Dimensioning of an industrial pavilion: Support of Eurocode Design with an Automated Structural Software

Gonçalo Santos Roque

U. PORTO

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Mestrado em Engenharia Mecânica
Major Projeto de Máquinas

Supervisor: José Luís Esteves (Eng.)

Second Supervisor: João Duarte Filipe Rios (Eng.)

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Resumo

As empresas estão constantemente a competir por maiores percentagens de mercado, para permanecerem competitivas estão constantemente à procura de melhoramentos de produtividade através da aplicação de filosofias que ajudam a reduzir os custos financeiros. Cerca de um terço do custo de um produto é estimado que seja reservado à logística quando este chega ao consumidor final, por isso, melhorar os processos logísticos é crucial para a prosperação de uma empresa. Este projeto foi desenvolvido no departamento de logística de uma empresa do ramo automóvel, em colaboração com o departamento de melhoria contínua e de engenharia, com o propósito de dimensionar uma nova estrutura de armazém que visa reduzir os custos operacionais, e também analisar e melhorar os processos logísticos e custos da empresa. Este projeto descreve o processo de desenho e dimensionamento de um novo armazém para a Empresa A, uma empresa do ramo automóvel, e também os passos feitos, materiais propostos e soluções estruturais de acordo com o Eurocódigo. Analise de restrições, nomeadamente financeiras, estruturais, operacionais, tecnológicas e geográficas assim como também as soluções propostas para as minimizar. Esta dissertação contextualiza a realidade e a pressão de trabalhar na indústria automóvel e a ordem de magnitude dos custos de novos empreendimentos industriais. O desenvolvimento deste projeto foi realizado pelo autor, durante os meses de fevereiro a junho de 2023, quando este trabalhava no departamento de logística da empresa A. Os principais objetivos do projeto foram cumpridos, e a empresa reconheceu que este trabalho foi uma grande ajuda no dimensionamento do seu novo armazém. Em projetos grandes como este, é normal que, várias oportunidades de melhoramento foram identificadas para consideração futura.

Palavras-chave: Pavilhão, Secção, Madres.

Abstract

Companies are increasingly competing for market share these days. To remain competitive, they are constantly seeking productivity and continuous improvement through the application of the lean philosophy and digitalization. It is estimated that one-third of a product's total costs are logistical when it reaches the final consumer. Improving logistics processes is therefore critical. This project was created in the logistics department of an automotive company, in collaboration with the continuous improvement department and the engineering department, with the primary goals of dimensioning a brand-new warehouse infrastructure to reduce the costs of operations, as well as analyzing and improving the company's logistics processes, costs and digital improvement status. This project is the description of the design process of a new warehouse for company A, an automotive company, with the corresponding steps taken, proposed materials and solutions according to the Eurocode. Analysis of the existing constraints, namely financial, structural, operational, technological, and geographic, as well as the solutions found to minimize them. To this end, this paper contextualizes the reality and pressure of working in the automotive sector and the capital expenditure order of magnitude of new industrial endeavors. This dissertation is about the period that the author worked at the Logistics Department of Company A, between February and June 2023. The main objectives of this project were achieved, and the company recognized that this work was a valuable help in dimensioning their new warehouse. As usual, in projects as big as this one, several improvement opportunities were identified for future consideration.

Keywords: Pavilion, Section, Purlins.

iv

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To my dad, for his hard work and for being a role model in life.

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To my younger brother, uncles, and cousins, thank you for distracting me from work when needed.

To all my grandparents and Lucinha, who inspired me to become an engineer and improve the world.

Gonçalo Santos Roque

"Do not go gentle into that good night,
Old age should burn and rave at close of day.
Rage, rage against the dying of the light."

Dylan Thomas, 1952

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Abbreviations and Symbols

Symbols

$Q_{k,i}$	Accompanying variable action
S_k	Characteristic value of snow load at ground level
$\varphi_{0,i}$ and $\gamma_{Q,i}$	Coefficients accompanying a variable action
H	Construction area height above sea level
dm and dp	Distance between purlins and frameworks
q_p	Dynamic peak pressure
C_e	Exposure coefficient
c_{pe10}	External pressure coefficient
$Q_{k,1}$	Leading variable action
Q_y	Load applied in the y direction
Q_z	Load applied in the z direction
E_{dy}	Load per meter applied in the y direction
E_{dz}	Load per meter applied in the z direction
σ_{sd}	Material yield strength
δ	Maximum admissible displacement
M_{max}	Maximum bending moment
v_m	Mean wind speed
I_y	Moment of inertia in axis y
I_z	Moment of inertia in axis z
c_0	Orography factor
$G_{k,j}$	Permanent actions applied on the structure
c_p	Pressure coefficient dependent on structure geometry
w_p	Pressure exerted on a surface by the wind
v_b	Reference value of the wind speed
W_y	Resistance module in axis y
W_z	Resistance module in axis z
c_r	Roughness factor
z_0	Roughness length
θ	Slope angle in degrees
S	Snow load
C_t	Thermal coefficient
k_I	Turbulence factor
z	Vertical direction structure height
E	Young's modulus
C_z	Zone dependent coefficient

Abbreviations

AGV Autonomous Guided Vehicle

CAE Computer Aided Engineering

SLS Serviceability Limit States

ULS Ultimate Limit States

Chapter 1

Introduction

1.1 Framework and motivation

The current dissertation describes the project developed while working in the logistics department during the first semester of 2023, however, it was linked to the engineering department since all the software needed to calculate the loads being applied to the warehouse infrastructure were used daily by them. The work was developed in an automotive industry company that manufactures metallic frames for seating, located in Aveiro's district. The first chapter will provide an explanation of the project's motivation and context, as well as a description of the project and the intended objectives and methodologies used to achieve them.

Company A currently works in three different locations to produce and export their products. To reduce the operating costs and increase efficiency, a project was proposed with limited time to implement. The idea was to centralize all the operations (production and logistics) in one structure to reduce the time that it takes to produce and deliver a product to the customer (lead time). Customers such as Peugeot Citroen (PSA), Ford, and Stellantis are some of the main clients of the company, so the project has enormous potential to have an impact in the company financial reports. The company's approach to a new factory, where all the production and external logistic requirements are significantly higher, required the construction of a brand-new building totaling approximately 17.000 m^2. With the introduction of a newly designed warehouse, the opportunity of totally remodeling old practices, regarding logistics and flows and production, used in the factory was presented.

This dissertation is presented with the definition of a new warehouse structure, as well as an introduction to implement new industry 4.0 practices. These concepts were implemented, bearing in mind, the adoption of the best practices in the sector, through the preparation of the new facilities. It also considers the reduction of manual labor using optimal routes inside the warehouse structure and the increase in operations efficiency.

Since my 3rd year in mechanical engineering, I started to develop a special interest regarding metallic structures with big dimensions. After my first encounter with Structural analysis, it was clear to me that I wanted to end my journey in Mechanical Engineering with this theme.

1.2   Dissertation structure

This dissertation was made in the scope of the Machine Design Specialization. So, the work presented here is concise and direct, and it is structured in six chapters with clear objectives.

- **Chapter** 1 - Introduction: Framework and motivation. Technical project specifications;

- **Chapter** 2 - Analytical Calculations: Structural solution chosen for the industrial building, preliminary calculations of general actions, dimensioning of roof and façade panels and purlins;

- **Chapter** 3 - 3D modelling of the structure in Autodesk Robot for Structural Analysis. Different Loads applied to the model and considerations taken;

- **Chapter** 4 - Structural Analysis and Ultimate State Limit verification according to Eurocode using the software;

- **Chapter** 5 - Results analysis, section members and optimization;

- **Chapter** 6 - Conclusion: , difficulties encountered and final considerations.

1.3   Warehouse technical specifications

In order to support all the internal and external logistic operations, and to have the same production work capacity as before, the dimensions of the new warehouse need to be enormous. With big structures comes big problems, so the main specifications of the warehouse as well as the physical constraints are specified below.

- Rectangular plan building (width = 100 m, length = 175 m, height of columns = 12 m);

- Duo-pitch roof with a pitch angle of 2,31º degrees. (Maximum height = 14 m);

- Structural framework made up of columns and beams in standard profiles (S275 steel);

- Framework columns recessed to the pavilion base;

- Distance between roof purlins is close to 2 m and between side rails = 2 m;

- Distance between frameworks is 5 m;

- The offices areas will be made external to the warehouse in the warehouse so there is no need to dimension it in the early project phase;

- There will be façade openings to consider the docks that will be used to load/unload trucks. It was prioritized to have a single roof span.

