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ENGINEERING STUDENTS' PERCEPTIONS OF SUSTAINABILITY IN THE REHABILITATION OF BUILDINGS: A CASE STUDY

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Abstract

The purpose of this case study is to analyse the perceptions and knowledge of university students, regarding the implementation of proper practices, towards a high level of sustainability of rehabilitated buildings. During 2016-17, a group of twenty-one students attended "Pathologies and Rehabilitation of Buildings", a third-year subject of a Portuguese Civil Engineering course, which aims to deepen the knowledge that will allow students to use sustainable practices in old buildings in need of rehabilitation. Qualitative and quantitative data was collected from observation and analysis of the rehabilitation process of a building located in the city of Porto, Portugal, as well as from the analysis of a questionnaire about how this practical activity has enriched students´ technical experience. The results indicate students' increasing awareness regarding the importance of practical knowledge about building rehabilitation, using sustainability criteria to transform highly deteriorated buildings into spaces whose dwellers can achieve an easier integration at the environmental, social and economic levels. Nevertheless, it *should be noted that only a few students reveal deeper knowledge of the building pathologies, of which the most common are humidity infiltrations and the lack of thermal insulation. The results of the case study will be used to improve teaching practice in this university course and to increase students´ practical application of sustainable rehabilitation concepts to the built environment. In this way, the establishment of the effectiveness of an active pedagogy, in order to prepare future engineers, capable of leading a building rehabilitation sustainable process, was a driving factor in this study.*

Keywords

Engineering Education; Building Rehabilitation; Sustainability; Students' Perceptions; Case Study

1. Introduction

Until 2007, the Portuguese construction sector was faced with an excess of new buildings, both residential and non-residential. Combined with this surplus, the international financial crisis led to the bankruptcy of most construction companies. The crisis and subsequent difficulties also meant that Portuguese families were suddenly unable to buy houses, as used to be common in Portugal. For instance, it became nearly impossible to secure loans from banks (Sousa, Silva & Almeida, 2012).

Stemming from these circumstances, over the past ten years a new approach to the housing sector has developed: as new houses were not being bought and the companies that built new houses were crushed, the remaining builders turned towards the rehabilitation of existing buildings. Incidentally, due to the time lapsed since the major construction boom started a few decades ago, the Portuguese housing stock is currently in need of major repairs (Matos, 2012). The turn towards mass rehabilitation of the housing stock also happens to be one of the most important steps in achieving sustainability in the construction sector (URBACT, 2015).

Academic education, and particularly engineering studies, has adapted its academic curriculum to include the retrofitting of buildings. For instance, at the University Fernando Pessoa, in Porto, the 1^{st} Cycle Undergraduate Degree of Civil engineering includes, in its 6th and last semester, the course of "Pathologies and Rehabilitation of Buildings", which is now being taught in an experimental basis for the second year.

This article focuses on a case study, divided into two parts, whose purpose is to improve the content of the aforementioned course. In the first part, a sustainable rehabilitation project is presented, followed by an analysis of its construction systems as well as the installed equipment that is responsible for a strong decrease of carbon dioxide emissions and the improvement of the building's environmental impact. The intention is to demonstrate how to retrofit buildings while taking into consideration the most recent principles of environmental sustainability, namely the Paris Agreement, which allow us to mitigate greenhouse gas emissions.

In the second part, the results of a questionnaire survey of a group of students are presented, in order to evaluate their perception on the subject of building rehabilitation. This survey was used to study the students' opinions on the "Pathologies and Rehabilitation of Buildings" course, the usefulness of study visits to construction sites, and the future of rehabilitation as a professional activity.

Moreover, the study aims to contribute to the definition of rehabilitation practices focused on achieving a low environmental impact in highly efficient building refurbishment, in comparison with standard or traditional rehabilitation.

2. Literature Review: Sustainability in Rehabilitation of Buildings

Ever since the Brundtland report - Our Common Future (1987), there have been several agreements identifying the most important environmental problems, such as climate changes. All have pointed towards solutions involving the reduction of energy consumption and the development of technologies for the use of renewable energies. The latest global agreement on climate change was reached in Paris in December 2015, and has already been ratified by more than 60 countries. This agreement presents an action plan to limit global warming to a value 'well below' of 2°C, which results from the emission of greenhouse gases, namely carbon dioxide (CO_2), and covers the period from 2020 onwards (EU, 2017). It aims to achieve a low carbon global trajectory, which improves resilience and reduces societies' vulnerability to climate changes.

In European city centres, the building rehabilitation sector has known an increased significance since the early 21st century (Neto, 2014). Since buildings are large consumers of energy, and therefore a high source of CO_2 emissions, sustainable rehabilitation of old buildings can strongly contribute to the protection of the environment (EIA, 2016).

This contribution is achieved through the use of efficient constructive systems and heating equipment (Sorrel, 2015):

- Applying strong thermal insulation to façades;
- Replacing the glazing of façades, exchanging existing frames for new ones with double glazing and polyamide thermally broken profiles, while also reducing ventilation infiltrations;
- Replacing domestic hot water systems, through the installation of high-efficiency equipment;
- Using LED lamps in interior lighting;
- Installing equipment that uses renewable energy, including:
    - Solar thermal panels for domestic hot water production;
    - Electric energy production systems for self-consumption which make use of renewable energy sources.

