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Design and Sustainable Processes Integrated in the Construction of Buildings: CASA TERRA – Atelier O'Reilly

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Abstract: The impact of a building on the environment is relevant in the context of the extraction of non-renewable materials due to its depletion of primary sources. From UN Agenda 21 in 1992, a new look at renewable materials such as wood and bamboo has been established. Another question that arises is how the architectural design can integrate conditions that minimize the use of primary energy without losing qualitative comfort conditions. The aim of this paper is to evaluate which features make a building more sustainable in the design and life cycle of the building. The methodological procedures start from the literature review, as well as from a case study of single-family housing "Casa terra - Atelier O'Reilly". In recent decades there has been an evolution in wood building systems with the production of new panels, as well as a development of communication and control systems allowed by the BIM (Building Information Model). Therefore, industrialized buildings associated with renewable materials with higher CO_2 absorption and a longer life cycle, combined with a bioclimatic project, have become indispensable for the survival of the environment and, consequently, the quality of life in cities.

Key words: sustainability, prefabrication, wood, industrialization

1. Introduction

From the 1970s, due to the energy crises generated by the scarcity of oil, society began to pay greater attention to the issues of natural resources and to the control of energy demand. Concomitantly, the world population grew exponentially, reaching "4 billion inhabitants in 1975". To analyze this growth, Richard Rogers (2012) [1] points out that in 1950, only 29% of the world population lived in urban areas. In 1965, this figure was already 36%; in 1990 it reached 50%. Leite (2012) [2] reinforces these rates of 50% of the population living in urban centers since 2007; by 2050 this population will correspond to more than 75%.

The fact is that environmental degradation intensified after the industrial revolution, leading the UN (United Nations Organization) to promote the Agenda 21 in Rio de Janeiro in 1992. Aiming at sustainable development, the agenda served as a planning tool for building a more conscious society. The term 21 was used due to the new development model for the 21st century: "Environmental protection, social justice and economic efficiency" [3]. Based on this convention, policies to encourage the use of renewable materials such as wood and bamboo have been implemented in Europe and Brazil, as a direct initiative to reduce the greenhouse effect, as these materials capture carbon dioxide (CO_2), retaining it throughout their useful life [4]. Another factor that can be highlighted: compared to steel and concrete, wood has less impact on the environment in the removal of natural materials and uses less embedded energy for its production.

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Continuing on the theme of sustainability, the UN meeting in New York stands out in 2015 for the development of an action plan called Agenda 2030, with 17 global sustainable development goals to be achieved in 15 years [5]. Items "Life on Land", "Sustainable Cities and Communities", "Responsible consumption and production" and "Industry, Innovation and Infrastructure" are related to forests and wood, investments in promoting the resolution of economic and environmental challenges, changes in consumption patterns and reduction of the ecological footprint, in addition to the sustainable management of forests, combating desertification and encouraging certified materials.

In the United States, buildings represent 39% of energy consumption and 39% of carbon dioxide emissions [6]. In Brazil, according to the Brazilian Council for Sustainable Construction [19], civil construction is responsible for several environmental impacts, measured in 2007, such as "decreased soil permeability, carbon dioxide emissions, consumption of up to 75% of natural resources extracted, about 50% of electricity consumption in the operation of buildings and 21% of the water consumed in the country".

In this sense, one can consider the application of local materials that use a small amount of energy for their application in the construction of buildings such as rammed earth walls, provided that the impact of their removal is assessed, or the application of renewable materials. Therefore, it is a priority for the market to think differently and sustainably, reducing resource expenditures and reducing waste by optimizing the efficiency of the design.

Keller Burke (2010) [7] highlight that to reduce energy costs, buildings must be designed in a bioclimatic way, integrating active and passive elements, including natural ventilation, geothermal energy, openings, the thermal efficiency of walls and roofs, chimney effect, among other hundreds of possibilities that must be designed for local environmental conditions, such as climate and humidity.

Wood, being a renewable material and carbon scavenger, appears as a viable solution to the issue raised. The concepts of sustainable construction, although increasingly widespread in Brazil, have not yet been absorbed on a large scale in the production of housing, such as the prefabricated construction process called dry construction, originally from the United States, where it is called wood frame or steel frame.

In Brazil, despite the advantageous cost-benefit ratios in the long run, compared to conventional materials (masonry and concrete), the use of wood in civil construction is still small. With the accelerated verticalization in São Paulo in the 1930s to 1960s, a material of great importance was concrete, and the use of wood has been limited to some isolated architectural examples or beach regions. In parallel, the lack of acceptance is directly linked to the lack of industrial and technological development and labor limitations, in addition to incentives for the production of elements and components of the high performance prefabricated construction, integrating quality and durability [8].

