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a colaboração no projeto de edifícios para atender metas ambientais

a collaborative approach on building design to meet environmental goals

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Abstract

This paper discusses the theme "participate+collaborate", focusing on design process in the architectural field to understand collaborative approach to match building environmental goals. The requirements influence the design processes so that the main gaps detected are related to the forms of interaction and collaboration among team members throughout the process. The fulfilment of environmental performance targets can be achieved, without harming other variables involved, since there is collaboration with a systemic approach between different specialists, from the initial stages of the project. Such statement is discussed based on a critical review of literature and results of the exploratory research carried out with the architects and consultants, during the sketch design stage of a nursery school project, in order to match the thermal and daylight comfort requirements of the PBE-Edifica energy label. This case study resembles a multidisciplinary process with tasks division, and the consultancies consist of computer simulations, identifying problems, assessing alternatives and indicating adequate solutions. The architects pondered the guidelines received with the other design limitations in order to take the decisions. In conclusion, it is necessary to develop the design process management from the initial stages to facilitate the collaboration among specialists.

Keywords: Design process, Collaborative process, Decision-making, Environmental performance goals

1 Introduction

The architectural design nature is complex and can be presented in a variety of ways. "Parti.cipar+co.laborar" are inherent activities to designing, which evidence the nature of the process Scrivener, Ball and Woodcock, 2000) and are increasingly present in contemporary times, especially when they involve complex themes and/or large scales. In these projects, work teams can bring together various participants, whether they are: users, clients, designers or experts from various fields of knowledge (Scrivener, Ball and Woodcock, 2000). Among different types of collective design process, such as the process with user participation (Sanders, 2000, 2006, 2009), the collaborative design with the participation of more than one expert is discussed in this article (Veloso and Elali, 2014).

The fulfilment of thermo-energetic and daylight performance goals involves several specialists and is influenced by the introduction of new procedures in design practice, related to the architect's specialization and needs, such as the quantification of environmental goals and adjustments in the way of organizing team works. Such needs are historically recent due to the introduction of bioclimatic principles and environmental sustainable concerns, as well as the introduction and obligation to meet regulations, standards and labels.The latter are linked to the need of measurable criteria to limit the impacts caused by the construction industry, such as the PBE-Edifica energy label, which is mandatory for Brazilian federal public buildings since 2014 (Brasil, 2014). These measures are supported by the concept of sustainability, in the context of contamination and scarcity of natural resources and climate change (Corbella and Yannas, 2003; Montaner, 2012), and regard, in the construction field, that architecture can have the role of reducing or even halting the impact caused by the uncontrolled consumption of resources (Sykes, 2013).

However, the traditional way of designing, which involves principles based on function, form and space, does not consider the fulfilment of quantitative criteria of energy efficiency (Al-Saadani and Bleil de Souza, 2016; Shi,et al., 2016). In general, the goals are expressed by quantitative values (BRASIL, 2009; 2012), but the architects rarely have the training with necessary depth to quantify these values, which often require the use of simulation tools[1] Al-Saadani and Bleil de Souza, 2016; Shi,et al., 2016). They are more familiar working qualitatively (Al-Saadani and Bleil de Souza, 2018),pondering the importance of each design parameter, according to the context and their different points of view (Mahfuz, 1995; Lawson, 2011).

The most common form of adaptation is the interaction with experts, in which the consultant suggests improvements to the designer.However, there is a disparity in the time needed for evaluation and the possibility of incorporating these results into the design process. The consultant can only evaluate the project with detailed information, usually at the end of the design process (Hensen and Lamberts, 2011). However, the designer benefits from evaluating the project since the early stages (Hobbs,et al., 2003), regarding the first design decisions are more impacting in the building performance (Burberry, 1983; Pedrini, 2003; Hensen and Lamberts, 2011) and possible modifications should be done at the early design.

Teamwork is suggested for a better interaction (Charnley, Lemon and Evans, 2011; Goldschimidt, 2014; Al-Saadani and Bleil de Souza, 2018). Communication between the members and the task measuring for the available time demand planning activities (Cross, 2011) in a collaborative way instead of splitting into parts, in which each member develops an unrelated activity to another (Al-Saadani and Bleil de Souza, 2016).

The process can be assumed collaborative when a single design requires the interaction of more than one expert, sharing goals, intentions (Simoff and Maher, 2000) and knowledge about the process and about the design (Kleinsmann, 2006). In the context of meeting performance goals, it is advisable to work with multidisciplinary teams, involving specialists from different fields, especially when the design becomes more complex (Al-Saadani and Bleil de Souza, 2018), seeking a more holistic view (Charnley, Lemon and Evans, 2011; Al-Saadani and Bleil de Souza, 2016). A design that involves multiple participants with different specialties demands more planning and organization by those involved.

Collaboration also brings new activities that need to be incorporated into the process, such as identifying, managing, and avoiding conflicts (Cross, 2011). Some collaborative processes already try to incorporate the integration of several members from the beginning of the project, such as the Integrated Project Delivery

(IPD) (AIA, 2007; Andrade and Ruschel, 2013). Papers indicate that IPD is fundamental to meeting requirements such as zero energy buildings (ZEB) (Garde, et al., 2014). Although, the main works developed in Brazil still do not focus on the use of IPD to meet environmental goals.

