Sustentabilidade no projeto de construções públicas: Estudo de caso de prédio no Campus da UEFS - BA

Sustainability in public design: Case study of a building on the UEFS - BA Campus

Sostenibilidad en el diseño de edificios públicos: estudio de caso de un edificio en el campus de la UEFS-BA

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Resumo: Este estudo avaliou a sustentabilidade da documentação técnica da licitação do projeto executivo do pavilhão de salas de aula da Universidade Estadual de Feira de Santana (UEFS), visando propor estratégias para integrar práticas

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sustentáveis, desde o planejamento. A metodologia consistiu em um estudo de caso com análise das escolhas de projeto em comparação a parâmetros de sustentabilidade de boas práticas da revisão na literatura e de normas de compras públicas, em especial a lei de licitações do Brasil e o guia de "Contratação Sustentável" do Ministério da Fazenda. No projeto arquitetônico, identificou-se o uso da ventilação e iluminação naturais, bem como a incorporação de jardins internos e externos, mas constatou-se a falta de indicadores urbanísticos e de diretrizes para a redução de resíduos e a adoção de materiais de baixo impacto. No projeto estrutural, a análise do solo foi outro ponto positivo, porém houve carência de indicadores sobre consumo de materiais e geração de resíduos. O projeto hidrossanitário estimou o consumo por usuário, mas não apresentou estratégias de reúso de água ou dispositivos economizadores. No contexto do projeto elétrico, as lacunas incluíram a ausência de lâmpadas LED e o uso de fontes de energia renováveis, embora tenha sido identificada a especificação de equipamentos de climatização eficientes. Como resultado, o estudo estabeleceu diretrizes e parâmetros ambientais para nortear novas construções no campus e edifícios públicos congêneres com menor impacto ambiental e maior eficiência no ciclo de vida.

Palavras-chave: aspectos ambientais; impactos ambientais; construções sustentáveis; construção civil.

Abstract: This study evaluated the sustainability of the technical and bidding documentation for the executive project of the classroom pavilion at the State University of Feira de Santana (UEFS), aiming to propose strategies for integrating sustainable practices from the planning stage. The methodology consisted of a case study analyzing the design choices in comparison to the sustainability parameters of best practices from the literature review and standards related to sustainability in public procurement, especially the Brazilian bidding law and the Guidelines: Sustainable Contracting of the Ministry of Finance. In the architectural design, the use of good practices was identified, such as natural ventilation and lighting, as well as the incorporation of internal and external gardens, but a lack of urban planning indicators and guidelines for waste reduction and the adoption of low-impact materials was noted. In the structural design, the soil analysis was a positive point, but there was a lack of indicators on material consumption and waste generation. The plumbing and sanitation design estimated consumption per user, but did not present strategies for water reuse or water-saving devices. In the context of the electrical design, the gaps included the absence of LED lamps and the use of renewable energy sources (e.g., photovoltaic or wind). However,

Contribuição dos autores segundo a Taxonomia CRediT
Sigla dos autores: Autor 1: Kindelly dos Santos Leal, KSL Autor 2: Tiago Assunção Santos, TAS Autor 3: Luis Claudio Alves Borja, LCAB KSL: investigation, data curation, formal analysis, visualization, and writing – original draft preparation. TAS: methodology and writing – review and editing. LCAB: project administration, supervision, conceptualization, methodology, resources, formal analysis, writing – review and editing, and supervision

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the specification of efficient air conditioning equipment was identified. As a result, the study established environmental guidelines and parameters to guide new constructions on campus and similar public buildings with less environmental impact and greater life cycle efficiency.

Keywords: environmental aspects; Environmental impacts; Sustainable constructions; civil construction.

Resumen: Este estudio evaluó la sostenibilidad de la documentación técnica para la licitación del proyecto ejecutivo del pabellón de aulas de la Universidad Estatal de Feira de Santana (UEFS), con el objetivo de proponer estrategias para integrar prácticas sostenibles desde la fase de planificación. La metodología consistió en un estudio de caso que analizó las opciones de diseño en comparación con los parámetros de sostenibilidad de las mejores prácticas revisadas en la literatura y las normas de contratación pública, especialmente la ley brasileña de licitaciones y la guía de "Contratación Sostenible" del Ministerio de Hacienda. En el diseño arquitectónico, se identificó el uso de ventilación e iluminación natural, así como la incorporación de jardines internos y externos, pero se observó una falta de indicadores de planificación urbana y directrices para la reducción de residuos y la adopción de materiales de bajo impacto. En el diseño estructural, el análisis de suelos fue otro punto positivo, pero se observó una falta de indicadores sobre el consumo de materiales y la generación de residuos. El diseño de plomería y saneamiento estimó el consumo por usuario, pero no presentó estrategias para la reutilización del agua ni dispositivos de ahorro de agua. En el contexto del diseño eléctrico, las deficiencias incluyeron la ausencia de lámparas LED y el uso de fuentes de energía renovables, aunque se identificó la especificación de equipos de aire acondicionado eficientes. Como resultado, el estudio estableció directrices y parámetros ambientales para guiar las nuevas construcciones en el campus y edificios públicos similares con un menor impacto ambiental y una mayor eficiencia en el ciclo de vida.

Palabras clave: aspectos ambientales; impactos ambientales; construcción sustentable; Construcción civil.

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1 INTRODUCTION

The construction industry is one of the main economic sectors in Brazil, and in 2019, it generated 274 billion reais in construction works and services, employing 1.9 million people (IBGE, 2019).

However, despite its significant economic contribution, the sector faces serious challenges related to environmental issues. High-resource consumption, pollutant emissions, and waste generation are problems associated with the construction industry.

In 2022, the demand for aggregates reached 640 million tons, including sand (374 million tons) and gravel (266 million tons) (ANEPAC, 2024). The cement industry, a fundamental element of civil construction, is a major emitter of CO_2. From 1950 to 2014, global production increased significantly, rising from 209.7 million tons to 2,476 million tons. Brazil is the sixth largest producer, behind only China, India, the United States, Russia, and Vietnam. This production negatively contributes to the consumption of fossil fuels and the emission of sulfur oxides (SOx), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (Bildirici, 2020) . The sector is responsible for one-third of global energy consumption and 40% of CO_2 emissions (Azevedo; Geraldi; Ghisi, 2020).

In addition to high consumption and emissions, the construction sector also plays a significant role in waste generation. In Brazil, construction and demolition waste, according to ABRELPE data, increased from 33 million tons in 2010 to 48.4 million tons in 2021 (an increase of 47%), with a rise in per capita collection from $174.3 kg.inhab^{-1}$ .day to $227 kg.inhab^{-1}$.day (ABRELPE, 2022). Furthermore, the construction sector is also associated with various neighborhood nuisances, such as noise generation and particulate emissions (Hankach *et al.*, 2021; Babazadeh *et al.*, 2024; Silveira, 2012; Araújo *et al.*, 2012; Gangolells *et al.*, 2009).

Reducing these impacts requires a set of actions, including reviewing traditional construction practices, incorporating environmental assessment systems, and enhancing the capabilities of stakeholders (designers, builders, developers, and public managers). In this context, promoting more sustainable practices is necessary, particularly by integrating social, economic, and environmental dimensions, while also considering the importance of observing the local context (Webb *et al.*, 2018).

