround us, to make sense of it, and to then present it clearly and accurately, forms the foundation on which the information age will finally fulfill its promise. Unless we give information a clear voice, its important stories will remain unheard, and ignorance will prevail."* [19, xvi]

The main criterion for selecting graphical representation rules was the ability to provide quick insight into meaningful information [19][20][21]. These rules were applied throughout the development of the tool. The effectiveness of charts in communication depends on how well they align with the capacities and strengths of the human visual processing system (Figure 5) (Table 5).

The use of pre-attentive attributes (Table 6) and Gestalt principles (Table 7) was prioritized to enhance the rapid perception of meaningful information.

Type	Attribute	Perceived Quantitatively?
Shape	Length	Yes
	Width	Yes, but limited
	Orientation	No
	Size	Yes, but limited
	Form	No
	Edge	No
Color	Hue	No
	Intensity	Yes, but limited
Position	2D Position	Yes
Motion	Direction	No

Table 6. Pre-attentive Processing Attributes

Source: [18][19][20]

Principle	Description
Proximity	Objects that are closer together are perceived as a group.
Similarity	Objects with similar attributes, such as color or shape, are perceived as a group.
Edge	Objects that appear to have a boundary, such as an outline around them, are perceived as a group.
Open Edge	Open structures are perceived as closed, complete, and regular whenever they are interpreted that way.
Continuity	Aligned and overlapping objects appear to be a continuation of one another and are perceived as a group.
Connection	Objects connected by a line are perceived as a group.

Table 7. Gestalt Principles of Visual Perception

Source: [18][19]

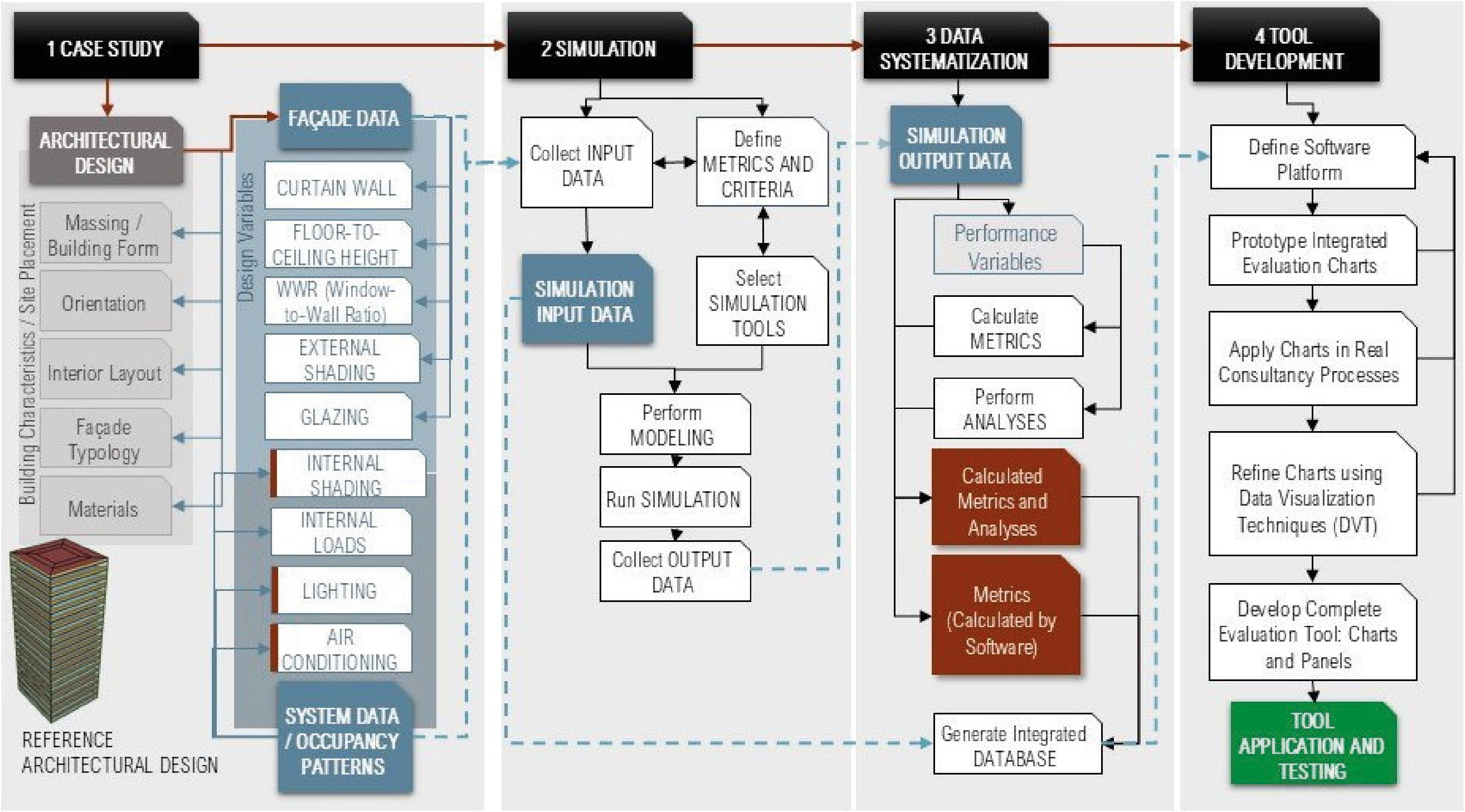

Figure 2. Development process flowchart of the P-Balance tool

Source: The author. Adapted from [18].