These goals management and quantification activities can be considered as new procedures that need to be incorporated into the design dynamics. But it is not clear how the flow of this information fits the process. Therefore, the analysis of the organization's records of the teams and their interaction can be references for a better understanding of how this collaborative process occurs in order to meet environmental goals, allowing reflections and contributions to their organization.

In addition, the academic researches involving meeting environmental performance goals generally focus on modelling and simulation methods developed by engineers and physicists, while the architect's perspective is often ignored, despite its importance in decision-making. Few projects focus on the integration of techniques for achieving goals in the design process, or on the perception of architects' techniques for performance evaluation (Shi, et al., 2016), or in the recognition that these techniques must adapt to the design process, not the opposite (Morbitzer, 2003). Thus, this paper is part of a doctoral research and aims to identify which considerations are pertinent to the early collaborative design process that aims to meet the goals of thermo-energetic and daylight performances, bringing the discussion closer to the perspective of the designer, who has other obligations beyond the fulfilment of environmental goals.

2 Method

The method consisted in performing an exploratory pilot case studyfor further research, and other cases. The requirements for selecting this specific case were: access to documents related to the early design stages (Kleinsmann, 2006); involvement of specialists with different types of attributions and tasks (Kleinsmann, 2006), at least one of them being in charge of the thermal and energetic performance of the building; and, after initial assessment, availability of records in number and quality, enough for analysis at a sketch design level. Based on these criteria, the selected design was the children's education building of a school in Parnamirim, in the metropolitan area of Natal / RN.

Thus, the case study assessed the meeting for the presentation of the report "Report of initial design guidelines for thermo-luminous performance and environmental certification PBE-EDIFICA", analysing indicators or resulting documents of the design process (sketches, conceptual diagrams, plans, modelling, reports, records of meetings and others), and the elaboration of the diagram DICA-M (according to item 2.1).

The design was developed by two architecture offices and the consultancy by a specialized company (one of the authors of the article was part of the consulting team). The consultants used simplified computational simulations to evaluate the design (Hensen and Lamberts, 2011) in softwares DesignBuilder (Designbuilder Software Ltd, 2000-2005), FlowDesign and Ecotect (Marsh, 2003), based on the sketches, AutoCAD and SketchUp plans and drawings at early stage.

The documents analyses were guided by questions based on Braun and Clarcke (2006) suggestions:

+ Characterization of the design problem:

  i. Which goal should be match?

  ii. What are the restrictions?

  iii. What is the problem to solve?

  iv. What is the nature of the design?

  v. What is its dimension?

+ Decision-making

  i. When and where did the solution come from?

  ii. What is the interdependence of the decisions?

  iii. What is the relationship between the level of technological complexity and the degree of autonomy in decision by the designer?

iv. What is the role of the consultant in making decisions? Does he/she propose solutions? Or does he/she just test solutions?

v. Do the decisions follow hierarchy (horizontal, vertical, other)?

vi. Does the goal increase the time needed for decision-making?

vii. What information is needed for decision-making? (What is considered? Why is it considered?)

viii. What information is a product of decision-making? (What results of it? Why is this result produced?)

ix. Finally, what decision is made at each stage of the project aiming to meet the goals?

+ Resources used (human, technological, informational, etc.)

i. What human resources are involved in meeting the goal?

ii. What technological resources are needed to evaluate the goal?

iii. What information resources are needed to evaluate the goal? Was it necessary to share what information? By what means?

2.1 DICA-M Diagram

The DICA-Multidisciplinary Diagram (DICA-M Diagram) is an expanded version, to represent the insertion of the multidisciplinary team in the DICA Diagram, developed by Dutra (2010). The diagram proposed by him is structured on the main measures for the development of bioclimatic projects: gathering of information, design decisions, conceptual synthesis (goals and targets), analysis, design synthesis, conjecture and Environmental Design Support Tools (EDST). Each of these categories is arranged in a line, in which an action is represented by a point. The points are linked chronologically by a line representing the design process.

The diagram application is expected to facilitate the visualization of design action sequences during the process, which action precedes the decision making, and in which action each team member is involved. It was developed to analyze bioclimatic design processes and it is understandable to meet environmental goals.

Information was added to the structure of the diagram developed by Dutra (2010), for the multidisciplinary version (Figure 1): the different members of the project team, represented by different colours (Figure 1A); the identification of moments of collective or individualized work along the process (Figure 1B); the identification of the phase and the design identification (Figure 1C).