Chapter 2

Analytical calculations

2.1 Structural solution

With a pavilion of these dimensions, a huge portion of the initial project time was dedicated to finding the right structural solution. The first idea, that was thought of, was to build a multispan roof with 4 spans of 25 m, however, in order to fit all the required plant equipment in an efficient way, a single span roof was chosen with pillars every 25 m and this module will be repeated for the framework every 5 m of length, totaling the required 175 m. According to the notes written by C. Reis Gomes [1], industrial pavilions are buildings that have as a fundamental requisite their functionality and not their visual aspect. They are known for having high ceiling heights and wide free spaces in order to move cargo with ease. There are many constructive solutions that can be explored in the initial phase of a project.

With a width as big as the one required by this project; it was initially thought of using a multi-span structure. The following **Figure** 2.1 shows a multispan structure without supporting trusses along the roof, however one of the main constrains of the structure was to have a single span roof to simplify the cabling and wiring of the machines and equipment used indoors.
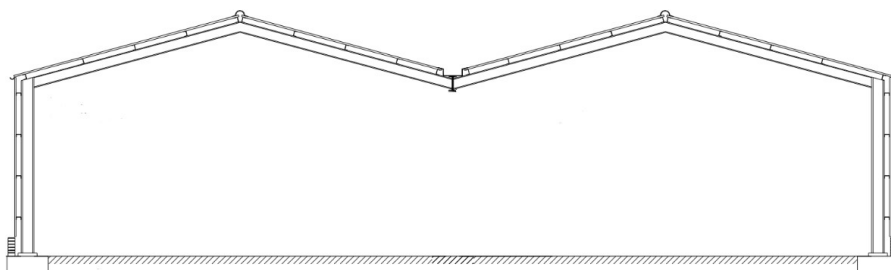

Figure 2.1: Multi Span building without supporting trusses along the roof.

However, the structure would be too complex and expensive to dimension. According to the project specifications, not all the area covered by the roof needs to be free space. Several pillars of support could be used since a big part of the building would be the production area, which does not

require a completely open space. The critical areas where free space would be a necessity are the loading and unloading areas, as well as the storing area. These areas are constantly populated with equipment and machinery, such as forklifts and small trains that require a certain area of operation without obstacles. The initial construction solution, in this iterative process, was to build a single span roof with low inclination and with frames every 5 m in length and 4 pillars divided by 100 m in width, that provide comfortable working areas of 100 m^2 (free space) to maneuver the required machines. The initial solution did not account with the support of trusses on the roof (**Figure** 2.2), to see if there is a possibility to have a "simple roof" with low costs and easier construction. There was also no need to over dimension the framework columns since there was no necessity to have a rolling bridge to lift heavy cargo.
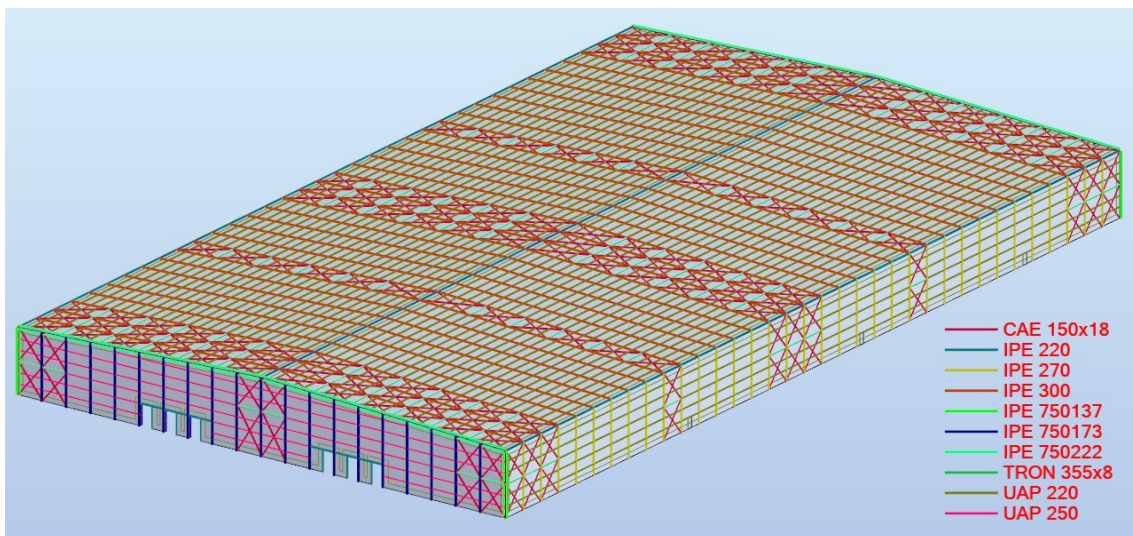
Figure 2.2: Final Pavilion Design without panels and single span roof.

Steel strength is an essential factor to consider when designing and constructing industrial buildings. Industrial buildings are subjected to significant stress due to heavy machinery, high loads, and severe weather conditions. The structural integrity of the building is crucial to ensure the safety of the workers and the durability of the structure. A high-strength steel frame can provide significant benefits to an industrial building. Also, it can increase the building's load-carrying capacity and improve resistance to seismic forces. Furthermore, high-strength steel can reduce the amount of steel required for the construction of the building, resulting in a lower cost in the overall construction of the building.

2.2   Location

Company A does not want to build a structure that is too far away from its current location in order to reduce the logistical costs of transferring all the equipment and stock from one place to another. The company plans to buy a slot of land that is close to its currently active facilities and the

terrain chosen to build the warehouse is in Aveiro's district at an altitude of 235 m above sea level (**Figure** 2.3). The terrain is an area with low vegetation, such as grass and isolated obstacles, trees, or buildings, with separations to the nearest structure of at least 20 obstacle heights, approximately 40 m. The terrain is not located near any sea or coastal area, and all the terrain is approximately at the same altitude, making it a perfect place to start a construction of this magnitude.
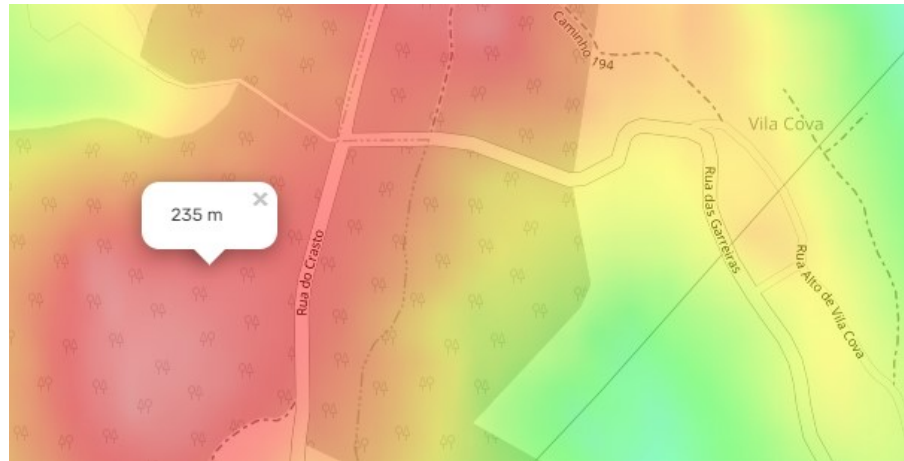
Figure 2.3: Terrain altitude, where the warehouse will be built (Topo Map).

2.3   General actions on the structure

Actions on the structure are divided into variable actions and permanent actions. The permanent actions include the structure's own weight, the weight of the coverings on the roof and side façades, self-weight of secondary structures, roof support purlins, side-rails, and bracing structures. The weight of any fixed equipment (such as a water or fluid system) must also be considered as permanent actions; however, it will not be taken into scope since the safety factors are going to include this factor. The variable actions, wind action, snow action, utilization overloads, roofing overload and thermal expansion are all considered in this analysis.