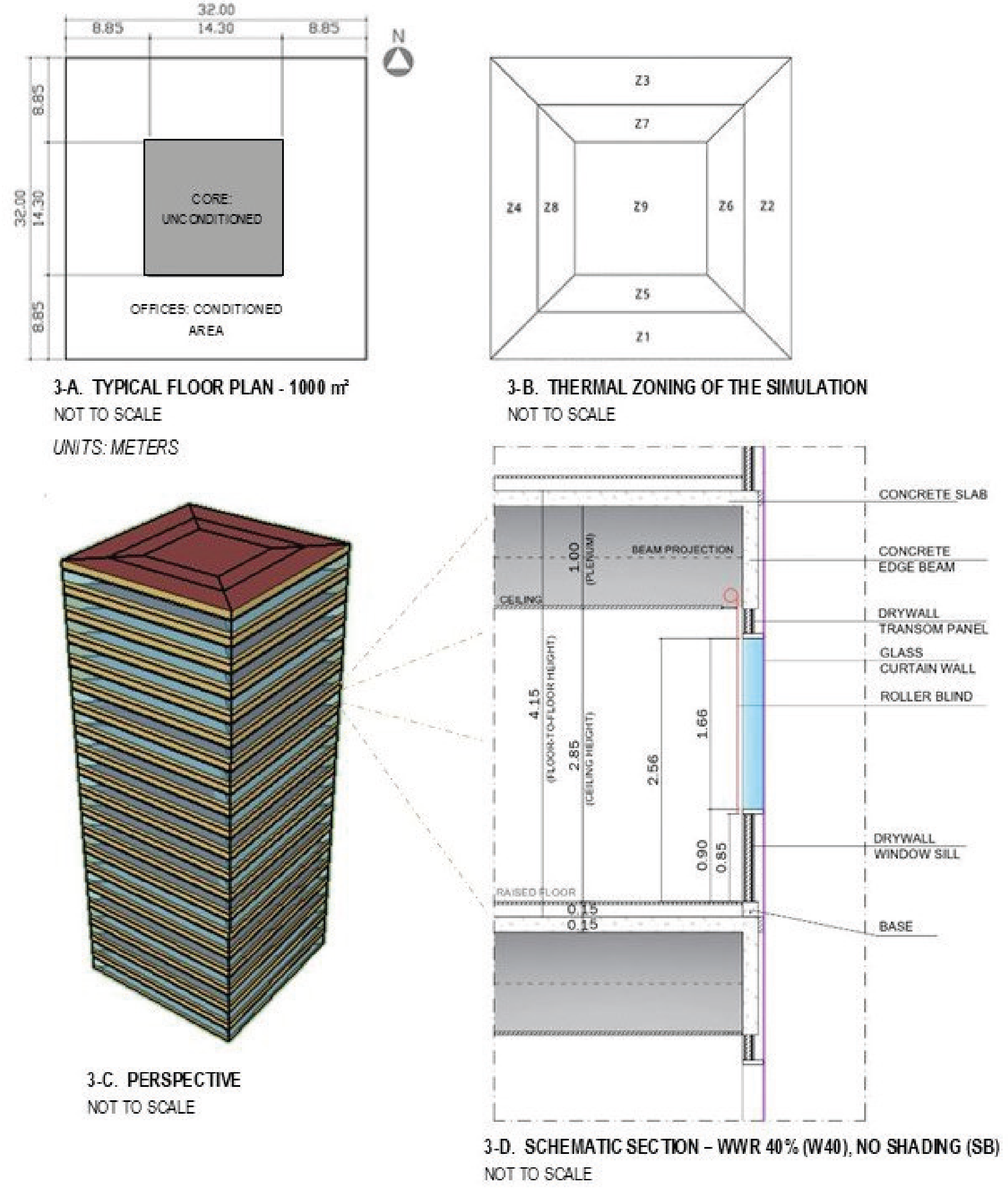

Figure 3. Reference office building

Notes: An approximate area of 1000 m² was adopted. The actual net area of the typical floor is 1024 m². The Window-to-Wall Ratio (WWR) expresses the relationship between the total façade area (external) and the transparent surface area.

Source: [16][17]

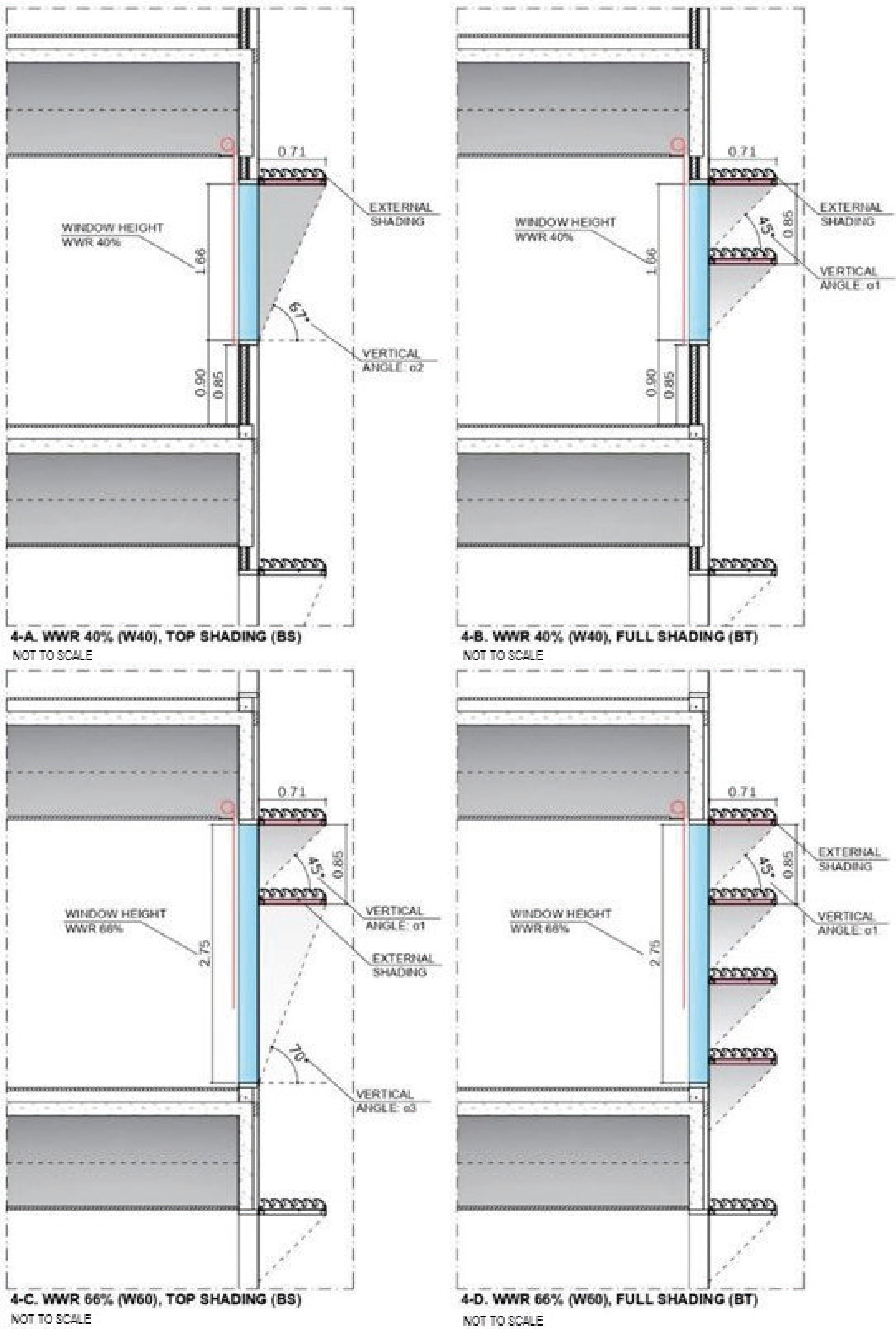

Figure 4. Schematic Sections with WWR and Shading Variations

Notes: The abbreviations BS and BT, referring to the Top Shading and Full Shading conditions, respectively, were maintained as in the original Portuguese version, since these codes were used in the naming of models within the database of simulated design alternatives.

Source: [16][17]

Blind ID	Description	Solar Transmittance (Tsol) [%]	Solar Reflectance (Rsol) [%]	Visible Transmittance (Tvis) [%]	Visible Reflectance (Rvis) [%]
P00	No Blind	-	-	-	-
P53	P53-UNIFLEX-STYLE4903-V03-FACE-OF3	4	53	5	53
P68	P68-UNIFLEX-3031-THSCR-WHITE-OF3	20	68	16	79
P71	P71-UNIFLEX-673-Pearl-PLTSC-OF5	7	71	7	70
Pext	Pext-UNIFLEX-TEXTILENE-80 - BLACK	27	10	27	10

Table 3. Simplified characterization of fabric types (internal blinds)

Source: The author. Adapted from [18].