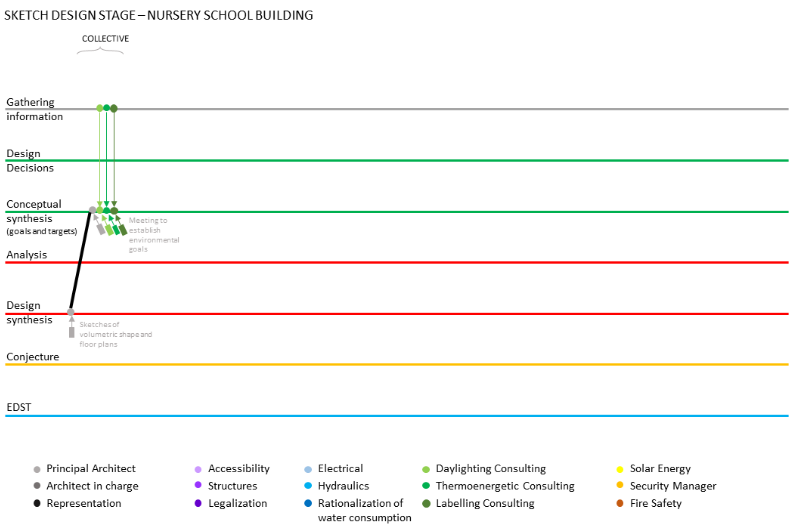

Fig. 1: DICA – M Diagram. Source: Adapted from Dutra (2010).

3 Case Study

The case study deals with the interaction between architects and consultants during the sketch design stage of a daytime nursery school. For the development of the project, the architects worked with concepts of welcoming, complexity, polyvalence, transparency, playfulness, religiousness, technology and sustainability (Figure 2). According to the architects, the energy label was required to quantify and prove the environmental comfort strategies adopted, demonstrating the commitment and innovation of the development.

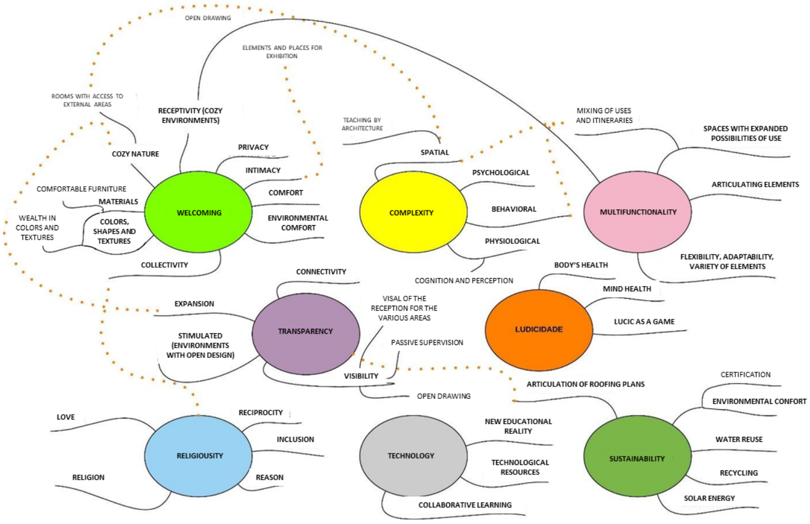

Fig. 2: Sketches of the sketch design stage study for the school: concept. Source: Images provided by the Architecture Firm Flora Nativa, 2016.

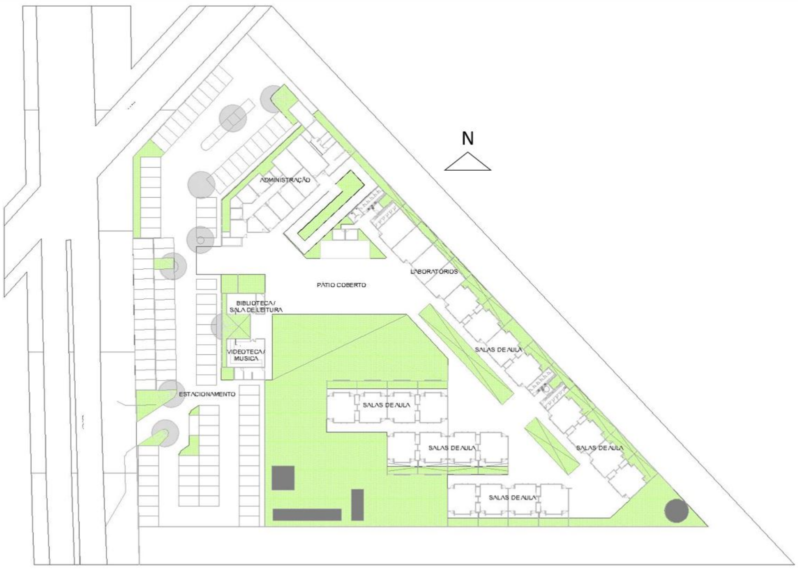

Fig. 3: Sketches of the sketch design stage study for the school: ground floor. Source: Images provided by the Architecture Firm Flora Nativa, 2016.

Fig. 4: Sketches of the sketch design stage study for the school: second floor. Source: Images provided by the Architecture Firm Flora Nativa, 2016.

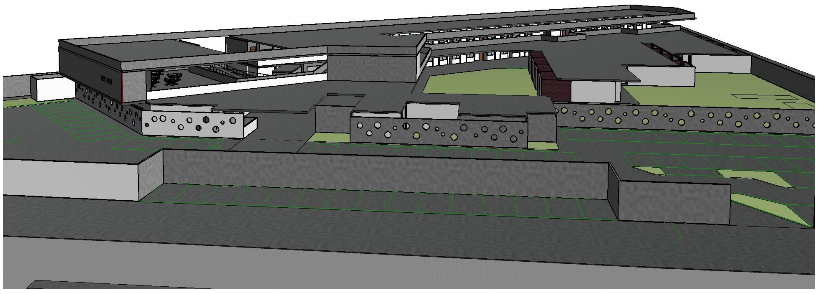

Fig. 5: Sketches of the sketch design stage study for the school: volumetric shape. Source: Images provided by the Architecture Firm Flora Nativa, 2016.