With the new technologies (BIM (Building Information Modeling)) the prefabrication industry in civil construction sees great positive impact on the construction quality. It contributes to increased precision, productivity, quality and optimization of resources. This allows that prefabricated modular processes accept differentiated designs that can be produced on a large scale. For Leite (2012) [2], a massive design "strategically involved with the current capacity for technical knowledge and industrial production" has the capacity to build millions of homes.

The aim of this paper is to evaluate the characteristics that make a building more sustainable, therefore the specific objectives are: evaluate design criteria, for example the sum of bioclimatic techniques; evaluate industrialized and vernacular construction techniques, and how the management of the project through digital technologies can contribute to reduce the impact on the environment.

2. Sustainable Development and Bioclimatic Architecture

The "United Nations Conferences on the Environment and Sustainable Development" seek to establish actions on a global scale in order to promote "environmental protection, social justice and economic efficiency" and take place every ten years. The "United Nations Framework Convention on Climate Change", in turn, resulted from the Kyoto Protocol in 1997, but became effective annually from 2005. Its main objective is to define "targets for the reduction of gas emissions that cause the greenhouse effect and global warming" [9]. Agenda 21 is the text resulting from the UN conference that took place in Rio de Janeiro in 1992, called ECO 21.

In 2015, the "2030 Agenda for Sustainable Development" highlighted the "sustainable development goals" [10]. These goals include "no poverty", "responsible consumption and production", "affordable and clean energy", "industry, innovation and infrastructure" and "sustainable cities and communities" in the context of the construction of buildings and its impacts.

In this context, the resumption of vernacular architecture takes place and its increment with more up-to-date technologies, aiming at obtaining more efficient means of building from an economic and environmental point of view, with a social stamp. Edwards (2008) [11] notes the relevance of the resumption of vernacular architecture: (...) the traditional architecture of all regions of the world can significantly help in understanding sustainable design and construction. Vernacular architecture uses materials locally available, local energy sources, mostly renewable, and adopts construction methods that encourage recycling and respect for nature. These characteristics can be observed in rural residences, as well as in urban buildings, especially in Africa, Asia and pre-industrial Europe. Through vernacular architecture, one can learn important aspects about buildings, individually, and urban planning, as well as the relationships between different human settlements and natural resources [11].

The relationship between energy consumption and environmental comfort was not seen as determinant, so bioclimatic architecture gained importance, as stated by Coberlla and Yannas [12]:

"Sustainable architecture is the most natural continuity of Bioclimatic, also considering the integration of the building with the totality of the environment, in order to make it part of a larger group. It is the architecture that wants to create buildings aiming to increase the quality of life of human beings in the built environment and its surroundings, integrating the characteristics of local life and climate, consuming the least amount of energy compatible with environmental comfort, to bequeath a less polluted world for the next generations." [12]

Sustainable construction or sustainable development are concepts that refer to a set of measures adopted during all stages of the project aimed at building sustainability [13]. For Smith (2010) [6], it is about "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Take into account not only the environmental impact of buildings during their life cycle, but also their economic, social and cultural considerations.

The Institute for the Development of Ecological Housing - IDHEA (2008) defined the parameters for a sustainable construction, valuing in the design and construction the "application of natural materials"; "management and saving of water, of the residues generated by the users, construction management"; "air quality and interior environment"; "energy efficiency, thermal and acoustic comfort"; as well as "use of green products, avoiding and reducing the use of materials such as PVC, lead and aluminum".

Through measures that seek the least impact on the environment, it is possible to establish responsible construction. Therefore, the building must be conceived — from the design phase — considering the choice of materials used, going through the management of waste in the worksite, the rationalization of non-renewable materials and the valuation of reuse or recycling, and a plan for the operation and maintenance of the building in its lifetime should be established [13].

For Rogers (2012) [1], "The future is here, but its impact on architecture is just beginning. Developing projects according to the nature cycle can bring architecture back to its own roots." [1].

Therefore, the design must integrate challenges to develop buildings that incorporate bioclimatic strategies and technologies, minimizing the use of active equipment, thus reducing energy costs as well as maintenance and operating costs. The author points out that "three quarters of the daily use of energy in buildings is still attributed to artificial lighting, heating and cooling". The designs begin to explore passive technologies that use renewable energy, coming from natural resources such as plants, wind, sun, land and water [1].