Metrics Group / Simulation Software	**Performance Metric**	**Description**	**Criterion**
Energy Efficiency (EnergyPlus)	**CTr total (%)**	Relative Total Thermal Load: variation in peak HVAC sizing load compared to the reference model (least thermally protected façade).	CTr < -10% = Class 1 0 ≥ CTr ≥ -10% = Class 2 CTr ≥ 0 = Class 5
	CONr (%)	Relative Energy Consumption: variation in total energy use compared to the reference model.	CONr < -15% = Class 1 0 ≥ CONr ≥ -15% = Class 2 CONr ≥ 0 = Class 5
	CAEr (%)	Relative Annual Energy Cost: variation in energy cost compared to the reference model.	CAEr < -15% = Class 1 0 ≥ CAEr ≥ -15% = Class 2 CAEr ≥ 0 = Class 5
Thermal Performance and Comfort (EnergyPlus)	**PMVh,a (%)**	Predicted Mean Vote – percentage of annual hours meeting ASHRAE 55 thermal comfort criteria.	PMVh,a ≥ 90% = Class 1 90% > PMVh,a ≥ 80% = Class 2 80% > PMVh,a ≥ 70% = Class 3 70% > PMVh,a ≥ 60% = Class 4 PMVh,a < 60% = Class 5
	DPJa,r (%)	Relative Annual Window Power Density: thermal load from windows divided by conditioned floor area (W/m^2), compared to the reference model.	DPJa,r < -15% = Class 1 0 ≥ DPJa,r ≥ -15% = Class 2 DPJa,r ≥ 0 = Class 5
Daylighting Performance (Rhino + Climate Studio)	**sDA (%)**	Spatial Daylight Autonomy: not relative.	sDA ≥ 75% = Class 1 75% > sDA ≥ 40% = Class 2 sDA < 40% = Class 5
	ASE (%)	Annual Sunlight Exposure: not relative.	ASE ≤ 10% = Class 1 10% < ASE ≤ 40% = Class 4 ASE > 40% = Class 5
	ASE blinds (%)	Annual Sunlight Exposure with active blinds: not relative.	ASEb ≤ 5% = Class 1 ASEb > 5% = Class 5
	UDIa (%)	Useful Daylight Illuminance – acceptable levels.	UDIa ≥ 75% = Class 1 75% > UDIa ≥ 50% = Class 2 50% > UDIa ≥ 35% = Class 3 35% > UDIa ≥ 20% = Class 4 UDIa < 20% = Class 5
	UDIe (%)	Useful Daylight Illuminance – excessive levels.	UDIe ≤ 10% = Class 1 10% < UDIe ≤ 30% = Class 3 30% < UDIe ≤ 50% = Class 4 UDIe > 50% = Class 5
General	Global Ranking Score	**Simple arithmetic mean of absolute values of each metric. Assigned zero if CTr ≥ 0, or if sDA < 40%, or ASE > 10%, or ASE blinds > 5%. Used as a complementary reference in the method. The score does not reflect hierarchical weighting, which is dynamically set by the design team during selection.**	**No defined criterion**

Table 4. Metrics and Indicators for the P-Balance Integrated Assessment

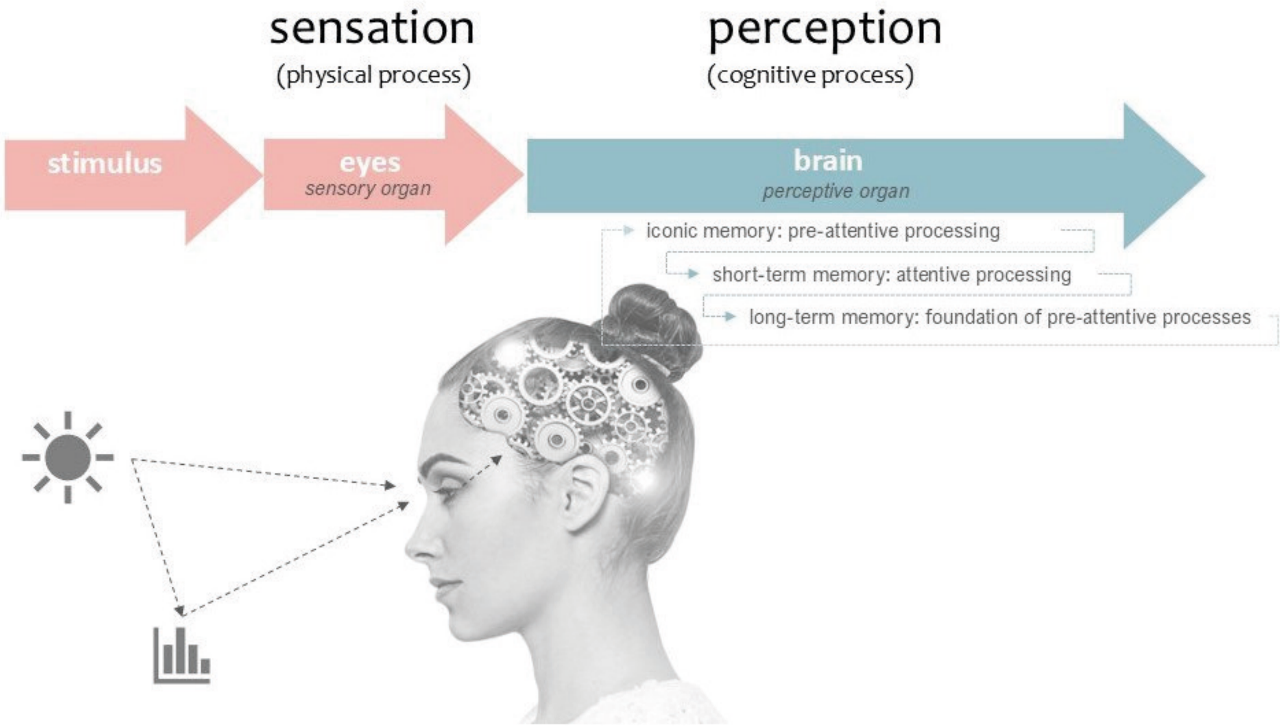

Figure 5. Schematic flow of visual perception and information processing

Source: [18][19]

Characteristic	Iconic Memory	Short-Term Memory	Long-Term Memory
Part of the process	Receives stimuli captured by the eyes	Receives visual information from Iconic Memory	Receives and stores information from Short-Term Memory
Responsible for	Recording visual information before sending it to Short-Term Memory	Generating meaningful visual information chunks	Storing information for future access, essential for our ability to recognize meaningful patterns
Duration	Extremely fast – less than 1 second	Fast but temporary – from a few seconds to several hours if accessed periodically	Slow – depends on repeated access to the information
Information Processing Type	Unconscious Automatic Pre-attentive	Conscious Cognitive effort Attentive	Conscious or not
Limits	Simultaneous perception limit for each type of pre-attentive attribute and for combinations. E.g., up to 8 colors, 4 sizes, 4 orientations.	3 or 4 chunks of information are stored at once; the size of each chunk may vary.	Not established

Table 5. Summary of the characteristics of memory types involved in the Visual Perception Process

Source: [18]