Fig. 6: Sketches of the sketch design stage study for the school: volumetric shape. Source: Images provided by the Architecture Firm Flora Nativa, 2016.

The initial drawing of the sketch design stage is composed of two floors (Figure 3 and 4), totalizing approximately 6.017 m² of constructed area. The predominant orientation of the building facades is Northeast, same orientation of most classrooms. The building also has three other parallel classroom areas, oriented to the South and the administrative area to the Northwest.

The project is located in Parnamirim/RN, at latitude of 05º 54 '56 "S and longitude of 35º 15' 46" W. The climate is warm and humid, with average temperatures around 27°C and relative humidity around 70%. The city is in Bioclimatic Zone 08, which recommends: natural ventilation; solar shading; night ventilation and internal air movement; ventilation combined with thermal inertia and evaporative cooling (ABNT, 2005).

4 Results

The interaction between architects and consultants occurred during the evaluation of the design for thermo-energetic, daylight performance and energy efficiency labelling, from a preliminary version of the sketch design stage. The initial information exchange between architects and consultants occurred through a meeting to define environmental goals to be met and an explanation of design concepts, constraints and initial ideas.

The preliminary evaluation of thermal performance consisted in: analysis of thermal loads, shading and natural ventilation; preliminary assessment of natural light optimization; and presentation of the energy label

PBE-Edifica. The thermal load analysis identified the thermal zone load sources, indicating the ones should be removed by natural ventilation or artificial conditioning. The main source of thermal load was solar radiation and it was suggested shading the openings.

The shading analysis assessed the current openings, observing their performance in terms of percentage (Figure 7). For those cases where the shading was not satisfactory, the consultants simulated some adequate and inadequate solar shading options. These analyses included the quantification of visible sky factor, to achieve daylight potential use.

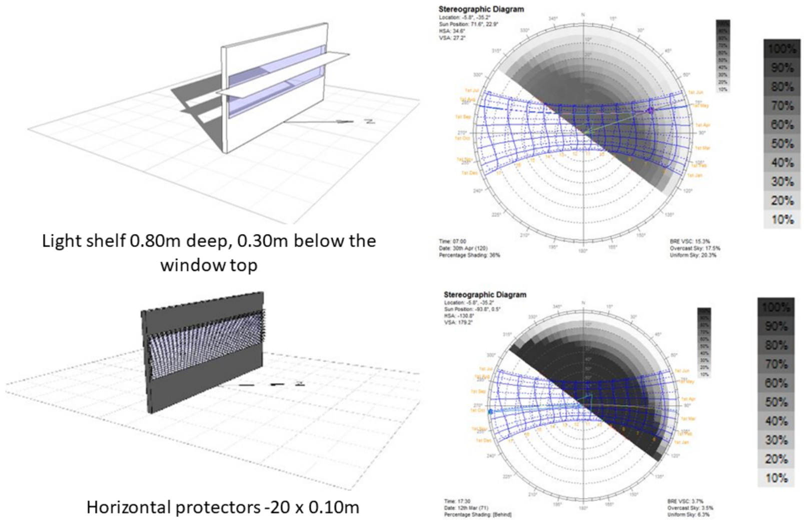

Fig. 7: Shading analyses of a room: examples of alternatives suggested to the project team (B) and not recommended (C) with respective shadow masks. Source: Dias, Rodrigues and Jankovic, 2016, pp.16-18.

The natural ventilation performance was assessed calculating the air renewal per hour of each thermal zone, and the need of increasing current opening dimensions. The windows specified, for the most part, were sliding windows, whose vent opening area corresponds to only 45% of the window area. For thermal zones considered to be unsatisfactory, alternative types of window that would increase the area for ventilation were introduced.

The influence of orientation on natural ventilation was also considered. Pressure coefficients were identified to verify the potential of crossed ventilation, the existence of wind barriers and recommended distances between building blocks. As a result, it was suggested a building form change, the use of wind deflectors or vertical elements to increase the pressure differences or redirect the wind trajectory.

The preliminary evaluation aimed a daylight optimization, performed qualitatively. The aspects assessed were: effective opening for lighting, room depth opening height ratios, furniture layout, room internal surface reflectances; opening orientation, opening solar shadings and surrounding obstructions. Architectural principles were presented for the optimization of daylight that could be applied to the project, and more efficient shading types were proposed for each orientation and the use of landscaping to obstruct the direct solar radiation on the openings and use of daylight were suggested (Figure 8).