The hundreds of possibilities for bioclimatic strategies include the use of walls with high thermal inertia, as well as the use of hygro-thermal elements, widely used in countries with hot and dry climates.

In the last five years in São Paulo, the thick rammed earth walls have been recovered as a bioclimatic strategy. Rammed earth is considered vernacular because in the state of São Paulo there are documents that demonstrate its application "since the 17th century" in places of clay soil. Pisani (2004) [14] points out that "rammed earth was initially brought by the Iberians, and originates from Northern Africa."

3. Industrialization and Constructive System

In the first half of the twentieth century, several countries started the prefabrication process, such as the United Kingdom, France, Germany and the United States, experimenting with prefabrication and standardization. In Germany, in 1914, Walter Gropius was one of the main advocates of industrialized construction at the Bauhaus. However, it was in the United States, in 1941-1952, that Gropius, together with Konrad Wachsmann, developed their main modular system for prefabricated housing. According to Gropius (2004) [15] industrialized construction allows for greater control and resolution of execution problems compared to the conventional process and allows to decrease the final value of buildings. In contrast, he points out that it requires greater precision in the connections.

According to Ordonez (1974) [16], in the European context after the Second World War, between 1945 and 1970, in view of the great need for mass housing, of low cost and fast production, prefabrication began as "the most significant manifestation of industrialization in construction", meeting the need for large-scale construction.

With the advancement of technology and the need to reduce raw materials (oil crisis in 1970), it was necessary to improve costs and reduce construction time. From 1980 onwards, we can note the involvement of architects and engineers to resume the concepts of modular construction, through the rationalization of materials with renewable raw materials, such as wood. In the global context, countries like Canada, Austria and Finland stood out in the research and production of projects using the wood frame system.

To reach the consumer products and automotive industries, prefabrication, or off-site construction, has been developed as an effective approach to industrialize construction projects and aim for higher levels of performance and strict control of qualitative standard. Therefore, they can be sustainable, in the sense that they are designed to last for generations, in addition to allowing changes in the arrangement of the internal space when they are no longer useful and being recycled for other uses [6, 17].

Wood and its use in the prefabricated method (wood frame) is one of the possibilities for replacing conventional non-renewable materials, as it offers technical and sustainability advantages, with high mechanical resistance, acoustic and thermal insulation (completed with rock wool); it also sequesters carbon in its composition, its production is inexpensive, it is a renewable material and it is possible to obtain a complete life cycle. This system can be called "light, dry, and/or framed system" and is characterized by having its main structure defined by a system of walls and slabs; these plans are "composed of countless pieces that form walls and floors" [18]. Therefore, the walls of the building work with a supporting structure, transmitting the load to the foundations and structural amounts of wood are used for the walls, sealed by OSBs (Oriented Strand Board). In Canada and the United States there are five-story buildings [8].

The concept of dry construction brings with it the definition of the absence of leftovers or waste, through the use of modular systems; and it also does not use water, sand and mortar, but instead uses qualified labor. With most of the production carried out in factories, the number of tasks performed at the building site under construction decreases and, consequently, the time for assembly at the construction site is reduced.

In the traditional system, several construction components are different and without communication with each other, produced by unskilled labor, with handcrafted bases, generating dimensional imprecision, low quality, and low technological control. These factors lead to a greater number of errors and waste of materials, resulting in losses and poor productivity.

4. Prefabrication and BIM Technology

The BIM technology is used as a support tool for the prefabrication industry due to the fact that it provides an accurate prototype of the building's physical components, prior to factory production. It is also possible to discriminate the operational stages of a building. However, it is necessary to train the professionals responsible for developing the project, in order to reduce cuts and waste, know the characteristics of the material, establish possible modulations, use the waste wisely and creatively, adding value to recycled products. Therefore, a change in project management and the compatibility between architects, engineers, complementary projects, construction companies and developers is necessary, creating an integrative design.

In addition to the verification of the design by prototypes, prefabrication offers the potential to incorporate real-time monitoring equipment for energy, air quality and water use in the factory production environment, allowing for an evaluation with greater performance throughout its life cycle [6].

Computer technology is a revolutionary achievement in the process of designing buildings with low energy consumption. There are several software available that generate models with air forecast, lighting and heat levels, while the design is still in the process of development and study [1].

In the United States, Canada and Europe, wooden buildings underwent a very different and more promising development process than in Brazil. In Europe, different architectural compositions were possible with the advancement of technology in the laminated wood industry. Currently, Austria is one of the countries that stand out the most in the laminated wood industry and the use of wood frame, with a large participation of the firm of architect Hermann Kaufman and their designs with a high level of precision and technology.

