ENERGY PERFORMANCE OF THE BUILDING ENVELOPE IN NON-FOOD RETAIL BUILDINGS

Case Study Analysis - Leroy Merlin Loulé

Rita Mendonça
rita.g.mendonca@ist.utl.pt

Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico, Universidade de Lisboa

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ABSTRACT –The present work aims to study the energy consumption of different constructive solutions for the envelope of a large retail building, the Leroy Merlin store located in Loulé, Portugal. BIM methodology was applied to the case study, namely by producing the store's building properties in a 3D model, using the Autodesk Revit software.

The first phase of the study consisted of creating the 3D reference model of the building according to the envelope's thermal properties. Data on energy consumption was simulated through Autodesk's Plug-in Insight 360º and was confirmed with the energy bills from this building. Then, 18 alternative solutions for the building envelope were tested for exterior walls, roofs and glazing. Results across solutions are consistent, as with higher thermal resistances of the envelope's materials lead to lower energy consumptions.

However, the alternative solutions for glazing have all led to similar simulation results in terms of energy consumption. Considering that glazing can be relevant in the building's energy consumption, differences in results should be expected.

Additionally, an economic analysis was carried out to assess the economic viability of tested solutions according to the investment payback period (PP), Net Present Value (NPV) and Internal Rate of Return (IRR). Hence, two viable alternative solutions for the building envelope were found with this study: solution 1 (0,25 m thick concrete block wall) and solution 6 (0,10 m sandwich panel).

Keywords: Retail buildings, Autodesk Revit, energy consumption, Sustainability, Building envelope, Plug-in Insight 360º

1. INTRODUCTION

Man's action on the environment has been visibly affecting the planet's balance ('Recursos Naturais Renováveis e Produção de Energia', 2014). In recent years, there has been a worrying concern with the environmental problems resulting from the intensified exploitation of natural resources, which result in economic problems, public health stress and ecosystems' disturbance. Given this reality, world leaders have been developing policies as to limit the consumption of finite resources and to promote sustainable development.

Buildings represent 40% of the world's total electricity consumption, thus contributing to the greenhouse effect (REN21,2021). In fact, the construction of buildings has been increasing, and it is expected that energy consumption will also increase, adding pressure to the restraint of greenhouse gas emissions.

Aiming at reducing energy consumption, the United Nations (UN), together with some leading countries, has developed regulation and recommendations that aim at enhancing energy efficiency, namely by recommending the use of sustainable materials that promote energy efficiency in the construction of buildings (Spinelli, Cambeiro and Konrad, 2017).

This study focuses on sustainable building envelope solutions that can promote energy efficiency in non-food retail buildings. Indeed, retail buildings are responsible for up to 9% of the energy consumption of the building sector (Ferreira *et al.*, 2018), which makes it an important sector for improving the energy efficiency of buildings.

A case study was selected to analyze the best envelope solutions to be used in a large retail building to improve its energy consumption. The Leroy Merlin store in Loulé, Portugal, was chosen. In this analysis, the BIM methodology was used, namely by producing a 3D model according to the store's envelope thermal properties (referenced ahead as "LM Loulé" model). This model was validated as robust since the total energy consumption simulated in the Plug-in Insight 360º was the same as the total annual energy consumption obtained in the store's annual energy bills. Then, 18 simulations were carried out, representing alternative envelope solutions to the existing building in terms of Walls, Roofs and Glazing. It was possible to evaluate the energy impact of these alternative solutions in comparison to the LM Loulé model.

The building envelope is composed of all the elements that make up the facades and the roof. It is estimated that the building envelope is responsible for about 25% of the total energy consumption (U.S. Department of Energy, 2017). As such, the choice of materials that constitute the building envelope contributes to the improvement of the building's energy performance.

The objective of this dissertation is to evaluate the influence of the envelope materials of a retail building in terms of the annual energy consumption and to analyze the return on investment for each alternative solution, based on the energy savings that each one allows.

2. SUSTAINABILITY, COMMERCIAL BUILDINGS AND BIM METHODOLOGY

2.1. Sustainability and sustainable development

Currently, there is a decrease of the availability of natural resources due to human exploitation. It is also verified that this unbalanced exploitation has had harmful consequences on the planet that are manifested through climate change. The environmental impacts can be measured according to several indicators, in which the high emissions of carbon dioxide (CO_2) and other greenhouse gases are highlighted ('Recursos Naturais Renováveis e Produção de Energia', 2014). In parallel, sustainability is associated with the ability for one to maintain and sustain itself (Pinheiro, 2019). An activity is sustainable when it has the capacity to persevere with quality. Sustainable development is related to the growth of something or the increment of a produced material; it is applied in the economic, environmental, and social spheres and consists of the process of changes to be applied whose purpose is sustainability in itself (Carvalho, 2019).

Energy production has a leading contribution to the world's environmental impacts, and efforts on improving energy efficiency, as well as to produce energy from renewable sources, are encouraged all over the world to address climate change and promote sustainability.

2.1.1. Legislative framework for energy efficiency in Portugal

The "sustainable movement" began in the 70s with the first United Nations conference in Stockholm, Sweden (Fischer Nunes Kita, 2018). After this conference, agendas were created to address sustainable development.

In 2015 a new agenda was created named "Transforming Our World: the 2030 Agenda for Sustainable Development". This agenda contained 17 goals and 169 recommendations that bring together the economic, social, and environmental categories for sustainable development (Fischer Nunes Kita, 2018).

Also in 2015, the Paris Agreement was formulated (the successor to the Kyoto Protocol), to reduce the emission of greenhouse gases and mitigate the increase of global temperature and stabilizing it to 1,5-2ºC until 2100 (Araujo, Cordeiro Neto and Seguin, 2020).

These goals and targets set out in the 2030 Agenda and in the Paris Agreement led to changes in the directives and energy regulation systems for the building sector at an international and national level.

In fact, since the 1990s, there has been a concern with the energy consumption in Portugal, more thoroughly addressed on the REH - Regulation of Energy Performance of Buildings and Housing (former Regulation of Thermal Behavior Characteristics of Buildings - RCCTE) and RECS - Regulation of Energy Performance of Buildings in Commerce and Services (former Regulation of Building Climatic Energy Systems - RSECE). It should be noted that these regulations are subject to changes over time (Vaquero, 2020). The Energy Certification System for Buildings (SCE) was implemented through Decree-Law 78/2006 and the European Directive for the Energy Performance of Buildings (EPBD), published in 2002 (European Commission, 2021), underwent changes in 2013, 2015, 2018 and in 2020 (see Figure 1 (Vaquero, 2020)).

