The Morphological Diagram:
A comprehensive toll for design and analysis in Architecture

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ABSTRACT: The architectural design in its complexity has suffered many changes, especially considering all matters related with sustainability and environmental quality. A better basis is requested to give architects more confidence to choose design strategies and to understand the consequences from the environmental point of view, especially those related to daylight. This article presents the use of Morphological Diagram for the evaluation of architectural designs, specially related to daylighting, aiming the development of repertory and critical sense of architects. The analysis is structured in three levels: Urban Space, Building and Room – presenting a list of Parameters end Variations related to the good balance between climatic insertion, daylighting use, solar control, natural ventilation and artificial light integration. The tool has been used in didactic exercises by many classes of graduation and post graduation students of Architecture and Lighting Design courses. The results of the use of this tool in these didactic experiences were positive, showing more confidence of the students when choosing between many alternatives of design and also when evaluating existent buildings. This can contribute to a better repertory of good solutions, aiming to the sustainability and environmental quality in the projects.

Keywords: Morphological Diagram, Architectural Design, Daylighting

INTRODUCTION

In an architectural project, daylight design have an important dimension, from the point of view of environmental, functional, aesthetical and qualitative aspects of architecture. To incorporate daylight in the design process, optimizing advantages and minimizing negative aspects, is crucial. But is clear the need of more references during the design process, to give architects more confidence to choose between many design strategies, and to understand the consequences, especially from the environmental point of view.

Many researches (GARROCHO, 2005; AMORIM, 2007; SILVA, 2007) show the difficulty of architects, especially in Brazilian context, to comply the exigencies of a good daylight design, equilibrating visible light and thermal gains, maintaining other demands, like functional, aesthetical, constructive and economic. Baker et al (1993) and IEA (2000) mention some ways to convince designers to optimize use of daylight in buildings: to show existing possibilities by means of exemplary case studies, to give information and analysis describing relevant aspects of case studies and to give architects tools and methods to help in design. As an example, Baker et al (1993), in his Morphological Box, proposed a repertory of forms and types, structured in an architectural grammar that allows the adaptation to specific programs.

In this article we present the use of the Morphological Diagram, adapted from Baker et al (1993), for the analysis of various architectural designs, aiming the development of repertory and critical sense of architects. The analysis is structured in three levels: Urban Space, Building and Room – presenting a list of Parameters and Variations related to the good balance between climatic insertion, daylighting use, solar control, natural ventilation and artificial light integration.

DAYLIGHTING AND ARCHITECTURAL DESIGN

Daylighting, coming from direct or diffuse radiation, is an important criteria to reach more environmental quality (comfort and energy efficiency, among others) and sustainability in spaces.

But architectural design, even being a technical-creative process where different questions are played, “doesn’t means the resolution of a mathematical equation, in which is possible to identify a defined sequence of operations that take to a unique result; being a process of synthesis and choose, it allows a large number of possible solutions, that will be more or less adequate...” (ROGORA, 1997, p. 65). This implies, necessarily, in a process of analyses (of conditioning factors, program of necessities, and so on) and synthesis that can present different solutions.

We can say that the traditional architectural project has a lot of uncertainties and steps conducted almost only by the designers' intuition; besides, normally "is based on criteria that are predominantly intuitive, visual and aesthetic, such as form, mass, space and volume"(BAKER *et al*, *op.cit*., p.11.1). The initial sketch of the design, critical for daylight use and environmental related aspects is almost always done in a short period, probably by a partner or principal.

Designers, in general (architects but also lighting designers) have strong interest in aesthetical aspects of light and in its use in the creation of scenes and ambiences, and these aspects are very important in the architectural and lighting design. Despite this, the actual Brazilian context, with a lack of culture, norms and regulations for environmental quality and energy efficiency for architectural projects[i], needs the dissemination of knowledge to stimulate more sustainable design (specially comfort and energy efficiency), making easier the application of this knowledge by the designers community.

THE TOOL: METHODOLOGY AND USE

From the concept of Baker et al (1993) that proposes a repertory of forms and types structured in an architectural Grammar, the tool called "Morphological Diagram" was adapted. The basis of the Morphological Diagram is the theory of architectural composition that works as a cumulative design tool, or "typological method", with a repertory of structured forms and types that allow these models to be adapted to specific programs. The tool intends to be a model to the analysis and evaluation of projects and can be also used during the design process (AMORIM, 2007).