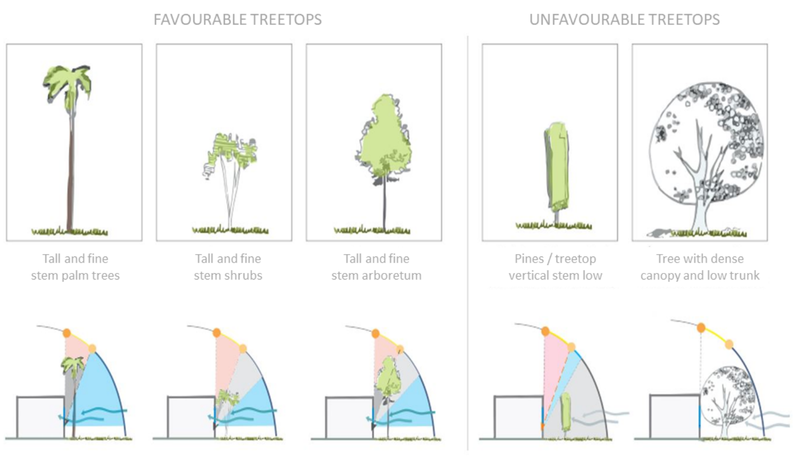

Fig. 8: Shading recommendation with favourable plant crowns for thermal and luminous optimization of environments for North in Natal / RN. Source: Dias, Rodrigues and Jankovic, 2016, p.32.

At the end, the energy label PBE-Edifica was presented concerning systems and calculation parameters. Recommendations were elaborate to address the regulation critical points in relation to the architecture project in order to achieve energy efficiency level A. The consultancy highlighted the importance of selecting the adequate roof material, the reduction of the opening area exposed to solar radiation and the external colours.

4.1 Document Analysis

Initially, the consultancy assessed the design performance and the design guidelines compatible with the project principles. This information was formatted in a 56-page report, which was presented at a meeting with the architects, which lasted approximately 3 hours. The meeting also contributed to explain the thermo-physical principles and bioclimatic strategies related to the analyses and allowed the architects to discuss the presented points.

From the information exchanged in this first phase, the architects in charge of the project development worked in two ways, trying to:

+ incorporate the suggestions given, trying to reconcile, mainly, aesthetic aspects of the building

+ understand bioclimatic principles to bring new design solutions to problems identified as critical from the illustrations and explanations.

The main constraints identified in this design phase were the irregular shape of the site, and its area already compromised with parking spaces, corresponding to the existing school building (current nursery, middle and high school). These two factors, in addition to the extensive program and pre-dimensioning, restricted the blocks orientation to parallel with the lot boundaries (Figure 9 and 10). Another noticeable restriction was the need for open visuals to keep the children in the supervisor's sight at practically any point of the school, and for children interaction with the vegetation. The need of open visuals led to further discussion about shading solution of the ground floor corridor, choosing vegetation (Figure 11 and 12).

In this first step, the goals guided the development of the solar shadings (Figure 11, 12 and 13), type of windows (Figure 13) and specification of wall and roof construction system. However, the orientation, which would facilitate natural ventilation, shading and hence daylighting, could not be changed. The available area restriction and the site format were considered as limiting factors. The preservation of the orientation resulted in design alternatives that would require a more in-depth study, such as incorporation of sheds, light shelves and use of sunshades that restrict the user's vision of the outside (Figure 14).

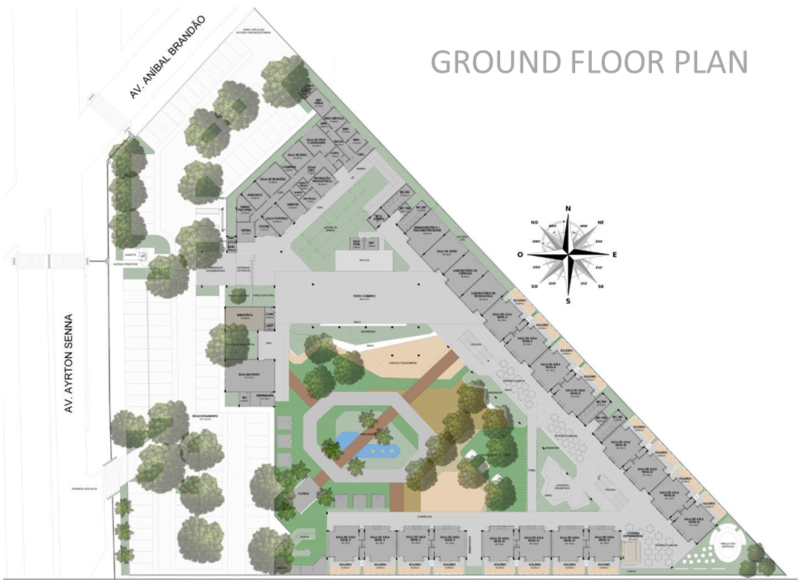

Fig. 9: Ground floor of school building after consulting for sketch design phase. Source: Images provided by the Architecture Firm Flora Nativa, 2017.

Fig. 10: Second floor of school building after consulting for sketch design phase. Source: Images provided by the Architecture Firm Flora Nativa, 2017.

Fig. 11: Internal Perspective of ground floor corridor, highlight for vegetation shading and architectural. Source: Images provided by the Architecture Firm Flora Nativa, 2017, adapted by Authors.

Fig. 12: Internal Perspective of ground floor corridor, highlight for vegetation shading and architectural. Source: Images provided by the Architecture Firm Flora Nativa, 2017, adapted by Authors.