The concept of sustainable construction, or green buildings, has gained prominence amid growing environmental concerns in the construction industry. This pursuit of balance between the environment, society, and economy increasingly demands strategies that consider energy efficiency, water conservation, selection of low-impact materials, aiming to minimize natural resource consumption and waste generation, as well as the health and well-being of workers and users, among other factors (Mariano; Trigo; Maruyama, 2021).

In this context, it is essential to understand the design phase of construction projects as an opportunity to integrate criteria aimed at sustainability from the project's inception, acting preventively. The decisions made in this initial phase significantly impact the environmental aspects throughout the buildings' life cycle (Roberts; Allen; Coley, 2020; Bissoli-dalvi *et al.*, 2013).

One aspect to consider in the effort to integrate environmental concerns into construction projects and improve processes is the ability of such actions to raise awareness and build capacity among the involved stakeholders. Considering that the design phase defines the decisions and direction that construction will follow, improving the incorporation of environmental information in these projects can positively impact the sustainability of the construction sector.

In this sense, public policymakers and large national contractors can play a fundamental role in disseminating environmentally responsible practices. Public administration deserves special attention as one of the primary consumers of the construction industry. However, despite the constitutional responsibility of the government to ensure environmental protection, studies indicate that few buildings are being designed in a sustainable model (Gaspar *et al.*, 2023).

Given this scenario, it is necessary to improve the sustainability standards of public contracts. To this end, project performance evaluation and analysis tools must be applied from the design phase, in addition to training public managers, bidding committees, and supervisory bodies, promoting the adoption of sustainable criteria in projects and works. To contribute to this debate on improving public procurement, this research investigated the presence of sustainability criteria and indicators in a bidding process (design, spreadsheets, and technical documents) based on a local case study.

The guiding question of the study was: "How can the definitions in technical and design documentation influence the sustainability of public works?". The study analyzed an educational building project, categorizing and analyzing design choices to identify key opportunities and gaps in executive and complementary plans that impact the project's environmental performance.

2 LITERATURE REVIEW

Sustainability has emerged as one of the key contemporary issues, and it is undeniable that the current development model has resulted in significant negative impacts on the environment. In recent decades, various authors have addressed the topic of sustainability in construction, as well as strategies and techniques for achieving more sustainable construction processes.

The excessive use of natural resources and environmental pollution have raised concerns within industrial sectors, leading to a recognition of their responsibility for environmental impacts (Thives; Ghisi; Thives Júnior, 2022). Additionally, climate change and energy crises reinforce the need to balance economic demands with environmental protection (Mishra; Sarsaiya; Gupta, 2022).

The most widely used concept of sustainability was popularized by the Brundtland Report, prepared by the World Commission on Environment and Development of the United Nations (UN) in 1987. According to the definition established in the report, sustainable development involves meeting the needs of the present generations without compromising the ability of future generations to meet their own needs (Bretschger; Valente, 2023).

Yılmaz e Bakış (2015) bring the concept to the construction sector, that sustainable construction must promote the conscious use of natural resources, ensuring that there is no depletion or degradation and preserving them for future generations. Therefore, the sustainable development model in the sector must encompass environmental protection, economic progress and social justice.

According to Degani (2010), the concern with sustainable development in building construction arises primarily due to the large quantity and variety of elements used throughout the building's life cycle. This concern is further heightened by the fact that buildings, as construction products, are designed to have a lifespan of decades. The author also notes that the most significant environmental impacts are associated with the depletion of natural resources and pollution.

To apply the principles of sustainable development throughout the project's life cycle, it is necessary to fully understand the various phenomena involved in the activities to be undertaken. This process aims to strike a balance between the natural environment and the built environment, with the creation of spaces that satisfy human needs, respect the environment, and promote economic equality (Yılmaz; Bakış, 2015; Bhyan; Shrivastava; Kumar, 2023). Martins, Costa e Santos (2022) emphasize that all spheres of sustainability—environmental, social, and economic—must be considered in construction projects, as they are interconnected.

Therefore, the low-impact construction concept adopted in this research was one in which solutions that integrate sustainability are adopted, through implementing strategies that aim to reduce negative impacts and promote positive results in all three dimensions (environmental, social and economic).

Guo e Su (2013) define sustainable construction as one that adopts strategies for the efficient use of resources (water, energy, materials) and control of waste generation and pollutant emission. Martins, Costa e Santos (2022) highlight that appropriate material sizing and incorporating innovations in construction systems contribute to reducing construction waste. Jáuregui, Vega e Santos (2021) broaden the perspective of sustainability, viewing it not only as resource and infrastructure efficiency but also as a contribution to society and the preservation of life.

Motta e Aguilar (2009) present a compilation of sustainable practices proposed by the Brazilian Council for Sustainable Construction and the Brazilian Association of Architecture Offices that can be adopted in civil construction, including:

i) Leveraging local natural conditions.

ii) Minimizing land use and understanding the natural environment.

iii) Designing and analyzing the surroundings.

iv) Avoiding or limiting impacts on the adjacent area (landscape, temperatures, heat gain, comfort sensation).

v) Ensuring environmental quality both internally and externally.

vi) Sustainable logistics for the construction foundation.

vii) Catering to the current and future needs of users.

viii) Using raw materials that contribute to the eco-efficiency of the process.

ix) Reducing energy consumption.

x) Reducing water consumption.

xi) Reducing, reusing, recycling, and properly managing solid waste.

xii) Providing technical information whenever possible and feasible.

xiii) Environmental knowledge: training of those involved in the process.

The concept of sustainability is directly related to the balance between three aspects that must be evaluated together to ensure the viability of sustainable projects: environmental, economic, and social (Monteiro; Conceição, 2022). Among these pillars, environmental aspects play a fundamental role, making it crucial to understand this concept and its implications.

According to the NBR ISO 14001:2015 standard, an environmental aspect can be defined as an "element of an organization's activities, products, or services that interacts or can interact with the environment." The standard further defines a significant environmental aspect as one that has or can have one or more significant environmental impacts. Correlating environmental aspects and impacts, the same standard defines an environmental impact as a "change in the environment, whether adverse or beneficial, wholly or partly resulting from the environmental aspects of an organization" (ABNT, 2015).

Cardoso e Araujo (2007) highlight that adverse impacts or environmental changes resulting from construction activities are consequences of the flow (inputs and outputs) from the various services and processes of construction activities. The authors further emphasize that these activities involve elements that interact with the environment, which are called "environmental aspects" and can be controlled by the construction team.

The design of engineering projects is a crucial stage in planning the construction of a building and its construction activities. Project choices at this early stage significantly influence environmental aspects and impacts throughout the buildings' life cycle. According to Barros (2016), one of the most common issues at this stage is related to the fragmented process of project development and the use of outdated tools for conveying information, which negatively impacts data generation, process optimization, and waste reduction.

To meet environmental sustainability criteria, designers in the construction field must evaluate factors beyond those traditionally considered. According to Bissoli-Dalvi *et al.* (2013), the selection and specifications of materials used during construction are essential for achieving this goal.

In summary, the cited studies indicate that incorporating and controlling sustainability indicators can assist designers in selecting materials based on sustainable criteria, as well as providing metrics for planning and controlling the execution of activities aimed at reducing negative impacts.

