VOLVER AL ÍNDICE

EFFICIENT AND SUSTAINABLE DESIGN FOR COMPACT HOUSES

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Civil construction is one of the fastest growing economies in the world, causing many damages to the environment and society, many of them related to energy consumption. Due to the intense relationship between environmental comfort and energy consumption in buildings, the environmental comfort conditions have been taking significant space in the construction industry. With global warming and the great consumption of raw materials, construction with sustainable materials and the use of passive techniques to ensure environmental comfort have been increasingly important, thus avoiding the use of artificial sources of cooling or heating in the buildings. The way the project is developed and the building techniques used can lead to great energy savings both during construction and during operation of the buildings. This work aims to propose a design model that could be used as a guideline for design, materials and techniques in the Southeast region of Brazil to obtain types of dwellings with thermal comfort, energy efficiency, efficient materials and techniques. A prototype house of 50m^2, with the possibility of being expanded, was designed in the city of Atibaia, in the State of São Paulo. The design was made according to the Bioclimatic Region 3 of Brazil, not only with enough opening for natural ventilation but also with openings which allow cross ventilation, a requirement for this region. The materials and techniques were chosen based on thermal comfort; the availability in the region; easiness and time of execution; durability and strength; precedence; possibility of reusing the material; dispose (biodegradable or recyclable). An efficient water management was designed, solar panels and vegetable garden located. It was planned to be implanted in a small lot, showing the possibility to treat sewer, generate energy, produce food and follow the recommendations to obtain comfort even in small lots.

1. INTRODUCTION

Humanity in its process of evolution and social organization has generated great transformations in the environment. From the moment the men began to fixate themselves, they began to look for housing.

Housing is a basic element of every human being, postulated as a human right (UN Universal Declaration of Human Rights, 1948). This right must be recognized and protected in the urban sphere, given its position as a fundamental right in the current Brazilian Constitution (Federal Constitution of 1988). Regardless of age, sex, social class or ethnicity, the realization of the right to housing must be basic to all human beings and its assurance must be related not only to their obtainment, but also to their quality, observing the health criteria for a decent housing and its cultural and social representation for the subjects that inhabit it (OKRETIC, 2013).

It is understood by decent housing the one that provides quality of life and economic and social development to the citizens. In addition, according to the World Charter for the Right to the City (Article 14 - Right to Housing), it should represent affordable expenditures according to the residents' income, be habitable and be in a suitable place, with infrastructure and supply of services and equipment.

However, the resources of the planet are finite and, therefore, it is necessary to Project considering the impact that the construction and the use of the building will cause, after all, as John presents us; John et al (2001), civil construction is the sector of the economy that consumes the most materials worldwide. Steel, cement, lime, sand, wood, water, energy etc. all this immense demand generates degradation and pollution in the places where these resources are extracted and even in the places where the constructions are made. They also say that 50% of gross raw materials in Japan are consumed by civil construction and in the US this consumption of natural resources rises up to around 75%.

The construction sector has an impact not only on raw material consumption, but also on the amount of rubble generated. In Brazil, it is estimated that more than 50% of solid waste generated by all human activities comes from the construction sector. These environmental aspects, added to the quality of life that the built environment provides, synthesize the relationships between construction and the environment (MMA, 2017).

Also according to the Ministry of the Environment (MMA, 2017), the challenges for the construction sector are diverse, but in a nutshell, they consist of reducing and optimizing the consumption of materials and energy, reducing generated waste, preserving the natural environment and improving the quality of the built environment.

Therefore, it is recommended:

- Changing the concepts of conventional architecture in the direction of flexible projects with the possibility of re-adjustment for future use changes and meeting new needs, reducing demolitions;
- Search for solutions that enhance the rational use of energy or renewable energies;
- Ecological water management;
- Reduction of the use of materials with high environmental impact;
- Reduction of building waste with modulation of components to reduce losses and specifications that allow the reuse of materials.

Housing is one of the points cited in Agenda 2030. In September 2015 leaders of all United Nations (UN, 2015) member states formally adopted a plan of action for the eradication of poverty, protection of the planet and prosperity and peace. This plan, Agenda 2030 for Sustainable Development, contains 17 goals, and the goal of number 11 is to make cities and human settlements inclusive, safe, resilient and sustainable (UN, 2015). For this it is necessary to design taking into consideration the sustainability and the comfort of the users.