The toll adapts the original concept adding categories based on specific matters of the climatic and constructive Brazilian context, and enlarging the analysis to include other environmental items, like natural ventilation, integration with artificial lighting and controls and so on. This enlargement is based in the fact that the built environment, by definition, must equilibrate thermal and lighting demands, by means of its form, envelope and openings; in this way, design decisions will include these concepts. The adaptation was made based on developer intuition and the experience in teaching environmental matters in architectural projects.

The Diagram was developed to be used in Brazilian context, taking into consideration the way of construction and building elements existent in the context. This explains the addition of usual window designs and possibilities to natural ventilation; also the repertory of solar protection elements was improved, adding elements like perforated blocks (*cobogós*), traditional in Brazilian architecture. The integration of Daylight with Artificial Light was based on the fact that this is very important to reach energy efficiency of the building. Good use of controls and integration can offer more visual comfort, glare control and energy efficiency.

The Diagram is divided in three levels, in this sequence: Urban Space, Building and Room that are considered enough to characterize the building and its relations with surroundings. Each Level has many Parameters, with some Variables (Figure 1).

LEVEL	PARAMETERS	VARIABLES
Urban Space	A - Urban layout	A1. Small urban blocks; A2. Large urban blocks; A3. Solar oriented blocks; A4. Superquadras; A5. North-south slabs; A6. East-west slabs; A7. Intermediary slabs; A8. Open blocks; A9. Towers; A10. Detached towers; A11. Other;
	B - Façades reflectance	B1. High; B2. Mean; B3. Low; B4. Other;
	C - Façades specularity	C1. High; C2. Mean; C3. Low; C4. Other;
	D - Street top lighting	D1. Profile angle 30º; D2. Profile angle from 30º to 60º; D3. Profile angle from 60º to 90º; D4. Profil angle of 90º; D5. Others;
II Building	E - Building plan layout	E1. Deep plans; E2. One level building; E3. Unilateral/ bilateral slabs; E4. Courtyard or atria; E5. Pilotis building; E6. Double shell building; E7. Others;
	F - Wall apertures ratio	F1. 25% aperture; F2. Between 25% and 50% aperture; F3. Between 50% and 75% aperture; F4. More than 75% aperture;
	G - Wall apertures distribution	G1. Symmetric façades; G2. Solar asymmetric façades; G3. Urban space asymmetric façades; G4. Others;
	H - Wall shading devices	H1. Portico and verandas; H2. Brise-soleil; H3. Cobogós; H4. Overhangs; H5. Pergulas; H6. Vegetation; H7. Others;
	I - Roof apertures	I1. Domus; I2. Monitor roof; I3. Shed; I4. Skylight; I5. Light duct; I6. No apertures; I7. Others;
	J - Natural ventilation strategies	J1. Cross ventilation; J2. Cross adjacent ventilation; J3. Chimney efect; J4. Single aperture; J5. No natural ventilation; J6. Others;

III Room	L - Room plan layout	L1. Unilateral; L2. Bilateral; L3. Deep room; L4. Outros;
	M - Light collecting position	M1. Within plane central; M2. Within plane skylight; M3. Between planes; M4. Between plane corners; M5. Window wall; M6. Others;
	N - Light collecting dimension	N1. Side light up to 15%; N2. Side light from 15% to 30%; N3. Side light over 30%; N4. Top light up to 15%; N5. Top light from 15% to 30%; N6. Top light over 30%;
	O - Light collecting shapes	O1. Intermediate window; O2. Horizontal window; O3. Vertical window; O4. Window wall; O5. Horizontal ceiling window; O6. Vertica ceiling windowl; O7. Total glazed ceiling;
	P - Light collecting control	P1. Sills; P2. Light shelves; P3. Overhangs; P4. Brise soleil; P5. Cobogós; P6. Curtains or solar control glazing or films; P7. Others;
	Q - Natural ventilation control	Q1. Horizontal window; Q2. Maxim-air or bascula; Q3. Pivoting window; Q4. Aberturas com lamelas; Q5. Guilhotina; Q6. Ceiling aperture; Q7. Others;
	R - Control and integration of artificial lighting	R1. On/ off; R2. On/ off with sensor; R3. Dimming; R4. Dimming with sensor; R5. People detector or step regulator; R6. Others.