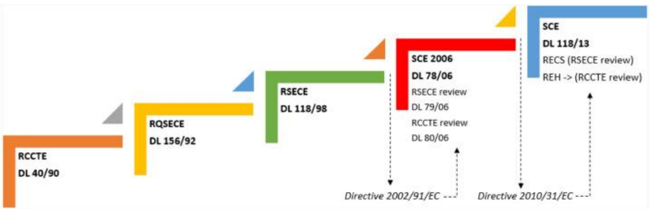

Figure 1- Evolution of energy regulations and directives

The aim of all the changes in the EPBD was to reduce the greenhouse gas emissions in the European Union and to increase energy efficiency by 2050 (DGEG, 2021).

Following all the policies developed to mitigate the harmful effects of human activity on the planet, particularly regarding the construction and operation of buildings, building certification was created. Building certification comprises several areas, but for the scope of this study, energy certification and sustainability certification are more relevant. Countries have created their own environmental certification systems for buildings, that have later developed into building sustainability assessment systems (Sugahara, Freitas and Cruz, 2021). As an example, in Portugal the LiderA

system, acronym for Leading for the Environment, has been developed in Portugal since 2003 by Professor Manuel Pinheiro (Pinheiro, 2010).
Likewise, energy certification is an important tool to assess the energy efficiency of a building in the operation phase. The entity that issues the energy certificate in Portugal is the Energy Agency (ADENE). The assessment is carried out by comparing the building to be certified with a reference model building. In this process, energy efficiency measures that can reduce energy consumption are identified. In Portugal, energy certification has been a mandatory requirement since 2013 (P&R - ADENE, 2019).

2.2. Retail buildings

Retail plays a fundamental role in the world economy in creating wealth, employment, and social relationships.
The case study portrayed in Chapters 3, 4 and 5 represents a retail building, more specifically the Leroy Merlin retail store in Loulé, Portugal.
Retail buildings are one of the building typologies with the highest carbon and energy intensity (EUI). This type of building is responsible for 9% of the energy consumption of European buildings and its EUI can range between 500 and 1000 kWh/m^2/year, especially for food retail (Gálvez-Martos et al., 2018). Retail energy consumption values are three times higher than residential buildings and five times higher than office buildings. These values show the energetic significance of this kind of typology of buildings within the building sector (Ferreira et al., 2018).
In the present study, a large retail building, the Leroy Merlin store in Loulé, was analyzed as a case study and alternative solutions for the building envelope were tested, to reduce the energy consumption and its correspondent annual energy costs. The building costs of each analyzed alternative solution were evaluated, and economic indicators were calculated to assess their economic viability, namely the payback period (PP), the Net Present Value (VAL) and the Internal Rate of Return (IRR).
The case study analysis was made based on the energy simulation of the reference building, as well as of alternative envelope solutions, recurring firstly to the Autodesk Revit software for the 3D building model and later to the Plug-in Insight 360º for the energy consumption simulations. Data regarding the case study's building materials (namely thermal properties) was based on information contained in the energy certificate of the Leroy Merlin Loulé store. Additionally, the choice of alternative envelope solutions was based on an array of energy certificates from Leroy Merlin stores in Portugal (about 40), in which the solutions chosen were the most frequent ones found in these energy certificates.

2.3. Sustainable solutions applied to the envelope of commercial buildings

The most prevalent constructive systems in existing Portuguese retail stores according to Mendes Amaral (2014) are lightweight sheet metal construction and external thermal insulation system such as External Thermal Insulation Composite System (ETICS) on simple concrete block masonry / brick and sandwich panels with sheet metal on the roofs. These typical solutions also found in Leroy Merlin stores' energy certificates.
There are several building materials that can constitute the building envelope, which have different thermal properties and, therefore, different thermal resistances. The use of materials with high thermal resistance makes it possible to reduce energy losses as they function as powerful thermal insulators (Nejeliski, Duarte and Ferreira, 2020).
Thermal conductivity (λ) is the reference material property used in Revit to simulate the energy performance of the building envelope. Energy certificates consulted for the case study and for the envelope solutions to be simulated referred to the thermal conductivity of building elements or to their resistance thermal (Rt). Therefore, the thermal transmission coefficient (U), thermal resistance and thermal conductivity of the materials to be simulated were calculated using Equations (1), (2) and (3), respectively.

$$\boldsymbol{U} = \frac{\mathbf{1}}{\mathbf{R}} \qquad (1)$$

Where:

U refers to the thermal transmission coefficient (W/m²·K), Rt refers to the Total Thermal Resistance of the building element (in m²·K/W).

$$\mathbf{Rt} = \mathbf{Rsi} + \mathbf{R1} + \mathbf{R2} + \mathbf{R3} + \ldots + \mathbf{Rn} + \mathbf{Rse} \qquad (2)$$

Where:

Rsi refers to the Interior Surface Thermal Resistance, Rse to the Exterior Surface Thermal Resistance (both according to norms by climate zone) and R1, R2, R3, Rn refers to the Thermal Resistance of each building material layer, which is obtained according to:

$$\boldsymbol{Rt} = \frac{\boldsymbol{e}}{\boldsymbol{\lambda}} \qquad (3)$$

Where:

e refers to the building material thickness (in meters) and λ refers to the thermal conductivity of the building material (in W/K·m).

The thermal transmission coefficient is thus inversely proportional to the Thermal Resistance.

2.4 3D modeling in optimizing the energy performance of buildings

The use of Building Information Modeling (BIM) tools in architecture and civil engineering have been intensified in the last decade for the advantages it offers in terms of gathering building data under a shared system (Sampaio and Gomes, 2021).