2.3.1   Snow actions

The snow load action is given in kN/m^2 and it is applied to the area of the horizontal projection of the roof. According to the [2] the snow load on roofs for a persistent/transient design situation is determined by:

$$S = \mu_i \cdot C_e \cdot C_t \cdot S_k \tag{2.1}$$

The parameters used in **Equation** 2.1 are defined as it follows:

- μ_i – Shape coefficient for snow loads. Since we are working with a flat roof, both with an inclination of about 2,3º degrees, meaning that our degree is between -5º and 5º, we can say that we are working with case (i) of the Eurocode [2]. The value of μ_i will be 0,8;

- C_e - Exposure Coefficient. The terrain falls under the "Normal" category, so the value of C_e is 1;

- C_t - Thermal Coefficient. This parameter is used when large snow loads are reduced due to high thermal effects, however, since the zone where the building is located is not known for having high temperatures the coefficient C_t will be equal to 1;

- S_k - Characteristic value of snow load at ground level. The snow magnitude of a certain area is quantified by this coefficient. According to the Portuguese National Annex [2], the district of Aveiro is located at zone Z_2 (**Figure** 2.4). The annex also states that S_k is determined by the following equation:

$$S_k = C_z \cdot \left[1 + \left(\frac{H}{500}\right)^2\right] \tag{2.2}$$

where:

- C_z is the zone dependent coefficient. Zone Z_2 is equivalent to $C_z = 0,2$;

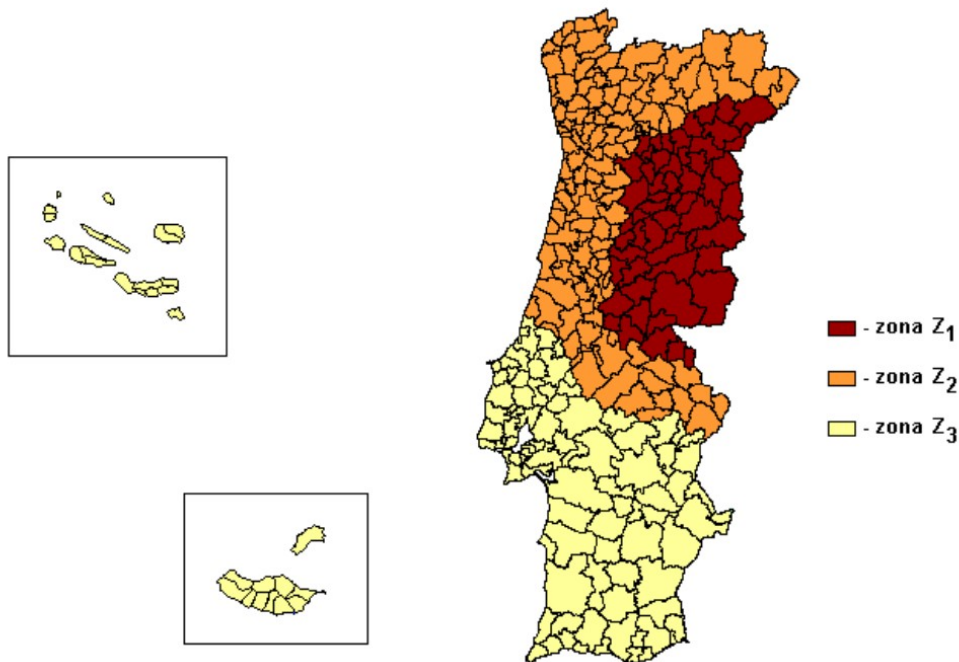- H is the altitude of the location, in meters $H = 235$ m.

Figure 2.4: Distribution of the zones regarding snow load at ground level in Portugal.

With this in mind, we get that:

$$S_k = 0,2 \cdot [1 + (\frac{235}{500})^2] = 0,244 \text{ kN/m}^2 \tag{2.3}$$

$$S = 0,8 \cdot 1 \cdot 1 \cdot 0,244 = 0,195 \text{ kN/m}^2 \tag{2.4}$$

The final value, considering the national annex, will be approximately 195 N/m^2.

2.3.2 Wind actions

Wind action is represented as a set of simplified pressures whose effects are equivalent to the extreme effects of turbulent winds on the structure. The action of the wind is a function of the roughness of the terrain, its location, and the physical configuration of the structure. These variable actions are dependent on the permeability of the structure walls and are applied in the inside and outside of the structure, perpendicular to the walls.

2.3.2.1 Reference values for basic wind

According to the Eurocode [3] the reference value of the wind speed v_b is given by:

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0} \tag{2.5}$$

The parameters used in **Equation** 2.5 are defined as it follows:

- c_{dir} - Directional coefficient;

- c_{season} – Seasonal coefficient;

- $v_{b,0}$ – Speed reference velocity.

These values are dependent on the specific type of direction of the wind, if the structure is built in the hotter months of the year, and on the zone where the structure will be constructed, respectively. Since there is no information regarding a specific wind direction in the building site and the construction is set to last for more than 6 months, we can define $c_{dir} = c_{season} = 1$. Company A's terrain is in Aveiro district, so we get according to the Portuguese National Annex [3] that $v_{b,0}$ = 27 m/s.

2.3.2.2 Mean wind

The mean windspeed is dependent on the altitude above ground level, the terrain roughness, and its orography. The influence of neighboring structures on the wind velocity should be considered. The Eurocode [3] states that we can calculate the average windspeed by the following expression:

$$v_m = c_r \cdot c_0 \cdot v_b \tag{2.6}$$

- c_r is the roughness factor, which accounts for variability of the mean wind velocity at the site due to its height above ground level and the ground roughness of the terrain upwind of the structure in the considered wind direction;

- c_0 is the orography factor which should be taken as 1;

- v_b is the previously calculated reference wind speed.

According to the Portuguese National Annex [3], for heights, z, that are between z_{min} = 3 m and z_{max} = 200 m the roughness factor can be calculated by the equation shown below:

$$c_r = 0,19 \cdot \left(\frac{z_0}{z_{0,II}}\right)^{0,07} \cdot \ln\frac{z}{z_0} \tag{2.7}$$

- z_0, the roughness length, is equal to 0,05 m;

- $z_{0,II}$ is also equal to 0,05 m, because our terrain is also a Category II terrain (**Table** 2.1);

- z is equal to the top height of our building, which is 14 m.

	Categoria de terreno	z_0 [m]	z_{min} [m]
I	Zona costeira exposta aos ventos de mar	0,005	1
II	Zona de vegetação rasteira, tal como erva, e obstáculos isolados (árvores, edifícios) com separações entre si de, pelo menos, 20 vezes a sua altura	0,05	3
III	Zona com uma cobertura regular de vegetação ou edifícios, ou com obstáculos isolados com separações entre si de, no máximo, 20 vezes a sua altura (por exemplo: zonas suburbanas, florestas permanentes)	0,3	8
IV	Zona na qual pelo menos 15 % da superfície está coberta por edifícios com uma altura média superior a 15 m	1,0	15

Table 2.1: Terrain categories and terrain parameters.

Finally, we can assume that the mean wind for our terrain and structure is v_m = 28,906 m/s as presented in the equation below:

$$v_m = 0,19 \cdot \left(\frac{0,05}{0,05}\right)^{0,07} \cdot \ln\frac{14}{0,05} \cdot 1 \cdot 27 = 28,906 \text{ m/s} \tag{2.8}$$

2.3.2.3 Wind turbulence

The turbulence intensity I_v at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity. Eurocode [3] states that we can get the turbulence coefficient by applying **Equation** 2.9, for heights, z, that are between z_{min} = 3 m and z_{max} = 200 m.

$$I_v = \frac{\sigma_v}{v_m} = \frac{k_I}{c_0 \cdot \ln\frac{z}{z_0}} \tag{2.9}$$

where:

- k_I - Turbulence factor, and the national annex recommends that this value is equal to 1;

- c_0 - orography factor described in **Equation** 2.6;

- z_0, z – roughness length and vertical direction height, respectively.

$$I_v = \frac{\sigma_v}{v_m} = \frac{1}{1 \cdot \ln\frac{14}{0,05}} = 0,177 \tag{2.10}$$

2.3.2.4   Dynamic peak pressure

The peak velocity pressure q_p at height z includes mean and short-term velocity fluctuations, is determined by the **Equation** 2.11 presented below:

$$q_p = \frac{1}{2} \cdot \rho \cdot v_m{}^2 \cdot [1 + 7\, I_v] \tag{2.11}$$

This parameter contains the coefficients: v_m, calculated in **Equation** 2.6, I_v described in the previous **Equation** 2.10 and the air density ρ, which is estimated to be = 1,25 kg/m³. With these values we can then obtain the value used for the dynamic peak pressure:

$$q_p = \frac{1}{2} \cdot 1,25 \cdot 28,906^2 \cdot [1 + 7 \cdot 0,177] = 1,171 \text{ kN/m}^2 \tag{2.12}$$

2.3.2.5   Pressure on surfaces by wind

The pressure exerted on a surface by the wind can be obtained by the following **Equation** 2.13:

$$w_p = q_p \cdot (z) \cdot c_p \tag{2.13}$$

In which:

- q_p - Represents the dynamic peak pressure, calculated in **Equation** 2.12;

- z - The reference height for the surface we are calculating the pressure;

- c_p - pressure coefficient that depends on the dimensions of the surface.