Figure 1: Levels I, II and III of Morphological Diagram – Urban Space, Building and Room – with Parameters and Variables (AMORIM, 2007)

Each proposed Variable in the three Levels is identified with an Icon that helps in the process of comprehension and interpretation of projects (Figure 2).

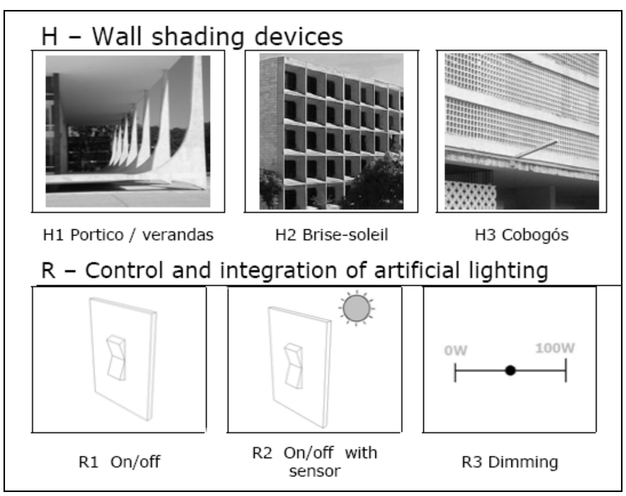


Figure 2: Examples of icons of Variables from Levels II and III (Building and Room) in the Morphological Diagram (AMORIM, 2007)

The use of Morphological Diagram to evaluate architectural designs requires the compilation of data in a sequence from Urban Space, Building and Room (that can be a single room of the Building or representative rooms that characterize it – e.g. classes in a school). The fulfillment begins with basic information about the building, as Typology, Localization (city, latitude, longitude, altitude), Data of Construction, Architect. Also data about Local Climate is asked (short description with Type of Climate, Temperatures– annual average and maximum/minimum averages – solar radiation, hours of sun, winds, rains) and the Solar Path Diagram. Also a plan or picture with building localization in urban context; and Parameters and Variables of each Level (Urban, Building and Room) are illustrated with pictures and drawings of the most important aspects.

When evaluating a project the proposal is to sign with color the aspects that are perceived as “optimizing points” in the project; that means aspects that need adjustments (in the daylight performance, thermal aspects or energy efficiency). The visualization of marked colored (gray or other color) allows the quick identification of the points to be optimized. The results are showed in the next page (Figures 3 and 4).

It is important to remember that the evaluations are based in the knowledge of the appropriate design strategies to local climate; the first information in the Diagram are regarding local climate, solar chart, and so on, and will be the basis to evaluate design solutions of each Architectural Project. The same design solution can be appropriate in temperate climates, but considered problematic in tropical climates. The Diagram can be use to evaluate projects during the process of design and after the completion, to be used again to check final result.

DIDACTIC EXPERIENCES

The Morphological Diagram was presented and proposed in a didactic exercise to graduation and post-graduation students (Faculty of Architecture and Urbanism-University of Brasilia[1]). It was also used by the students of a post graduation courses in Lighting Design (University Castelo Branco and University Cruzeiro do Sul[2]). The proposed exercise was the use of Morphological Diagram to analysis and evaluation of an architectural project. The idea was to select one architectural Project, considered good from the point of view of climatic insertion, daylighting use, comfort and energy efficiency. From this point, it is considered that the exercise would help to verify the real Project condition, evaluated with Levels, Parameters and Variables of the Diagram.

[1] 50 graduation students and 7 post-graduation students (in 2007).

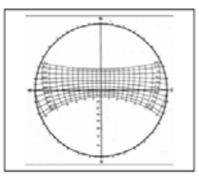
[2] Twelve classes of different cities from 2006 to almost 340 students (most architects, but 20% from ohter professions- engineers, administrators, interior designers and others).