Revit was the selected software to work with the case study and it operates according to the BIM methodology. Drawings of the store's plans in 2D using CAD (Computer-aided design) software served as a database for the 3D Revit model (Vinicius Pereira Holanda and Lacroix, 2018). The use of software that works under the BIM methodology allows for the reduction of design errors, for improvements in the design quality and the reduction of construction costs, specifically by the ease of simulating alternative solutions in the software platform, which results can be iterated and translated into measurable indicators (such as the EUI).
Scenarios for the reductions of energy consumption and for the increasement of the energy performance of the building during its operational phase can be tested.
The use of more sustainable materials, that is, from the perspective that they allow a lower energy consumption throughout the building's life cycle, is thus possible to measure through this methodology (Najjar et al., 2019). The most frequently encountered problems that generate less accurate results are related to interoperability problems between the 3D model (BIM) and the building energy model (BEM). In other words, between the premises that underlie the energy simulation and the building model itself. The transition of information between these two models allows to simulate scenarios that enable more energy-conscious building decisions. However, the interoperability between BIM and BEM is still a field with some limitations and under research (Fernald *et al.*, 2018).

2.4.1 Autodesk Revit and Insight 360º Plug-in as Energy Performance Modeling Tools

The simulation of energy consumption for the different building envelope solutions in the case study presented in Chapter 3 was carried out using Autodesk Revit software, which operates according to the BIM methodology, using the Insight 360º Plug-in for the energy analysis simulation. Together with the Plug-in Insight 360º, Revit allows to quickly simulate energy consumption in different scenarios as to improve energy efficiency and reduce energy consumption, in building services areas such as HVAC, or lighting, or in passive design areas such as thermal performance and solar orientation.
Autodesk Revit is a BIM software used to create 3D design models that consider local weather data. It groups building elements by categories and families (Fernald et al., 2018).
The Plug-in Insight 360º calculates the model's energy consumption according to the characteristics assigned to materials in the Revit software. In the user interface, it is possible to compare the simulated solution to pre-defined options, assessing immediately energy consumption impacts for each of these options (Fernald et al., 2018). These pre-defined options include photovoltaic panel solutions, geographic orientation of the model, shading and orientation of windows, general building solutions based on certain thermal characteristics, ventilation, efficiency in lighting, HVAC and building operating hours. By choosing each of the various options, the energy intensity (EUI) and average energy annual costs are automatically changed and updated in the results' benchmark windows. These predefined options are in accordance to the Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE Standard 90.1) and the American directive Architecture 2030 (Kamel and Memari, 2019).
The main disadvantage of the Plug-in Insight 360º is the impossibility of comparing alternative customized scenarios besides the pre-defined options, which are in accordance with American standards. To be able to compare alternative customized solutions other than the pre-defined ones using this Plug-in, a different 3D model must be simulated for each of these alternatives. Changes made to the 3D model are not updated in the previously elaborated energy model. A new energy model needs to be generated. The online interface does not allow changes to the BIM model. If the model has geometric inconsistencies or is incomplete, the simulation will not run in the Plug-in Insight 360º (Fernald *et al.*, 2018).
Hence, when a more rigorous energy analysis is needed, it is advisable to use other energy modeling software, as this is a limitation yet to be addressed by Revit.

3. METHODOLOGY

3.1 Case study

The case study of this dissertation is the retail building Leroy Merlin located in Loulé, more specifically in Caliços – Loteamento 1/ 2015, Lote 3, in the parish of Almancil, municipality of Loulé. The store was built from March to December 2017, opening on the 16th December, 2017. Leroy Merlin Loulé consists of two parking floors in the basement plan, plus the store floor, the mezzanine for staff support and a roof with limited access with photovoltaic panels and skylights (Figure 2). The retail building has a floor area of 16 473.90 m² and a sales area of 8 799 m². It is important to point out that the photovoltaic panels were only installed in October 2018. The adoption of photovoltaic panels allowed for a reduction in the building's energy consumption in terms of grid energy.
The energy certification of Leroy Merlin Loulé retail building is B-.

Figure 2 -Case Study images- Leroy Merlin Loulé

The basement floors function as parking and the entrance to them is on floor -2. The parking floors -1 and -2 are ventilated. The main facade of the building faces south-east.

3.2 Elaboration of the 3D model in Autodesk Revit

The modeling of the exterior walls, interior walls, floor slabs and glazing was carried out based on the information on the construction materials contained in the store's energy certificate (info present in Table 1).
The 3D Loulé model, called "LM Loulé model "is shown in the Figure 3.

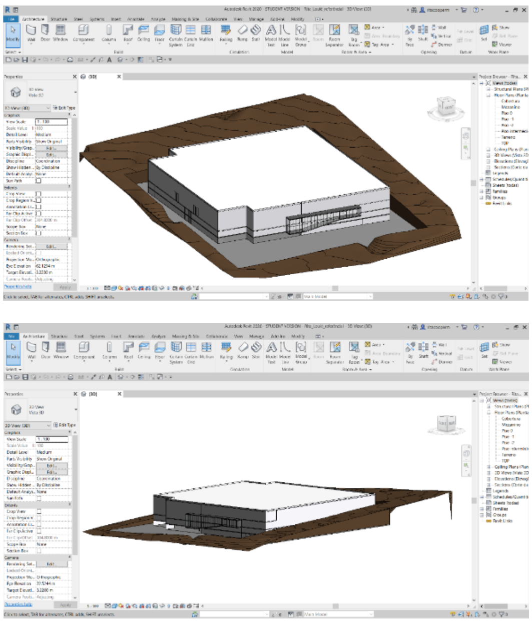

Figure 3 - LM Loulé model images

3.3 Energy simulation through Plug-in Insight 360º

To create the energy model of LM Loulé, obtained in subchapter 3.2, the option *Analyze* and *Generate* of the Revit software was used. In the *Energy Settings*, the icon ***Use Building Elements*** was selected and in the *Advanced options*, the chosen *Building Type* category was *Office*. Although the program has the *Retail* option, it was noticed throughout the simulations that it does not effectively reproduce the reality of the energy consumption of this type of building (perhaps because the Retail option considers by default lighting energy consumptions above 15 W/m²/year).
To complete the energy simulations, the working hours (*Building Operating Schedule*) selected were ***12/7*** (12 hours, 7 days a week) and, lastly, the option ***Detailed Elements*** was also selected, as to create the energy simulation model according to the thermal resistances defined in the building elements' materials.

Figure 4 shows the LM Loulé energy model created to be exported and analyzed by the Insight 360º plug-in.