3 METHODOLOGY

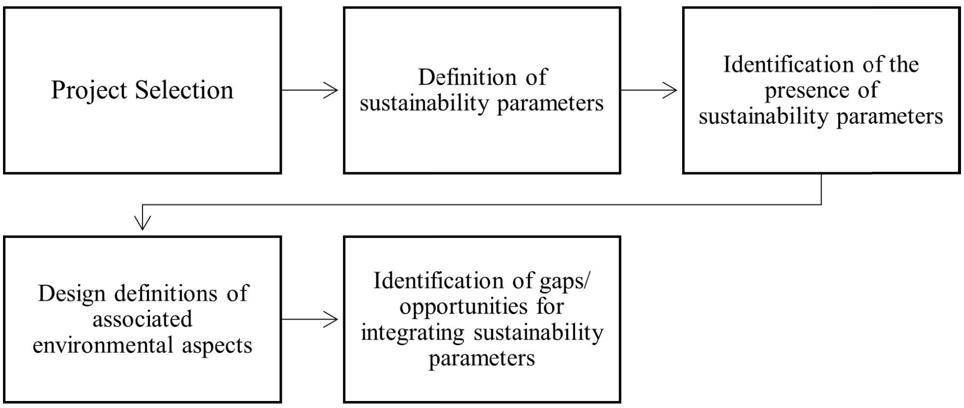
To assess the environmental performance of a public construction project, a case study method was adopted, selecting the construction of an educational building at the State University of Feira de Santana (UEFS) as the subject of study (Figure 1)

Figure 1 – New Classroom Pavilion of UEFS

Source: Authors (2024)

Figure 2 illustrates the flow of the methodology adopted for mapping and analyzing the sustainability criteria present in the construction projects of the study subject for this research.

Figure 2 – Flowchart adopted to identify and analyze sustainability criteria in the case study

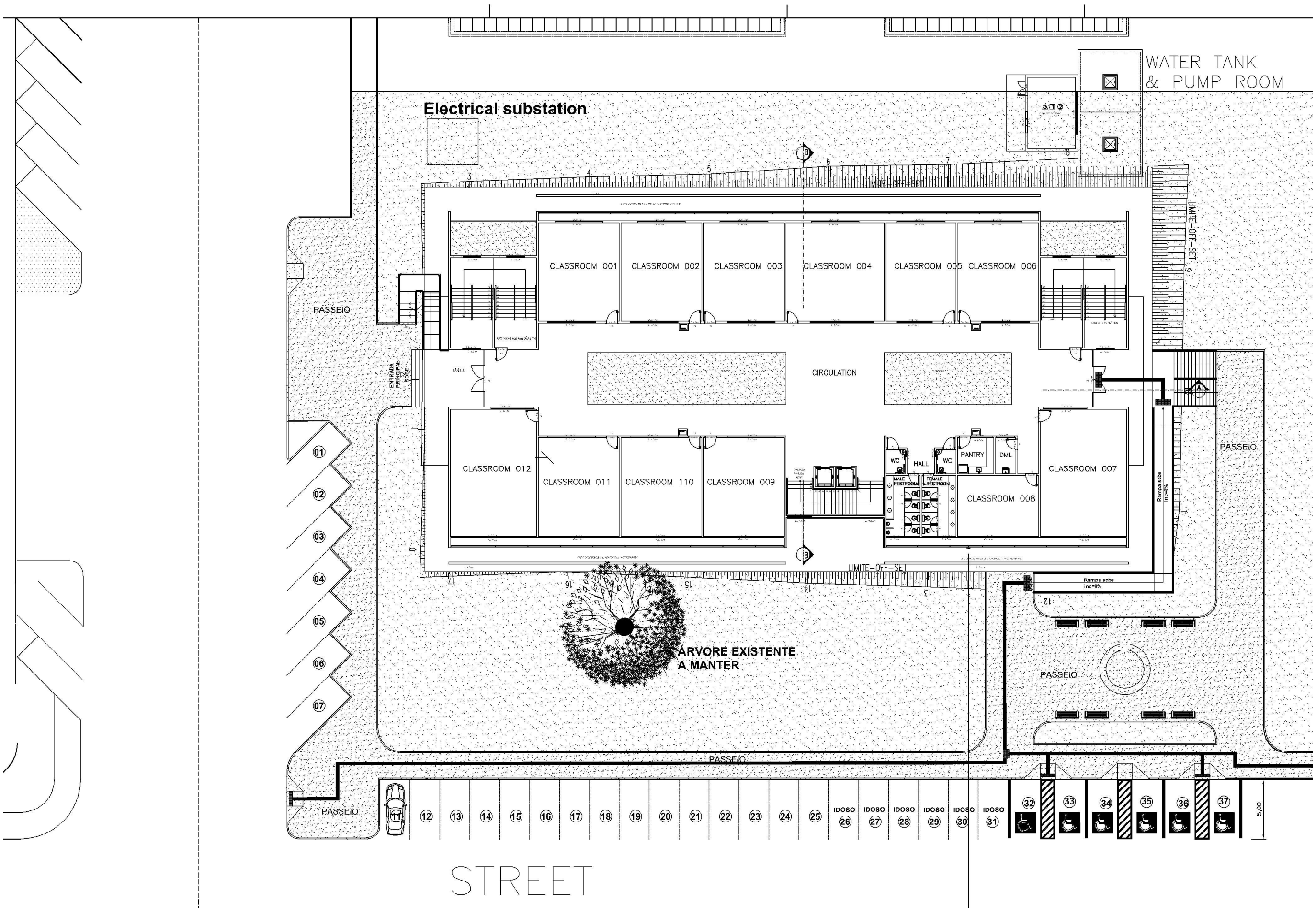


Source: Authors (2024)

The document analysis phase of this research was implemented on the architectural, landscaping, structural, foundation, plumbing, electrical, and other technical documents (such as the bid notice, terms of reference, technical reports, and budget spreadsheets) for the bidding of the UEFS classroom pavilion. Public bid notice No. 13/2022 was published in the edition of 23/02/2023 in the Official Gazette of the State of Bahia, and the projects and their attachments were obtained directly from the Bahia State Urban Development Company (CONDER) electronic portal.

According to the Terms of Reference for the bidding process, the Classroom Pavilion project was designed to accommodate 1,116 students per class shift, located on a plot of land measuring 4,670.00 m² (Figure 3).

Figure 3 – UEFS Classroom Pavilion - Site Plant



Source: Adapted by the authors from the original project (2024)

The general description of the Classroom Pavilion, including the number of floors, construction stage, and areas, is presented in Table 1.

The total built area of the project was 4,152.08 m² distributed across three floors (ground floor, 1st, and 2nd floors), with each floor including the following spaces:

- 12 classrooms;
- 1 male restroom with 4 toilets and 2 urinals;

- 1 female restroom with 4 toilets;
- 1 male accessible restroom;
- 1 female accessible restroom;
- 1 cleaning materials storage room;
- 1 pantry (except on the 1st floor).