In Brazil, the use of BIM is not yet fully inserted in architecture firms, developers and construction companies. The integrative and participatory method of all complementaries was not put into practice by the hierarchical and projectual structure that exists in the market. In parallel, manufacturers have also not progressed in the use of software and in the production of indexes and parameters for re-application in future projects.

Concomitant with the difficulties of implementing BIM, the large housing deficit that exists in Brazil (around 7 million units in 2010) is noteworthy, and it is possible to overcome this number in a few years, provided that the country adopts smart systems of premolded or prefabricated industrialized housing construction, with recent technologies and qualified labor. "In other words, it is possible and desirable to look for massive design parameters to resolve quickly and with quality design and architecture solutions." [2].

In view of the numbers of the Brazilian housing deficit and sustainability in civil construction, this waste of materials and poor productivity due to rework become impractical. The need to build in mass and with quality converges positively with the characteristics of prefabrication (steel frame or wood frame).

Brazilian civil construction needs to adopt, not as an exception, but as a rule, industrialized construction systems, transforming works into assemblies, cleaner, faster and more efficient. This is valid for buildings in general and is essential for the promotion of collective housing on a large scale [2].

Therefore, with the increase in the demand for buildings due to the increased population in cities, development is needed that does not harm the environment and its natural resources. As a result, industrialized civil construction had and has to rethink its processes, transferring part of the scope to manufacturing technology and adding concern for sustainable development. For architects, digital manufacturing and sustainability towards the masses are more relevant today than ten years ago [6].

5. Method

For the development of this article, the argumentative bibliographic, case study and iconographic research methods were used. The use of bibliographic references, works and articles related to the theme of this study, combined with the analysis of the case study, will assist in the full understanding of the topic discussed, such as dry construction techniques, construction industrialization, sustainability, bioclimatic architecture.

The case study in question refers to a residential project, designed by architecture firm Atelier O'Reilly, known as Casa Terra, due to its award in the context of sustainability. Finally, the analysis of iconographic research for a better understanding of the techniques and subjects covered throughout the research.

6. Result and Discussion – Casa Terra

The building named "Casa Terra" (Fig. 1) is a single-family residential building with seven hundred square meters, designed by Atelier O'Reilly architecture firm, and was ranked first in the 5th Saint-Gobain Architecture Award — Sustainable Habitat in 2017, in the residential project category.

For this project, the firm sought, through studies, to recognize the potential of "sustainable buildings in the residential sector, as an effective response to the current challenge of raising awareness and disseminating bioclimatic architecture". According to O'Reilly (2018) [20], author of the design, "reducing the negative impact and maximizing the positive impact is the key premise of this project."

The design was developed in 2D software, and 3D simulations of natural ventilation, heat stroke, radiation in the surroundings and energy efficiency studies were carried out in the search for efficiency, which guided the design party to achieve the best performance, with premises of bioclimatic architecture that resulted in strategies like Table 1 [20].

The strategies integrated into the design are represented according to Fig. 2 and demonstrate the integration between the architectural party and bioclimatic architecture.

Fig. 1 3D view, Casa Terra.

Table 1 Bioclimatic strategies applied in the design.

North facing solar orientation protects from the summer sun and allows the winter sun to enter
Chimney effect with central voids, with zenith openings and greater natural lighting
Earth walls absorb heat during the day and heat radiation at night
Green roof for thermal acoustic insulation
Cross ventilation
Insulation integrated into the Wood frame wall system

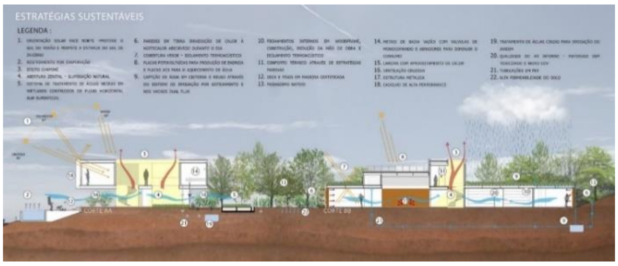

Fig. 2 Details, Casa Terra.

In the construction process, O'Reilly (2018) [20] describes that they associated: earth, steel and wood frame, with earth walls (rammed earth system), reusing the earth that would be discarded after cutting the land; use of materials without toxicity and low emission of volatile organic compounds (VOC) and internal closures in wood frame.