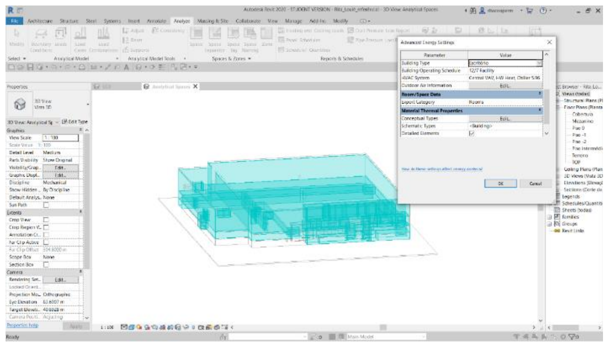

Figure 4 – LM Loulé energy model

After the creation of the LM Loulé energy model, it was possible to obtain an energy simulation using the Plug-in Insight 360º in terms of the building's annual energy consumption. The result obtained was 148 kWh/m²/year. Figure 5 shows the analysis returned by the Insight 360º plug-in.

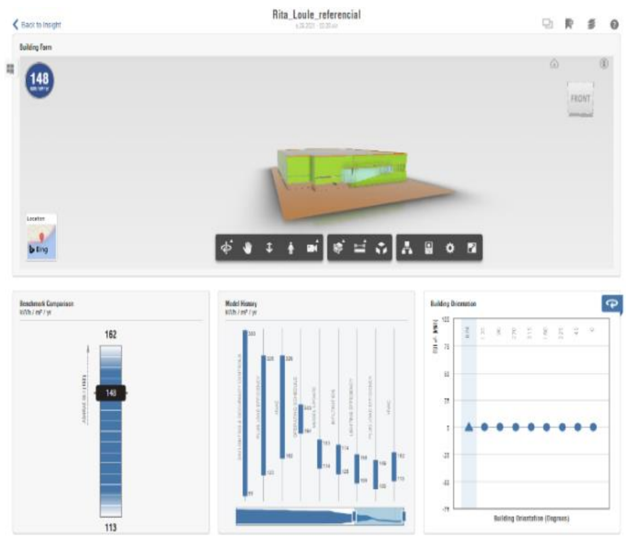

Figure 5 - Result of the simulation of the Loulé energy model

The value of 0,10 € was provided by Leroy Merlin as the average cost of kWh purchased from energy grid and it's the input value for EUI Settings used in plug-in Insight 360º to obtain energy consumption and annual cost.

3.2 Validation of the model against the building's energy bills

The validation of the 3D model LM Loulé implied its calibration towards real energy consumption. The simulation pointed an energy consumption equal to 148 kWh/m²/year. The energy bills for the year 2018 were consulted to validate this value. This was the year chosen because as of 2018 on the store were installed photovoltaic panels and it began to have less energy consumption from the grid, thus making the energy metering analysis more difficult.
The energy consumption obtained from the energy bills of 2018 was also 148 kWh/m²/year, which validated

model calibration. Nevertheless, the total annual energy consumption expected for the store according to its energy certificate was 1 211 233 kWh/year against the store's real annual energy consumption of 1 301 612 kWh/year, which accounts for a deviation of 6,9% in terms the energy's certificate expectations (and proves how much as user preferences and opening hours can impact energy consumption results).

4. PROPOSAL OF ALTERNATIVE SOLUTIONS FOR GREATER ENERGY SAVINGS

To find better building envelope solutions in terms of energy consumption, 18 simulations were carried out with alternative building materials. Alternative solutions were based on the referential 3D model LM Loulé and differed from it in only one constructive element. Three sets of simulations were tested. These sets referred to the layers of exterior walls, roofs and glazing. The alternative solutions presented in Table 2 were selected out of those most used in the envelopes of Leroy Merlin stores in Portugal. These solutions were later designated as Simulations 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18.

Table 1- Elements of the LM Loulé envelope (case study)

Simulations	***Elements and main features to simulate***	
LM Loulé (Case Study)	Walls	PD - Exterior wall with a thickness of 6,0 cm, white color (light shade), with the following composition: rigid polyurethane foam (PUR), sandwich panels of 35-50 kg/ m^3 (Rt = 1,62 m^2. °C/ W) with a thickness of 6,0 cm ;
	Roofs	COB - Exterior coverage with a thickness of 34,0cm, white color (light shade), ceiling in lightened slab of ceramic blocks with 21 to 28cm height (2 rows of holes) of =30 cm (Rt= 0,23 m^2°C/ W) with a thickness of 23,0 cm; rock wool 35-100 kg/ m^3 (Rt=2.50 m^2°C/W) with a thickness of 10,0 cm; flexible waterproofing membrane impregnated with bitumen (Rt=0,04m^2°C/W) with a thickness of 1,0 cm ;
	Glazing	Exterior vertical glazing span, single metallic frame with thermal cut and without grid, with laminated double glazing + colorless Guardian Float ExtraClear 10+10 with PVB Clear 1,52 + 16mm Air + SunGuard SN 70/37 HT; U= 3,70 W/ m^2. °C ;

Table 2- Proposals for alternative solutions to optimize energy consumption at LM Loulé