Table 1 – Description of the Classroom Pavilion

Characteristic	**Value**
1. General	
Total number of floors	3
Characteristic	14
Construction stage (at collection)	Complemetion
2. Areas and Urban Standards	
Plot area (m²)	4 670.00
Ground floor area (m²)	1 541.88
1st floor area (m²)	1 305.10
2nd floor area (m²)	1 305.10
Total built area (m²)	4 125.08
Calculated utilization index	0.89
Calculated occupancy index	0.33
Parking spaces	57

Source: Analysis of architectural projects.

3.1 Definition of Sustainability Parameters

The definition of the parameters for analyzing the bidding projects for the Classroom Pavilion was based on a literature review and on normative criteria for sustainable public procurement of the Brazilian government, with emphasis on Law No. 14,133/2021 (New Bidding Law) (BRASIL, 2021), Ordinance No. 507- (BRASIL, 2014b), of December 16, 2014, which established sustainability practices within the scope of the federal government, as well as the guide "Guidelines: Sustainable Procurement" from the Ministry of Finance (BRASIL, 2014a).

For each design discipline (e.g. architecture, structural, installations, etc.), parameters were defined to be checked in the documents set. Environmental aspects directly related to these parameters were then identified, to allow the analysis of how design choices can influence the environment.

The initial design disciplines analyzed were the architectural and landscaping projects. In this context, it is important to highlight that architectural definitions directly impact the consumption of natural resources and influence various other project areas (structures and installations). Therefore, the environmental performance aspects of the architectural and landscaping projects were defined to identify the measures that promote the passive use of natural resources, integrating environmental comfort (ergonomic, thermal, lighting, and acoustic) and the overall project performance.

Additionally, an extra objective in analyzing this class of projects was to identify solutions for addressing local environmental conditions, such as air temperature, solar radiation, winds, and noise, as well as utilization of natural light and vegetation.

The choices made in the structural and foundation designs are also essential to reach a building's sustainability, as the activities resulting from the execution processes of structures can generate various environmental impacts. In this regard, parameters were defined to identify keys environmental information in these projects, such as material consumption (e.g. water, steel, concrete, aggregates) and indications for the reuse of materials.

Furthermore, still within the scope of design disciplines, the efficient use of water is an important parameter for overall sustainability in a project, about water usage, is associated with the efficient use of water. In light of the importance of defining methods to achieve this goal early in the design phase, the documentation and graphic materials were examined to identify the presence of techniques that promote better water utilization and devices that prevent waste. An example of this case is evaluating the feasibility of using alternative water sources, such as rainwater harvesting and greywater reuse.

Finally, recognizing the importance of energy efficiency in achieving sustainability in buildings, specific evaluation parameters were defined for the electrical design class. These parameters aimed to analyze the strategies adopted by the building project for reducing energy consumption, utilizing renewable energy sources, and implementing other practices that generate both financial savings and positive environmental impacts.

4 RESULTS

In the following sections, a brief characterization of the project definitions for the UEFS Classroom Pavilion will be presented, along with the identification of the defined sustainability parameters, as well as the main environmental aspects that can be generated or avoided.

4.1 Architectural and Landscaping Design

In the architectural and landscaping projects, thirteen sustainability parameters were established and analyzed. Table 2 presents these parameters, highlighting the presence of each in the projects.

Table 2 – Presence of Sustainability Parameters in the Architectural and Landscaping Projects

Parameters	Presence
Utilization of natural and local site conditions	No
Use of gardens to mitigate temperature	Yes
Indication of local plant species	Yes
Use of surrounding vegetation for shading the building	Yes
Definition of cladding layout	Yes
Definition of urbanistic indices	No
Definition of built area per estimated number of users	No
Design of window and door frames	Yes
Presence of natural ventilation in all environments	Yes
Geographical positioning of the building to enhance thermal comfort	Yes
Adoption of other architectural solutions to improve thermal comfort	Yes
Use of light colors for walls, ceilings, and floors	Yes
Adoption of architectural solutions to improve acoustic comfort	Yes

Source: Prepared by the authors (2024)

4.1.1 Definition of Built Area per Estimated Number of Users and Urbanistic Indices

Urbanistic indices provide information about land use and occupancy, such as the occupancy coefficient, utilization coefficient, and permeability rate, as established by city master plans. The utilization index (UI), which represents the relationship between the built area and the estimated number of users, provides relevant information about land use and occupation, which its associated with environmental issues from the services demand (e.g. water, energy, and public transport).

Analyzing the project, it was found that there was a lack of information regarding urbanistic indices in the graphic representation sheets and descriptive reports, as the information was limited to the representation of the land area boundary and the built area (Figure 3).

Although the building is in a reserved area (university campus), the lack of details regarding urbanistic indices commonly found in urban center buildings, such as the occupancy coefficient, utilization coefficient, and permeability rate, represents a significant gap. The need to adopt these indices goes beyond attending only a legal compliance, they provide parameters for an integrated analysis of the project's sustainability. These parameters are essential for understanding land use and occupancy, directly influencing the project's configuration within the urban context (Bhering, 2019).

4.1.2 Utilization of Natural and Local Conditions of the Site

In the architectural drawings of the classroom building, the relationship between construction and soil was limited to the site plan, with no further details identified, such as the natural conditions of the land, soil profile for cut and fill predictions, and its representation on the cross-section plan. This information gap may lead to difficulties in planning and executing earthworks with an increase in the generation of excavation waste and the need to acquire and transport soil to landfills.

It is important that the project's design incorporates techniques that consider the natural profile of the land, thereby reducing, for example, the need for cutting and filling (Callefi; Miotto; Silva, 2020), and consequently the processes of operating and transporting materials and machinery. This soil movement is associated with significant environmental aspects, such as particulate matter emissions, material circulation, waste generation and management, as well as water consumption and wastage during soil compaction.

In addition to these factors, there are considerations regarding pollution emissions (resulting from fuel combustion), noise, and vibration emissions because of the movement of heavy vehicles and machinery, such as excavators, backhoes, and dump trucks.

4.1.3 Use of Surrounding Vegetation for Shading the Building, Use of Gardens to Mitigate Temperature, and Local Plant Species Recommendations

The architectural design chosen predicts the use of several plant species on the exterior of the building (Figure 3), distributed along the left lateral and rear facades. This solution can contribute to improving the thermal comfort conditions of the building, targeting a reduction in the temperature of the exterior walls through the cooling effect of plant evapotranspiration and shading to decrease the direct incidence of solar radiation (Matheus *et al.*, 2016).

Additionally, the project preserves an existing tree in the surrounding area of the development, which is an action that minimizes impacts on the landscape and the local ecosystem. It is also noteworthy that preserving native vegetation mitigates negative environmental aspects throughout the life cycle, such as the release of fibers due to the cutting of trunks at the source, the generation and management of waste, the use of cutting equipment, vehicle circulation, and the increase in waste volume sent to landfills.