Fig. 13: Internal Perspective of classroom with windows configuration highlighted. Source: Images provided by the Architecture Firm Flora Nativa, 2017, adapted by Authors.

Fig. 14: Internal Perspective of and solarium, highlighting the shading. Source: Images provided by the Architecture Firm Flora Nativa, 2017, adapted by Authors.

The need of refining decisions suggest a deeper development of design solutions in the early stages of the project, such as the specific type of shading for each opening, the current type and opening area for ventilation, and the incorporation of sheds and light shelves. Such design solutions are usually elaborated only in the detailing phase. Furthermore, incorporating sheds and light shelves restricts solutions based on previous experiences that can be incorporated without thinking in detail about their impact on building (Rodrigues and Pedrini, 2017).

Despite the goal objectivity, there is no only way to solve the problem. Thus, the interaction with the designers and their demand to understand the thermo-physical concepts emphasized that subjectivity is also present in the design solution. The identified information flow is shown in Table 1.

WHAT IS CONSIDERED?	WHY IS IT CONSIDERED?	WHAT RESULTS OF IT?	WHY IS THIS RESULT PRODUCED?
Modeling for simulation: geometry; orientation; thermal zones; glazed area; configuration of the openings; solar protection; roof; wall; equipment; lighting system; air conditioning system; climatic file; use and occupation; and routines.	Thermal performance analysis to verify thermal load sources	Contribution of thermal radiation loads (MWh) in: external and internal windows (circulation), occupation (metabolism), equipment, lighting, internal walls, floor, covering and external walls.	It is possible to direct the efficiency actions to the elements that most contribute to the warm-up of the room.
Dimensions of the openings; Elements already defined for each opening; Elements that cause obstruction	Shading analysis	Solar protection options that would be appropriate for the opening in question and which ones would not be appropriate.	Exemplification of adequacy and inadequacy for sunshine and daylight.
Modeling for simulation: geometry; orientation; thermal zones; glazed area; configuration of the openings; solar protection; climatic file; routines.	Analysis of natural ventilation by calculating the air renewal per hour in each thermal zone.	Recommendation to adjust the size of the effective opening area for ventilation. Examples of windows with bigger effective ventilation area.	Perception of ventilation by user Opening type (two-leaf slide) has low effective ventilation area.
Pressure coefficients; Orientation; Geometry; and Location of the openings	Analysis of the influence of orientation on natural ventilation; Verify the potential of ventilation to cross rooms.	Suggestion of using wind collectors or vertical elements. Wind barriers were identified.	Need to increase pressure difference or redirect wind flow; need to readjust the distances between the blocks to avoid a wind barrier.
Effective opening for lighting; depth of the rooms x height of the openings; furniture layout; reflectance of interior surfaces; orientation of the openings; solar protection; and surroundings obstruction.	Qualitative preliminary evaluation to daylight optimization	Illustrated architectural principles; More efficient shading type for each orientation; Suggested use of landscaping	Adequacy exemplifying the best use of daylight; Need to reconcile obstruction of direct radiation in the openings and use of daylight.
Labelling criteria: U-value and absorption of walls and roof; glass; glazed area; wrapping area; shading; geometry; and orientation.	Indication of critical points of the PBE-Edifica label	Importance of roof material; reduction of opening area exposed to radiation; and coatings colors.	Identification of critical points of the regulation impact on architectural design achieve the A level of energy efficiency

Table 1: Synthesis table with information flow. Source: Own production, 2018.

4.2 DICA-M Diagram applied to pilot study case

The analysis of the DICA-M diagram applied to the pilot study (Figure 15) begins when the author of the project contacts the environmental performance consultants (thermal, lighting and labelling). In this first contact, the architect already had the architectural programming defined, in terms of determining objectives, constraints and concepts that should be developed. A ground floor, second floor and volume sketchs had also been developed to what the designer intended. Thus, the interaction between the principal architect and the consultants began with the establishment of the performance goals, in a face-to-face meeting, through a collective discussion.

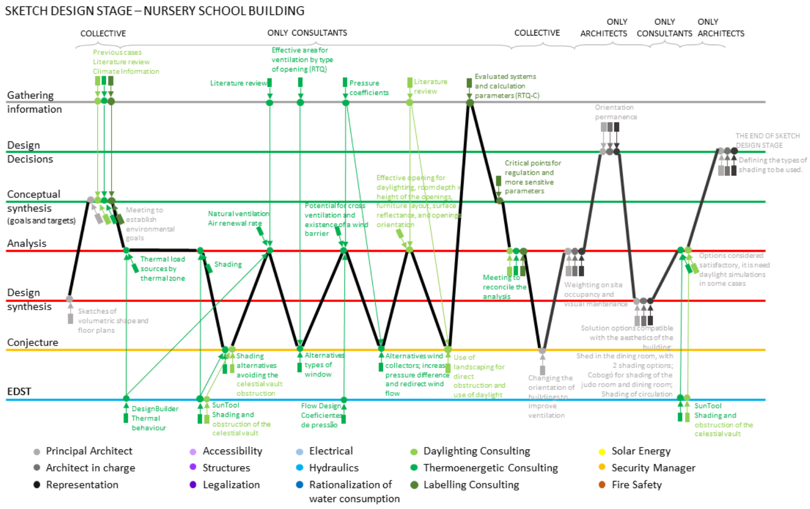

Fig. 15: DICA-M Diagram of the Pilot Case. Source: Dutra (2010) adapted by the Authors.