The following **Figure** 2.5 represents the variation of the pressure coefficient with the area of the surface. The values of, c_{pe1} are intended for the calculation of small elements and connections with an area equal to or less than 1 m². c_{pe10} values are used to calculate the overall strength of buildings.
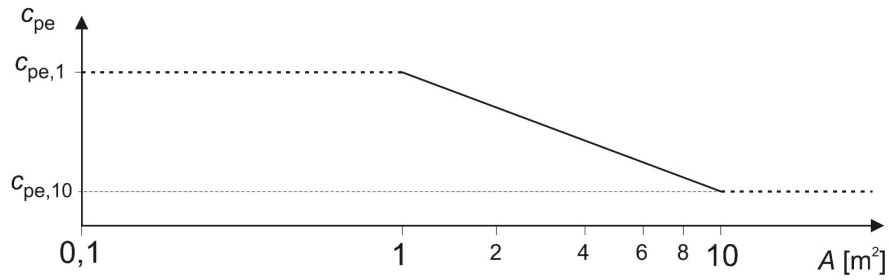
Figure 2.5: Variation of the pressure coefficient with the area of the surface [3].

To properly measure the influence of wind on a surface a direction convention is established. A pressure exerted against the surface is classified as positive, and the symmetric of this, called suction, is defined as negative. **Figure** 2.6 gives some examples on how the direction of the pressure is considered according to the Eurocode [3].
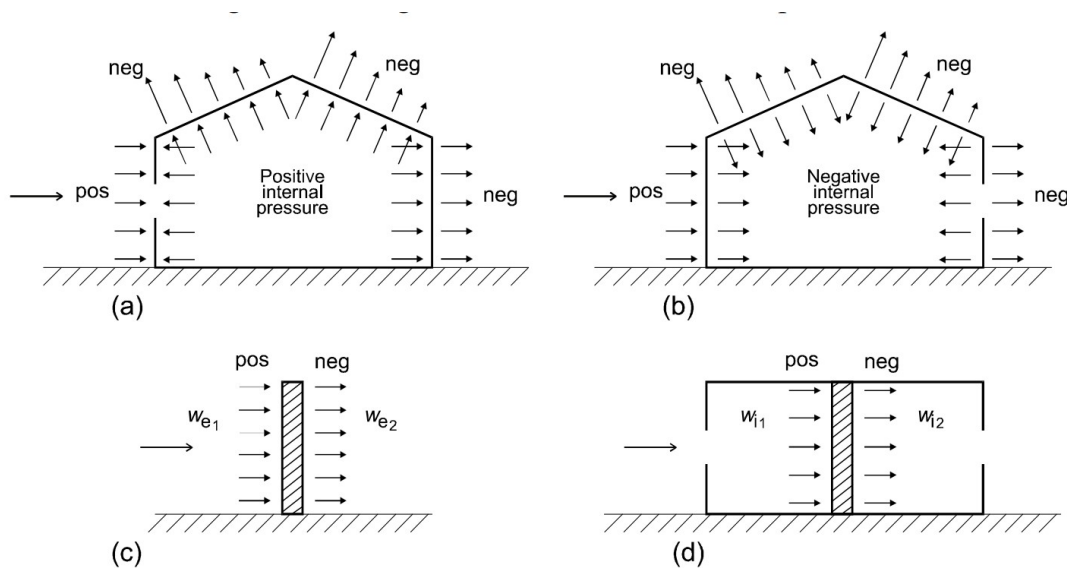
Figure 2.6: Direction of pressure applied on plain surfaces.

Wind effects on vertical rectangular walls

When calculating the loads applied on the surface of our structure, we must take into account both the longitudinal wind and the transversal wind. In **Figure** 2.7 we can see how the shape of the profile of velocity pressure is, in a vertical plain wall.
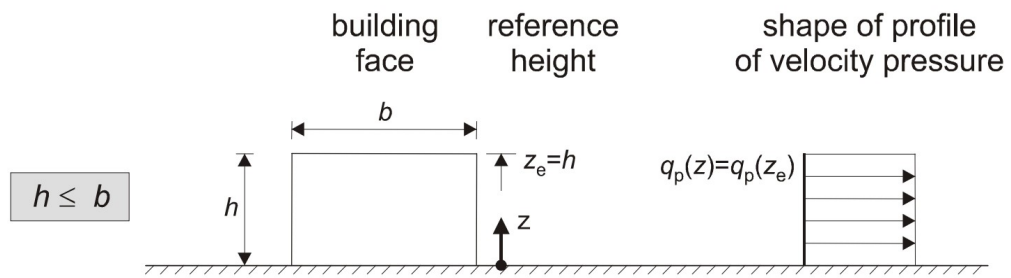
Figure 2.7: Reference height and the shape of profile of velocity pressure.

Longitudinal wind

For the dimensions of the longitudinal wind:

- h = 14 m;

- b = 100 m;

- d = 175 m.
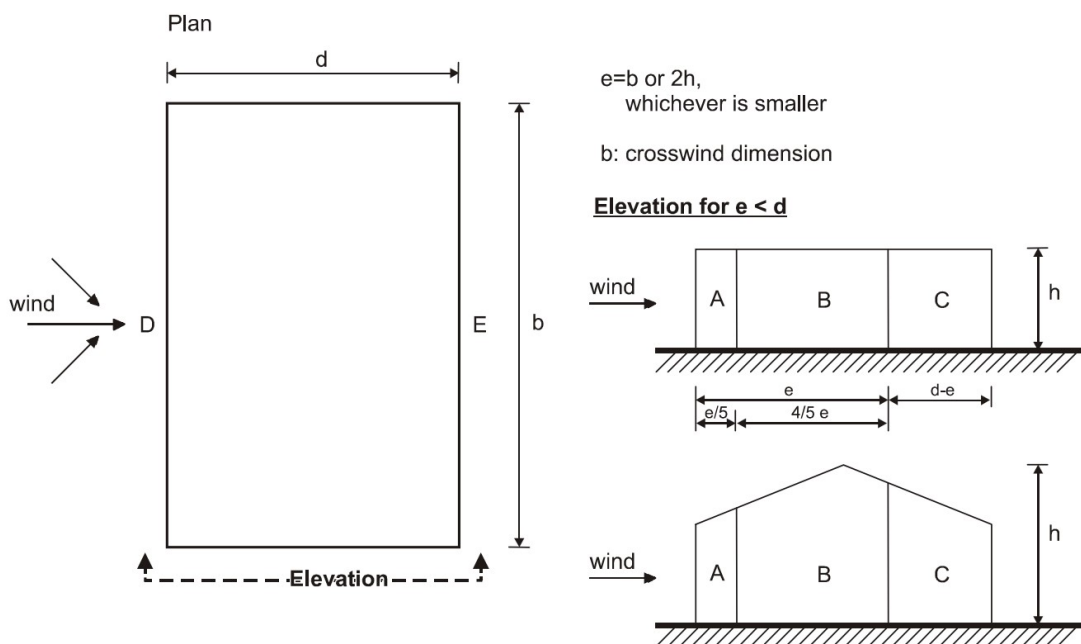
Figure 2.8: Wall geometric division of pressure wind action.

The value of e, which is a dimension used to segregate the areas of effect of the wind pressure (**Figure** 2.8), is set to be the minimum of the values of b or 2h. In our case e = 2h = 28 m. We should also define the ratio between h/d, in order to get the pressure coefficients.

- h/d = 0,080 $\leq$ 0,25 (longitudinal wind).

Zona	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
$\leq$0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

Table 2.2: Recommended values for the exterior pressure coefficient for rectangular buildings with vertical walls [3].

Using **Table** 2.2 and the coefficient h/d we can obtain the values for the external pressure coefficients for longitudinal wind, which are represented in **Table** 2.3.

Table 2.3: External pressure coefficients for longitudinal wind.

Zone	A	B	C	D	E
cpe10	-1,2	-0,8	-0,5	+0,7	-0,3

Using the same logic as the previous one, we can also use **Table** 2.2 to get the values used for the transversal wind, however the parameters used are different since the wind direction changes. The value of e remains the same as the longitudinal wind.

- h = 14 m;

- b = 175 m;

- d = 100 m;

- h/d = 0,14 $\leq$ 0,25 (transversal wind).

The values for the transversal wind external pressure coefficients for each one of the walls are represented in **Table** 2.4.