Simulations	***Elements and main features to simulate***
Walls	1- Exterior wall consisting of a 0,25 m thick concrete block, thermal resistance (Rt) equal to 0,33 (m^2. ºC) / W ;
	2- Exterior wall composed of: sandwich panel with 5 cm thick, thermal conductivity coefficient 0,037 W/ m.ºC and Rt = 1,351 m^2. °C/W ;
	3- Exterior wall made up (from outside to inside) by: metallic zinc plate with 0,002 m thick, thermal conductivity of 110 W/(m.ºC), thermal insulation in rock wool with 0,046 m thick, conductivity of 0,045 W/(m.ºC) and Rt = 1,02 m^2.ºC/W, zinc metal plate with 0,002 m of thickness and thermal conductivity of 110 W/(m.ºC) ;
	4- Light-colored exterior wall consisting of a sandwich panel with thermal insulation, 8 cm thick, thermal conductivity equal to 0,02 W/ (m^2. ºC) and density equal to 40 kg/m^3, resulting in a transmission coefficient thermal equal to 0,24 W/m^2. °C ;
	5- Outer wall made up (from outside to inside) by: reinforced concrete with 0.25 m thick and Rt = 0.11 m^2. ºC/W, 0.04 m thick air box and Rt = 0.18 m^2. ºC/W, 0.04 m thick rock wool and Rt = 1 m^2. ºC/W and 0.025 m plasterboard with Rt =0.1 m^2. °C/W ;
	6- Sheet wall of 100 mm formed from the inside to the outside by 0,001 m of steel with a resistance of 0,00002 m^2. ºC/W, 0,068 m of Air Spaces (Walls) with resistance of 0,18 m^2. °C/W, 0,03 m of Rock Wool 35 -100 kg/m^3 with resistance of 0,75 m^2. °C/W, 0,001 m of Steel with resistance of 0,00002 m^2. °C/W ;
	7- Exterior Wall Masonry 0,150 m made from the inside to the outside by 0,02 m of traditional mortars and plasters 1800-2000 kg/m^3 with a resistance of 0,01538 m^2. °C / W, 0,11 m of Concrete Blocks - lightweight 0,10 m or 0,11 m with resistance of 0,27 m^2. ºC/W, 0,02m of traditional mortars and plasters 1800-2000 kg/m^3 with resistance of 0,01538 m^2. °C/W ;
Roofs	8- Exterior coverage (sloping) made up (from outside to inside) by: Sandwich panel with 5 cm thickness and thermal resistance of 1,75 m^2. °C/W; air box with thermal resistance of 0,16 m^2. °C /W; Plasterboard with 0,02 m thickness and thermal conductivity coefficient of 0,25 W/mºC ;
	9- Exterior coverage made up (from outside to inside) by: Waterproofing fabric, 0,04 m thick insulation and thermal transmission coefficient of 0,037W/m^2. ºC and lightened slab with 0,15 m thick ceramic blocks ;
	10- Exterior coverage made up (from outside to inside) waterproofing screen with 0,002 m thick, conductivity of 0,14 W/(m.ºC) and thermal resistance of 0,01 m^2. ºC /W, 0,002 m thick zinc metal sheet, conductivity of 110 W/(m.ºC) and negligible thermal resistance, thermal insulation in rock wool 0,06 m thick, conductivity of 0,045 W/(m. °C) and thermal resistance of 1,33 m^2. °C /W, 0,002 m thick zinc metal sheet, conductivity of 110 W/ (m. °C) and negligible thermal resistance ;
	11- Exterior cover made up (from outside to inside) by a flexible membrane impregnated with bitumen with a thermal transmission coefficient equal to 0,23 W/ (m^2. ºC) and density equal to 1100 kg/m^3; metallic sheet with thermal conductivity equal to 110 W/(m.ºC) and density equal to 7200 kg/m^3; thermal insulation (PUR) with 5 cm thickness, thermal conductivity equal to 0,037 W/(m.ºC) and density equal to 50 kg/m^3 and sheet metal with thermal conductivity equal to 110 W/(m.ºC) and mass volume equal to 7200 kg/m^3 ;
	12- FLAT COB - Exterior coverage of light color is composed of (outside to interior): polyvinyl chloride (PVC) with 0,002 m thick and thermal conductivity coefficient of 0,17 W/ m.ºC, medium rock wool 35-100 kg/m^3 with 0,06 m thick and thermal conductivity coefficient of 0,04 W/m.ºC and steel with 0,001 m thickness and thermal conductivity of 50 W/m .°C ;
	13- Exterior coverage made up (from outside to inside) by: pure asphalt mesh with negligible thermal resistance and rock wool (sandwich panel) 0,08 m thick and thermal resistance of 1,9 m^2. °C/W ;
	14- Panel ceiling Fresco zone made up from the inside to the outside by 0,1 m of rigid polyurethane foam (PUR) with a resistance of 2,7027 m^2. °C/W ;
	15- Horizontal fiber cement roof consisting from the inside to the outside by 0,347 m of horizontal roofs (on terrace) without thermal insulation (Ascending Flow) (Solid slab) with a resistance of 0,435 m^2. °C/W ;
	16- Cover consisting of: reinforced concrete with 0,2 m thick and thermal resistance of 0,1 m^2. ºC/W, thermal insulation 0,03 m thick and thermal resistance of 0,81 m^2. °C/W and screed with 0,1 m thick and thermal resistance of 0,08 m^2. °C/W ;
Glazing	17- The external vertical glazed openings are made of double glazing (6+14+6), with fixed metallic frames. The solar factor of the glass for a normal incidence to the span is 0,78. The thermal transmission coefficient is 2,90 W/m^2. °C. The glazed openings do not have sun protection devices ;
	18- Plate in alveolar polycarbonate, 16 mm opal, with ultraviolet treatment, with metallic frame with thermal cut, with fixed opening type, with a thermal transmission coefficient of 3,3 W/ m^2. °C ;

5. ANALYSIS OF RESULTS

5.1 Presentation of simulation results obtained in Revit

Simulations 1, 2, 3, 4, 5, 6, and 7 corresponded to alternative solutions related to Walls. Simulations 8, 9, 10, 11, 12, 13, 14, 15, and 16 corresponded to alternative solutions related to Roofs. Simulations 17 and 18 corresponded to alternative solutions related to Glazing.

In Table 3, Table 4 and Table 5 the annual energy consumption (in terms of EUI), the annual energy costs (in terms of €/m^2) and the thermal resistance (Rt) of Walls, Roofs and Glazing simulations can be consulted.

Table 3- Energy consumption and energy costs obtained for Walls per m²

Results Plug-in Insight 360º Walls per m²			
Simulations	kWh/ m²/year	€/ m²/ year	Rt (Thermal resistance) m². K/ W
LM Loulé model	148	12	1,62
1	157	11,7	0,33
2	150	12,8	1,35
3	151	11,9	1,02
4	147	12	2,95
5	167	11,6	0,16
6	151	11,9	1,84
7	160	11,7	0,93

Table 4- Energy consumption and energy costs obtained for Roofs per m²

Results Plug-in Insight 360º Roofs per m²			
Simulations	kWh/ m²/year	€/ m²/ year	Rt (Thermal resistance) m². K/ W
LM Loulé model	148	12	1,62
8	147	12	1,99
9	181	11,9	0,26
10	152	11,9	1,35
11	151	11,9	1,53
12	145	12	14,94
13	150	12	1,90
14	147	12	11,50
15	169	11,8	0,44
16	156	11,9	0,99

Table 5- Energy consumption and energy costs obtained for Glazing per m²

Results Plug-in Insight 360º Glazing per m²			
Simulations	kWh/ m²/year	€/ m²/ year	Rt (Thermal resistance) m². K/ W
LM Loulé model	148	12	0,2681
17	148	12	0,2336
18	148	12	0,2429

Table 5 shows that energy consumption and annual costs are the same for all alternative glazing solutions. Considering that the results of Simulations 17 and 18 were unsatisfactory, six new different simulations were tested in an additional, simplified 3D model.