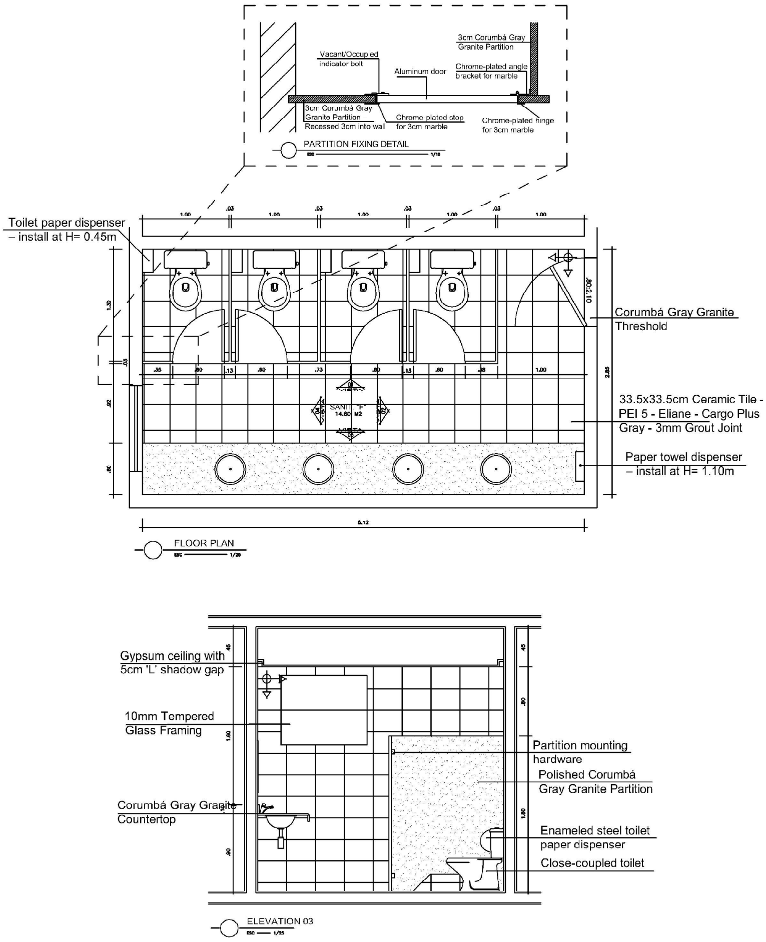
Another bioclimatic strategy adopted in the architectural layout is the allocation of gardens both in the building's interior areas and on the external faces of the development (Figure 3), which contributes to environmental comfort and improves the building's energy efficiency.

Another sustainable parameter observed in the landscaping project was the recommendation of plant species that are more readily available from local suppliers, reducing transportation and its associated emissions. Additionally, using local species facilitates their adaptation to the region's climate and soil, minimizing harm to the local ecosystem and often requiring less water for maintenance.

4.1.4 Definition of Cladding Layout

The cladding layout plan defines the modulation of the cladding, that is, the arrangement of the ceramic tiles in each room. The project for the UEFS classroom pavilion includes a graphical representation of the cladding modulation per room, both on the floor and on the walls (Figure 4), indicating the manufacturer's specifications, size, and type.

Figure 4 – Details of the Tile Layout in the Classroom Building Project



Source: Adapted by the authors from the original project (2024)

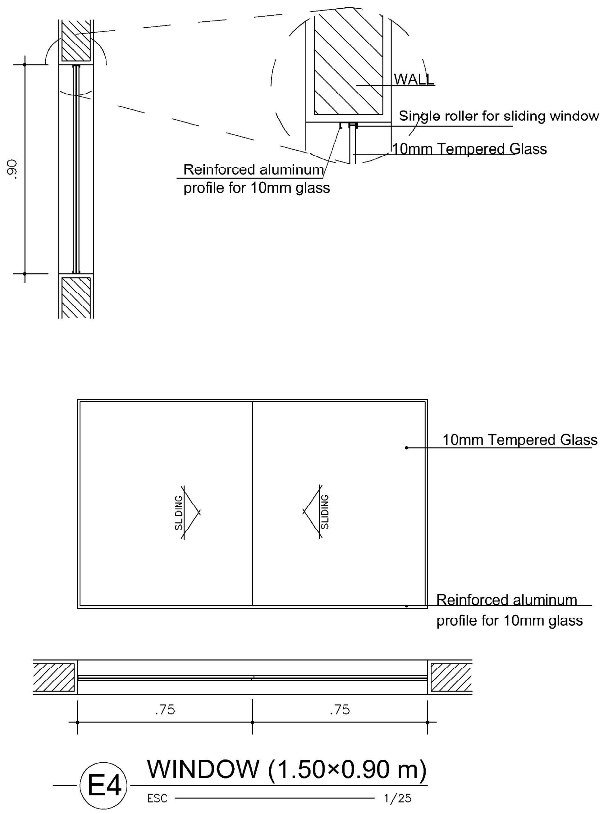
It was also noted that pagination of the ceramics would require cutting the tiles on both the sides and bottom of the walls. In this case, a less impactful decision would have been to provide a ceramic size that would minimize the need for cutting. Although some cuts in the ceramic tiles are expected, the project follows the traditional model and does not provide an estimate of the amount of waste generated.

The existence of the ceramic pagination project presents some advantages for the enterprise, directly contributing to the optimization of consumption, reducing waste (costs, raw materials, energy, and water), and minimizing rework by labor (Jáuregui; Vega; Santos, 2021).

4.1.5 Window and Door Design

The architectural project of the UEFS classroom building presents the details and specifications for the doors and windows, including information about the frame material, type of opening, and dimensions (Figure 5). From an environmental perspective, this level of detail is important for optimizing resources and efficiently planning purchases, preventing errors in production and installation, and consequently avoiding waste, reworking, and optimizing the construction schedule, indicating the manufacturer's specifications, size, and type.

Figure 5 – Details of the Window and Door Frames from the Pavilion Project



Source: Adapted by the authors from the original project (2024)

Window and door frames impact building comfort, lighting, and climate. Therefore, the frames project and their materials have to match the requirements (ABNT, 2013), which standards the performance criteria.

However, the project does not provide information on whether the specified frames meet the requirements set by this standard. This aspect is important not only to ensure constructive efficiency but also to ensure compliance with regulatory standards related to the performance and durability of the frames.

4.1.6 Presence of Natural Ventilation in All Environments

Through the analysis of the architectural project, it is possible to identify the presence of openings that allow natural ventilation in all rooms of the building.

The adoption of a cross-ventilation system takes advantage of natural conditions by utilizing pressure differences between zones to increase air flow, reducing the need for artificial lighting and air conditioning, and consequently, energy consumption (Morais; Labaki, 2017).

On the other hand, the design of the classroom pavilion includes the installation of split-type air conditioning units in the rooms, totaling 72 units with capacities ranging from 30,000 to 48,000 BTUs, which will require significant energy consumption in operation.

In this regard, it would be important for future projects to prioritize greater use of natural ventilation, reducing the need to activate the air conditioning system. In cases where artificial cooling is necessary, environmental parameters should be considered, such as selecting more eco-efficient units, carefully positioning condensers (to avoid excessive solar exposure), and employing smart systems with automation for operation times, presence control, and other factors.

4.1.7 Geographic Positioning of the Building to Enhance Thermal Comfort

The geographic positioning of the building was a strategy adopted during the design phase to provide thermal comfort for users and minimize energy consumption from the air conditioning systems. In the architectural design of the case study, the longitudinal axis of the roof was oriented in the East-West direction. This arrangement ensures that the building faces north, reducing direct sunlight exposure in the classrooms during the summer. This design choice helps to optimize the internal thermal conditions, creating a more pleasant and energy-efficient space (Toroxel; Silva, 2024).