The two-story building (ground floor and upper floor) uses external earth walls. This technique increases the thermal inertia and the walls capture the sun on the outer face and its inside works like a "water jug" [20], keeping the temperature within the average established for thermal comfort (between 20 and 23 degrees), according to Fig. 3.

Within the proposal of using the wood frame in the side closings and in the "I" beams of the roof slab, 1.50 meter modules were used in order to reduce waste in civil construction and decrease the assembly time, demonstrating the feasibility of the industrialized process and the flexibility of use in a residential project as shown in Fig. 4. However, few companies offer competitive solutions in terms of cost and execution, so the project had to be revised as it requires specialized labor and the construction system is not yet known by most Brazilian builders [20].

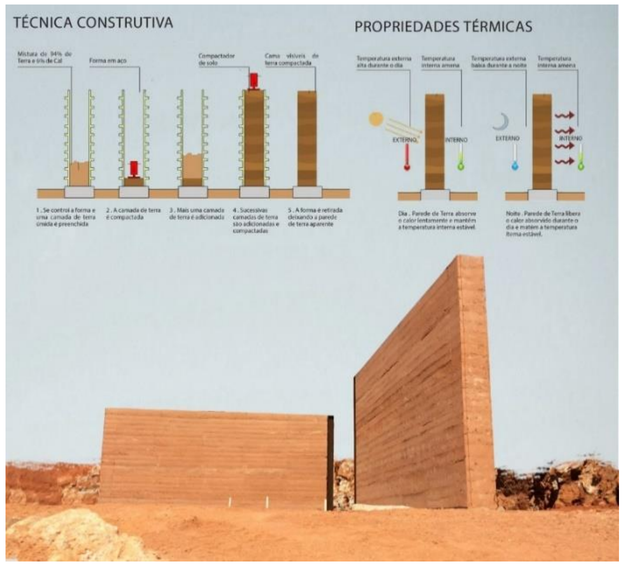

Fig. 3 Rammed earth walls, Casa Terra.

Fig. 4 Casa Terra wood frame walls and slab.

The project shows that the prefabricated panels and the industrialization of the process do not invalidate the different options of dimensions and did not harm the creative process of the architectural party, in addition to integrating bioclimatic architecture with the residential theme.

The association of the different construction systems that contributed directly to increase the efficiency of the construction, reducing the execution time, costs and waste, is observed in this project. Therefore, the project allows to affirm that it produces less impact on the surroundings due to the use of the land, the rescue of carbon by the wood as well as the retraining and education of labor.

Other highlights in the "Casa Terra" design indicate better internal quality, focused on performance concepts such as "thermal and acoustic efficiency, control of relative humidity inside the building, indoor air quality". Points highlighted in Keeler and Burke (2010) [7] as a project that contributed to the environment in terms of environmental and social impacts, which allows us to state that when we integrate bioclimatic techniques there is a lower energy expenditure over the life of the project.

5. Conclusion

The research identified that sustainability parameters is something that requires a balanced and rational response of social, environmental and economic aspects in the treatment of goods, infrastructure and buildings to improve quality of life. For these three factors mentioned to be associated with the civil construction market, there are still challenges related to technology, qualified labor and dissemination of concern with the environment and its degradation.

Therefore, in sustainable design and construction one must take a holistic view and integrate bioclimatic issues to increase spatial qualities, with efficiency in the search for more durable construction, with parameters for choosing renewable materials that can be industrialized such as wood, and application of vernacular techniques avoiding the disposal of materials removed from the site.

Lightweight systems like wood frame can be a viable alternative for rationalization and industrialization in sustainable construction, for minimizing the impacts on foundations, and, therefore, in the relationship between civil construction and the environment. Other factors are the improvement in productivity at the construction site through off-site prefabrication. This industrialization is supported by software and BIM, which help in the creation of a more integrated, standardized design with numerical parameters validated with prototypes in the factory.

It is observed that the Brazilian civil construction market still does not interpret prefabrication in wood as an alternative because of the lack of widespread dissemination, standards and regularization, in addition to competitive prices compared to the traditional system and the need to use qualified labor.

It is concluded that the rationalization of the construction process and the management of projects by the BIM system are key for the reduction of waste and losses in the construction site. However, the breaking of paradigms and the creation of standards that encourage new construction methods are some instruments for the larger scale implantation in the Brazilian market. The innovations in construction in general are used in large scale projects in the medium-high standard institutional and single-family residential architecture, as demonstrated in the case study, and it is not accessible to the lower social classes.

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