Table 2.4: External pressure coefficients for transversal wind.

Zone	A	B	C	D	E
cpe10	-1,2	-0,8	-0,5	+0,7	-0,3

Internal pressure coefficient for vertical walls and with openings

The internal pressure coefficient c_{pi}, depends on the dimension and place of the openings around the building envelope. When we have equal wind permeability on the building walls, we can consider c_{pi} as the worst case possible, the coefficient c_{pi} between +0,2 and -0,3. However,

since we have the total number of docks that are going to be used for loading/unloading of the trucks we can use the graph in **Figure** 2.9 to calculate the inner pressure coefficient. The ideal situation, idealized by the Logistics Manager and the number of inbound/outbound trucks daily, includes 6 docks on each of the bigger length sizes of the warehouse. Each one of these docks has an area of approximately 10,0 m² which equates to about 120,0 m² of total building opening areas. Adding an additional 36 m² to consider doors and extra opening we get a total value of 156,0 m² for the sum of all the opening areas. To get the value of the internal pressure coefficient c_{pi}, we first need to get the value of the ratio between h/d as calculated before, for transversal and longitudinal winds; and also, the value of μ that is defined by:

$$\mu = \frac{\sum Sum\ of\ all\ the\ areas\ when\ c_{pe}\ is\ negative\ or\ equal\ to\ 0}{\sum Sum\ of\ all\ the\ opening\ areas} \tag{2.14}$$
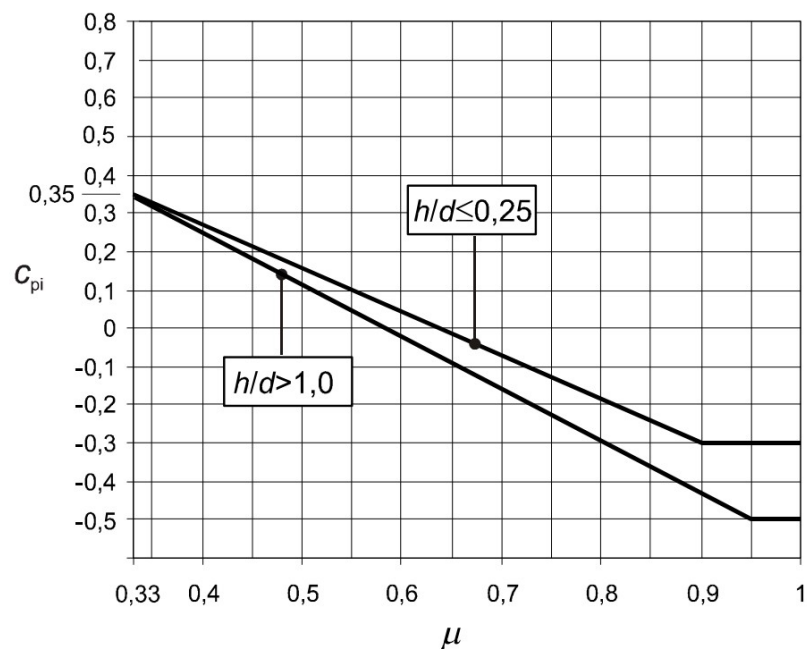

Figure 2.9: Dependance of $c_{pi,}$ in order to μ and h/d.

For both the longitudinal and transversal winds, the sum of all opening areas is much smaller than the sum of all the areas when c_{pe} is negative or equal to 0. **Figure** 2.9 shows that for values of $\mu > 0,95$ the internal pressure coefficient, $c_{pi,}$ converges to a constant value according to the h/d ratio. Since both winds have a ratio of h/d $< 0,25$ we can consider that the c_{pi} should be equal to -0,3, for both transversal and longitudinal winds.

External pressure for flat roofs

Flat roofs are defined by having a slope, θ, between -5º and 5º. There are several types of roofs such as: Sharp eaves, with parapets, curved eaves, and mansard eaves. Both suction and pressure should be considered for the calculation of c_{pe10}. The roof will be divided into 4 different zones,

and in our case, there are no indications of the existence of parapets. Therefore, using **Table** 2.5 for the roof type "Sharp Eaves" we can obtain the external pressure coefficients for flat roofs, c_{pe10}. The values are presented in **Table** 2.6.

Roof type		Zone							
		F		**G**		**H**		**I**	
		$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
Sharp eaves		-1,8	-2,5	-1,2	-2,0	-0,7	-1,2	+0,2	
								-0,2	
With Parapets	$h_p/h=0,025$	-1,6	-2,2	-1,1	-1,8	-0,7	-1,2	+0,2	
								-0,2	
	$h_p/h=0,05$	-1,4	-2,0	-0,9	-1,6	-0,7	-1,2	+0,2	
								-0,2	
	$h_p/h=0,10$	-1,2	-1,8	-0,8	-1,4	-0,7	-1,2	+0,2	
								-0,2	
Curved Eaves	$r/h = 0,05$	-1,0	-1,5	-1,2	-1,8	-0,4		+0,2	
								-0,2	
	$r/h = 0,10$	-0,7	-1,2	-0,8	-1,4	-0,3		+0,2	
								-0,2	
	$r/h = 0,20$	-0,5	-0,8	-0,5	-0,8	-0,3		+0,2	
								-0,2	
Mansard Eaves	$\alpha = 30°$	-1,0	-1,5	-1,0	-1,5	-0,3		+0,2	
								-0,2	
	$\alpha = 45°$	-1,2	-1,8	-1,3	-1,9	-0,4		+0,2	
								-0,2	
	$\alpha = 60°$	-1,3	-1,9	-1,3	-1,9	-0,5		+0,2	
								-0,2	

Table 2.5: External pressure coefficients for flat roofs.

Table 2.6: External pressure coefficients for flat roofs [3].

Zone	F	G	H	I
c_{pe10}	-1,8	-1,2	-0,7	+0,2 (pressure)-0,2 (suction)

Resulting pressure final calculations

Since we have calculated all pressure coefficients of the structure and the internal pressure coefficient is equal on all surfaces (-0,3), we can calculate the resulting pressure coefficients.

Table 2.7: Resulting pressure coefficients for all the surfaces of our structure.

Resulting pressure coefficients						
Transversal Wind	Façade	A	B	C	D	E
		-0,9	-0,5	-0,2	+1,0	0,0
Longitudinal Wind	Façade	A	B	C	D	E
		-0,9	-0,5	-0,2	+1,0	0,0
Transversal Wind	Roof	F	G	H	I	
	Suction	-1,5	-0,9	-0,4	+0,1	
	Pressure	-1,5	-0,9	-0,4	+0,1	
Longitudinal Wind	Roof	F	G	H	I	
	Suction	-1,5	-0,9	-0,4	+0,1	
	Pressure	-1,5	-0,9	-0,4	+0,5	

Using **Table** 2.7 we can see the resulting pressure coefficients along the pavilion structure. Below in **Figure** 2.10 and **Figure** 2.11 we can observe the graphical visualization of these effects and the different areas where these forces are applied, for the longitudinal and transversal winds.
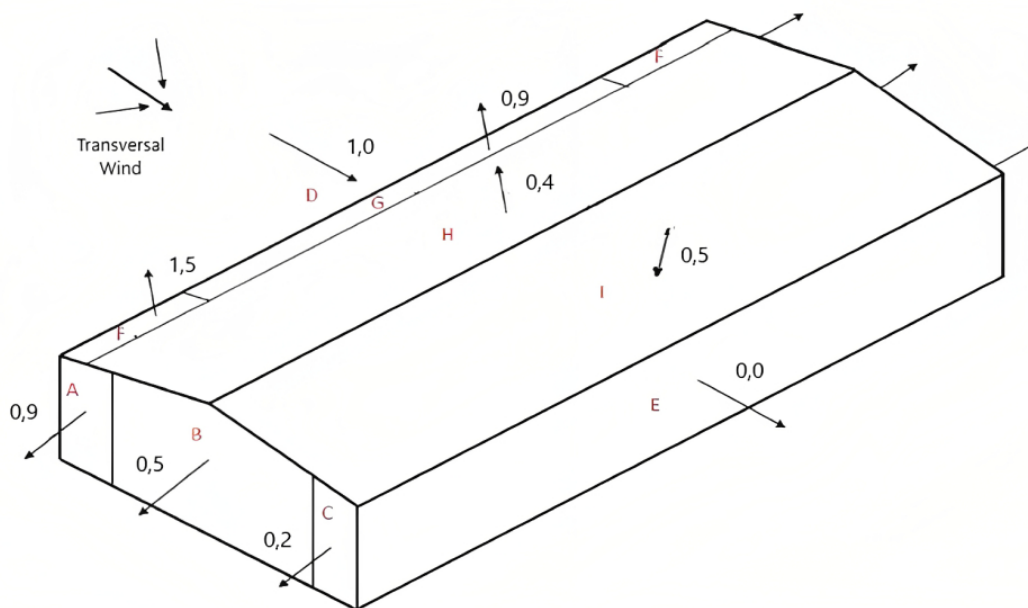