It was found that the energy simulation in the Plug-in Insight 360º was not sensitive to changes made in the glazing materials. Considering that two 3D models were tested and the simulations led to similar results, it is suggested that either limitations are due to the low representation of glazing in terms of the thermal dynamic of the buildings tested or that the software oversimplifies its impact for more expedite energy simulations. To verify this hypothesis, further research would have to be carried out, namely by testing results in a dynamic fluid's software such as EnergyPlus, which is outside the scope of this study.

The results relating to Glazing were excluded from the next chapter.

5.2 Results comparison

Table 6- Walls Results in kWh/year and €/year

Results Plug-in Insight 360º Walls			
Simulations	kWh/year	€/ year	Rt (Thermal resistance) m². K/ W
LM Loulé model	2 209 142,28	179 119,64	1,62
1	2 343 482,01	174 641,65	0,33
2	2 238 995,55	191 060,95	1,35
3	2 253 922,19	177 626,98	1,02
4	2 194 215,64	179 119,64	2,95
5	2 492 748,38	173 148,99	0,16
6	2 253 922,19	177 626,98	1,84
7	2 388 261,92	174 641,65	0,93

Table 7 - Roofs Results in kWh/year and €/year

Results Plug-in Insight 360º Roofs			
Simulations	kWh/year	€/ year	Rt (Thermal resistance) m². K/ W
LM Loulé model	2 209 142,28	179 119,64	1,62
8	2 194 215,64	179 119,64	1,99
9	2 701 721,30	177 626,98	0,26
10	2 268 848,82	177 626,98	1,35
11	2 253 922,19	177 626,98	1,53
12	2 164 362,37	179 119,64	14,94
13	2 238 995,55	179 119,64	1,90
14	2 194 215,64	179 119,64	11,50
15	2 522 601,65	176 134,32	0,44
16	2 328 555,37	177 626,98	0,99

Simulations of different alternative solutions range their annual energy consumption between 140 and 160 kWh/m^2/year and their associated annual energy costs between 11 and 12 €/m^2/year. Analyzing the results of the Walls simulations (Figure 6), Simulation 2 stands out for presenting the highest annual costs on energy. Contrary, Simulation 5 corresponds to the lowest annual energy costs and, simultaneously, the highest annual energy consumption. Simulation 4 corresponds to the lowest annual energy consumption. Simulations 3 and 6 present very similar results regarding energy consumption and annual energy costs. Analyzing the results of the Roofs simulations (Figure 7), Simulations 9 and 12 correspond to the highest and lowest annual energy consumption. Simulations 8 and 14 are similar in value and slightly below the LM Loulé model in terms of annual energy consumption. Simulation 15 presents the lowest annual energy costs.

It was expected a proportionality between annual energy consumption and annual energy costs, since a value of €0.10 per kWh was provided in the settings of the Insight 360º plug-in for energy costs. However, this was not the case, and annual energy costs varied according to the solution simulated.

One of the hypotheses for obtaining these results may be related to the BEM model and to the assumption of parameters by Green Studio Building, which is the computational tool for energy analysis integrated in Autodesk Revit (Autodesk, 2014). Changing envelope building materials may lead to the assumption of different HVAC solutions by the systems, in turn powered by a combination of fuels and energy. Energy mix values to support HVAC systems are assumed by the software according to the location of the project and apparently, they overrule user input. Energy values per kWh in Insight 360º ranged from 0.07 to 0.09 € per kWh.

Despite these limitations, the results obtained by Insight 360º were validated and will be further analyzed in the economic study.

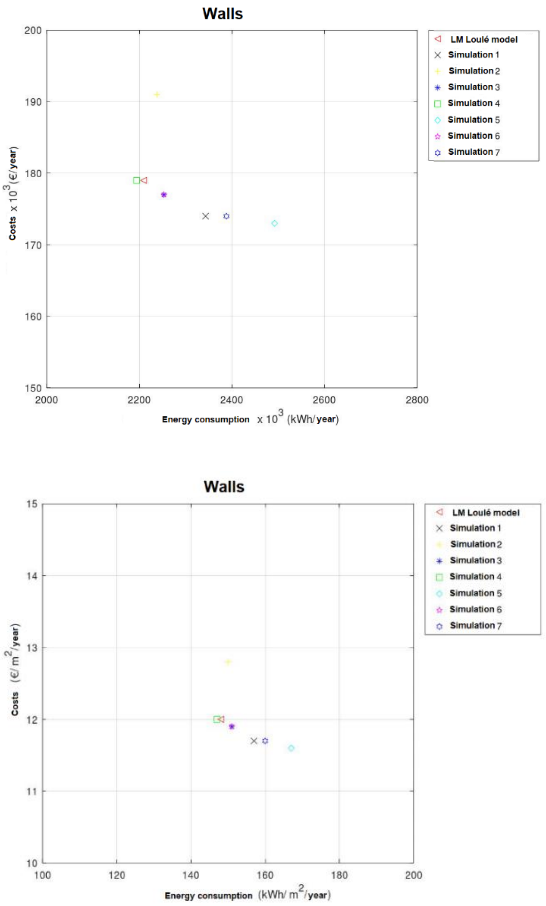

Figure 6 - Results for Walls simulations

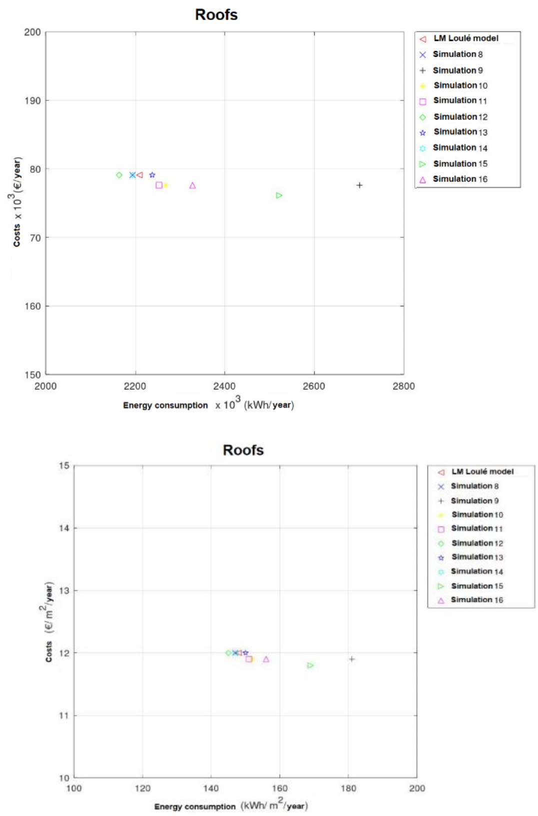

Figure 7 - Results for Roofs simulations

In Figure 8 Simulations related to Walls and Roofs are represented in black and blue, correspondingly.