In this sense, the rehabilitation of buildings is a multiple intervention process, as defined by several authors. Thus, for Appleton (2003) (free translation), "The rehabilitation of buildings is currently recognized as a national necessity, in which opportunities converge for: economic development, the defence and safeguarding of cultural and heritage assets; the improvement of living conditions and energy consumption and social dynamism."

According to Freitas (2012) (free translation), "Rehabilitation is comprised of set of interventions in a building which aim to recover and benefit it, making it fit for the intended use. It consists of solving the various anomalies accumulated over time, while simultaneously seeking a modernization, in order to improve the functional performance of the building."

3. Methodology

The first objective of this case study is to analyse the perceptions and improve the knowledge of university students regarding the implementation of proper practices, towards a high level of sustainability of rehabilitated buildings by studying a building during its rehabilitation.

The second objective is to analyse how this practical activity has enriched students´ technical experience by collecting, by written questionnaire to the students, qualitative and quantitative data from observation and analysis of the mentioned rehabilitation process.

This case study combines the qualitative and descriptive analysis of the rehabilitation process of a building in the city of Porto, northern Portugal, with the quantitative analysis of a questionnaire survey applied to the students of the civil engineering course. Data collection occurred during the 2016-17 school year, using a sample of twenty-one students, including four Erasmus students, who attended "Pathologies and Rehabilitation of Buildings", a third year subject of a Portuguese Civil Engineering course, at the Fernando Pessoa University.

The study was carried out in two stages. Firstly, quantitative data was gathered and analysed using written questionnaires applied to the students, after their visit to a building undergoing the process of rehabilitation.

Secondly, we examined a full rehabilitation process of a building, from design to construction, regarding the use of sustainable practices in old buildings.

As this is a case study, it is circumscribed to a specific context (Yin, 2011) – in this case engineering education, - in an attempt to reach a deeper understanding of sustainable building rehabilitation.

4. Case Study

The case study chosen was a building in rehabilitation, which was planned to follow the principles of sustainable rehabilitation in its environmental aspects.

The sources and instruments of data collection used were as follows:

- Listing the removal of materials for reuse or recycling;
- Listing the replacement of degraded materials with new materials which had reuse or recycling potential;
- Quantification of the use, in the rehabilitation works, of
    - equipment of renewable origin, operating with solar renewable energy, and/or low-energy embedded;
    - equipment for lighting and heating of sanitary waters of high energy efficiency;
    - sustainable materials;
    - recyclable materials.

Studying the collected data will help calculate the reduction in electricity and natural gas consumption, - compared to the same energy consumptions in a similar building that was rehabilitated in a traditional way, with no thermal insulation or efficient equipment, - as well as the reduction of CO_2 emissions.

In addition, after the analysis of the rehabilitation project described above, a questionnaire survey was applied to twenty-one students. The analysis of the answers will facilitate an in-depth look into students' opinions and perceptions regarding the rehabilitation of buildings.

4.1 Building Rehabilitation Project for Sustainable Housing

The case study focused on a one-hundred-year-old single family residence, which was abandoned for almost 40 years, due to lack of basic conditions for inhabitability. Located in Porto, it was acquired to be transformed into a residence for university students.

4.1.1 Description of Environmental Rehabilitation Processes

The analysis of this case study consists firstly of quantifying the various products resulting from the demolition, which were separated for recycling, as well as those that would be reused in the reconstruction.

Secondly, we will analyse types and quantities of sustainable materials used in construction, belonging to the following groups: materials of renewable origin, recyclable materials, and highly efficient materials or equipment.

Finally, we will analyse the reduction of CO_2 emissions obtained by the use of these materials or equipment, when compared to standard construction or traditional rehabilitation.

4.1.2 Demolition and Separation Process for Recycling

The waste meant for recycling was prepared to be transported by truck and separated by types of waste, in order to be led to selective deposits located in the municipality. The main categories are:

- Any timber extracted from the building structure - roof structure, roof linings, windows, floors and pavement beams - which could not be reused due to its advanced deterioration;
- All of the window glazing;
- Other ceramic and coating products, such as old plasters, sanitary ware, floor screeds.

The demolition products for recycling and their quantities are described in table 6.

4.1.3 Deconstruction and Separation Process for Rehabilitation and Reconstruction

The deconstruction process (Kibert & Chini, 2000) was prepared in order to group materials by type, in order to facilitate cleaning and storage. It focused on disassembling the following elements:

- Granite masonry, in order to proceed to its assembly in the new places indicated in the project;
- Roof tiles, for posterior washing and reapplication on the new roof;
- Exterior and interior hydraulic tiles, for later rehabilitation and reapplication in the areas indicated in the project;
- Iron grids of windows and external doors, for treatment and mounting in the same places, as seen in Figures 1 and 2;
- Wooden interior doors, for treatment, painting and assembly in the same places from which they were removed.

Figure 1: *Iron grid in original location above the entrance door of case study*

Figure 2: *The grid depicted in Figure 1 after treatment and painting of case study*

Table 1 shows the quantities of each of the materials included in the deconstruction process and respective percentages. We estimate that the deconstruction process included the majority of demolition products: 63.4%, almost two-thirds of the total tonnage. Secondly, although recycling accounts for the smallest share of demolition products, only 14.7% of total demolition tonnage (ceramic and coating products) was not recycled into new materials or reused, since aggregates were delivered into a deposit for such materials.