After this first stage, there was a moment for the consultants' analysis, without the participation of the architects. The analyses, in general, were carried out basing on bibliographic references and computer simulations. During that time, the movement from analysis to conjecture was frequent, due to the consultant needs to exemplify, through images, solutions that perform adequately, or not, to support the understanding of the architects at the moment of the design decision.

The third moment was a collective discussion, again, when the consultants presented the analyses to the architects. At the meeting, part presential and part by videoconference, the consultants introduced the analyses and attempted to explain the thermo-physical principles underlying the results. At the end of the presentation, the architects elaborated new solutions, considering other factors involved in the project, such as aesthetics and site occupancy, and questioned the consultant about them.

The new design decisions and syntheses required the second cycle of analyses, which was carried out and sent virtually to the architects in a report. Because the analyses were made based on the design syntheses proposed by the architects, after the analyses, they proceeded to decision-making.

5 Final considerations

The sketch design studied is part of the theme "parti.cipar+co.laborar", approaching the definition of a collaborative design, in which a multidisciplinary team works with the division of tasks and meetings to adjust the understanding and the decisions taken. The timing of the meeting can be perceived with a strong tendency towards collaboration and collective decision-making. Many challenges still need to be overcome for effective collaboration, which include managing the design process from the earliest stages, such as understanding the need to hold regular meetings to discuss the issues from the points of view of the various members involved.

In the early design phase of the case studied, the considerations emphasized issues related to shape, orientation, and anticipated shading guidelines and window characteristics to quantify room air renewal. Decision-making has permeated two main moments: when architects only follow consultants' recommendations, or when they attempt to understand thermo-physical principles to appropriate the definitions and propose new project solutions from that understanding. The second posture indicates a greater degree of autonomy and validity of the design decisions.

In future analyses, interviews with designers and consultants and/or annotation and recording of meetings should be incorporated to complement gaps in document understanding. It is important to repeat the study with a greater number of cases and design phases, allowing the analysis of recurrences and similarities between the reflections of the designers.

References

ABNT, 2005. *Desempenho térmico de edificações Parte 3: Zoneamento bioclimático brasileiro e diretrizes construtivas para habitações unifamiliares de interesse social - NBR 15220-3.* Rio de Janeiro: ABNT.

AIA, T. A. I. O. A., 2007. *Integrated project delivery: a guide.* [s.l.]: AIA. Available at: <https://info.aia.org/SiteObjects/files/IPD_Guide_2007.pdf> [Accessed 13 October 2017].

Al-Saadani, S. and Bleil de Souza, C., 2016. Of collaboration or condemnation? Exploring the promise and pitfalls of architect-consultant collaborations for building performance simulation. *Energy Research and Social Science*,19, p.15. Available at: <http://dx.doi.org/10.1016/j.erss.2016.04.016> [Accessed 13 July 2018].

Al-Saadani, S. and Bleil de Souza, C., 2018. Architect-BPS consultante collaborations: Harmony or hardship? *Journal of Building Performance Simulation*, 11(4), pp.391-413. Available at: <https://doi.org/10.1080/19401493.2017.1379092> [Accessed 15 July 2018].

Andrade, M. L. V. X. and Ruschel, R., 2013. Building Information Modeling (BIM). In: D. C. C. K., Kowaltowski, D. D. C., Moreira, J. R.D., Petreche and M. M., Fabríco,ed., 2013. *O processo de projeto em arquitetura: da teoria à tecnologia.* São Paulo: Oficina de textos.

Augenbroe, G., 2003. Trends in Building Simulation. In: A. M., Malkawi and G., Augenbroe, ed., 2003. *Advanced Building Simulation.* New York/London: Spon Press. Chap. 1, p.20.

Brasil, 2009. *RTQ-C - Regulamento Técnico da Qualidade do Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos.* Rio de Janeiro: INMETRO.

Brasil, 2012. Portaria nº 18, de 16 de janeiro de 2012. Regulamento Técnico da Qualidade para o Nível de Eficiência Energética em Edificações Residenciais. *Diário Oficial da União*, Rio de Janeiro, 16 Jan. Available at: <http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001788.pdf> [Accessed 24 June 2018].

Brasil, 2014. Instrução Normativa nº 2, de 4 de junho de 2014. *Diário Oficial da União*, Rio de Janeiro, 4 Jun.

Braun, V. and Clarcke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3(2), pp.77-101. Available at: <http://dx.doi.org/10.1191/1478088706qp063oa> [Accessed 24 June 18].

Burberry, P., 1983. *Mitchell's Practical thermal design in buildings.* London: Batsford Academic and Educational.

Charnley, F., Lemon, M. and Evans, S., 2011. Exploring the process of whole system design. *Design Studies,*32(2), pp.23. Available at: <http://www.sciencedirect.com/science/article/pii/S0142694X10000621> [Accessed 08 May 2017].