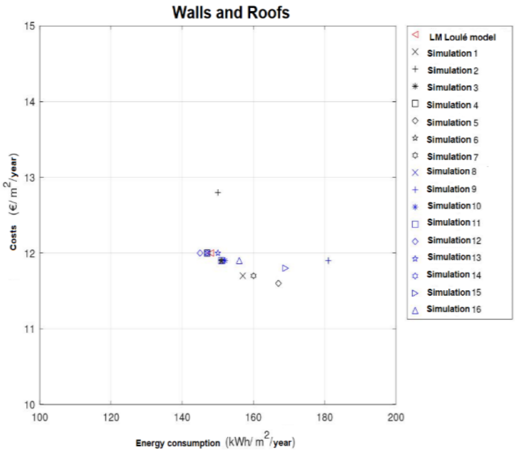

Figure 8 – Walls and Roofs results per m2

Solutions related to Walls and Roofs with lower energy consumption and lower annual energy costs were obtained.

- Solutions with lower annual energy consumption – 4,8,12,14;
- Solutions with lower annual energy costs – 1,3,5,6,7,9,10,11,15,16.

In the next subchapter, the economic analysis of envelope solutions will be carried out to test the economic viability of these solutions.

5.3 Calculation of payback period

A certain building solution can have better thermal performance, but nevertheless, have an initial investment cost that is too high to be implemented. Therefore, it is necessary to evaluate the payback period of the alternative building solutions proposed in this study, in order to find those most appropriate from the energy efficiency and cost perspective. For this purpose, the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Actual Payback Period (PPactual) were calculated.
Table 8 summarizes the investment costs of the alternative envelope solutions, obtained through the website *Gerador de Preços*, and the annual energy costs resulting from the energy simulations using Insight 360º.

Table 8 - Investment Costs and Costs obtained with energy simulations

Investment Costs and Costs obtained with energy simulations for the alternative solutions		
Simulations	Investment Cost	energy simulation solutions cost
	€	€/ year
LM Loulé model	5 293 216,60	179 119,64
1	5 268 639,11	174 641,65
2	5 171 856,55	191 060,95
3	5 267 875,40	177 626,98
4	5 326 542,02	179 119,64
5	5 212 333,04	173 148,99
6	5 278 428,45	177 626,98
7	5 239 132,23	174 641,65
8	5 303 716,36	179 119,64
9	5 259 766,05	177 626,98
10	5 255 956,40	177 626,98
11	5 295 260,80	177 626,98
12	5 100 597,15	179 119,64
13	5 203 829,29	179 119,64
14	5 107 008,51	179 119,64
15	5 059 248,55	176 134,32
16	5 472 455,83	177 626,98

Simulations 15 and 16 correspond to the lowest and highest investment costs of alternative solutions, respectively. Regarding the results obtained in the energy simulations using Plug-in Insight 360º, Simulations 2 and 5 present the highest and lowest annual energy costs.

Investment costs allowed to calculate the differential cost (Iϑ), given by Equation (4).

$$I_v = \boldsymbol{SimulationCost_{LM\ Loul\acute{e}} - SimulationCost_i} \qquad (4)$$

where the $\text{SimulationCost}_{\text{LMLoulé}}$ and the SimulationCost_i are the building costs obtained by the website *Gerador de Preços*, for the Simulation LM_Loulé (the store as built) and for i, respectively.

The annual energy costs, resulting from the energy simulations using Plug-in Insight 360º, made it possible to calculate the annual energy savings. These savings correspond to the Annual Cash Flow (CF_{annual}) obtained through Equation (5).

$$\boldsymbol{CF_{annual} = AnnualCost_{LM\ Loul\acute{e}} - AnnualCost_i} \qquad (5)$$

where the $\text{AnnualCost}_{\text{LMLoulé}}$ and the Annual Cost_i are the annual energy costs, obtained in the energy simulations using Plug-in Insight 360º, for the Simulation LM Loulé (the base model simulation) and for i (alternative simulations analyzed in this dissertation), respectively.

In this study, it was considered that the life cycle of the retail building corresponded to 15 years, as typical periods between major refurbishments in retail buildings (Inaba, J. and Clouette B. (2014)). It was possible to calculate the savings along the building life cycle (Life Cycle Savings) for all simulations. And using the equation (6) it was also possible to calculate Total savings in €.

The Total savings in € of each simulation corresponds to the sum of the differential costs and savings over the life cycle.

$$\text{Total savings} = I_\vartheta + \text{LifeCycleSavings}_i \qquad (6)$$

Table 9 shows all the calculated costs and savings.

Table 9 - Investment costs and saving results

Simulations	Differential cost (Iϑ)	CFannual	Life Cycle Savings	Total savings
	€	€/ year	€	€
LM Loulé model	Solution/reference model			
1	24 577,49	4 477,99	67 169,87	91 747,36
2	121 360,06	-11 941,31	-179 119,64	-57 759,59
3	25 341,20	1 492,66	22 389,96	47 731,16
4	-33 325,42	0,00	0,00	-33 325,42
5	80 883,56	5 970,65	89 559,82	170 443,38
6	14 788,15	1 492,66	22 389,96	37 178,11
7	54 084,37	4 477,99	67 169,87	121 254,24
8	-10 499,76	0,00	0,00	-10 499,76
9	33 450,56	1 492,66	22 389,96	55 840,51
10	37 260,20	1 492,66	22 389,96	59 650,16
11	-2 044,20	1 492,66	22 389,96	20 345,75
12	192 619,45	0,00	0,00	192 619,45
13	89 387,32	0,00	0,00	89 387,32
14	186 208,09	0,00	0,00	186 208,09
15	233 968,05	2 985,33	-44 779,91	278 747,96
16	-179 239,23	1 492,66	22 389,96	-156 849,27

The actual investment payback period (PP) allows to assess the best alternative solution tested. The simulation that presents the lowest actual PP translates to the alternative solution that requires less time to recover the investment capital. To obtain the actual PP, it was necessary to calculate the NPV and the IRR.