Figure 2.10: Transversal Wind Resulting Forces (Pressure Case).
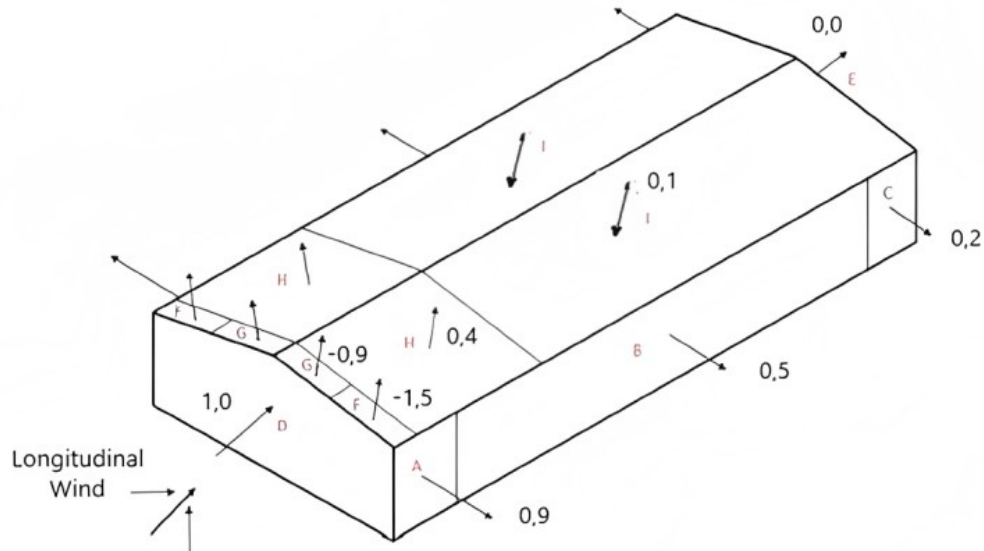
Figure 2.11: Longitudinal Wind Resulting Pressure Coefficients (Suction Case).

2.4   Combination of actions

In order to fully dimension the roof panels, we need to calculate the effects of actions applied on the roof. These actions cannot act simultaneously, and shouldn't be considered together when we are sizing the roof and side façade panels. The actions acting on the structure can appear combined in different ways to simulate all the possible real-life situations.

2.4.1   Roof covers

According to the Eurocode [4], the equation used to calculate the combination of actions for a persistent or transient design situations is given by the following expression:

$$\sum_{j \geq 1} \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \sum_{i > 1} \gamma_{Q,i} \cdot \varphi_{0,i} \cdot Q_{k,i} \qquad (2.15)$$

where:

- $G_{k,j}$ – permanent actions applied on the structure;

- $Q_{k,1}$ – leading variable action;

- $Q_{k,i}$ – accompanying variable action.

The coefficients γ and φ are obtained from following the national annex presented in Portuguese National Annex [4]. The values have different values for the different design situations and are dependent on the direction of the accompanied action. For cases where the accompanying variable load action is favorable the value of these coefficients is equal to 0. Using this calculation method is a good base for all kinds of calculations because there is no need for a further safety factor when dimensioning other parts of the structure. For our project we will use 3 different combinations of actions in order to determine what is the worst case possible. It will be considered the values, previously calculated, for the pressure coefficients that equate to the worst cases. When calculating the panels for roof covers, c_{pe10} = -1,5 for suction and c_{pe10} = +0,5 for pressure. The snow and wind loads are, respectively, considered as S=195 N/m^2 and q$_p$=1171 N/m^2.

- Variable Base Action of Wind (Suction);

$$E_d = 1171 \cdot 1,5 \cdot 1,5 = 2196 \ \text{N/m}^2 \tag{2.16}$$

- Variable Base Action of Snow with Variable Wind Action (Pressure);

$$E_d = 195 \cdot 1,5 + 1171 \cdot 1,5 \cdot 0,5 \cdot 0,6 = 820 \ \text{N/m}^2 \tag{2.17}$$

- Variable Base Overload Action combined with Variable Snow and Wind (Pressure) actions.

$$E_d = 1,5 \cdot 400 + 195 \cdot 1,5 \cdot 0,5 + 1171 \cdot 0,5 \cdot 1,5 \cdot 0,6 = 1273 \ \text{N/m}^2 \tag{2.18}$$

According to the value obtained by the actions above, we can see that the Variable Base Action of Wind (Suction) is the worst case. Meaning that we are going to dimension the roof panels with those loading actions in mind. When it comes to building structures, one of the most important factors to consider is the cost of materials, metal beams are a key component in many building projects, and finding affordable suppliers is crucial to keeping the capital expenditure under control. One strategy that can help reduce costs is choosing national suppliers. The initial list was composed of three national suppliers: Perfitec, FTB and Panelesach. Taking in mind the costs and previous experience of the company working with these suppliers, Perfitec Panels were the chosen ones, and their catalogs present us with all the information needed to complete our initial analysis, furthermore all their panels meet the requirements for the maximum beam deflection (**Figure** 2.12).

The chosen panel was the ROOFTEC (N Fireclass) S120 2,5m from Perfitec and it has a weight of 213,5 N/m^2 (**Figure** 2.13).
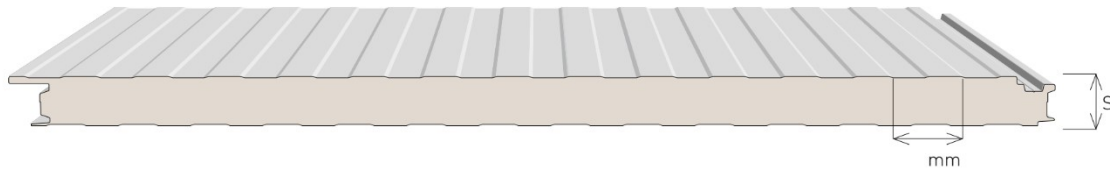
Figure 2.12: Perfitec Roof Panel (N Fireclass).

	CONDIÇÕES DE CARGA					CARGA ÚTIL UNIFORMEMENTE DISTRIBUIDA EM KG/m² - KN/m²											
ESP s mm	K		PESO PAINEL Kg/m²		U.M.												
	Kcal m².h.ºC	W m².K	0,6+0,5	0,5+0,5		2,00	2,50	3,00	3,50	4,00	5,00	2,00	2,50	3,00	3,50	4,00	5,00
50	0,67	0,75	14,76	13,84	Kg/m²	123	96	78	65			136	106	86	72	61	
					KN/m²	1,21	0,94	0,77	0,64			1,33	1,04	0,84	0,71	0,60	
80	0,44	0,50	17,76	16,84	Kg/m²	203	159	130	109	93		223	175	143	120	103	79
					KN/m²	1,99	1,56	1,28	1,07	0,91		2,19	1,72	1,40	1,18	1,01	0,77
100	0,35	0,40	19,76	18,84	Kg/m²	256	201	164	138	118	91	281	221	181	152	131	101
					KN/m²	2,51	1,97	1,61	1,35	1,16	0,89	2,76	2,17	1,78	1,49	1,29	0,99
120	0,30	0,33	21,76	20,84	Kg/m²	309	243	199	168	144	111	339	267	219	185	159	123
					KN/m²	3,03	2,38	1,95	1,65	1,41	1,09	3,33	2,62	2,15	1,81	1,56	1,21

N.B.: Os valores nesta tabela são para uma flecha f ≤ 1/ 200 de vão /´(m) e referem-se a painéis com a espessura de chapa de 0,5+0,5mm

Figure 2.13: Relation between the load applied and the length and thickness of a panel (Perfitec) used for the roof covers.

2.4.2 Façade covers

Both in the front and lateral façades the worst case of loading conditions is the same. When dimensioning the panels for these façades we should consider the longitudinal wind for the lateral ones and the transversal wind for the front ones. The pressure coefficient for both cases is +1,00 according to **Table** 2.7. Accounting with the safety factor of 1,5 from the Eurocode [4] we get that the panels for these façades should be able to withstand a load, at least:

$$w = 1171 \cdot 1 \cdot 1,5 = 1756 \, \text{N/m}^2 \tag{2.19}$$

Choosing the same type of panels used for the roof covers, from Perfitec, we can consult **Figure** 2.14 to see the thickness that we need to support the loads applied to the structure.

