Carioca modern façades: improving the performance of existing Brazilian modern buildings through their shading systems, the Bristol case study

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Abstract. In the 1940s, modern Rio de Janeiro architects developed passive systems to improve buildings performance, without resorting to air conditioning systems. This article continues a research that studies the performance of a set of eight buildings, from the Carioca School, investigating in a prospective sense, how to improve their performance through computational methods. The authors select a new case study from these buildings, the Bristol building, and analyse the building performance, regarding insolation and illuminance, using the software Ladybug and Honeybee. Based on the simulation data, they use combinatorial modelling to change the position of each of the shading type's modules, of the Bristol west façade to improve performance. Results suggest that is possible to improve the building performance, and the modern buildings legacy, using computational methods to improve and reduce energy consumption, encouraging natural systems and diminishing the need for artificial air conditioning systems.

Keywords: Generative design, Shading performance, Insolation and illuminance analysis, Combinatorial modelling, Carioca modern façades

1 Introduction and context

1.1 The modern façade, tropical contributions

The authors frame the research *Carioca Modern Façades* and address the Brazilian and Carioca contribution for modern architecture in a previous article (Mateus et al., 2022). Although the first modern design influences in Brazil are from abroad, Brazilian Architects soon developed a peculiar contribution for modern architecture, namely designing daylight shading systems to face tropical weather conditions, namely to avoid heat and light reflection in glass façades. This weather challenges are not so present for example in European and North American countries that faces other construction challenges. Modern buildings are associated with the use of large windows that in tropical climate receive the harsh summer sun and overheat, due to the lack of specific protection that half-closed windows cannot provide. Modest workshops then have to choose an alternative: either bake or barely protect themselves by means of awnings or shutters, a weak protection against the sun's reflections in the glass windows.