Corbella, O. and Yannas, S., 2003. *Em Busca de uma arquitetura sustentável para os trópicos.* Rio de Janeiro: Revan.

Cross, N., 2011. *Design Thinking: Understanding how designers think and work.* London/New York: Bloomsbury Academic.

Designbuilder, 2000-2005. DesignBuilder Software Ltda.

Dias, A. R. D., Rodrigues, C. O. D. M. and Jankovic, M. D. M. G. S., 2016. *Relatório de diretrizes de projeto visando desempenho térmo-luminoso e certificação PBE-Edifica* - Colégio Salesiano Dom Bosco, Natal/RN. Edifício Eficiente. Natal: [s.n.].

Dutra, L., 2010. *Design process and environmental information: applicability of support design tools.* Ph.D. AA School of Architecture.

Garde, F., Leonir, A., Scognamiglio, A., Aelenei, D., Waldren, D., Rostvik, H. N., Ayoub, J., Aelenei, L., Donn, M., Tardif, M. and Cory, S., 2014. Design of Net Zero Energy Building: Feedback from international projects. *Energy Procedia,*61, p.4. Available at: <https://doi.org/10.1016/j.egypro.2014.11.1011> [Accessed 01 April 2018].

GOLDSCHIMIDT, G. **Linkography:** unfolding the design process. Cambridge/Londres: MIT Press, 2014.

Hensen, H. L. M. and Lamberts, R., 2011. Introduction to building performance simulation. In: H. L. M., Hensen and R. Lamberts, ed., 2011. *Building performance simulation for design and operation*. v. 1. New York: Spon Press. Chap. 1, p.12.

Hobbs, D., Morbitzer, C., Spires, B., Strachan, P. and Webster, J., 2003. Experience of using building simulation within the design process of an architectural practice. In: *8th International Ibpsa Conference*, Eindhoven, Netherlands. Proceedings...

Kleinsmann, M. S., 2006. *Understanding collaborative design.* Ph.D. Proefschrift Technische Universiteit Delft.

Lawson, B., 2011. *Como arquitetos e designers pensam.* São Paulo: Oficina de textos.

Mahfuz, E., 1995. *Ensaio sobre a razão compositiva.* Belo Horizonte: UFV/AP Cultural.

Marsh, A., 2003. *Ecotect.* Perth: Square One Research PTY LTD.

Montaner, J. M., 2012. *A modernidade superada: ensaios sobre arquitetura contemporânea.* 2nd ed. São Paulo: G. Gili.

Morbitzer, C. A., 2003. *Towards the Integration of Simulation into the Building Desing Process.* Ph.D. University of Strathclyde.

Pedrini, A., 2003. *Integration of low energy strategies to the early stages of design process of office buildings in warm climate.* Ph.D. University of Queensland.

Rodrigues, C. O. D. M. and Pedrini, A., 2017. Integração da simulação termoenergética nas primeiras fases do processo projetual: o estudo de seis casos. *Ambiente Construído,* 17(1). Available at: <http://dx.doi.org/10.1590/s1678-86212017000100134> [Accessed 14 June 2017].

Sanders, E., 2000. Generative Tools for Co-designing. In: S. A. R., Scrivener, L. J., Ball, et al., 2000. *Co-design 2000.* London: Springer-Verlag.

Sanders, E., 2009. Exploring co-creation on a large scale: designing for new healthcare environments. In: P. J., Stappers, 2009. *Symposium designing for, with, and from user experience.* Delft: Delft University of Technology. p.17.

Sanders, E. B. N., 2006. Design Research in 2006. *Design Research Society,*1, p. 8. Available at: <http://www.maketools.com/articles-papers/DesignResearchin2006_Sanders_06.pdf> [Accessed 13 October 2017].

Scrivener, S. A. R., Ball, L. J. and Woodcock, A., 2000. Preface. In: S. A. R., Scrivener, L. J., Ball, et al., 2000. *Co-design 2000.* London: Springer-Verlag.

Shi, X., Tian, Z., Chen, W., Si, B. and Jin, X., 2016. A review on building energy efficient design optimization rom the perspective of architects. *Renewable and Sustainable Energy Reviews*,65, p.12. Available at: <http://dx.doi.org/10.1016/j.rser.2016.07.050> [Accessed 05 July 2018].

Sykes, A. K., 2013. Introdução. In: A. K., Sykes, ed., 2013. *O campo ampliado da arquitetura.* São Paulo: Cosac Nayfe.

Veloso, M. and Elali, G., 2014. Projeto como construção coletiva: da participação à colaboração: os desafios do ensino. In: *3rd. Encontro da Associação Nacional de Pesquisa e Pós-graduação em Arquitetura e Urbanismo São Paulo - ANPARQ*, 2014. Anais...

Wilde, P. D., 2004. *Computational support for the selection of energy saving building components.* Ph.D. Delft University of Technology.

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1 The simulation tools allow foreseeing the environmental behavior of a building, in terms of heat flow, temperature and energy consumption, among others (Wilde, 2004). The building’s characteristics ate modeled

in software that calculates its behavior, using algorithms that reproduce complex physical processes (Augenbroe, 2003; Wilde, 2004; Hensen and Lamberts, 2011).