4.1.8 Adoption of Other Architectural Solutions to Improve Thermal and Acoustic Comfort

Various techniques can be adopted to enhance thermal and acoustic comfort in buildings.

Regarding thermal comfort solutions in the design of the classroom pavilion, the presence of fixed metal brise-soleils on façades with windows was identified. These are intended to control solar radiation through shading, preventing direct sunlight from entering the rooms.

Another solution implemented was the cement hollow elements such as “cobogós” in the building’s enclosure system, which facilitates air circulation and improves thermal comfort. Additionally, cobogós allow the entry of natural light, contributing to the building’s energy efficiency.

Among the project’s choices, in addition to the previously mentioned solutions, there was also a decision to use light colors for walls, ceilings, and floors. This measure makes the spaces brighter, reducing energy consumption, and helps maintain internal temperature, as light colors absorb less heat.

The roof design included thermal-acoustic tiles, which assist in temperature control (thermal comfort) by improving thermal performance. This is due to the reflective properties of the metal surface of the tiles, the low thermal conductivity of the expanded polystyrene (the internal filling material), and the rapid dissipation of absorbed heat (Tokusumi; Foiato, 2019).

The thermal acoustic roof tiles adopted in the roof also contribute to acoustic comfort by reducing the transmission of external noise into the internal spaces, enhancing the acoustic comfort for users. Regarding this parameter, the project also specifies the conventional gypsum ceilings. However, when compared to other materials available on the market, such as gypsum board with PVC film or perforated ceiling (type “rigitone”). It is observed that conventional gypsum ceiling offers inferior acoustic performance and has greater durability issues, requiring more maintenance.

4.2 Structural and Foundation Projects

Table 3 shows the set sustainability parameters in the structural and foundation projects. Each parameter was evaluated with its respective indication of presence (Yes/No) in the projects.

Table 3 – Presence of Sustainability Parameters in Structural and Foundation Projects

Parameters	Presence
Soil Analysis	Yes
Quantity of concrete	Yes
Quantity of formwork	Yes
Quantity of steel	Yes
Project for reuse of formwork	No
Quantity of water	No
Waste generation rate	No
Noise generation rate	No
Vibration generation rate	No
Excavation volume	No

Source: Authors (2024)

4.2.1 Soil Analysis

The geotechnical investigation and your soil evaluation procedures are fundamental for the construction project, especially the SPT (standard proctor test). Through these tests, it is possible to understand the soil layers, and their characteristics (e.g. strengths, composition, level of the groundwater). Therefore, it is crucial that soil testing is conducted with an adequate number of boreholes to reveal the subsurface profile of the terrain, thereby reducing uncertainties.

The soil testing report for the UEFS classroom pavilion identified that the test was conducted with 9 boreholes, a quantity considered sufficient for recognizing the area where construction will be carried out, as established by ABNT NBR 8036/1983.

It is important to highlight that the absence of soil testing or conducting the test with a quantity of boreholes under the necessary could result in inadequate foundation sizing by undersizing (increasing risk) or oversizing (increasing costs).

The execution of foundations is associated with a range of relevant environmental aspects, such as noise and vibration emission, consumption of natural resources, water use and waste, soil movement, particulate matter emission, waste management, material loss due to debris, consumption of manufactured resources, circulation of materials, equipment, machinery, and vehicles, and material storage, among others.

4.2.2 Concrete, Steel, and Water Quantities

The structural project (superstructure and infrastructure) in the case study shows the bills of quantities (in tables) for concrete and steel, as usual in this kind of project. However, to allow for an environmental assessment it would be necessary to include the expected quantities of timber and water in the process. The inclusion of these consumptions will make the bill of quantities more faithful to what is expected, including allowing their use as data sources to predict and control environmental aspects and impacts throughout the construction phases.

In this regard, the quantities of materials can be used to predict environmental aspects during the project and planning phases, guiding the selection of construction techniques and systems with lower environmental impact and mitigating potential environmental impacts arising from the adopted construction activities.

In general, structural projects do not detail the water demanded to produce their elements (e.g. beams, slabs, and pillars). This may be because of the low cost of water when compared to other concrete inputs, such as cement, additives, and aggregates. However, water consumption has significant environmental impacts, such as water scarcity and alterations to local ecosystem dynamics.

Table 4 presents the main indicators of steel, formwork, and concrete consumption calculated from the absolute quantities of each input in the project and bidding documents for the Pavilion of Classes, and a comparison with values for similar typology buildings observed in a study performed by Botelho e Marchetti (2011). The obtained values are not significantly different from those reported by Botelho e Marchetti (2011), except for the formwork-to-concrete ratio, where the value for the Pavilion of Classes (2.76 m²/m³) is considerably lower than the average (7.00 m²/m³) reported by Botelho e Marchetti (2011).

The rebar consumption in construction works is directly related to the use of resources, storage, loading/ unloading, and circulation of machinery on site.

Additionally, several occupational risks are associated with the reinforced concrete in the construction

Table 4 – Comparison of Steel, Formwork, and Construction Data Indicators for the Pavilion Project with Values Predicted by Botelho and Marcati (2011)

Indicators	Pavilion of Classes	Botelho e Marchetti (2011)
INFRASTRUCTURE		
Steel/Concrete (kg/m³)	82.94	70.00
Formwork/Concrete (m²/m³)	2.76	7.00
SUPERSTRUCTURE		
Steel/Concrete (kg/m³)	81.38	100.00
Formwork/Concrete (m²/m³)	10.00	12.00
INFRASTRUCTURE + SUPERSTRUCTURE		
Steel / AC (kg/m²)	18.54	23.00
Formwork / AC (m²/m²)	1.98	2.76
Concrete / AC (m³/m²)	0.23	0.23

Note: Constructed area (AC) of the pavilion equals 4,152.08 m²

Source: Authors (2024)

site, during the phases of production the formwork (cutting and assembly), the rebar frames (cutting, handling, bending, and assembly), and the concrete (batching, mixing, transporting, placing, compacting, and curing). In addition to those mentioned above, one can cite water consumption for concrete processing, energy consumption, noise, and vibration.

To minimize these aspects, it is necessary to evaluate the mix and origin of the concrete. The choice to use ready-mix concrete reduces some environmental aspects such as water demand on site, storage of inputs, and the generation and management of waste. On the other hand, the necessity for concrete mixer trucks aggravates some environmental issues such as noise emissions and pollutant emissions from fuel combustion.

4.2.3 Quantity of Formwork and Formwork Reuse Project

The analyzed structural project provides only the quantity of formwork and the floor plan with the respective sections of their beams, columns, and slabs. However, it is noted that there is an absence of the formwork and shoring design, which should detail the positioning of wailers, props, and braces, as well as the arrangement of longitudinal and cross members, and the distribution of plywood sheets. The budget analysis reveals the intention to use resin-coated and plastic-coated wooden formwork, but the documentation lacks guidelines to encourage the reuse of this material.

The choice of formworks material and manufacture impacts the reuse rate, and consequently the environmental performance relative to reducing waste generation, wood consumption, and material storage on construction sites (key aspects in this service). In this context, the use of plastic-coated plywood allows for a greater number of reuses of the formwork compared to resin-coated plywood.