Table 1: *Division of Demolition Products by Type Versus Global of Case Study*

Type of demolition	Materials / tons / percentage of total		
	Materials	**Tons**	**Percentages**
Deconstruction	Granite masonry	35	42.9
	Roof tiles	8	9.8
	Interior wood elements	1	1.2
	Painted / hydraulic tiles	7	9.0
	Iron grids	0,4	0.5
Recycling	Timber	18	21.7
	Glazing	0,2	0.2
	Ceramic and coating products	12	14.7

4.1.4 The Use of Sustainable Materials

The use of sustainable materials was an ideal included in the project, independently of whether they were of renewable origin or simply naturally abundant or even recyclable, as long as they had a small impact on the environment.

- Materials of renewable origin, predominantly vegetal:
  - Floors and roofs consisting of panels of a material derived from wood, designated as OSB - Oriented Strand Board;
  - Flooring, windows, exterior and interior doors, as well as their panels, trims and accessories, all in wood;
  - Thermal insulation in façades in black cork agglomerate, four centimetres thick;
- Materials of mineral origin, naturally abundant, with low embedded energy, and of local or regional production:
  - Structural steel, used in pillars, paving and roofing;
  - Rockwool, used in acoustic insulation between compartments, where it was placed horizontally or vertically;
  - Plasterboards, used in separation of rooms and stairs, and also in ceilings.
- Materials or equipment that provide a high reduction of energy consumption due to their efficiency or technology:
  - Thermal insulation plates consisting of extruded polystyrene (XPS) foam, eight centimetres thick, applied to the building envelope;

- LED - Light Emitting Diode lamps - 4W lamps fitted throughout the inner spaces;
- A central heating system with a condensing boiler (efficiency of 107.6%) with hot water distribution to the radiators installed in heated spaces;
- Double glazing in all exterior windows, with a low coefficient of thermal transmission, protected by white wooden shutters, providing solar protection in the summer;
- Four thermal solar panels with 10.0 m^2 of absorption area, working in conjunction with a 750 litre cylinder to provide enough hot water to the twelve estimated occupants of the building;
- Six solar photovoltaic collectors, with a total output of 1.5 kWp.

- Use of recyclable materials in the construction process:
  - All the wood used in construction;
  - Copper wires for electrical installations;
  - Aluminium profiles of the backyard windows;
  - Interior and exterior window glazing;
  - Iron grids for windows.

4.1.5 Percentages for Sustainable Materials and Recyclable Materials

Consulting the project's quantities of materials and/or components to be used in construction, it was possible to determine the approximate tonnages of sustainable and recyclable materials previously referred, as shown in Table 2.

Table 2: *Sustainable and Recyclable Materials used in Construction of Case Study*

Type of materials	Materials / tons / percentage of total		
	Materials	Tons	Percentages
Sustainable	OSB	8.0	5.7
	Wood	6.5	4.6
	Cork insulation	0.2	< 0.1
	Solar panels / boiler	0.3	< 0.1
	Extruded polystyrene	0.2	< 0.1
	LED lighting	0.1	< 0.1
Recyclable	Steel	12.0	8.6
	Glazing	0.9	< 0.1

	Rock wool	0.3	< 0.1
	Pasterboard	1.0	< 0.1
	Copper wires	0.1	< 0.1
	Aluminium	0.6	< 0.1
Reusable after deconstruction	Materials shown in Table 6	51.4	36.7
Total materials		**81.6**	**55.6**

The significant quantities of recyclable and sustainable materials used in construction, as shown above, resulted in a significant reduction of total embedded energy in construction.

Taking into account that the estimated total tonnage of the constructed building is 140 tons, by analysing Table 7, deconstruction includes the greater part of construction products – roughly one-third of the overall construction tonnage, or 36.7%. The use of materials with sustainable characteristics constitutes 10.3% of the total, and the use of recyclable materials 8.6% of the total construction. Thus, the sum of the tonnages of sustainable materials with those of recyclable materials and reusable materials constitutes 55.6% of the total estimated tonnage of the building. In other words, most of the materials either have been reused, are recycled, or are classified as sustainable.

4.1.6 Annual Energy Savings due to Efficient Equipment

Considering that the case study focuses on a highly energetically efficient, environmentally low-impact building rehabilitation, it is important to look into its energy consumptions regarding the three following areas:

1) Energy consumption for heating;
2) Energy consumption for heating domestic water, including the use of solar energy;
3) Energy consumption for indoor lighting, using solar photovoltaic energy.

The objective is to demonstrate, in comparative terms, the reduction of energy consumption after the building's rehabilitation, for each of the three situations described above, in relation to the two standard situations described as follows:

1) Building similar to the case study with standard thermal insulation and standard efficiency equipment, as provided under Portuguese Law (REH, 2013).
2) Building similar to the one included in the case study, but without thermal insulation or highly-efficient equipment, as is common in traditional rehabilitation.

Thus, for each type of consumption described in 1), 2) and 3), simulation results will be presented for the three cases defined above - case study, standard insulated building and traditional non-insulated building.

1) Reduction of Energy Consumption for Heating

The figures presented for the standard insulated building and for the traditional non-insulated building result from a simulation, using the spreadsheet provided by the Portuguese Law for the energy certification of similar buildings (REH, 2013).