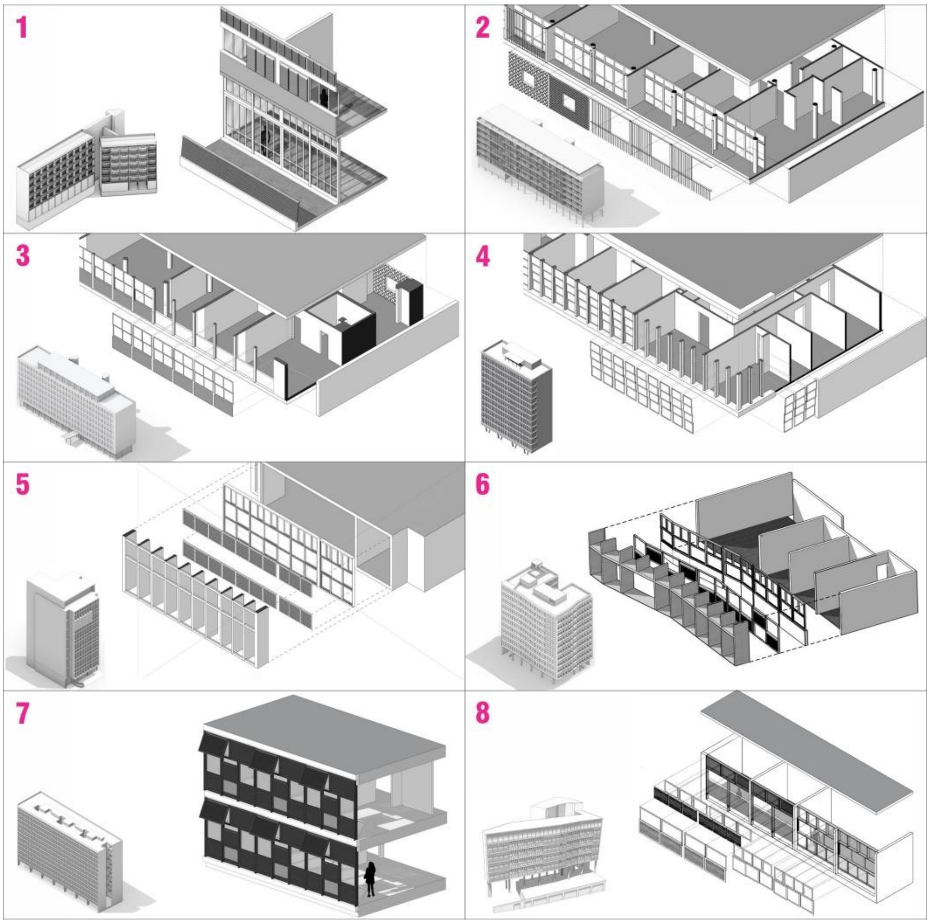

Figure 1. Buildings studied regarding volume and façade system: 1- Building Barreto, Irmãos Roberto, 1947; 2- Building Bristol, Lucio Costa, 1950; 3- Building Nova Cintra, Lucio Costa, 1948; 4- Building Gravatá, Sérgio Bernardes, 1952; 5- Building MMM Roberto, Irmãos Roberto, 1945; 6- Building D. Fátima, Irmãos Roberto, 1951; 7- Building Angel Ramirez, Irmãos Roberto, 1954; 8- Building Sambaíba, Irmãos Roberto, 1953. Source: Adapted from Mara Eskinazi, Authors, 2022.

These weather conditions arose the curiosity of North American Architects that visit the country to understand how Brazilians face this problem (Goodwin & Smith, 1943). These architects produced "Brazil Builds: Architecture new and old 1652-1942" a MOMA exhibition and catalogue that reports the Brazilian modern shading systems, the solutions developed by young Brazilian architects to face the climate problem. The façades developed different systems, using sunshades, sun protection elements and filters that are unique in Brazilian architecture. These solutions created in Rio de Janeiro spread in the country. The Brazilian façade solutions provoked the expansion of the building envelope, creating new in-between spaces.

The solid-void webs generated by combinations of glass panels, thick balconies and filters configure a layer system, with different degrees of permeability, beyond the façades sealing function. Based on this idea, research investigates a universe of eight modern residential buildings in Rio de Janeiro (Figure 1). The authors grouped the buildings in four façade design categories: (1) The façade intermediated by balconies: Buildings Julio Barros Barreto (Irmãos Roberto, 1947) and Bristol (Lucio Costa, 1950) (1,2 Fig.1); (2) The façade intermediated by glass planes: Buildings Nova Cintra (Lucio Costa, 1948) and Baron Gravatá (Sérgio Bernardes, 1952) (3,4 Fig.1); (3) The façade intermediated by coupled concrete brise-soleil: Buildings MMM Roberto and Dona Fátima and Finúsia (Irmãos Roberto, 1945 and 1951) (5,6 Fig.1); (4) The façade intermediated by filters, cobogós, shutters and trusses: Buildings Ramirez and Sambaíba (Irmãos Roberto, 1954 and 1953) (7,8 Fig.1). The authors detailed the general context of this research in a previous publication that uses as a case study the Nova Cintra building. This article continues the research studying the Bristol building, also by Lucio Costa.

The four categories, or design strategies proposed, derived from the technical possibilities enabled by the Domino System by Le Corbusier (1914-1917). The first relation between the four design categories and the domino system concerns the autonomy of the façade and the distinction between the building structural and non-structural elements, or between structure and closure. This principle of the domino system is explicit in the Bristol Building longitudinal façades. The second relation factor concerns the way in which each building incorporates the displacement of the pillars for the building interior, a solution that Fanelli & Gargiani (2014) and Eskinazi & Penter (2019) elect as the fundamental constructive principle of Le Corbusier's five points theory – from which the other points derive, mainly the façade strips and the windows strips. This resource enables larger spans and frames with increased interior daylight and ventilation, exploring the relation between the interior and the exterior landscape. It is an important resource for expanding and dilating, "thickening" the façade envelope. The third and final relation factor concerns the in-between spaces intermediating the public and private domains created by this expansion. The development of different expansion patterns of the closing planes overcomes the flat façade, creates "in-between" space that belongs both to the interior and to the exterior, generating transition spaces

(Leatherbarrow & Mostafavi, 2002). Therefore, the domino system, by realizing Le Corbusier's 5 points and by enabling the implementation of the four design strategies mentioned above, plays a decisive role enhancing the façade as an intermediary element of spatial relations between interior and exterior.