Another factor that contributes to increasing the reuse rate of formwork is the repetition of elements. Therefore, in the project for the classroom pavilion, would be possible to achieve a high rate of reuse, as the layout of the building repeats between floors and follows a certain modularity, which is one of the positive aspects of the design, such as the standard distance between columns. This modular typology reduces the environmental impact associated with waste generation and the consumption of natural resources.

4.2.4 Waste, Noise, and Vibration Generation Rates

Although complex and challenging to implement, incorporating waste, noise, and vibration generation rates as environmental indicators is necessary for controlling and monitoring the performance of activities on the construction site. In the analysis of the classroom pavilion projects (specifications and graphical documents), these indicators or measures for control and mitigation were not identified. Including these indicators in the project could play a significant role in decision-making, aiming strategies to minimize environmental and occupational impacts from waste generation, noise emission, and vibration.

Aspects related to these parameters have the potential to generate significant environmental impacts, such as increased landfill volume, discomfort for the surrounding community, noise pollution, changes in safety conditions, pressure on urban services, and damage to nearby buildings. Thus, incorporating these parameters into future projects can be a valuable tool for incorporating measures aimed at mitigating these environmental impacts, and promoting more sustainable practices during construction.

4.2.5 Volume of Excavation

The project does not directly provide information about the volume of soil excavation required for the foundations, despite it being an important environmental indicator for controlling aspects relative to soil movement (loading, unloading, and transportation).

The excavation volume is often not detailed for the middle building projects in Brazil, only estimated in the budget spreadsheet, similarly to this case (933.83 m³). Analyzing this service reveals various significant environmental aspects, such as soil movement, waste generation, collapse risk, dust emission, and heavy machinery circulation (especially in mechanized excavation cases, as in the study object).

Furthermore, the use of heavy machinery contributes to other relevant environmental impacts, including noise emission and pollutant release from fuel combustion (Ebrahimi *et al.*, 2020; Cardoso; Fiorani; Degani, 2006; Cardoso; Araujo, 2007). Including the excavation volume as a parameter in the project would allow for better control and planning of these environmental impacts associated with excavation.

4.3 Hydrosanitary Project

In evaluating the hydraulic project, the study considered five parameters were identified. Table 5 shows the summary of the analyzed information, highlighting the presence of each parameter in the project.

Table 5 – Presence of Sustainability Parameters in the Hydrosanitary Project

Parameters	Presence
Indication of total water demand	Yes
Indication of water volume per estimated number of users	Yes
Reuse of rainwater and greywate	No
Water use reduction instruments	No
On-site sewage treatment system	Yes

Source: Authors (2024)

4.3.1 Indication of Total Water Demand and Volume of Water per Estimated Number of Users

The project under review provides detailed information about these parameters in the descriptive report. The definition of total water demand allows designers to identify opportunities to implement technologies and practices that reduce water consumption. This can include specifying water-saving devices, such as low-flow faucets, dual-flush toilets, and flow-reducing showerheads. However, the use of these devices was not identified.

The inclusion of the indication of water volume per estimated number of users is also a positive practice. This information is essential for sizing the systems and serves as a tool for comparing estimated water consumption in the project with actual consumption once the building is in use. Furthermore, water consumption can vary significantly depending on the type of building, its purposes, and the number of people it serves, especially in university environments with their flow patterns (Silva; Brandão; Ribeiro, 2022; Estrada; Kalbusch; Henning, 2021; Coelho *et al.*, 2019; Salla *et al.*, 2013).

Another positive action would be to adopt individual water meters for campus buildings. By indicating the water volume per user and having a reliable metering system, the project would provide a reference standard that could be used to compare consumption with other similar projects on campus. This would help identify issues such as leaks and promote more efficient and sustainable consumption practices. Cost savings are also a significant benefit, as sizing the systems based on a water consumption demand closer to actual usage can substantially reduce the costs from the systems installation and operation.

4.3.2 Reuse of Rainwater and Gray Water

The analyzed project did not identify specifications or recommendations for the implementation of graywater treatment and reuse systems, or rainwater storage. This absence represents a missed opportunity that could promote sustainable water resource management practices and minimize the environmental impacts of water use, especially considering that the project is planned to be replicated in five other buildings.

Rainwater harvesting and gray water reuse systems are important strategies to reduce the demand for potable water and minimize water resource waste (Barbosa; Bezerra; Sant'ana, 2018). Additionally, it presents economic benefits, as it promotes cost savings on water bills (Moura *et al.*, 2020). From an environmental perspective, rainwater harvesting would also reduce stormwater runoff to drainage systems. Furthermore, it decreases the exploitation of groundwater, preserving aquifers and preventing the depletion of the water table.

4.3.3 Installation of Water-Saving Devices

Water-saving devices, such as low-flow faucets, high-efficiency showers, and dual-flush toilets, are a sustainable choice as they promote potable water conservation, reduce energy consumption (due to decreased hot water use), and minimize the load on water treatment systems (Bottega *et al.*, 2022; Gnoatto; Kalbusch; Henning, 2020; Falcão; Silveira, 2020). These devices enable users to use the appropriate amount of water by employing technologies that limit the flow rate.

The analyzed project found no specifications or recommendations for using water-saving devices. It is important to emphasize that incorporating these devices not only brings environmental benefits, such as the conservation of water resources and reduction of the water footprint, but it also contributes to long-term sustainability by promoting responsible water use and preserving aquatic ecosystems.

4.3.4 On-Site Sewage Treatment System

The design of the classroom pavilion opted for an individual sewage treatment and final disposal system, consisting of a septic tank and infiltration trenches. The project's descriptive memorial justifies the adoption of this solution as one consequence of the absence of a collective sewage system serving the entire university campus.

For this case, the septic tank with an infiltration trench is an alternative for wastewater treatment, considering the absence of a centralized system (Guterres; Kaiser; Siqueira, 2021). The buildings already implemented on the campus have adopted similar individualized systems, generally consisting of a septic tank, anaerobic filter, and vertical absorbent well (sump).

One of the main benefits is the localized treatment of wastewater, which reduces the need to transport large volumes of sewage to distant treatment plants, thereby saving energy and reducing pollutant emissions associated with transportation.

However, it is important to note that this system requires careful planning and regular maintenance to prevent potential soil contamination, which could negatively impact the local flora and groundwater.

4.4 Electrical Project

For the electrical project, seven sustainability parameters were established and analyzed. Table 6 presents these parameters, highlighting their presence in the projects.

Table 6 – Presence of Sustainability Parameters in the Electrical Project

Parameters	Presence
Energy-efficient lighting design	No
Use of low-consumption lamps	No
Energy generation from photovoltaic or wind systems	No
Electrical energy consumption forecast by estimated number of users	No
Building automation project	No
Presence sensors for lighting	No
Specification of equipment with lower consumption and better efficiency	Yes

Source: Authors (2024)

4.4.1 Energy-efficient lighting design and use of low-consumption lamps

The supplementary projects for the UEFS classroom pavilion do not include information on a lighting design focused on energy efficiency. Including a lighting design is essential, it promotes energy efficiency by ensuring that the lighting is adequate for the space's needs while minimizing energy waste (Bezerra *et al.*, 2017; Soares *et al.*, 2015). This aspect not only promotes lower electricity consumption and reduces the building's energy bills but also contributes to environmental preservation by decreasing the carbon emissions associated with electricity consumption.