Scenarios were created for the traditional and the standard building. A traditional rehabilitation would not include central heating nor efficient equipment, only standard heaters powered by electricity with efficiency of 100%. On the other hand, a standard rehabilitation would use a natural gas standard boiler with an efficiency of 89%. The values related to the case study building are calculated according a natural gas condensing boiler with an efficiency of 107.6%.

As seen in Figure 3, the case study building has 63% less needs regarding heating energy than a traditional building, and 27% less than a standard building.

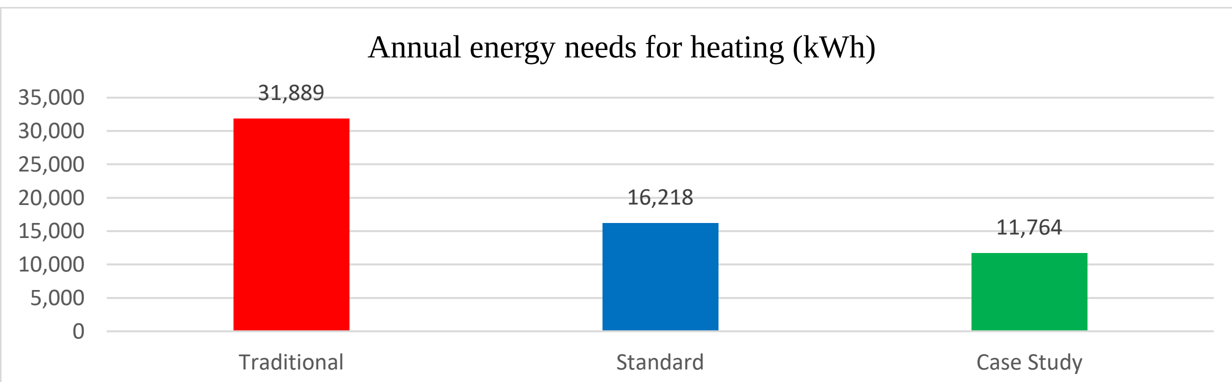

Figure 3: *Comparison of Annual Energy needs for Heating for the Case Study*

The following results, in Figure 4, compare natural gas consumption in the three situations. In this figure the case study building consumes 70% less natural gas for heating purposes than the traditional building, and 40% less than the standard building.

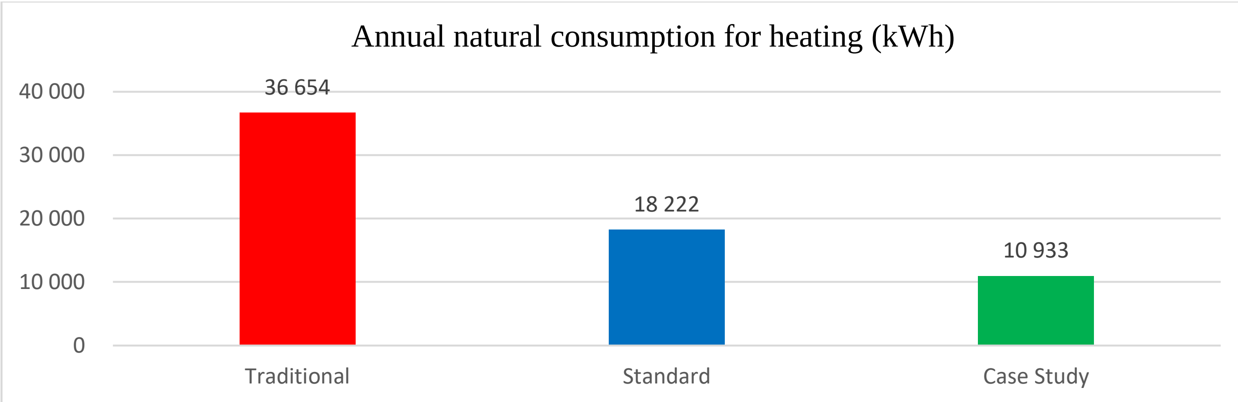

Figure 4: *Comparison of Annual Natural Gas Consumption for Heating for the Case Study*

2) Reduction of Energy Consumption for Domestic Hot Water

Considering the number of building occupants and average consumption of hot water, which is 520 litres per day, calculations were made to allow for the same type of comparison presented in the previous section.

As for heating consumption, scenarios were also created for the traditional and the standard building. A traditional rehabilitation would not include solar panels nor efficient equipment, only a hot water system by electric cylinder with efficiency of 86%. Likewise, a standard rehabilitation would employ solar panels within the regulatory areas allowed by Portuguese Law, and use a natural gas standard boiler with an efficiency of 89%. The values related to the case study building are calculated according to the equipment installed - four solar panels with 10.0 m² of area and a natural gas condensing boiler with an efficiency of 107.6%.

As seen in figure 5, the case study building consumes 81% less natural gas for water heating than the traditional building, and 48% less than the standard building. These values are justified by the renewable energy component, shown in figure 5, and by the efficiency of the installed equipment.