1.2 Bristol Building Adaptation Mechanism

Architect Lucio Costa found in Park Guinle, in the terrain of an old Palace in Botafogo the place to design a master plan to test modern architecture ideals and adapt them to the tropical context. Costa proposed six buildings, designing and constructing three buildings: Nova Cintra (1948), Bristol (1950) and Caledônia (1952), buildings detached in the terrain in columns and with roof garden. The Irmãos Roberto later designed the other buildings in the plan. Lucio Costa's buildings advocate the modernist ideal of a machine elevated in a green space, with a nature framed view. Costa reformulates the Corbusier's view for a tropical context, with harsh daylight improving the building energy performance developing an architectural filter (Fig.2).

Park Guinle landscape has a central garden with an oval depression in the center, and a building in the terrain entrance, the Nova Cintra building, delimited by Gago Coutinho Street, with a north-south longitudinal orientation. In turn, the Bristol and New Caledônia buildings are on the edge of the terrain with a steep slope, and east-west orientation. The three buildings measure approximately 65 x 15m and have a concrete structure with span 4 x 6m. After addressing the Nova Cintra building energy performance (Mateus et al., 2022), research addresses the Nova Cintra ability to adapt to hot and humid climatic context. The Nova Cintra adaptation ability is due to its north-south implantation in columns, placing the internal walls longitudinal to this axis to take advantage of prevailing winds, creating good natural ventilation. These factors are associated with a differentiated treatment of the north and south façades. The north façade creates a filter combining the use of balconies (in between-space) with cobogó and brise-soleil. Unlike the Nova Cintra building, the Bristol and Nova Caledônia buildings have an east-west orientation that poses different challenges. The façade that receives more sun is the west façade, facing the park, while the east facade faces the lot back.

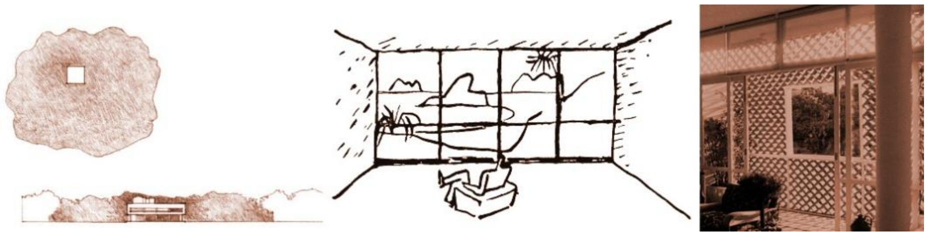

Figure 2. The modernist machine, a box surrounded by nature (adapted from Ching 2007), framing nature (adapted from sketches by Le Corbusier visiting Brazil, La Maison des Hommes 1942), and nature adapted to the tropics, Bristol Building photo.

Thus, the west façade has a double function: it must open to the park view (according to Corbusier's ideas), but at the same time it must provide protection from the strong afternoon sun. In this sense, Lucio Costa's ingenious proposal combines the use of cobogós and brise-soleil with smaller, perfectly framed windows. This way, Costa filters the strong afternoon daylight, while simultaneously opening strategic views to the park. The Bristol building has a structure of pilotis and concrete slabs, with internal independent walls and independent façade filters, developed in detail in an article by Eskinazi and Engel (2021). Another article addresses this building façade arrangement using shape grammars (Chokyu & Dias 2015). These buildings have a different adaptation mechanism than the Nova Cintra building. On the west façade, they present more diverse cobogó types and there are balconies in the rooms, but these balconies are smaller in the social areas. This article studies the performance of this façade prospectively.

2 Methodology: Bristol Building

2.1 System expansion

This research uses computational processes in a subversive manner as modern buildings did in their time, questioning and reflecting on architectural making. Computation enables to discover and develop combinatorial processes for passive systems, expanding the use of the original systems. How to recombine the existing modules to improve the passive shading system? Authors rely in computer simulation to measure performance and reflect how to improve. Authors drawn different processes, according to the specificities of each building, to improve the façades performance:

1 - Recombine existing modules [A, B, C], exchanging positions, with new recombination, for example [B, C, A];

2 - Use existing modules, opening and closing shading panels, windows or muxarabis [A+, A-, A] > [A-, A+, A-];

3 - Change parameters of modules, for example change spacing parameters or brises shading angle (mathematical optimization). The authors address the first process and the third (Mateus & Henriques, 2023).