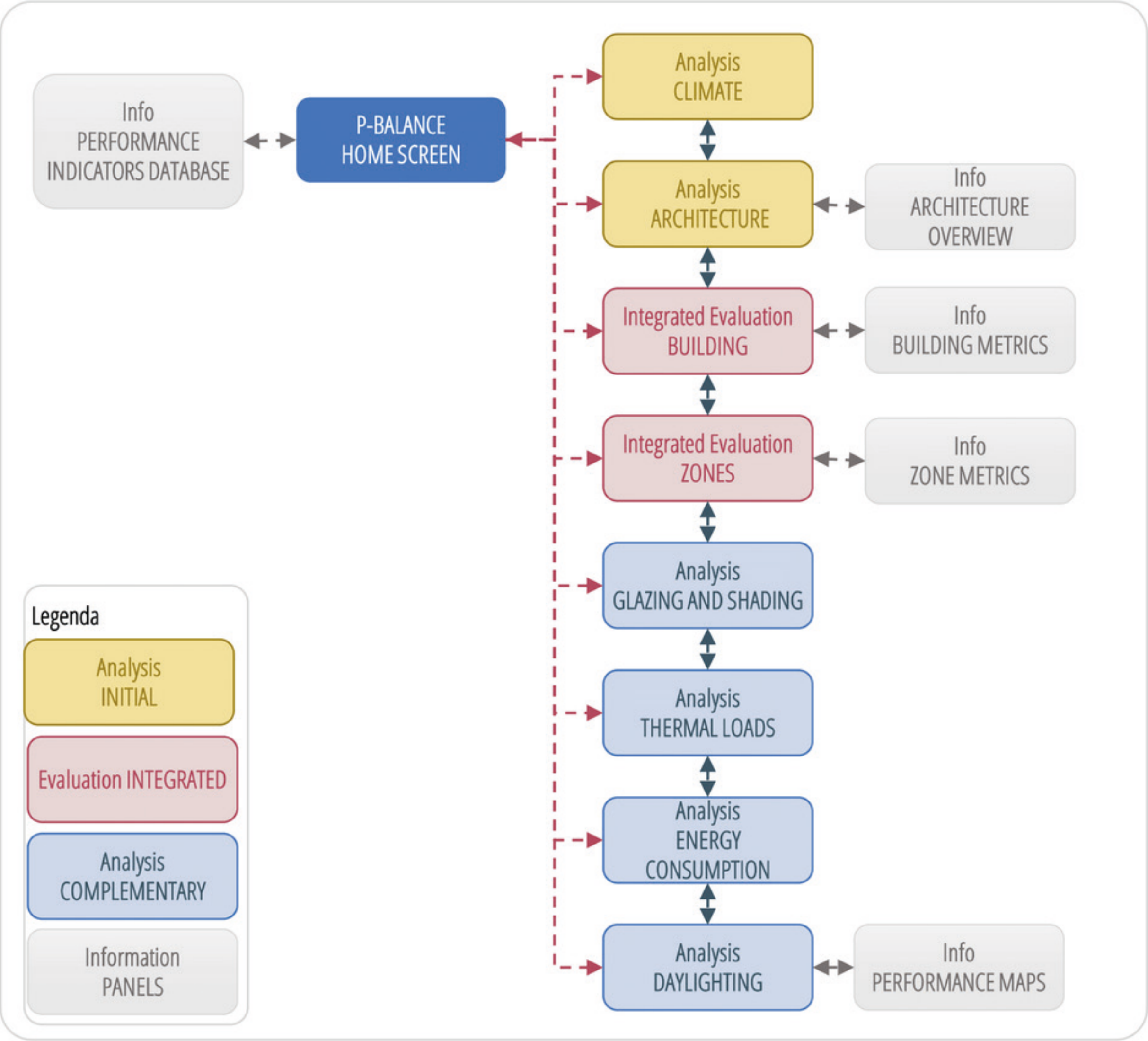

Figura 6. P-Balance Tool: Flowchart and Interface Structure
Source: [18]

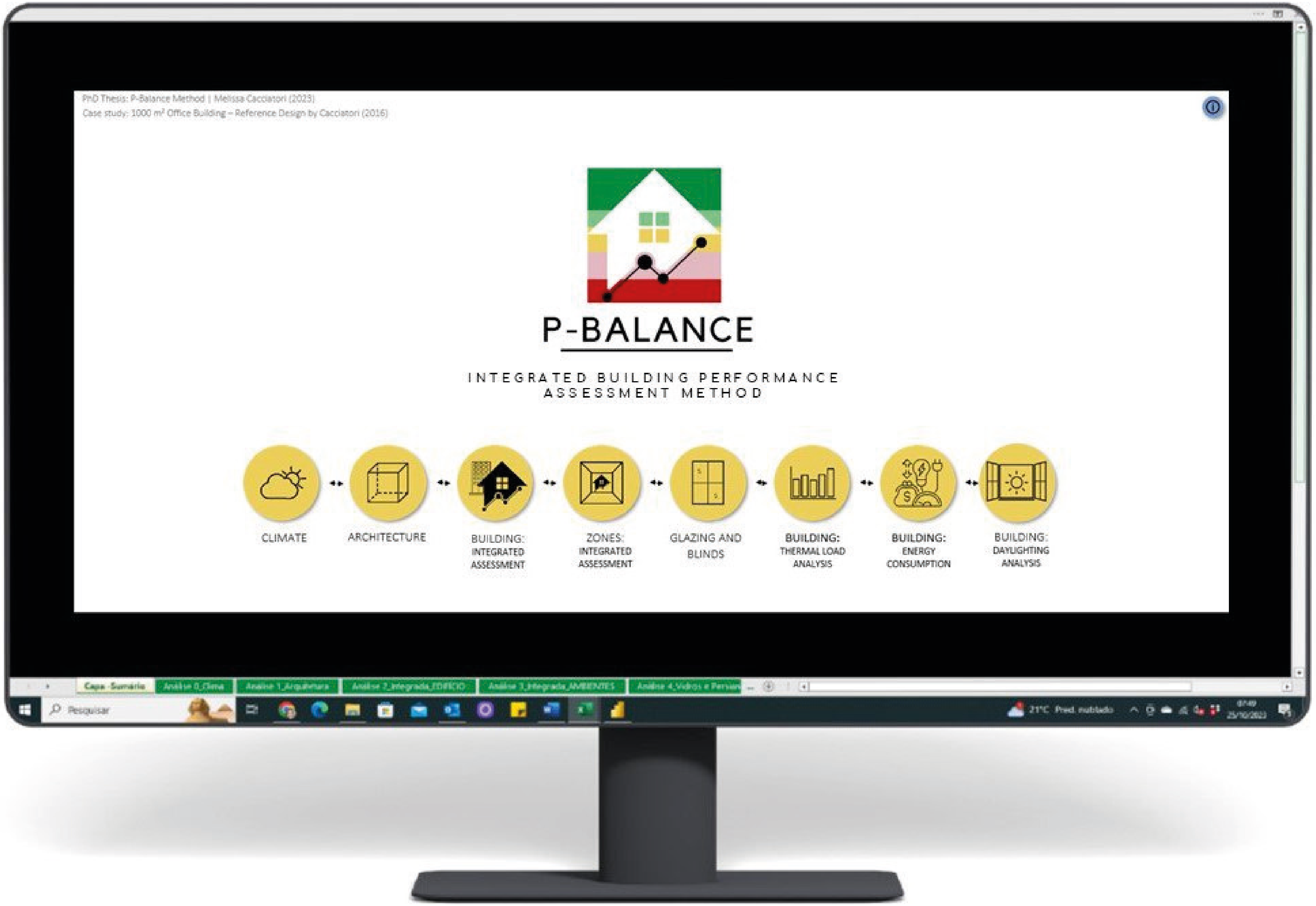

Figure 7. P-Balance Tool – Illustration of the Home Screen

Source: [18]

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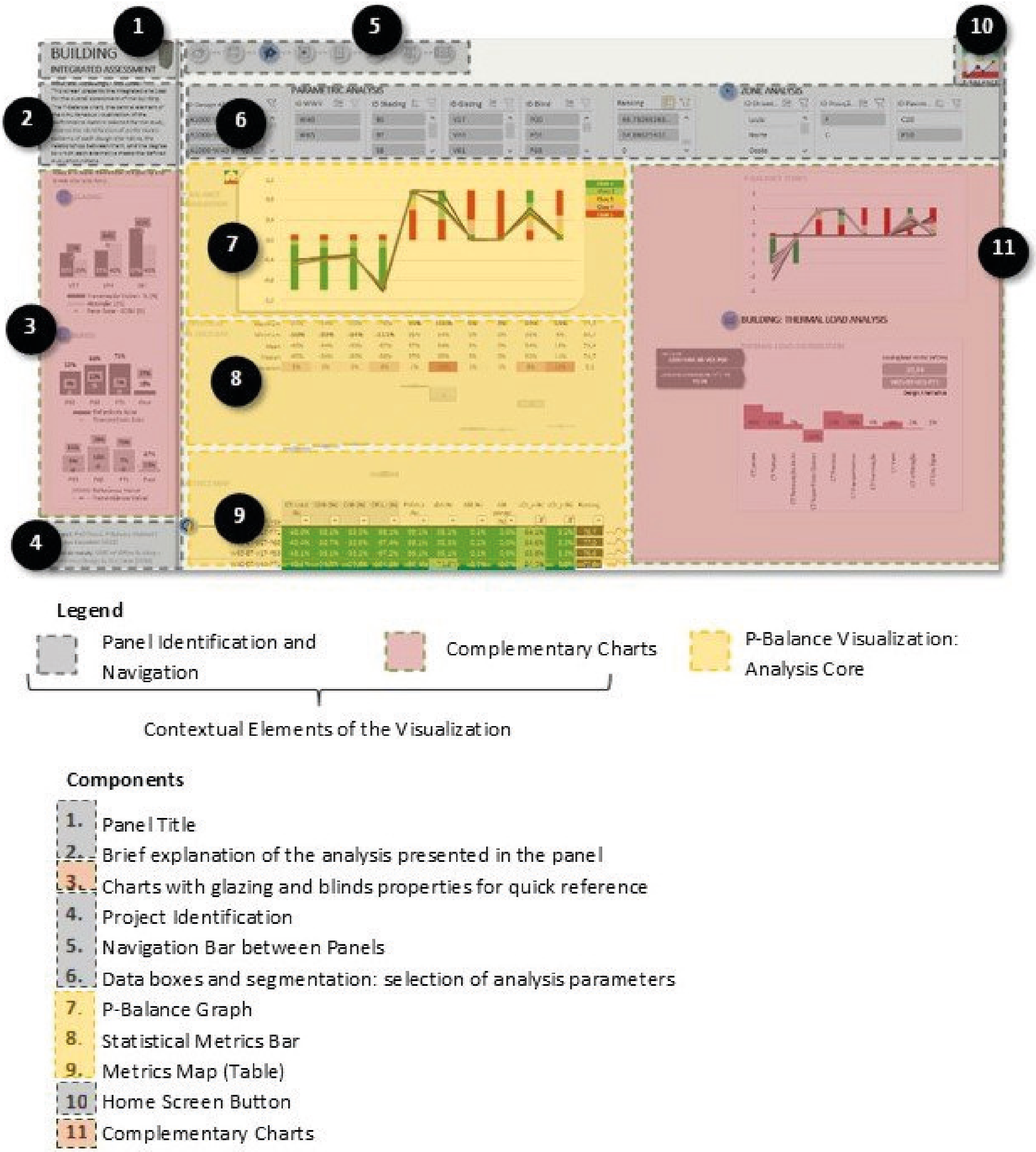