CONDIÇÕES DE CARGA				CARGA ÚTIL UNIFORMEMENTE DISTRIBUIDA EM KG/m² - KN/m²												
ESP s mm	K		PESO PAINEL Kg/m²		U.M.												
	Kcal m².h.ºC	W m².K	0,6+0,5	0,5+0,5		2,00	2,50	3,00	3,50	4,00	5,00	2,00	2,50	3,00	3,50	4,00	5,00
50	0,67	0,75	14,76	13,84	Kg/m²	123	96	78	65			136	106	86	72	61	
					KN/m²	1,21	0,94	0,77	0,64			1,33	1,04	0,84	0,71	0,60	
80	0,44	0,50	17,76	16,84	Kg/m²	203	159	130	109	93		223	175	143	120	103	79
					KN/m²	1,99	1,56	1,28	1,07	0,91		2,19	1,72	1,40	1,18	1,01	0,77
100	0,35	0,40	19,76	18,84	Kg/m²	256	201	164	138	118	91	281	221	181	152	131	101
					KN/m²	2,51	1,97	1,61	1,35	1,16	0,89	2,76	2,17	1,78	1,49	1,29	0,99
120	0,30	0,33	21,76	20,84	Kg/m²	309	243	199	168	144	111	339	267	219	185	159	123
					KN/m²	3,03	2,38	1,95	1,65	1,41	1,09	3,33	2,62	2,15	1,81	1,56	1,21

N.B.: Os valores nesta tabela são para uma flecha f ≤ 1/ 200 de vão / (m) e referem-se a painéis com a espessura de chapa de 0,5+0,5mm

Figure 2.14: Relation between the load applied and the length and thickness of a panel (Perfitec) used for the side façade.

The chosen panel was the ROOFTEC (N Fireclass) S80 2,0m from Perfitec. The panel has a weight of 174 N/m² and should be used for purlins distance between 2 m.

With the main dimensions of the structure defined and the panels for the roof cover and the side façades chosen we can ask the supplier (Perfitec) to give us a rough estimate of the overall costs of assembling, buying, and transporting the panels to our construction site. With these overall costs we are able to perform a future analysis of the return of investment and the liquidity needed to make this project go forward.

2.5   Purlin dimensioning

A purlin is a beam or a bar used for structural support in buildings. Purlins are normally used to support the roof structure, meaning the ply board or the panels that cover it, are usually made to last longer than 20 years, so they are a very important part when dimensioning the structure. In our case the purlins must support over 175 m of roof such they have a big relevance in this project. The value of the wind loads is 1171 N/m² and the value for the self-weight of the panels is 174 N/m².

2.5.1   Lateral purlins

The lateral façade purlins are only exposed to wind loadings and the self-weight of the panels and purlins; the wind will be acting horizontally and the weight vertically on the main axis of the purlin, this situation creates a situation where the purlins are subject to bending in two axes.
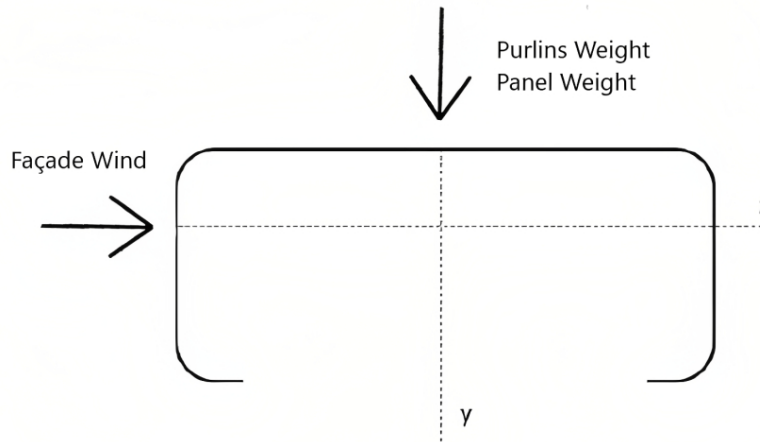
Figure 2.15: Applied loads to side façade purlins.

The wind and self-weight actions are accompanied by the coefficients γ_w= 1,5 and γ_P = 1,35, according to the Eurocode [4]. According to rough estimates, we can see that the action with longitudinal wind is the most critical one so we can approximate the resistance modules of the profile W_y and W_z, to see what the ideal profile for the purlins design is. The longitudinal wind pressure is not equally distributed along the whole span, so we will take the worst, that corresponds to a c_{pe10}= -0,9. The following **Equation** 2.20 represents the load per meter applied to the side façade purlins.

$$E_{dz} = 1,5 \cdot 1171 \cdot 0,9 = 1580,9 \, \text{N}/m \tag{2.20}$$

We have a distance between purlins of dm=2 m and a distance between frames of dp=5 m, therefore we have:

$$Q_z = E_{dz} \cdot dm = 1580,9 \cdot 2 = 3161,7 \, \text{N/m} \tag{2.21}$$

Assuming a continuous beam over 2 spans that causes a 40% decrease in deflection in relation to the case of the simply supported beam, and a low carbon steel S275 (σ_{sd}= 275 MPa).

$$M_{y \, max} = \frac{Q \, L^2}{10} = \frac{3161,7 \cdot 5^2}{10} = 7,90 \, \text{kNm} \tag{2.22}$$

$$W_y \geq \frac{M_{max}}{\sigma_{sd}} \geq 28,73 \, cm^3 \tag{2.23}$$

The preference when choosing a supplier for the purlins was to select the national one, close to the building site and compatible with the rest of the panels. Luckily for us, the chosen supplier for the panels, Perfitec, is also a manufacturer of purlins.

Cross-section C is normally used for the lateral side purlins (**Figure** 2.15), so we can check the supplier catalog to see if there is any solution that satisfies the condition in **Equation** 2.23. After several iterations the profile C250 x 2,5 has a resistance module of 69,73 cm^3 in the yy axis, which is a bit bigger than the required one but is the necessary one when we are also accounting with bending on the zz axis. We will choose this C profile accounting this time for self-weight and check all the calculations again.

PROPRIE-DADES BRUTAS		H	b	b1	t	kg/m	Abr	s	Iy	Iz	ry	rz	Wel y	Wel z
	UNIDADES	mm	mm	mm	mm	kg	mm2	m²/m	mm4	mm4	mm2	mm2	mm3	mm3
C100	c100 x 1,5	100	60	18	1,5	2,86	364	0,486	604194	189190	40	22	12083	5015
	c100 x 2,0				2,0	3,79	482	0,486	792941	246423	40	22	15858	6536
	c100 x 2,5				2,5	4,68	596	0,486	970100	298814	40	22	19402	7923
C120	c120 x 1,5	120	60	18	1,5	3,09	393	0,528	918150	202045	48	22	15302	5133
	c120 x 2,0				2,0	4,1	522	0,528	1207118	263201	48	22	20118	6691
	c120 x 2,5				2,5	5,09	648	0,528	1487783	321412	48	22	24796	8176
C150	c150 x 1,5	150	60	18	1,5	3,44	437	0,587	1531144	216639	59	22	20415	5228
	c150 x 2,0				2,0	4,56	580	0,587	2016712	282204	59	22	26889	6817
	c150 x 2,5				2,5	5,67	721	0,587	2490161	344615	59	22	33202	8332
C200	c200 x 1,5	200	60	22	1,5	4,12	524	0,702	3085200	258951	76	22	30852	6015
	c200 x 2,0				2,0	5,47	696	0,702	4072662	337562	76	22	40726	7851
	c200 x 2,5				2,5	6,8	866	0,702	5040024	412502	76	22	50400	9606
C250	c250 x 2,0	250	60	24	2,0	6,33	806	0,81	7061230	377310	93	22	56489	8472
	c250 x 2,5				2,5	7,86	1001	0,81	8716429	458766	93	22	69731	10309
C300	c300 x 2,0	300	60	26	2,0	7,18	914	0,918	11117270	412110	110	21	74115	9010
	c300 x 2,5				2,5	8,92	1136	0,918	13741570	501329	110	21	91610	10973

Figure 2.16: Purlin profile C250 x 2,0 and C250 x 2,5 properties (Perfitec).

The profile has a mass per meter of 7,86 kg/m, which equates to a load of 77,10 N/m. The resistance modules are W_y= 69,73 cm^3 and W_z= 10,31 cm^3. The moments of inertia I_y = 8,72 x 10^{-6} m^4 and I_z = 4,59 x 10^{-7} m^4 (**Figure** 2.16).