With the absence of a specific lighting project in the pavilion project, there is no analysis of the distribution, intensity, and color temperature of the light for the building. Consequently, this limits the opportunity to improve the conditions of visual comfort and productivity of students (Bezerra *et al.*, 2017; Soares *et al.*, 2015).

Additionally, the analysis of the electrical project for the classroom pavilion noted that tubular fluorescent lamps (16 and 32 Watts) were adopted for the classrooms and compact fluorescent lamps (23 Watts) for smaller rooms, when in both cases LED lamps could have been specified. LED lamps provide higher energy efficiency and have a significantly longer lifespan when compared to fluorescent lamps (Paixão, 2021). As a result, this would reduce energy consumption and fewer lamp replacements, consequently minimizing waste generation, and making the pavilion's lighting system more efficient and environmentally responsible.

4.4.2 Estimated Energy Consumption per Number of Users

The estimated energy consumption per number of users plays a critical role in assessing the environmental performance of a building. Similarly, the per capita demand for water. This data (consumption per capita estimated) highlights opportunities to implement technologies and practices that reduce electricity consumption by specifying efficient devices and systems, such as low-consumption lamps, automated lighting, effective thermal insulation, and more (Mariano; Trigo; Maruyama, 2021).

Another important point is that energy consumption can vary significantly depending on the type of building, its purposes, and the number of people served throughout the day. Therefore, by indicating the energy consumption per user and your aggregation, the project provides a benchmark that can be used to compare consumption with other similar projects, identifying and adopting more efficient and sustainable practices.

In the analysis of the electrical project for the lecture hall pavilion, this indicator was not identified. Therefore, its inclusion is essential to promote energy efficiency and environmental responsibility.

4.4.3 Generation of Energy through Photovoltaic or Wind Systems

The project under analysis does not include provisions for energy generation through alternative sources such as photovoltaic or wind systems. Although these systems require a higher initial investment and a technical-economic feasibility study, they can offer several benefits. These include reducing reliance on grid electricity and lowering costs (Silva *et al.*, 2020), as well as decreasing greenhouse gas emissions and enhancing energy resilience (Muqeet *et al.*, 2021).

Firstly, generating energy from the sun or wind utilizes clean and renewable energy sources, reducing dependence on non-renewable sources. When well-designed and combined with energy storage, these systems can enable buildings to become energy self-sufficient, decreasing their reliance on external energy sources and increasing energy resilience. This approach helps to preserve natural resources and mitigate climate change.

Another significant aspect is the reduction of greenhouse gas emissions. Generating energy from renewable sources contributes to lowering the carbon footprint of buildings, playing a substantial role in climate change mitigation, and consequently promoting environmental sustainability.

Additionally, renewable energy generation can alleviate peak electricity demand, if it can be compatible with the periods of highest availability of this energy source. This helps to improve the stability of local electrical grids, reduce the campus's electricity bills, and lessen the strain on the electrical grid infrastructure.

4.4.4 Building Automation Design and Presence Sensors for Lighting

The analysis of the project documentation did not identify the use of building automation systems with the use of sensors to control the activation of lighting fixtures or air conditioning units.

Building automation would enable the integration of presence sensors with lighting systems, resulting in lighting that automatically adjusts based on the presence of people in the building's environment. Presence sensors can turn off lights when an area is empty, significantly saving energy; they could also be used for controlling air conditioning systems by managing their activation and deactivation.

Furthermore, automation systems allow it to schedule specific times to turn lights on and off to promote the adoption of natural lighting whenever possible. This reduces energy waste and, consequently, minimizes operational costs.

4.4.5 Definition of Equipment with Lower Consumption and Optimal Efficiency

The selection of energy-efficient equipment directly contributes to reducing electricity usage, lowering carbon emissions, and decreasing operational costs. Additionally, efficient equipment often has a longer lifespan, reducing the need for frequent replacements and, consequently, minimizing waste generation.

In the context of the UEFS classroom building projects, the commitment to selecting energy-efficient equipment is evident only through the HVAC (Heating, Ventilation, and Air Conditioning) project. This project is responsible for sizing the equipment tasked with controlling the ambient temperature according to the specific needs of each space. This approach considers factors such as the purpose of the space, its dimensions, the expected occupancy, and the geographic location. As a result, the equipment is selected with the goal of achieving maximum energy efficiency without compromising thermal comfort and indoor air quality.

5 CONCLUSION

A detailed analysis of the projects related to the construction of the UEFS classroom building corroborates the importance of considering environmental and sustainable aspects from the early stages of the project. Sustainability for engineering projects must extend beyond cost-effectiveness, safety, and comfort. Sustainability must encompass the wide range of factors that impact the entire building's lifecycle and the surrounding environment.

Although the analysis of the projects revealed several design decisions that favor the sustainability of the building, such as provisions for natural ventilation and lighting, the use of brise-soleils, and the integration of vegetation and central gardens, several gaps were also identified that require a more assertive approach to ensure the building's effective sustainability.

In this sense, the bellow topics address the conclusions for each analyzed theme and offer recommendations that could be incorporated into the project, considering its replication in new units and future projects, aiming to reduce impact throughout the lifecycle of buildings on the campus.

The soil investigation, conducted with the appropriate number of boreholes, stands out as a good practice for characterizing the terrain in the structural design. However, it would be important to incorporate some indicators, such as waste generation rate and excavation volume, into the structural projects. The absence of these parameters restricts an adequate assessment and management of environmental impacts generated by soil movement and emissions (e.g. particulates and combustion gases), potential risks that could be prevented.

Information on the estimated quantities of concrete and steel in structural projects and their correlations (steel/concrete/strength ratio) provide important data for assessing and controlling environmental impacts.

However, it is necessary to address the gap in indicators such as water quantity, waste generation rate, noise, vibration, and excavation volume, as this gap could compromise environmental management during construction.

The approach to the hydrosanitary project is notable for considering water and sewage demand; however, the absence of strategies for rainwater harvesting and graywater reuse represents a missed opportunity. Considering the increasing water scarcity, not implementing these sustainable practices compromises the system's efficiency and resilience, undermining responsible resource management. Opportunities to improve water use include installing water meters with telemetering devices for flow measurement per building, adopting rainwater harvesting and reuse systems, and using water-saving devices such as low-flow toilets and automatic shutoff faucets.

The lack of a luminotechnical project and the absence of alternative energy sources such as photovoltaic or wind power highlight a gap in energy efficiency. To address this, the following improvements are suggested: replacing fluorescent tube lamps with LED lamps; incorporating photovoltaic systems to meet part of the energy demand; and automating the operation of air conditioning and lighting systems to consider user presence and usage times.

The lack of emphasis on choosing efficient equipment points to a limitation in sustainable management during the building project. Automation and careful equipment selection would reduce energy consumption, operational costs, and environmental impacts.

The pursuit of sustainability in public buildings, such as the UEFS classroom pavilion, requires broadening the scope of the projects to include environmental indicators, strategies for water resource management, and the integration of alternative energy sources. Addressing these gaps in future pavilions can help ensure that university buildings move closer to a benchmark for sustainable practices in public construction.

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