Figure 8. Global Integrated Building Assessment Panel

Source: [18]

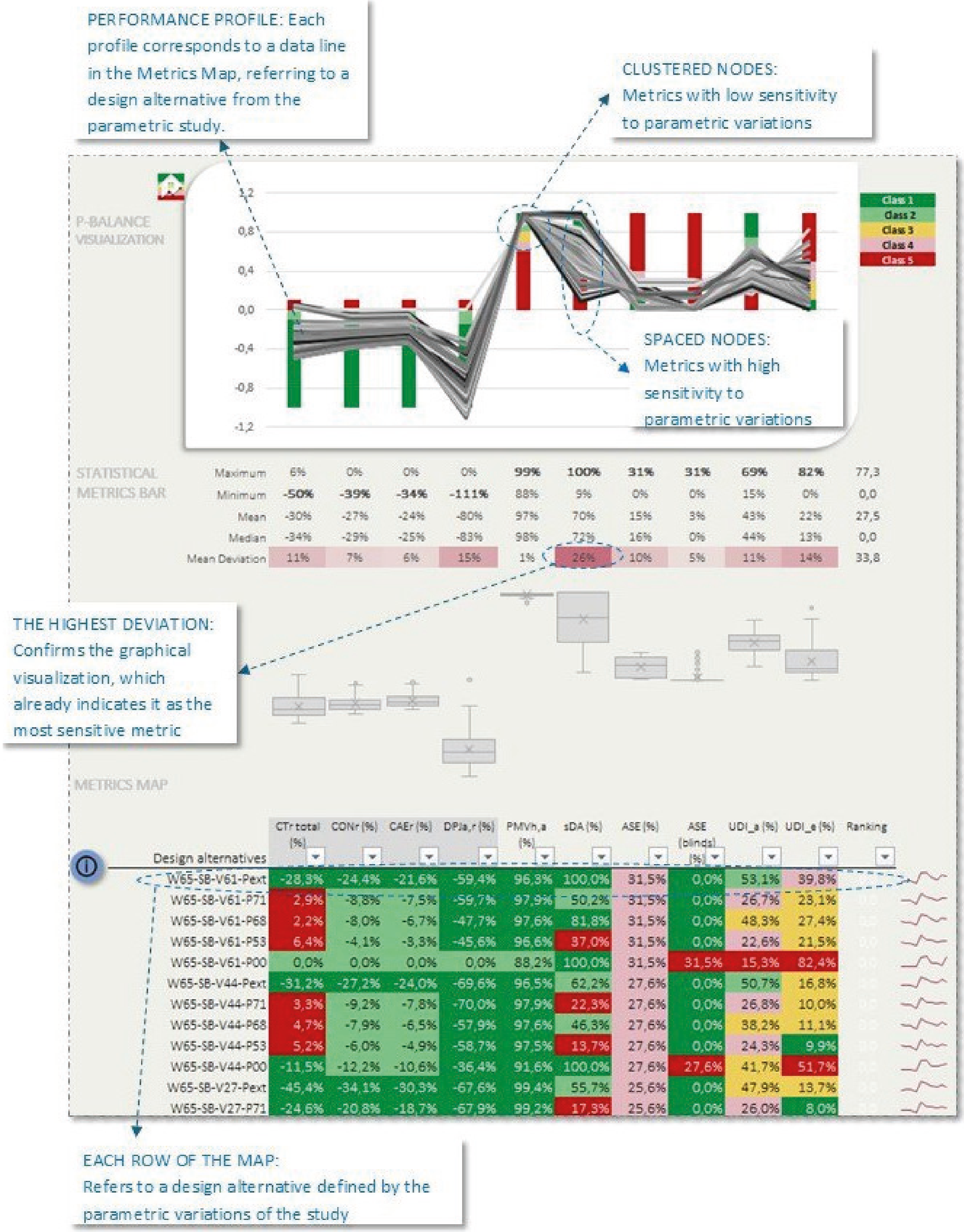


Figure 9. P-Balance Visualization – P-Balance Graph, Statistical Indicators Bar, Indicator Map

Source: The author. Adapted from [18].

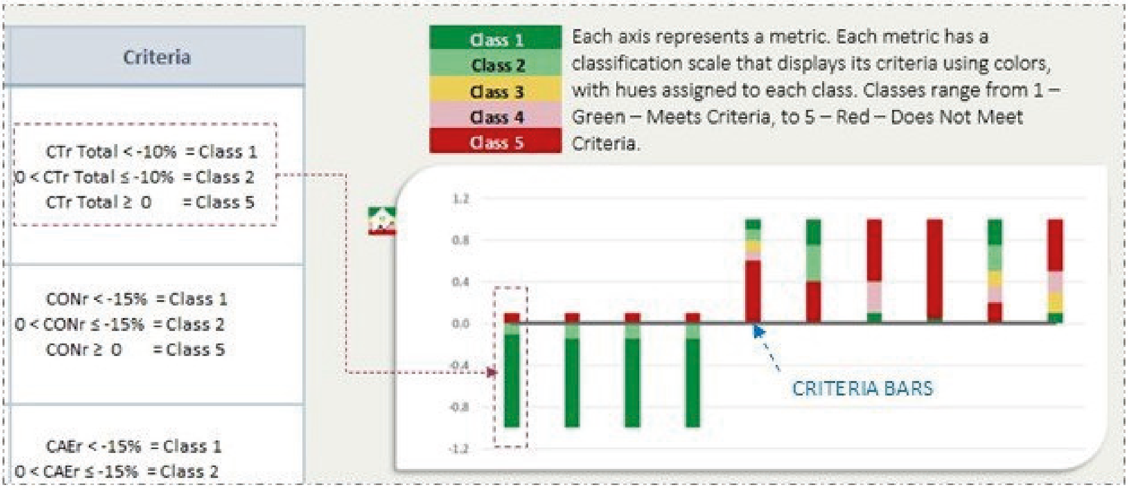


Figure 10: P-Balance Graph Formatting Process: Classification Criteria Bars

Source: [18]

RESULTS

The final product is the P-Balance tool, which comprises eight analysis panels (Figures 6 and 7), including two Integrated Evaluation panels: one for the overall building assessment and another for zone-based assessment, which enables façade analysis by orientation.