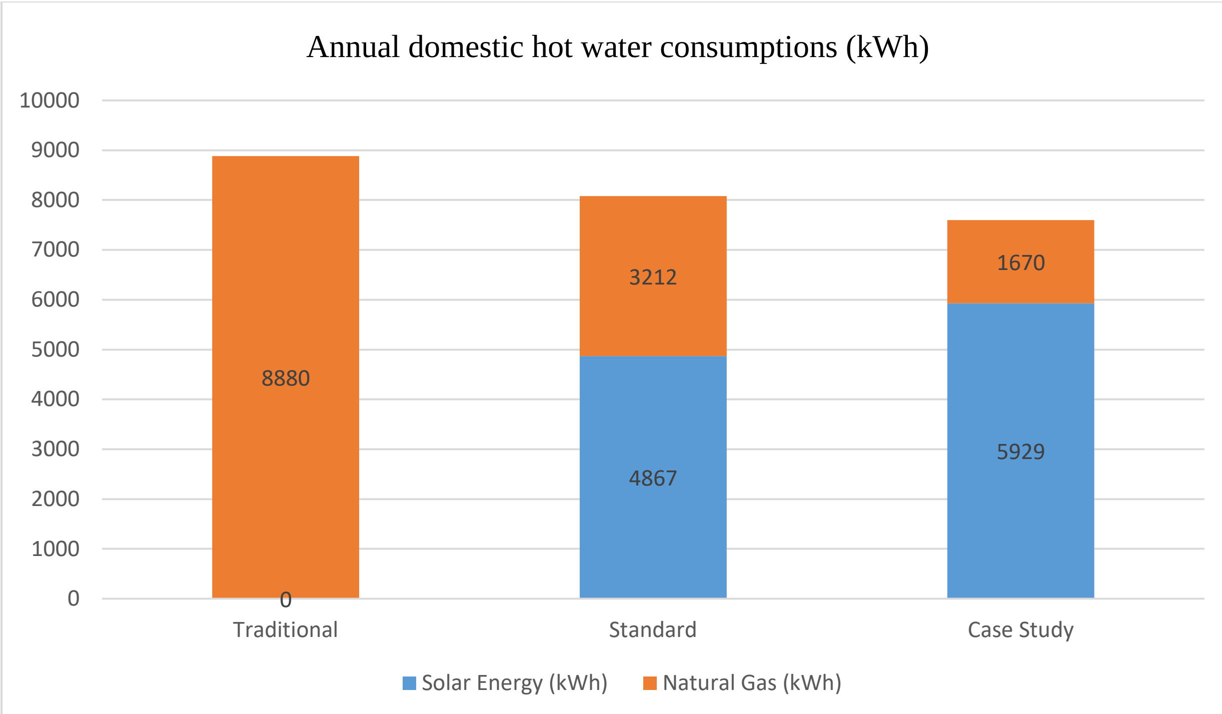

Figure 5: *Comparison of Annual Natural Gas Consumption for Water Heating, Considering the use of Solar Energy of the Case Study*

3) Reduction of Energy Consumption for Lighting

For the simulation of the traditional building, it was considered that a lighting system with traditional lamps would be installed, which would be equivalent to a hourly consumption of 12W per square metre of floor space. The standard building scenario took into account an efficient lighting system with a hourly consumption of 4W per square metre of floor space. The values resulting from the case study were calculated according to the equipment actually installed. As the space area of the building is 399 m^2, the average consumption for lighting is of 3.2 W / m^2.

As seen in Figure 6, in what concerns interior lighting the case study building consumes 60% less electricity than the traditional building, and 20% less than the standard building. These values are justified by the use of LED lamps, according to a study of lighting technology undertaken during the design phase.