According to Ferreira (2012), good technological solutions and architectural design in the scales of the building and housing unit are those committed to reducing environmental impacts and, above all, to the comfort of the user, in the correct dimensioning of the romos and in the adoption of appropriate orientations of the buildings, that privilege the capture of the prevailing winds and the natural illumination, and the arrangements of the environments in the units, in order to attend to the different profiles and familiar compositions and social groups.

2. METHODOLOGICAL STRATEGY

For the beginning of the project some aspects must be considered. In order to make the process easier and smoother, a table (Table 1) was elaborated, to be filled as soon as the design process begins. As the process of the project evolves, it is important to go back to this table to check if these aspects are being taking into consideration during the process.

The second column is to be filled with information about characteristics of the lot and its surroundings. After completing it, it is possible to fill the third column, making choices about the project, building materials and technics, and how the residence will be constructed and operated.

Table 1. Design Organization

	Requirement	Characteristics / What is Available	Applied to the project
1	Bioclimatic zone	3	Check section 2.1
2	Climate	Tropical climate of altitude	Check section 2.1
3	Predominant wind	South/Southeast	Check section 2.2
4	Lot	6,0m x 25,0m North perpendicular	Flat lot, standard of low-income neighbourhoods in the city of
5	Available materials	Earth, all kids of bricks Proximity to major centres	Soil-cement brick Green roof Bamboo
6	Available Technics	Varied, specially masonry.	Soil-cement brick Green roof
7	Available Labour Force	Varied - many people from other states in the city.	Varied - many people from other states in the city.
8	Residents	2, 4 or 6 residents. Varied types or cultures.	Modular project.
9	Water Management	There is sewage collector in 60% of Atibaia. Only 50% of it is treated (SAAE, 2018).	2 kinds of water use – provided and rain water. Sewage treatment in lot – grey and black water
10	Energy Management	Energy provided	Natural lighting and ventilation according to the region. Solar Panels
11	Waste During construction and	On average more than 50% of solid waste comes from construction (MMA 2017). Only 60% of Brazilian cities send the waste to landfill, others send to controlled landfill or garbage dump) (PRSB, 2017). Atibaia has no landfill, it sends to one at 30km away. And the recycling of materials is in very precarious process.	Project to reduce waste generation during construction and operation. Separation of material to be recycled during construction and operation. Building monitoring to reduce waste. Material reduction manual handed for workers and residents. Vegetable garden.

Items 1 to 3 of the table are most considered in the section 2.1 Bioclimatic Recommendation; items 4 to 8 in the section 2.2 Design; item 9 in the section 2.3 Water Management, item 10 in the section 2.4 Energy Management and item 11 in the section 2.5 Waste. Nevertheless, all of them are interconnected and were taken into consideration when the project was designed and the techniques or materials were chosen.

2.1. Bioclimatic Recommendations

The residence to be analysed was designed in the city of Atibaia, Southeast of Brazil. Atibaia has, according to INMET (National Institute of Meteorology), maximum temperatures between 27°C and 29°C; minimum temperatures between 16°C and 18°C; the average temperatures between 22°C and 24°C and relative air humidity between 80% and 85%.

These data were recorded between 1961 and 1990. The INMET data are being updated, but have not yet been to the city of Atibaia.

Identification of the Bioclimatic Zone and Recommendations

ABNT NBR 15220 establishes a Brazilian bioclimatic zoning (divided into eight zones) covering a set of recommendations and constructive strategies for single-family housing of social interest. The city of Atibaia/SP is inserted in Bioclimatic Zone 3. According to ABNT 15220-3 the recommendations for Bioclimatic Zone 3 are:

- Medium openings;
- Light reflective walls;
- Isolated light roof;
- Summer –
- Cross ventilation;
- Winter –
- Solar heating of the building;
- Heavy internal walls;
- Allow insolation of the rooms

Verification of conformity with ABNT 15220-3

Below are the criteria established by ABNT 15220-3 and the verification of the conformities in the project.

In relation to the openings, the standard prescribes that, for Bioclimatic Zone 3, the openings must be average size, that is, they should have 15% to 25% of the floor area. In addition, cross ventilation and natural lighting are required. This was applied to all rooms.

Regarding external walls, the standard requires that they be light reflective, with thermal transmittance of ≤3,6(W/m^2.K) and thermal delay of ≤4,3%.

For the internal walls, it is requested that they be heavy, with thermal transmittance of ≤2,20(W/m^2.K) and thermal delay of ≥6,5%.