To demonstrate the tool in this article, the Integrated Building Evaluation panel is presented (Figure 8). Figure 9 details the components of the P-Balance Visualization, described below:

The P-Balance Chart is a parallel coordinates plot, the type most recommended by Data Visualization Techniques (DVT) for multi-objective analysis. A single line on the plot, called a profile, encodes the performance pattern across multiple metrics and their trade-offs. This condensed representation replaces dozens of individual charts, which would otherwise require mental integration through repeated consultation. The set of lines, each representing a different design alternative, allows the identification of the most sensitive metrics by the spacing between 2D points (nodes).

In this tool, the parallel coordinates plot is combined with a stacked bar chart that displays classification criteria for each metric using a five-color scale (Figure 10). This combination enables users to quickly assess whether the criteria are met. In alignment with cognitive limitations of pre-attentive attributes, the scale is restricted to five categories.

The Statistical Metrics Bar summarizes the values shown in the Metrics Map, providing quick access to minimum, maximum, and average values. The color gradient in the standard deviation row highlights the most sensitive metric, which can also be spotted in the chart.

The Metrics Map is designed based on the heatmap concept. It allows for attentive analysis of both individual values and the overall dataset, while also revealing how each metric is classified according to the evaluation criteria.

P-BALANCE INTEGRATED EVALUATION METHOD

The tool enables a visual, interactive, and participatory multi-objective evaluation method (Figures 11 and 12), based on sequences of design alternative selections guided by chromatic performance classifications and project-specific assumptions or constraints regarding the parameters considered.

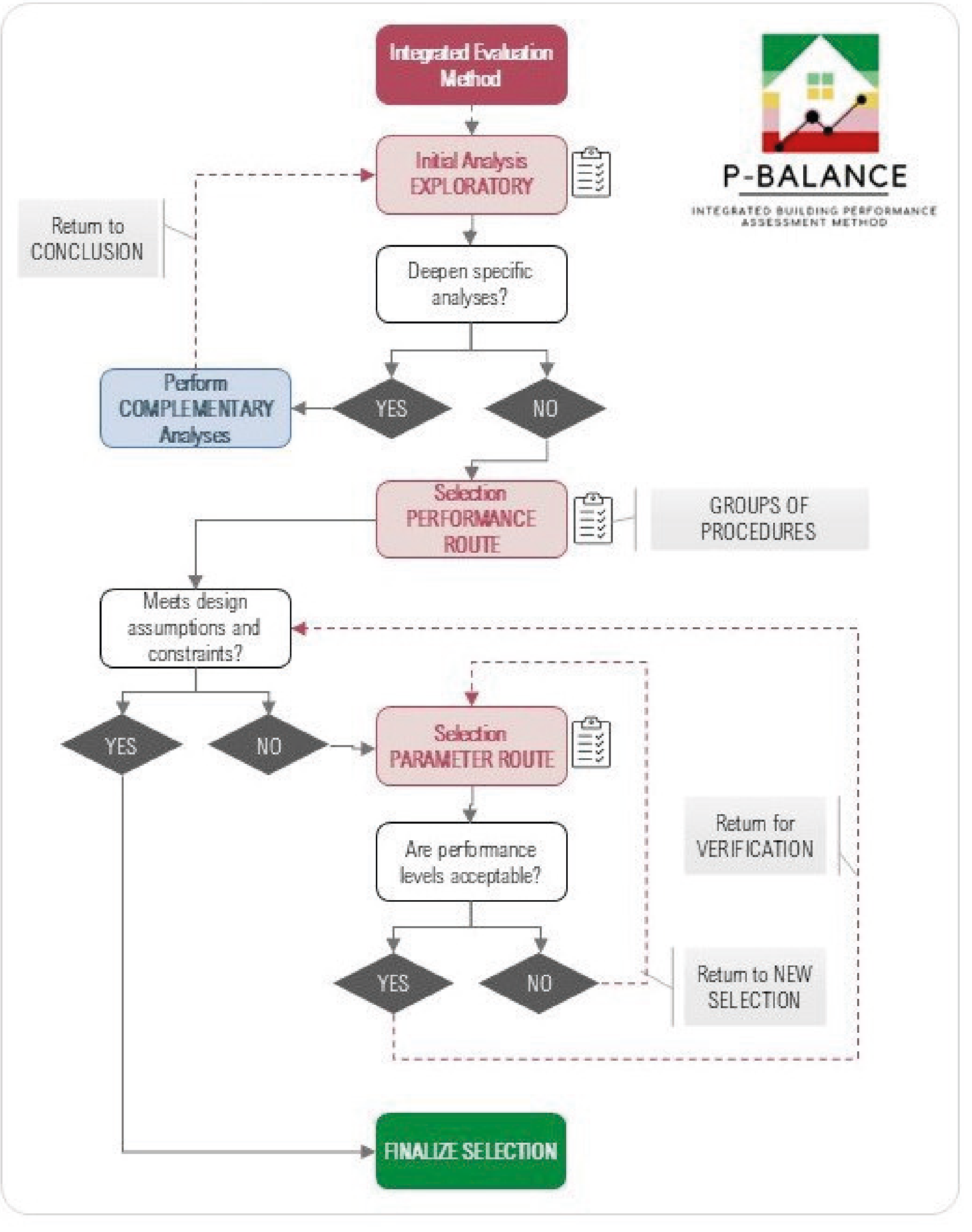


Figure 11. P-Balance Integrated Evaluation Method – Process Flowchart

Source: [18]

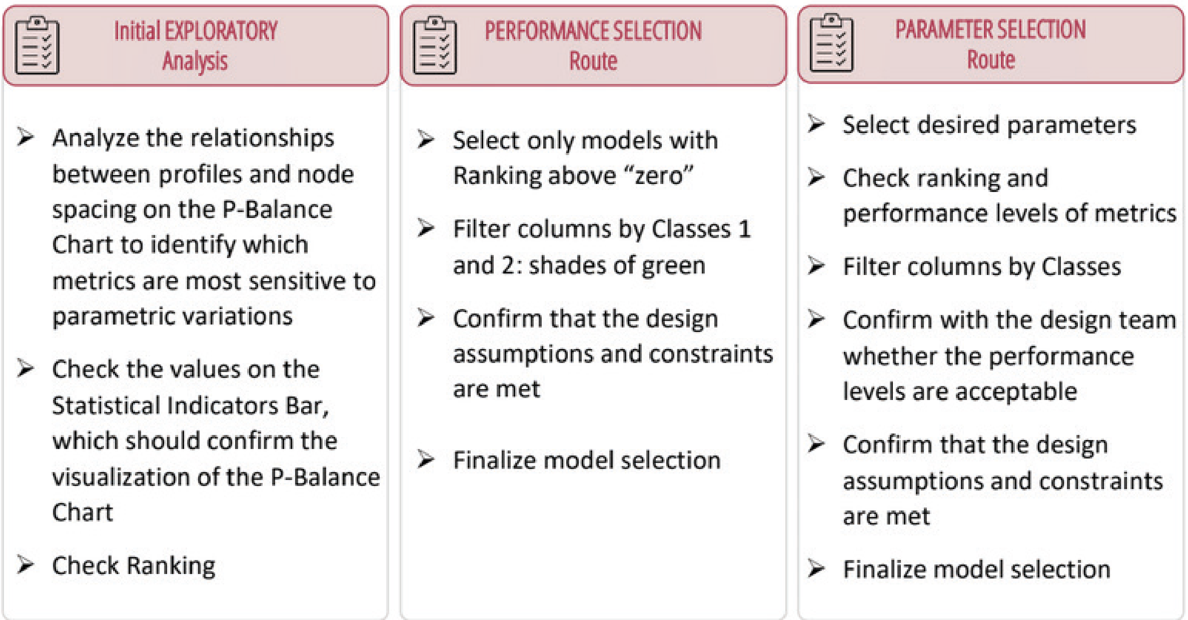


Figure 12. P-Balance Integrated Evaluation Method – Procedure Groups

Source: [18]

Figures 13 and 14 illustrate the application of the two selection routes: one based on highest performance and the other on predefined design parameters.