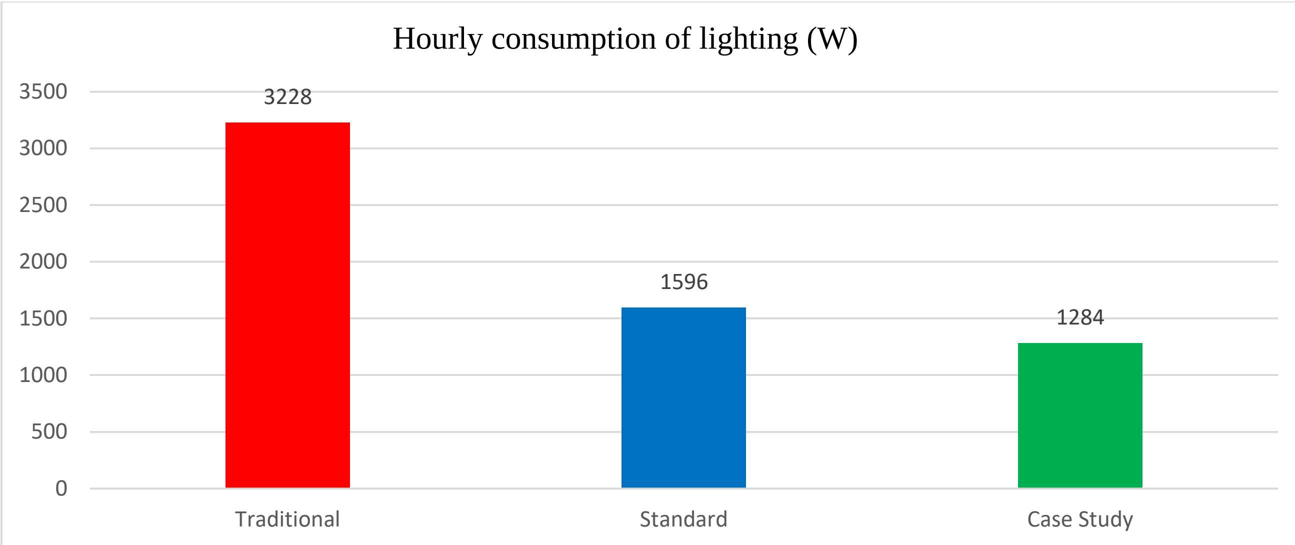

Figure 6: *Hourly Consumption for Lighting of the Case Study*

4.1.5 Reduction of CO_2 Emissions Resulting of Heating, DHW and Lighting

Reducing energy consumption means reducing CO_2 emissions into the atmosphere. Annual CO_2 emissions for heating, domestic hot water and lighting are shown in figure 7, for the three comparison situations.

The figures presented for the heating and DHW emissions correspond to the consumption in kWh shown in figures 4 and 5 for each of the annual natural gas consumption of the boiler, multiplied by a factor of 0.202 kgCO_2 / kWh, according to the provisions of Portuguese Law (DGEG, 2013).

CO_2 emissions presented for the traditional and standard simulations of lighting consumption, due to the fact that lamps are powered by electricity, are multiplied by a factor of 0.144 kgCO_2 / kWh, according to the provisions of Portuguese Law (DGEG, 2013). Since lighting consumption unit is per hour, calculations were made for an average daily consumption of 12 hours of lighting during the year.

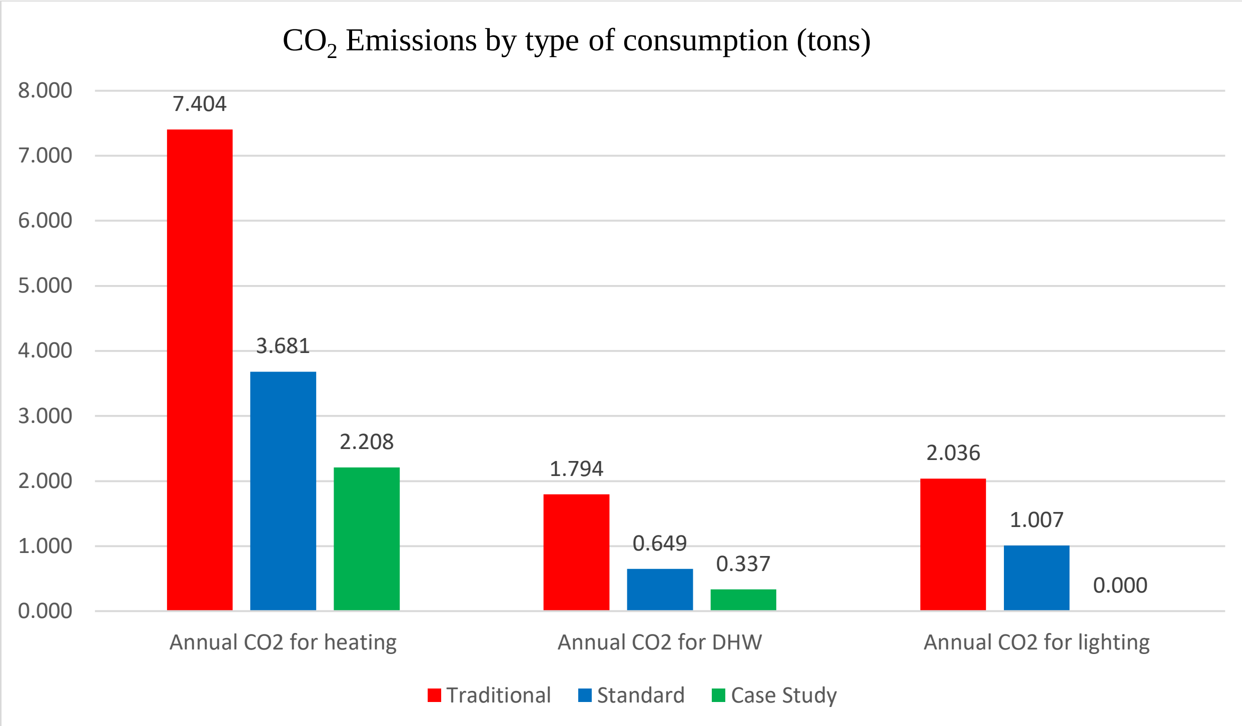

Figure 7: *Comparison of Annual CO_2 for Heating*

It can be seen, in figure 7, that annual CO_2 emissions for lighting are equal to zero in the case study calculation. This is due to the fact that photovoltaic solar panels provide electricity for interior lighting in a percentage of 100% during the year, resulting that, for this type of consumption, there are no CO_2 emissions.

Finally, total results of CO_2 emissions for heating, domestic hot water and lighting are presented in Figure 8 for the three examples.

Comparing the results for the three combined consumption situations, our case study building emits 77% less CO_2 than the traditional building and 52% less than the standard building, which contributes to the sustainability value of the mode of rehabilitation presented in this study.