Different architectural projects were chose to be evaluated. These projects were initially identified by the students were “good”; the Diagram was used to evaluate this first impression. The students identified existing buildings (or projects), and collected information about it, by means of visits, photos, interviews with users and in some cases, measurements (especially illuminances). These information should be enough to complete the Morphological Diagram. The students had from 15 to 30 days to complete the exercise.

The most frequent typologies of buildings selected by the students were office buildings, university buildings or schools, shopping centers, residential buildings, hospitals and churches. It’s interesting to observe that many good projects built between 1960 and 1970 were identified. This period is especially rich in architectural examples with climatic insertion and the use of solar control elements, like *brise soleil*, different façades in each orientation, limited use of glass, what is not common in other periods. (See example in Figure 3).

EDIFÍCIO NIEMEYER – BELO HORIZONTE

Building information



Local solar chart

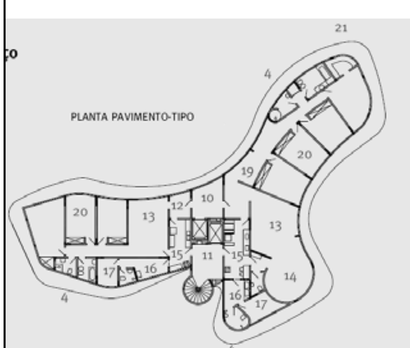
Climate

Type: Tropical of Altitude,
Annual average temperature: 21º C
Monthly average (maxim): 31º C
Monthly average (minimum): 16º C

Building: Edificio Niemeyer
Tipology: Residential multifamiliar building
Localization: Belo Horizonte
Latitude: 19º55’15” S
Longitude: 43º56’16” W
Altitude: 858,00m
Architect: Oscar Niemeyer
Date: 1978

Location of Niemeyer Building

External view



Building´s plan

External view with brise soleil

LEVEL	PARAMETERS	VARIABLES
I Urban Space	**A** Urban layout	**A7** Intermediary slates
	B Facades reflectance	**B3** Low
	C Facades specularity	**C3** Low
	D Street top lighting	**D4** 90º
II Building	**E** Building plan layout	**E5** Pilotis
	F Wall apertures ratio	**F3** Between 50% and 75% apertures
	G Wall apertures distribution	**G1** Symmetric facades
	H Wall shading devices	**H2** Brise-soleil
	I Roof apertures	**I6** Domus and sheds
	J Natural ventilation strategies	**J4** Single aperture
III Room	**L** Room plan layout	**L1** Unilateral
	M Light collecting position	**M6** Others
	N Light collecting dimension	**N3** More than 30% aperture
	O Light collecting shapes	**O2** Horizontal window
	P Light collecting control	**P4** Brise soleil
	Q Natural ventilation control	**Q2** Bascula
	R Control and integration of artificial light	**R5** People detector or step regulator

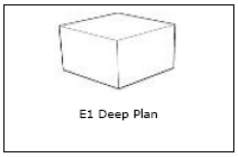
Figure 3: Morphological Diagram of Niemeyer Building (residential) – Belo Horizonte (1978)[3]

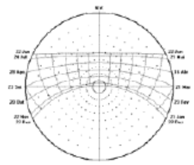
On the other hand, some more recent buildings were also selected, especially those with some appeal osustainability, or special interesting architecture from aesthetical point of view. In this case, the exercise could help students to verify if the claimed “sustainability” was really efficient (see example in Figure 4).

[3] Elaborated by Aryelle Cardoso Moreira, Daniela Turchetti and Philippe Andrade –Post Graduation Course of Belo Horizonte.

EDIFÍCIO SUÍTE VOLLARD - CURITIBA

Building information



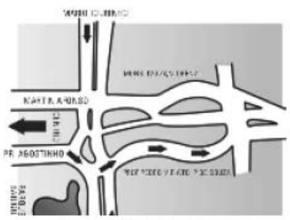


Local solar chart

Building: Edifício Suíte Vollard
Tipology: Residential Multifamiliar
Localization: Ecoville - Curitiba- PR
Latitude*: -25,25º
Architect: Bruno Franco
Date: 2004