2.2 Bristol Building study

The research after studying the Nova Cintra building, addresses as a case study the Bristol building (Figure 2). The west façade is analysed in depth, as it faces extreme solar conditions, investigating how to recombine the existing façade systems to improve the building performance.

2.3 Digital models preparation

Modelling these research eight buildings relied in visual and textual programming in Python, both in Grasshopper. To translate the two-dimensional data obtained through sections, facades and plans, into 3D, uses an organization by material and floor level. The floor organization uses as inputs the elements grouped by material, copied as output and oriented to its world coordinates, for the each target floor. This agile model uses instance copies, instead of duplicating data. The geometry preparation follows three steps: baselines transformation into 3D, positioning in the site-plan and vertical displacement according to the floor. This data organization by level produces the complete building volume with materials, surrounding buildings and terrain in Rhino, in a target area of 350 x 350 m. Instead of the classical representation model, research relies in a model, geo-located, with local weather files, using structured data to evaluate performance.

The authors use then the models in grasshopper to analyse the insolation and illuminance (Figure 3). The insolation is measured in Wh/m2 or kWh/m2 for yearly envelope daylight (roof and facades, including shading), and total solar irradiation (TSI), in kWh, on the envelope surfaces. The illuminance is the radiation that, after filtered by shading, enters the building. Suitable daylight values are between 100 and 3.000 lux. Below 100 lux, daylight is insufficient and above 3.000, excessive. High illuminance might require artificial cooling.

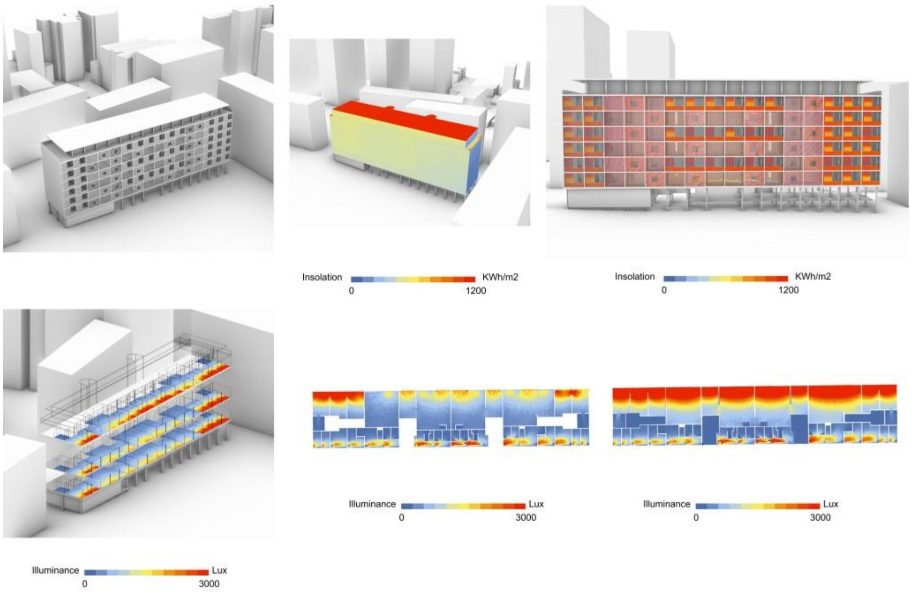

Figure 3. Bristol building Model (from up to down, left to right): 3D building model; envelope insolation analysis; west façade detailed insolation analysis; illuminance analysis in the winter solstice (June 21^{st} at 12h) of the first, third and sixth floors; third floor illuminance analysis with and without shading. Source: Authors, 2023.