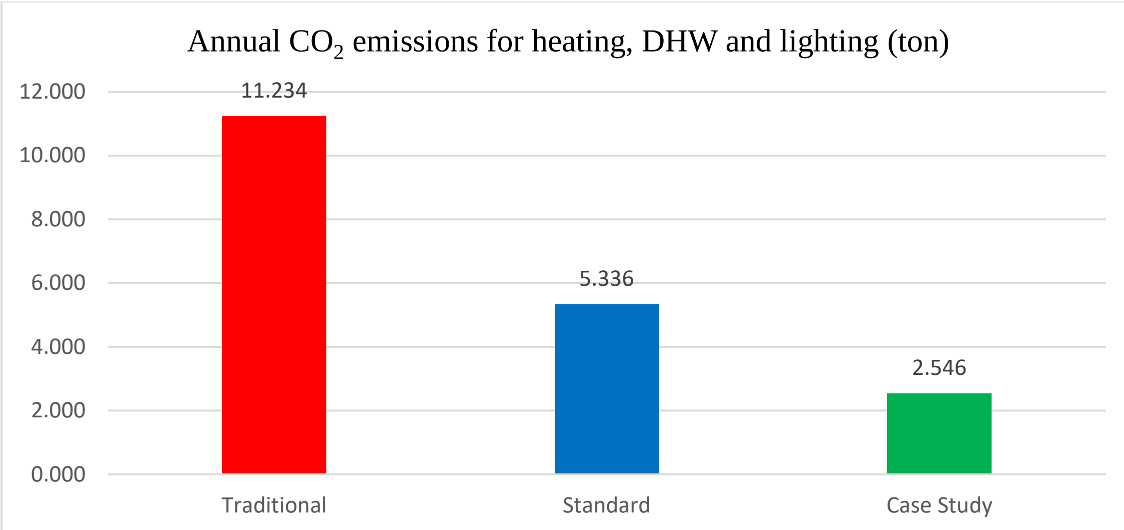

Figure 8: *Comparison of Annual CO_2 Total Emissions*

4.2. Questionnaire Survey

As mentioned in the methodology chapter, after the analysis of the rehabilitation project described in previous chapter, a questionnaire survey was applied to twenty-one students during the school year 2016-2017. The analysis of the answers will facilitate an in-depth look into students' opinions and perceptions regarding the rehabilitation of buildings.

Concerning the characterization of the sample, we verify that the students are predominantly male (71,4%) and between twenty-one and twenty-five years of age (52,4%). After their visit to the case study, an evaluation was made of their sensitivity to the overall process of building rehabilitation by filling an individual questionnaire survey. This data collection instrument focused on the positioning of the students in the discipline of Pathologies and Rehabilitation of Buildings. It also shows the opinion of students in what concerns buildings rehabilitation, as a professional activity and as a source of development of the city of Porto.

The questionnaire had three groups of questions, focused on different themes:

- Students' motivation for academic learning of building rehabilitation concepts - it was considered that the answers to this question could improve the preparation of the discipline in the Civil Engineering course;
- Usefulness of study visits to buildings during the process of rehabilitation - it was felt that the answers to this question could improve the future planning of site visits to rehabilitation works;

- Students' opinion on the future of building rehabilitation as a professional activity, integrated in the economic development of the region where they study and work, and its contribution to the social improvement of the same region.

4.2.1 Analysis of Results

The first group of questions included the students' opinion on the discipline and its usefulness regarding future practice, as well as their perception of the concept of rehabilitation, rehabilitation techniques, and their pathologies. The results are shown in Tables 3, 4, and 5.

Table 3: *Student Motivation for the Course*

Motivation	Units	%
Motivating subjects for students' commercial and professional career	6	28.6
Interest in rehabilitation as a process of building transformation	11	52.4
Bring new life to abandoned and degraded buildings	3	14.2
Do not know / Do not respond	1	4.8
Total	21	100.0

The majority of responses (52.4%) show a particular interest in the rehabilitation techniques; students' interest in the commercial / professional career (28.6%) and the social factors of rehabilitation (14.2%) are less representative.

Table 4: *Students' Perception about Building Rehabilitation*

Definition of Buildings' Rehabilitation	Units	%
Study of the pre-existence and elaboration of project keeping its identity	6	28.6
Adjustment of the layout to improve comfort and habitability	3	14.3
Give new use with safety and comfort	2	9.5
Correction of existing pathologies while maintaining use	8	38.1
Change the use to vacant building	2	9.5
Total	21	100.0

For most students (38.1%), rehabilitation consists of a simple process of correction of pathologies without change of use. The remaining processes, involving changing of use or large rehabilitations of empty buildings, are less recognized as rehabilitation.

Table 5: *Most Observed Pathologies by Students in Buildings (Multiple Answers)*

Types of Pathologies Observed	Units	%
Infiltration of moisture with deterioration of interior coatings	13	30.2
Fissures in vertical interior and exterior walls	10	23.3
Appearance of fungi in interiors	1	2.3
Degradation of coatings	5	11.6
Degradation of pavements	2	4.7
Structural Degradation	8	18,6
Roofs damaged	2	4.7
Lack of maintenance	1	2.3
Poor thermal / acoustic insulation	1	2.3
Total	43	100.0

Most of the responses (53.5%) correspond to the most common problems of building pathologies - moisture infiltration (30.2%) and fissure cracking (23.3%).