The demonstration of the Parameter-Based Selection Route considers the following design assumptions:

- Do not include insulated glazing type V27.
- Do not consider façades fully shaded by brise-soleils (BT).
- Include only alternatives with 65% WWR.

Figure 15 enables a comparison between the parametric design alternatives resulting from each selection route. It is worth noting that this process is completed in just a few minutes and, within an integrated design approach, all participants can evaluate the performance differences between the selected alternatives and confirm design assumptions and constraints.

CONCLUSION

The development of the P-Balance tool was essentially guided by the application of Data Visualization Techniques (DVT), with a focus on pre-attentive data and information processing. The P-Balance Visualization enables fast and simultaneous visual perception of multiple performance metrics and design alternatives, avoiding the need to consult dozens of individual charts for each metric type and reducing the mental effort required to integrate data—factors that often hinder effective evaluation and communication.

When prototypes of the tool were applied in real consulting contexts, qualitative observations confirmed that the tool met its intended goals:

a) Communication was noticeably more fluid and effective when transferring information to decision-makers, resulting in technical acceptance of the consultancy service with minimal revisions and no technical doubts that could hinder its use.

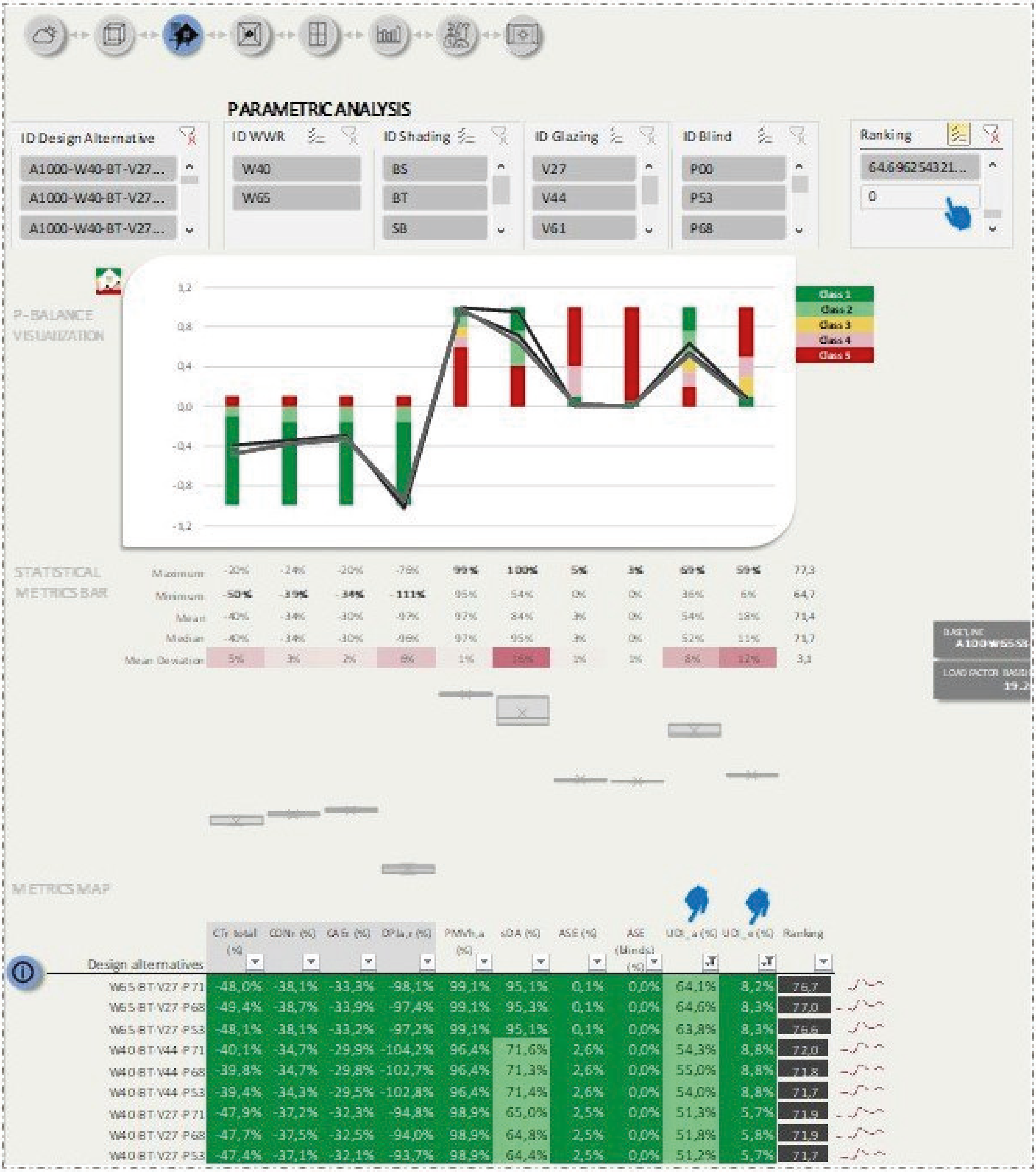


Figure 13. P-Balance Visualization – Selection Route by Highest Performance in the Integrated Building Evaluation – Ranking > 0 and Filter: Classes 1 and 2 in UDI_a and UDI_e Columns

Source: [18].