2.4 Building numerical and graphical analysis

After preparing the parametric model, research relies on Ladybug and Honeybee software to analyse the building envelope, to identify witch envelope surfaces have higher and lower insolation throughout the year (Figure 3). The roof surface has higher insolation, 802 kWh/m^2, followed by the north and west façades with 697 kWh/m^2 and 632 kWh/m^2, respectively. The roof receives also the higher total solar irradiation (TSI), 1.870.737 kWh (50,7% of the entire envelope), the west façade has the second highest, 839.468 kWh (22,8%). In the west façade, of the five shading types, X-shaped cobogó with window obtains the highest insolation, 426 kWh/m^2, followed by X-shaped cobogó, with 238 kWh/m^2, and Circular-shaped cobogó, with 125 kWh/m^2. However, regarding TSI, is brise-soleil that receives more insolation, 269.018 kWh (65% of all shading types), due to having higher total area, 1.039 m^2, followed by X-shaped cobogó with window, with 83.124 kWh (20%) and 426 m^2, and Circular-shaped cobogó, with 29.081 kWh (7%) and 313 m^2.

Research analyse then the interior rooms performance of first, third and sixth floors near the west façade of the building, regarding illuminance. For the remaining floors, the interpolation of the values reduces calculation time. The analyses are for winter solstice (June 21st 12h), sun lowest position, summer solstice (December 22nd 12h), sun highest position, and autumn equinox (March 20th 12h), with sun in an intermediate position, relatively to their annual trajectory. For winter solstice, the floors average illuminance is 1.153 lux. The value increases for 1.836 lux in autumn equinox, registering a light decrease for 1.792 lux in summer solstice. Thus, at all analysed periods the illuminance values are in a suitable range of values, between 100 and 3.000 lux. Figure 3 displays the blocking capacity of the Bristol shading types in the west façade, regarding solar rays, showing illuminance for the intermediate floor, comparing the solution with and without shadings, for winter solstice period. The solution with shading diminishes considerably the illuminance. In the rooms near the west façade, the red color extension in plans's upper parts, that represents areas with higher illuminance, increases in the plan without shading.

2.5 Applied criteria

The west façade analysis enabled developing alternatives with improved performance. As references we consider research by Henriques (2012), Kirimtat (2016), Barber (2020), Vazquez (2020), Venâncio (2020) and Mateus (2021), that address the relation between architecture and climate, developing generative design systems, as parametric modelling and shape grammars, to generate solutions for building envelopes and their shading systems, with improved performance regarding insolation and illuminance.

This research develops combinatorial modelling methods that depart from the existing shading types in the Bristol building: circular-shaped cobogó (Letter A), circular-shaped cobogó with window (Letter B), X-shaped cobogó

(Letter C), X-shaped cobogó with window (Letter D) and brise-soleil (Letter E). There are detailed insolation and illuminance analyses for this five shading types, considering the 96 possible positions in west façade. The analyses are: 1) insolation in posterior plan after the shading, considering the shading, in Wh/m^2; 2) insolation in the posterior plan after the shading, without shading, in Wh/m^2; average illuminance in the rooms near west façade, in lux; 4) points number in rooms near west façade, with illuminance between 300 and 750 lux. Analyses are in winter (June 21st) and summer (December 22nd) solstices, at 10 12 and 16 hours, with CB sky, in the year's extreme situations. We explored after different shading type's combinations to improve performance by: 1) minimize insolation after shading, in Wh/m^2; 2) maximize points number in the rooms interior, with illuminance between 300 and 750 lux, as recommended by ABNT (2013); 3) maximize average illuminance (lux) in the rooms interior.

These three criteria are considered as objectives, to benefit of the building's shading, minimizing solar radiation (objective 1), maximizing the point number with suitable illuminance (objective 2) and maximizing average illuminance (objective 3) in interior rooms. We automatize the data collect with visual and textual programming, creating an alphanumeric label-code for each simulation, of the type "BristolLuxCB21Jun10_O_P6C15_LetterA", with 2+2+2x6x6 = 76 analyses. Analyses consider the building envelope in the urban context, climatic data and building materials. We rely on graphical representations to interpret the emergent patterns, and identify eventual model errors.

2.6 Combinatorial modelling and multi-objective optimization

Results use normalization in 0 to 1 scale, using then the combinatorial modelling optimization process developed for Nova Cintra building. Considering the different analysis scenarios (June and December at 10h, 12h and 16h), to improve performance for each of the 96 modules of the Bristol building west façade. Authors rely on conditionals to sort best values for each module, using Python: the solution for each scenario corresponds to a phrase composed by a list of letters A, B, C, D, and E with 96 elements. Solutions consider three objectives: minimize insolation, maximize point number with illuminance between 300 and 750 lux and maximize average illuminance. Multi-objective optimization process evaluates each shading type in each module, selecting shading type with best results for the three objectives. The research tested the use of the same weight and then changing individual weights to understand their behavior and performance for each objective.