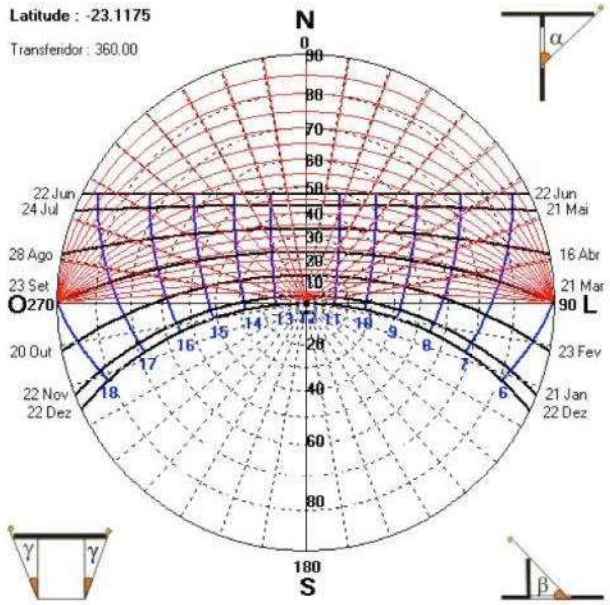
To meet these requirements, soil-cement brick walls was chosen which has a thermal transmittance of 2.0 (W/m^2.K) and a thermal delay of 5.55% (Wilson, et al., 2010). Although it does not comply with the thermal delay requirement, it serves well the thermal transmittance for the external and internal walls, and is between to both in thermal delay and has other benefits in relation to sustainability.

Regarding the roof, the standard requires to be light isolated, with thermal transmittance ≤2,0 (W/m^2.K) and thermal delay ≤3,3%. In the project, green roof was used, which has thermal transmittance of ≤2,0 (W/m^2.K) (Anexo V, 2013) and thermal delay 2,0% (Matheus, et al., 2016) meeting this criterion.

Windows are facing the sun in all rooms, meeting the solar heating requirement of the building.

The standard also states that it must allow sunlight in the rooms. In the proposed project, all environments have winter sunshine. For this, the façade with more openings was designed facing North. The bedrooms have windows to the East and/or North. To the south there is the wall dividing the lot, with no openings (Figure 1).

By the solar analysis of the façades it is possible to notice that in the hottest months there is no direct sunshine on the North façade, but in the colder months there is sunshine all day long. The bedrooms have windows to the east façade, which receives sunshine during the whole morning both in summer and winter. The west façade, which receives the afternoon sun both in summer and winter, has the living room window, protected by trees.



City: Atibaia - SP		
North Façade		
Year Time	From	To
Summer	---	---
Winter	6:30	17:00

Prevailing sun in the coldest months of the year.

Largest façade of the residence. No sun protection. Solar panels on the roof.

Figure 1. Solar Analyses – North Façade

2.2. Design

The project model was made for a lot of 150m2, with 6m front and 25m depths. This size of lot was chosen for being a standard dimension of lots in low-income neighbourhoods in Southeast, Brazil. The project was designed in order to be able to be built in modules, according to the residents' needs. The first module is approximately 50m2 with one bedroom and one bathroom (Figure 2).

In front of the lot 5,0m was maintained without any construction, as well as 1,5m of one side of the lot, according to the urban legislation. In these 5,0m there is the garage.

By legislation the minimum required of permeable area is 10% of the total area of the lot. However it was left 33.56%. Some cities of Southeast require 30% of permeable area. The project would meet this requirement.

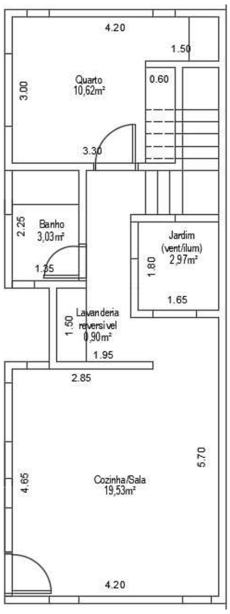


Figure 2.a.

Figure 2.b.

Figure 2.c.

Figure 2. Model 1 (Figure 2a – Plan, Figure 2b Lay-Out, Figure 2c - lot).

Figure 3.a.

Figure 3.b.

Figure 3.c.

Figure 3. Model 2. (Figure 3a – Ground level lay-out, Figure 3b First Floor Lay-Out, Figure 3c - lot).