The results for the second subject are included in Table 6 and refer to the perception of utility of study visits to buildings during the process of rehabilitation.

Table 6: *Reasons for Visits to Works (Multiple Answers)*

Reasons for Visiting a Building Rehabilitation Site	Units	%
Linking theoretical concepts to practice	8	36.5
Observation of intermediate stages of construction	2	9.1
Observation of the use of modern methods on old materials	1	4.5
Making physical contact with the building, more important than learning in books or by pictures	7	31.8
Make physical contact with old construction methods	1	4.5
Observing pathologies in situ and how the work of correction of the pathologies is developed	3	13,6
Total	22	100.0

Most of the answers (68.3%) correspond to an ideal that students possess, of their knowledge being boosted by contact with the building site – the mentioned “linking concepts to practice” (36.5%); the other answers also value this contact, although they refer to more specific subjects (31.8%).

Finally, the results included in Table 7 refer to the students' opinion on the third subject - the benefits, to the city of Porto, of rehabilitation works throughout the past five years.

Table 7: *Evolution of the Rehabilitation of Buildings in the City of Oporto (Multiple Answers)*

Reasons for Rehabilitation	Units	%
The process of building rehabilitation is very present in the city	6	20.7
The rehabilitation process does not always maintain or improve the architectural value and identity of pre-existent buildings	9	31.1
The main cause of the rehabilitation of the city is the increase in tourism	8	27.6
Rehabilitation is making the city more attractive and comfortable while maintaining its identity and history	5	17.2
Rehabilitation is bringing people back to the city	1	3.4
Total	29	100.0

There is a majority of opinions (58.7%) revealing that the students think that the rehabilitation process always maintains or improves the architectural value and identity of the pre-existence (31.1%), and that the main cause of the rehabilitation of the city is the increase in tourism (27.6%). Although these perceptions are debatable, these two factors are nevertheless closely linked, since it is possible that a high increase of tourism in a short time will result in a loss of historical and architectural identity in the rehabilitation of buildings.

4.2.2 Discussion of Results

In a global analysis of the individual questionnaire surveys, in addition to the results described in the tables, it was found that the students' perception is that the rehabilitation of buildings constitutes a professional and technical area of strong interest for the course of Civil Engineering, and that visits to rehabilitation work sites are indispensable to their education.

It was also verified that the students have a perception of rehabilitation processes that is more oriented towards the basic recovery of construction systems in their use phase, through improving the buildings' operability, safety and comfort.

Finally, students realize that, sometimes, rehabilitation processes are not conducted in the most ethical or historical sense, resulting in work of inferior quality to what should have been executed, according to the aesthetic and constructive characteristics of the old building.

5. Conclusions and Recommendations

This case study, pertaining to a sustainable rehabilitation of a residential building, was chosen with the purpose of drawing the Pathologies and Rehabilitation of Buildings students' attention to the Paris Agreement on Climate Change. With it in mind, we intend to improve the subject of Energy Rehabilitation of Buildings included in the Civil Engineering course of the Fernando Pessoa University. This improvement will occur through the creation of a set of theoretical guidelines and practical examples, in order to provide rehabilitation solutions that strongly enhance the environmental performance of existing buildings.

In order to demonstrate what it means to substantially improve the environmental performance of rehabilitation, a comparative study was presented between a traditional, a standard and a sustainable rehabilitation process, regarding the reduction of CO_2 emissions. The results point to the positive environmental impact of sustainable rehabilitation. This positive impact is achieved due to the following factors:

- A careful plan to use deconstruction products will prevent the use of new materials, thus substantially reducing the embedded energy of the rehabilitated building's materials. In this case study, 63.4% of the total tonnage of deconstruction was used on the rehabilitation process;
- The materials with sustainable and recyclable characteristics being used constitute 18.9% of the total construction materials. To this value we added the percentage materials reused after deconstruction, 36.7%, which means that most of the materials used are environmentally-friendly;
- Considering heating, DHW and lighting consumptions, our sustainable rehabilitation building emits 77% less CO2 than the traditional building and 52% less than the standard building.

These results confirm the sustainability of the rehabilitation process as presented in this study, to better prepare future engineers attending the course of "Pathologies and Rehabilitation of Buildings. However, despite these positive results, the path towards producing sustainable rehabilitation buildings is still at the beginning. Therefore, we must continue to improve teaching and learning strategies, analysing case studies concerning the use of engineering solutions that will protect the environment, because "On the climate there is no plan B because there is no planet B" (Macron, 2017).

5.1 Scope of Future Research

With this case study, we can conclude that there is a close relationship between building sustainable rehabilitation and achieving benefits throughout its life cycle, through the expectation of future reduced costs of energy bills and building operation. Moreover, there is a considerable difference in costs reduction when we choose to optimize sustainable features when comparing with standard procedures (Ferreira, 2017).

On the other hand, each building can be treated as a different case study, because there are no buildings equal to each other. So, future research can wide the study of different buildings in order to define which is the optimum performance that can be reached by each building so that its term of return on investment will not exceed a 4-5 year period.

5.2 Research Limitation

One important research limitation is that the optimization of sustainable characteristics in design is always subjected to the owner's budget. Stakeholders with low budgets and selling purposes are not willing to invest in sustainable construction or energy efficiency optimization, which is a process that only specific legislation can ensure the application of optimized sustainable building practices.

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