3 Results

The results using multi-objective optimization with the same weight (five first columns of Table 1), equally value insolation, point number with ideal illuminance and average illuminance (ins 1, illuPt 1, illuAvg 1), showing that Letter C prevails in June and December scenarios with the exception Jun 10h, where Letter E prevails. Valuing the point number with ideal illuminance (ins 0.2, illuPt 0.6, illuAvg 0.2), Letter C prevails in the same scenarios, and is the shading type with best results. However, for Jun 10h the best result is letter E. Finally, favouring average illuminance (ins 0.2, illuPt 0.2, illuAvg 0.6) Letter A prevails in the June scenarios (10, 12 and 16h), while Letter E in December (10, 12 and 16h). Overall, Letter A is the best solution considering the average illuminance presenting 273 and letter E 227 results.

In short, Letter C, which refers to the X-shaped cobogó without window, is the best solution using the same weight and valuing point number objective with ideal illuminance. Valuing average illuminance Letter A, the Circular-shaped cobogó, has the best results. To improve analysis we use graphical representation, translating letters with colours as in Figures 4 and 5. For the cases with same weight and point number, with ideal illuminance, that consider the shading types that are more open i.e. receives more sun, Letter B (pink), Letter D (green) and Letter E (orange) are best solutions in Jun 10h scenario, as the sun does not shines on this period directly on the west façade. At Jun 16h and Dec 16h scenarios, type Letter C (blue), the most closed shading, offers best solutions. Therefore, Letter C blocks more the daylight inside the building, during periods with more incident daylight.

Considering more average illuminance, in Jun 10h scenario a closed shading type, namely Letter A (red), is better, to control excessive average illuminance, maintaining interior illuminance ranges (100 to 3.000 lux). In Jun 16h and Dec 16h scenarios increase more open shading types, as Letter E (orange), to increase interior average illuminance, comparatively to the situation in Jun 10h scenario.

Table 1. Multi-objective analysis shading types (A, B, C, D, E) weights for insolation, points number illuminance 300-750 lux and average illuminance.

Letter	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Multi	ins, illuPt, illuM (1-1-1)					ins, illuPt, iluM (0.2-0.6-0.2)					ins, illuPt, illuM (0.2-0.2-0.6)				
Jun 10h	1	23	26	15	31	2	28	26	3	37	51	17	8	3	17
Jun 12h	6	22	46	22	0	5	30	49	12	0	69	6	0	0	21
Jun 16h	1	2	66	21	6	0	1	86	8	1	54	2	5	0	35
Dec 10h	1	27	46	19	3	3	32	52	8	1	33	2	0	0	61
Dec 12h	1	7	48	35	5	0	8	68	19	1	28	1	6	19	42
Dec 16h	13	5	45	8	25	0	0	95	0	1	38	6	1	0	51
SUM	23	86	27	120	70	10	99	376	50	41	273	34	193	22	227
AVG	4	14	46	20	12	2	17	63	8	7	46	6	32	4	38

Source: Authors, 2023

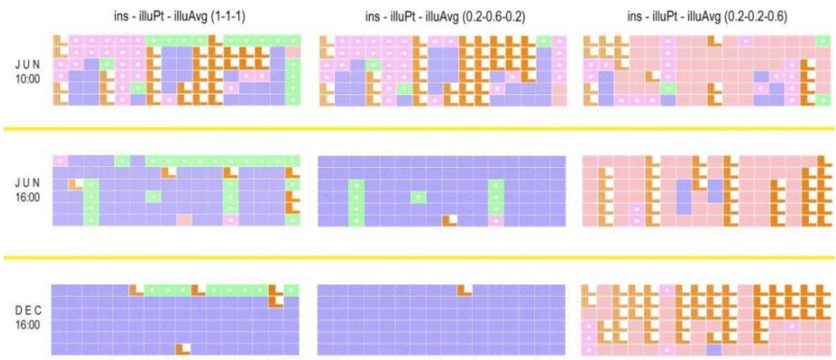

Figure 4. Combinatorial optimization, graphical results shading types Letter A (red), B (pink), C (blue), D (green) and E (orange), optimized according to objectives and weights indicated in the columns. Source: Authors, 2023.