The project was developed for a couple or even a single person. The proposal of the possibility of expansion is in the event that more people come to live in the house; if the couple has children, for example. The social class question was not taken into account, because, although the lot chosen is the size of one of low-income neighbourhoods, the house is small and the materials are accessible for the lower classes; it is intended to be comfortable and meet the needs of anyone who has an interest in living in a small dwelling, regardless of the social class.

Figure 4.a.

Figure 4.b.

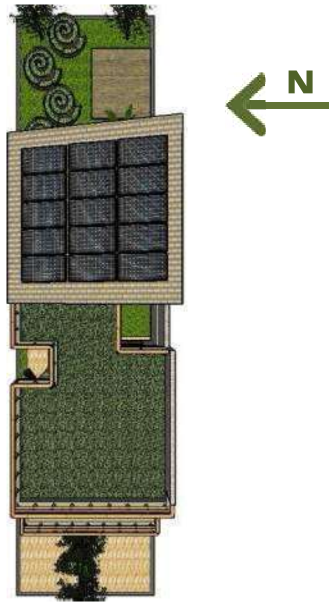


Figure 4.c.

Figure 4. Model 3 (Figure 4a – Ground level lay-out, Figure 4b First Floor Lay-Out, Figure 4c - lot).

2.3. Water Management

Regarding water management, the project was designed to use three types of water, with the intention of using as little water as possible from the concessionaire.

Clean water (from the concessionaire) is used for shower and faucets of the kitchen and bathrooms. Rainwater collected from the green roof is sent to the filter and to the cistern to be used in the outdoor basin and faucets for irrigation or washing the areas outdoors (Figure 5). In the green roof the rainwater collected is already previously filtered (by the drainage sheet and roots of the plants), so it can be sent directly to the filter and cistern, there is no need to be send to brick and sand filter previously.

The grey water passes through a grease trap and is sent to be treated in an anaerobic tank and later to be used to flush and for infiltration - irrigation of trees (Figure 5).

The black water, from the toilet, is sent to the evapotranspiration tank. This system was chosen because it is a clean and safe system and almost exclusively made by materials that would be discarded - old tyre and rubble (Figure 5). In addition it creates a garden for the residence.

Figure 5.a.

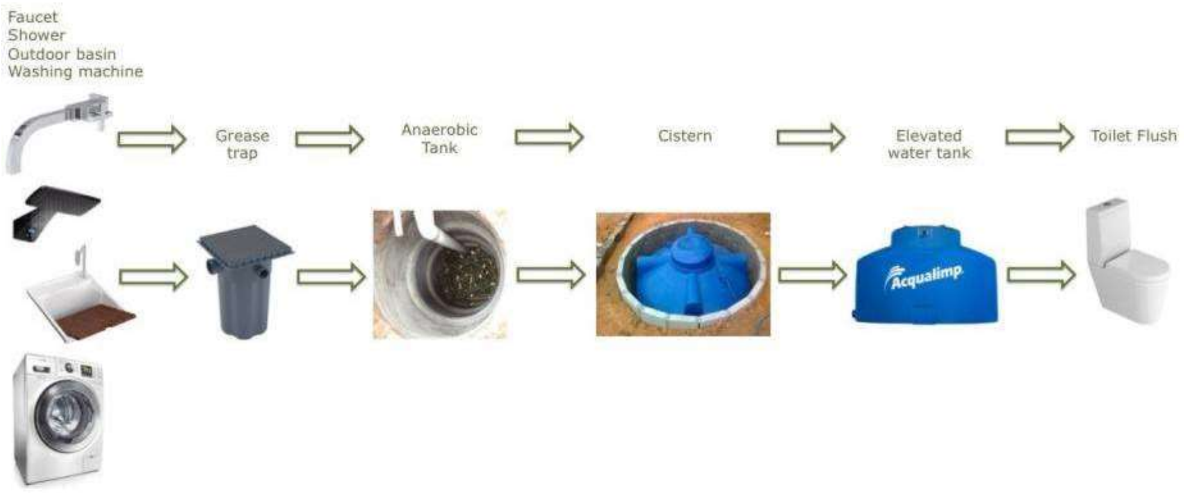


Figure 5.b.

Figure 5.c.

Figure 5. Water Management (Figure 5a – Black water, Figure 5b Grey water, Figure 5c – rain water).