The NPV (7) corresponds to the difference between the sum of the actual CF (Cash Flow = annual energy savings) during the building life cycle and the initial investment (Nogueira, 2011). In this study, the NPV was obtained using the known variables, that is to say that this parameter was calculated based on the Iϑ and CF_{annual}. A constant discount rate (r) equal to 0,03 was assumed, where t is the year of exploration.

$$\boldsymbol{NPV = \sum_{t=0}^{n} \frac{CFannual_t}{(1+r)^t} - I_\vartheta} \qquad (7)$$

Considering the results in Table 10, it is concluded that Simulations 1 and 6 have a positive NPV, which means that they are economically better than Simulation LM Loulé.

The IRR (8) corresponds to the rate that allows the sum of the updated CF to be equaled to the initial investment, that is, the rate that allows the NPV to be equaled to zero (Cordeiro *et al.*, 2018).

$$\boldsymbol{-Iv + \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} = 0} \qquad (8)$$

The actual payback period (9) corresponds to the number of years needed to recover the initial investment, that is, the number of years needed for the NPV to be equal to zero (Leckner and Zmeureanu, 2011).

$$\boldsymbol{PP_{actual} = \frac{1-(1+IRR)^{-15}}{IRR}} \qquad (9)$$

Observing the values in Table 10, it is concluded that Simulations 1 and 6 lead to positive NPV and IRR, which translates into viable PP. Simulations 3, 5, 7, 9, 10 and 15 have negative NPV and IRR, which is reflected in PP that are longer than the project life cycle, and are not viable.

Table 10- Payback period results

Payback period for the alternative and viable solutions					
Simulations	Sum actual CF	Iϑ	NPV	IRR	PP
	€	€	€		year
LM Loulé model	Solution/reference model for calculating PP				
1	53 457,97	24 577,49	28 880,47	0,13	6,48
3	17 819,32	25 341,20	-7 521,88	-0,04	21,86
5	71 277,29	80 883,56	-9 606,27	-0,02	17,18
6	17 819,32	14 788,15	3 031,17	0,03	12,27
7	53 457,97	54 084,37	-626,41	0,00	15,19
9	17 819,32	33 450,56	-15 631,23	-0,07	29,37
10	17 819,32	37 260,20	-19 440,88	-0,09	32,92
15	35 638,64	233 968,05	-198 329,41	-0,18	108,86

5.4 Limitations

Most of the limitations and uncertainties found throughout this work were observed in the energy simulations results of glazing originated by the Plug-in Insight 360º. In the analysis of results, the simulations related to Glazing presented in Chapter 5 were excluded from the comparative analysis due to inconclusive results.
The *Retail* option in the *Building Type* for the energy model in Revit software always originated energy consumption results much higher than expected and, therefore, the use of this option was not validated. The *Office* option was chosen as a more aligned option.
These limitations may however represent opportunities for future studies.

6. CONCLUSIONS AND FUTURE WORKS

This dissertation set out to study 18 alternative building solutions for the envelope of the Leroy Merlin store in Loulé, to achieve lower annual energy consumption (in terms of EUI) and lower annual energy costs (in €).
The results facilitate the choice of envelope solutions to be applied in the construction and renovation of retail stores, based on thermal performance, in turn impacting energy costs. Results will be useful for retailers and designers in supporting the decision-making process of constructive solutions for this type of buildings.
In terms of the Walls simulations, Simulation 5 (0.25 m reinforced concrete wall) corresponded to the highest annual energy consumption and, simultaneously, to the lowest annual energy costs. Simulation 4 (0,08 m thick wall sandwich panel with thermal insulation) corresponded to the alternative solution with lower annual energy consumption. Analyzing the results of the Roofs simulations, it was observed that Simulations 9 (lightened slab with 0,15 m thick ceramic blocks – roof solution) and 12 (deck with PVC 0,06 m – roof solution) corresponded to the highest and lowest annual energy consumption, respectively. Simulation 15 (solid slab with fiber cement asbestos-free 0,347 m - roof solution) was the alternative solution with the lowest annual energy costs.
Summarizing the obtained results with Revit and Insight 360º Plug-in:

- Solutions with lower annual energy consumption than the LM Loulé model – 4,8,12,14;
- Solutions with lower annual energy costs than the LM Loulé model – 1,3,5,6,7,9,10,11,15,16.

It is important to mention that the results obtained through the simulations of the energy models of the solutions were questioned. It was expected a proportionality between annual energy consumption and annual energy costs, since a value of €0.10 per kWh was provided in the settings of the Insight 360º plug-in for energy costs. However, this was not the case, and annual energy costs varied according to the solution simulated, from 0.07 to 0.09 €/kWh.
Annual energy cost values provided by Insight 360º were used for the economic analysis of the solutions. However, a future study based on user input of an energy cost of 0.10€/kWh across all building solutions is suggested. This higher value can make more solutions economically viable.
Comparing the investment costs and energy savings of alternative building envelope solutions over the life cycle of the retail store, it was found that the Simulations 1, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14 and 15 were more economical viable than the store as built.
Finally, the actual payback period was calculated, and it was concluded that only solutions 1 (0,25 m thick concrete block wall) and 6 (0,10 m sandwich panel) were economically viable, with a payback period inferior to 15 years.
Further research could focus on the energy consumption simulation of other innovative building solutions for the envelope of retail buildings.
Despite limitations regarding the impact of glazing in the energy simulations of the building, the objective of the study was fulfilled. In general, building materials with higher thermal resistances lead to lower energy consumption costs.
Several typical alternative building solutions in retail stores were studied in order to access their correspondence in the building's energy performance and the most efficient solutions were found from an energy efficiency point of view and also in terms of return on investment.

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