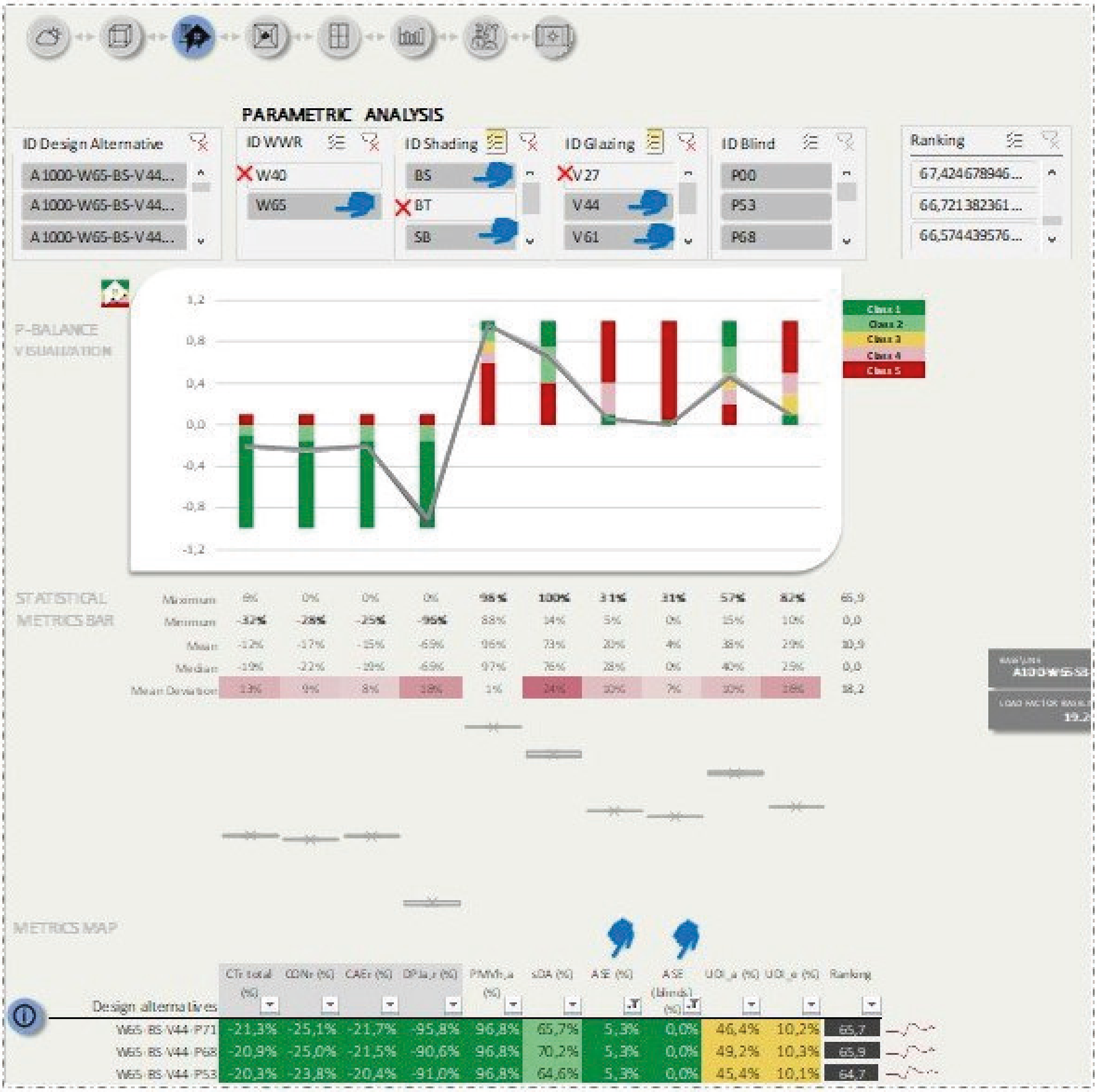
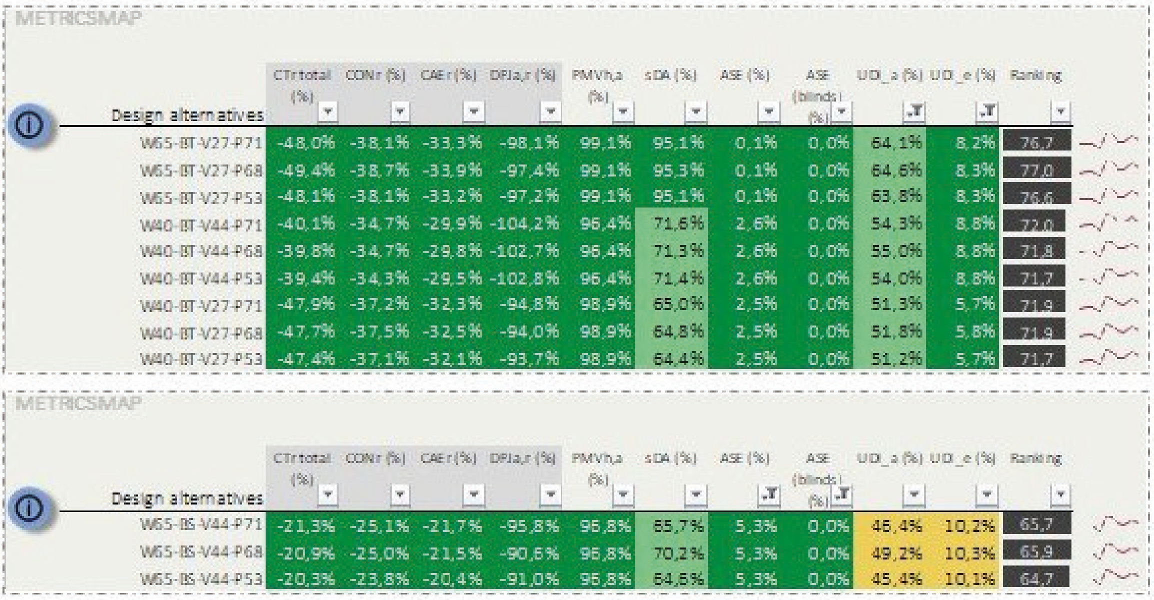


Figure 14. P-Balance Visualization – Selection Route by Parameters in the Integrated Building Evaluation – Application of Design Assumptions + Filter: Class 1 in ASE and ASE Blinds Columns
Source: [18].



METRICSMAP

Design alternatives	CTrtotal (%)	CONr (%)	CAEr (%)	DPJa,r (%)	PMVh,a (%)	sDA (%)	ASE (%)	ASE (blinds) (%)	UDI_a (%)	UDI_e (%)	Ranking
W65-BT-V27-P71	-48,0%	-38,1%	-33,3%	-98,1%	99,1%	95,1%	0,1%	0,0%	64,1%	8,2%	76,7
W65-BT-V27-P68	-49,4%	-38,7%	-33,9%	-97,4%	99,1%	95,3%	0,1%	0,0%	64,6%	8,3%	77,0
W65-BT-V27-P53	-48,1%	-38,1%	-33,2%	-97,2%	99,1%	95,1%	0,1%	0,0%	63,8%	8,3%	76,6
W40-BT-V44-P71	-40,1%	-34,7%	-29,9%	-104,2%	96,4%	71,6%	2,6%	0,0%	54,3%	8,8%	72,0
W40-BT-V44-P68	-39,8%	-34,7%	-29,8%	-102,7%	96,4%	71,3%	2,6%	0,0%	55,0%	8,8%	71,8
W40-BT-V44-P53	-39,4%	-34,3%	-29,5%	-102,8%	96,4%	71,4%	2,6%	0,0%	54,0%	8,8%	71,7
W40-BT-V27-P71	-47,9%	-37,2%	-32,3%	-94,8%	98,9%	65,0%	2,5%	0,0%	51,3%	5,7%	71,9
W40-BT-V27-P68	-47,7%	-37,5%	-32,5%	-94,0%	98,9%	64,8%	2,5%	0,0%	51,8%	5,8%	71,9
W40-BT-V27-P53	-47,4%	-37,1%	-32,1%	-93,7%	98,9%	64,4%	2,5%	0,0%	51,2%	5,7%	71,7

METRICSMAP

Design alternatives	CTrtotal (%)	CONr (%)	CAEr (%)	DPJa,r (%)	PMVh,a (%)	sDA (%)	ASE (%)	ASE (blinds) (%)	UDI_a (%)	UDI_e (%)	Ranking
W65-BS-V44-P71	-21,3%	-25,1%	-21,7%	-95,8%	95,8%	65,7%	5,3%	0,0%	46,4%	10,2%	65,7
W65-BS-V44-P68	-20,9%	-25,0%	-21,5%	-90,6%	95,8%	70,2%	5,3%	0,0%	49,2%	10,3%	65,9
W65-BS-V44-P53	-20,3%	-23,8%	-20,4%	-91,0%	95,8%	64,6%	5,3%	0,0%	45,4%	10,1%	64,7

Figure 15. Comparison Between the Results of the Selection Routes

Source: [18]

b) With well-defined workflows, the evaluation process became more consistent and assertive, significantly reducing the time spent on analysis and reporting. Review requests were minimal—when present, they were limited to minor edits or design changes treated as scope additions. This improved the economic viability of consulting services, strengthened technical confidence, and enhanced perceived value.

During presentations of the final version of the tool, decision-makers and design teams described the visualization as "user-friendly", said they felt like active participants in the process, and understood the "balance" between the metrics.

The P-Balance methodological tool proves to be a promising means for implementing Performance-Oriented Design (POD) and Integrated Design (ID) approaches, as it promotes:

1. Sharing of technical, economic, or aesthetic considerations among team members, allowing them to influence decisions.

2. Transparent decision-making supported by accessible information and clearly defined processes.

3. Strengthened accountability of decision-makers toward stakeholders.

4. Encouragement of open debate to consider diverse perspectives.

Additionally, the following aspects are highlighted:

a) The tool's educational potential, as the interactive selection method fosters the creation of specialized knowledge assets within the project team.

b) Developed in Excel, the tool is accessible, allowing most simulation professionals to make adjustments and adaptations.

c) The tool is flexible, allowing for customization of visual elements, inclusion or exclusion of metrics, adaptation of classification bars, application to any architectural typology, and adjustments to evaluation processes.

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