2.4. Energy Management

The proposed project must also be energy efficient. For this, in addition to the recommendations of ventilation and lighting openings for the region, the materials are in accordance with the recommendations for the region. The lighting was analysed according to the depth of each environment, so that there is natural light in all areas of the rooms. De acordo com Lamberts a penetração útil da luz natural pela janela é limitada a uma distancia de aproximadamente 1,5 vezes a altura da parte superior da janela (LAMBERTS, et. al 2014). According to Lamberts (2014) the useful penetration of natural light through the window is limited to a distance of approximately 1.5 times the height of the upper part of the window. This was measured and followed in all rooms. The way the openings were designed, within the comfort standards, helps to avoid the need for daytime artificial light and the use of artificial cooling and/or heating.

The project was made so that photovoltaic panels using the ongrid system, that is, connected to the energy concessionaire, supply the energy. A survey of needs was done for the three design Models.

For Model 1, with the prediction of two residents, taking into account that these people will consume 180KWh/month, the house will have an installed photovoltaic generation system and will produce an average of 2.160KWh/year with 7 panels (Figure 6). The occupied area will be of approximately 16m^2. The panels are positioned in the water tank/staircase tower. The photovoltaic energy was designed to supply all the demand of the house.

If the house is extended to Model2, with the prediction of four residents, it is necessary to install four more panels. Taking into account that this family will consume on average 300KWh/month, the house will need to have an installed photovoltaic generation system to produce an average of 3.600KWh/year with 12panels (Figure 6). The occupied area will be approximately 25m^2.

If it is expanded to Model 3 it will be necessary to install four more plates, 15 plates in total (Figure 6). The occupied area will be approximately 35m^2.

Figure 6.a.

Figure 6.b.

Figure 6.c.

Figure 6. Perspectives (Figure 6a – Model 1, Figure 6b Model 2, Figure 6c – Model 3).

In addition, all appliances must be labelled with Procel A, the high score of the Brazilian energy efficiency labelling, seeking higher energy efficiency. LED bulbs must be used also to aid in energy efficiency, reducing consumption.

2.5. Waste

Modular soil-cement brick is a good choice because, among other benefits, it generates little debris when compared to other wall materials, after all it is a modular brick. Furthermore, it is not burnt in its production, generating less CO2 when it is produced.

The construction site was designed not to waste material and/or work during construction. The part that will be garden must remain without pavement, on ground. Where there will be floor, the counter floor must be made as soon as possible to assist in the maintenance of clean work and also to assist in the transportation of materials during construction. At the entrance of the lot there is an area for a box for stone and for a box for sand. At the back of the lot there is the site for the construction container, and for the disposal of paper, plastic and metal. The cement bags should be stored in the container to be used in the holes of the bricks for concreting the gutters. Papers, plastics and metals should be sent for recycling. The container is rented until the house is covered, for storage of material.

Furthermore, the project was designed so that there is no waste of finishing materials. These materials were selected according to the measurements of the rooms to be used, to avoid the need to cut them and generate rubble.

For the use of the residence it was designed a place for storage of recyclable garbage. It is closed and easily accessible to both the outside and the kitchen and also easy to access to be collected. It is divided with the location of the cooking gas canister (Figure 7). A garden site was also designed so residents have easy access to better quality vegetables. In addition, it avoids food waste during transportation and storage, thus contributing to decrease the amount of waste sent to landfills.

1 – Water tanks tower
2 – Cistern 1
3 – Evapotranspiration\tank
4 – Anaerobic tank
5 – Recyclable garbage/cooking gas canister
6 – Grease Trap
7 – Cistern 2
8 – Vegetable garden
9 – Native fruit tree

Figure 7. Lot Section.

Throughout the construction the monitoring must be done to avoid waste of materials. Also, a booklet should be delivered both to the builders and to the residents, to encourage the reduction of consumption, as well as to help them make the correct separation of recyclable materials.

3. CONCLUSION

For the development of the project, seven criteria were taken into account: climate, location, water, energy, materials, waste and users.

Each of these items influenced the execution of the project, and the composition of all was what generated the final creation of the project.

With these recommendations, it is intended to emphasize the importance of the project phase, in which all the requirements presented should be considered. For the building to meet specifications, it is imperative that the project be well executed.

It was designed to be built in a small lot, showing the possibility to treat sewer, generate energy, produce food and follow the recommendations to obtain comfort even in small lots.

In addition, it is important to emphasize the importance of a planned and organized building site and use of the building in order to minimize waste and contribute to the environment.

More than an ideal, finalized project, it was sought to obtain a form of organization of project and residence use that can be replicated in other regions of Brazil, with different climates and cultures.

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