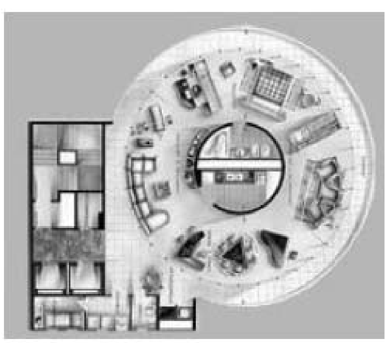
Climate

Tipe: Subtropical
Annual average temperature: 22,00 °C
Monthly average: 18,5° C



Location of the building

External view



Building´s plan

Internal view

LEVEL	PARAMETERS	VARIABLES
I Urban Space	**A** Urban layout	**A1** Small urban blocks
	B Facades reflectance	**B1** High
	C Facades specularity	**C3** Low
	D Street top lighting	**D1** Profile angle 30° **D4** 90°
II Building	**E** Plan and form	**E7** Other
	F Wall apertures ration	**F4** More than 75% aperture
	G Wall apertures distribution	**G2** Other
	H Wall shading devices	**H1** Porticos and verandas
	I Roof apertures	**I6** No
	J Natural ventilation strategies	**J2** Cross ventilation
III Room	**L** Room plan layout	**L1** Unilateral
	M Light collecting position	**M5** Window wall
	N Light collecting dimension	**N3** More than 30% aperture
	O Light collecting shapes	**O4** Window wall
	P Light collecting control	**P7** Others
	Q Natural ventilation control	**Q1** Horizontal window **Q2** Bascula
	R Control and integration of artificial light	**R3** Manual dimming **R4** Dimming with sensor

Figure 4: Morphological Diagram of Suíte Vollard (residential) – Curitiba (2004)[4]

University buildings were also frequently identified as good examples, showing that this typology is rich of interesting solutions. The reason is probably that normally these buildings are designed by teachers of Architectural Faculties themselves, with special attention to climatic aspects.

The projects evaluation in some cases confirmed the initial impression, in other cases it showed problems that were not initially identified. In general, almost all the projects had some critical point, what in the exercise was called "points of optimization" in the Project. This kind of approach creates a positive diagnostic that suggest improvements in the Project. The evaluation is complemented by a short text, that explains why some

[4] Elaborated by Andressa Caroline, Chen Tso Ken, Márcio Buzetti, Mônica Nazareth and Raphael Tomaz –Post Graduation Course of Curitiba.

points were considered “optimization points” in the Morphological Diagram.[5]

After the completion of this exercise, the students were invited to answer a Questionnaire about the use of Morphological Diagram. The Questionnaire had 6 questions, asking about:

- the efficacy of the tool to analyses of existing projects, and also exploring the possibility of it´s use in the design process;
- aspects more cleared after the use of the tool (relations between urban design/thermal comfort/ daylighting; relations between building/daylighting, relations between facades morphology daylighting, ventilation and control and integration of artificial lighting);
- graphical and textual quality of the tool;
- sugestions to improvement of the tool.

103 questionnaires were answered. Almost all the students (98%) answered that the Diagram is a useful tool to evaluate an existing Project, especially to understand the relations between daylighting, comfort and energy efficiency in the architectural design.

The aspects considered more cleared with the use of Diagram were: the relationship between façades and daylighting (69%) the relationship between building and daylighting (62%), the relationship between urban form and thermal comfort (61%). Were also mentioned aspects related with ventilation of building (43%), relationship between urban form and daylighting (35%) and aspects of control and integration of artificial lighting in the project.

CONCLUSION

In general, the experience with Morphological Diagram as an evaluation tool of projects has been positive. The tool helps students to evaluate projects and give more confidence to evaluate and propose adequate solutions from the point of views of climatic insertion, use of daylighting, comfort and energy efficiency.

It’s also interesting mention that the tool helps architects to create repertory of good design solutions that can be used in new sustainable projects. All these facts can be relevant, especially considering new demands for sustainability in Brazilian context and the urgent need of professionals to supply this demand.

One possible evolution of this tool could create scales of values adapted to various climates, trying to relate the use of specific design strategies to each climate. This could help to produce more precise and quantitative evaluations of different designs. The scale could provide more precise evaluations to designers, indicating right solutions to daylight design on that specific climatic context.

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[5] The students were oriented to fulfill in gray color the spaces of Variables considering the need of optimization in each project, regarding Urban Space, Building and Room.