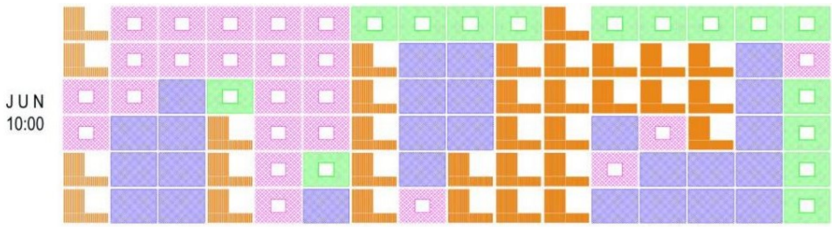

Figure 5. Combinatorial optimization, graphical results June 21st 10:00, considering insolation, illuminance points and average illuminance. Source: Authors, 2023.

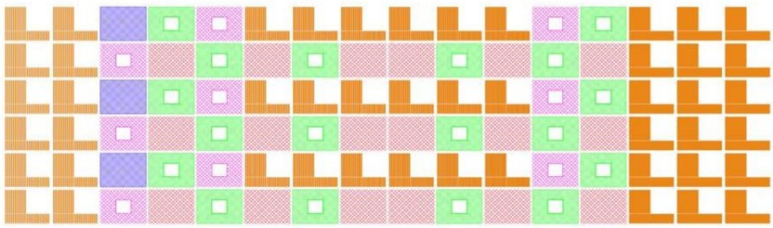

Figure 6. Original patterns of the west façade. Source: Authors, 2023**.**

4 Results Discussion

The computational models simulated five shading types (A, B, C, D and E) at Bristol building west façade, determining performance according to insolation, point number with ideal illuminance and average illuminance. Research uses combinatorial modelling and multi-objective optimization to select best shading type's combinations, valuing all criteria equally. Table 1 and Figures 4 and 5 displays the new combinatorial patterns for the west façade. Figure 6 displays the original west façade pattern. The combinatorial patterns obtained are less periodic and more asymmetric than the original. Using different weights and multi-objective optimization enables to improve solutions awareness. Weights with best results value more maximum average illuminance (ins 0.2, illuPt 0.2, illuAvg 0.6). Fit values for average illuminance are between 100 and 3.000 lux. Below 100 lux and above 3.000 lux have null score. The improvements achieved by the objective maximum average illuminance are, for Jun 10h, 12h and 16h, of 29%, 35% and 46%, and in Dec 10h, 12h and 16h, of 18%, 26% and 150%, which represents an average improvement of 50,7%. Considering the three objectives with equal ponderation (ins 1, illuPt 1, illuAvg 1) or valuing more the objective of point number with ideal illuminance (ins 0.2, illuPt 0.6, illuAvg 0.2), the improvement achieved is smaller, in average 14,8% and 19,9%. Research uses textual algorithm in Python to collect each objective analysis results, to use combinatorial modelling to search the best string combination (shading types) for each module, considering each objective separately. Finally, research uses multi-objective optimization to test the system sensibility, choosing the best combination considering weights defined. Future research intends to deepen the multi-objective optimization process, using *Octopus* for Grasshopper, comparing the results using textual programming in Python. Research intends to compare these results with the previous case study Nova Cintra Building.

5 Conclusions

This research departs from the modern shading systems, due to their originality and capacity to mitigate the tropical climate. Computational methods can expand the use of passive systems, to avoid the use of air conditioning artificial systems. Research addresses eight buildings from the Carioca School. This article analyses the Bristol building envelope regarding insolation and illuminance, and the west façade in detail. Authors use computational models to simulate and compare the west façade shading types performance, applying combinatorial modelling to find shading types combinations for the façade, regarding: insolation, point number with ideal illuminance and average illuminance. Results confirm that computational methods can improve traditional shading systems performance, innovating from tradition.

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