2.5.1.1 Ultimate limit states (ULS)

$$Q_y = 1,35 \cdot 174 \cdot 2 + 1,35 \cdot 77,10 = 573,90 \, \text{N/m} \tag{2.24}$$

$$M_{z \, max} = \frac{Q \, L^2}{10} = \frac{573,90 \cdot 5^2}{10} = 1,43 \, \text{kNm} \tag{2.25}$$

$$\sigma_{sd} = \frac{M_y}{W_y} + \frac{M_z}{W_z} = \frac{7900}{69,73 \times 10^{-6}} + \frac{1430}{10,31 \times 10^{-6}} = 252 \, [MPa] < 275 \, MPa \tag{2.26}$$

2.5.1.2 Serviceability limit states (SLS)

- q_{wind} (Load due to wind forces) = 1171 $\cdot$ 1,5 $\cdot$ 2 = 3513 N/m^2;

- $q_{p,panels}$ (Load due to weight of panels) = 174 $\cdot$ 2 = 348 N/m^2;

- $q_{p,purlins}$ (Load due to weight of purlins) = 77,10 N/m^2.

The maximum admissible displacement is calculated as:

$$\delta_{max} = \frac{L}{200} = \frac{5}{200} = 0,025 \tag{2.27}$$

$$\delta_z = \frac{q_y \cdot L^4}{384 \cdot E \cdot I_z} = \frac{(348,00 + 77,10) \cdot 5^4}{384 \cdot 210 \cdot 10^9 \cdot 4,59 \text{ x } 10^{-7}} = 0,0071 \; m \tag{2.28}$$

$$\delta_y = \frac{q_z \cdot L^4}{384 \cdot E \cdot I_y} = \frac{(3513,00) \cdot 5^4}{384 \cdot 210 \cdot 10^9 \cdot 8,72 \text{ x } 10^{-6}} = 0,0031 \; m \tag{2.29}$$

Both the Ultimate Limit States (ULS) and the Serviceability Limit States (SLS) are verified; therefore, we can conclude that we can use the purlin C250 x 2,5 for our façade structure.

2.5.2   Roof purlins

In order to dimension the roof purlins, we should use the base action of overload, variable actions of snow and wind and permanent actions of both the purlins and the panels weight. According to the Eurocode [4], the wind actions are accompanied by the coefficients γ_w= 1,5 and φ_w = 0,6 and the snow actions are followed by coefficients γ_s = 1,5 and φ_s = 0,5. The overload action has a coefficient of γ_{over} = 1,5 and the panel's weight coefficient is equal to γ_p= 1,35. The value used for the wind loads is going to be 1171 N/m^2, snow load applies a pressure of 0,195N/m^2 and, finally, the overload as a load of 400 N/m^2. The self-weight of the panels has a value of 213,5 N/m^2 and the distance between purlins chosen was 2,5 m. The bending of the purlin applied in both its main axis needs to be decomposed since the loads of the weight, snow and overload are not applied perpendicular to the purlin, since there is an inclination of θ=2,3°. We have for each of the specified loads:

- Overload - $Q_{over} - 400 \; N/m^2$;

- Snow - $Q_{snow} - 195 \; N/m^2$;

- Wind - $Q_{wind} - 214 \; N/m^2$;

- Weight - $Q_{panel} - 400 \; N/m^2$;

- Distance between roof panels and purlins – dm = 2,5.

The following **Figure** 2.17 depicts the orientation of each applied load to the roof purlins.
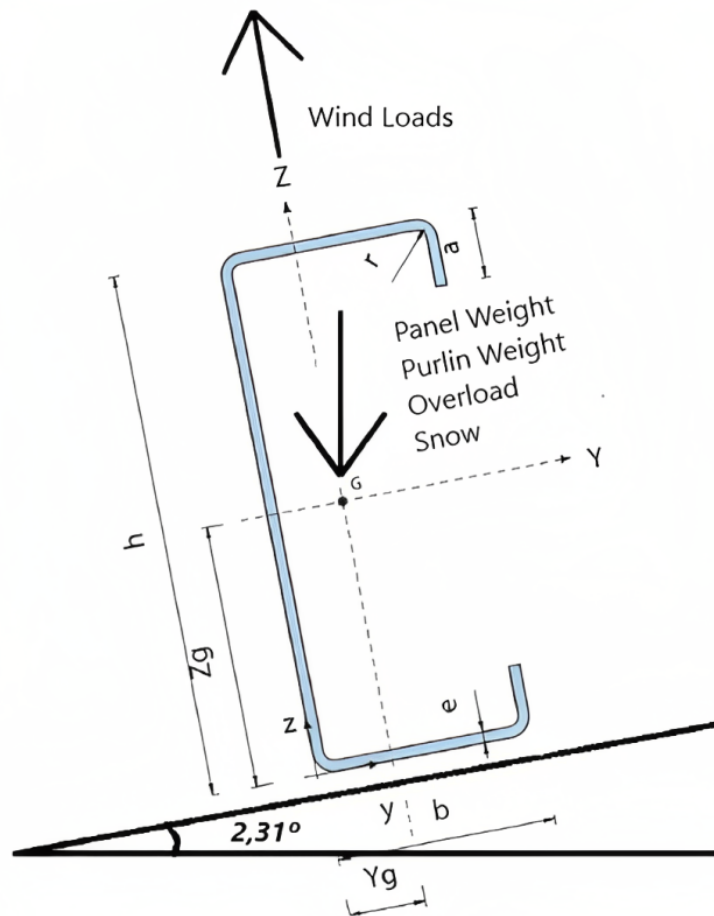
Figure 2.17: Applied loads to the roof purlin with inclination.

2.5.2.1 Overload

$$q_{over,y} = Q_{over} \cdot dm \cdot \sin\theta = 400 \cdot 2,5 \cdot 0,0403 = 40,306 \; N/m \qquad (2.30)$$

$$q_{over,z} = Q_{over} \cdot dm \cdot \cos\theta = 400 \cdot 2,5 \cdot 0,9992 = 999,20 \; N/m \qquad (2.31)$$

2.5.2.2 Snow

$$q_{snow,y} = Q_{snow} \cdot dm \cdot \sin\theta = 195 \cdot 2,5 \cdot 0,0403 = 19,650 \; N/m \qquad (2.32)$$

$$q_{snow,z} = Q_{snow} \cdot dm \cdot \cos\theta = 195 \cdot 2,5 \cdot 0,9992 = 487,100 \; N/m \qquad (2.33)$$

2.5.2.3 Self-weight

$$q_{panel,y} = Q_{panel} \cdot dm \cdot \sin\theta = 214 \cdot 2,5 \cdot 0,0403 = 21,513 \; N/m \qquad (2.34)$$

$$q_{panel,z} = Q_{panel} \cdot dm \cdot \cos\theta = 214 \cdot 2,5 \cdot 0,9992 = 533,32 \ N/m \tag{2.35}$$

2.5.2.4 Transversal wind

$$q_{wind,z} = Q_{wind} \cdot dm = 1171 \cdot 2,5 \cdot = 2927,50 \ N/m \tag{2.36}$$

In the case of transversal wind (pressure) the pressure coefficient $c_p = 0,5$ corresponds to the worst case possible. With that in mind, we can use this to dimension the roof purlins in a safe way.

Considering the coefficients $\gamma_w=1,5$, $\varphi_w=0,5$, $\gamma_s=1,5$, $\varphi_s=0,6$, $\gamma_{over}=1,5$, $\gamma_p=1,35$ and the loads presented above, we can calculate the resulting loads by length in both axis of bending for the roof purlins.

In z:

$$q_z = 1,5 \cdot 0,5 \cdot 2927 + 1,5 \cdot 0,6 \cdot 487 + 1,5 \cdot 999,2 + 1,35 \cdot 533,32 = 4852,77 \ N/m \tag{2.37}$$

In y:

$$q_y = 1,5 \cdot 0,6 \cdot 19,65 + 1,5 \cdot 40,31 + 1,35 \cdot 21,51 = 107,20 \ N/m \tag{2.38}$$

The maximum bending is calculated as shown:

$$M_{y \ max} = \frac{Q \ L^2}{10} = \frac{4852,77 \cdot 5^2}{10} = 12,13 \ \text{kNm} \tag{2.39}$$

$$M_{z \ max} = \frac{Q \ L^2}{10} = \frac{107,20 \cdot 5^2}{10} = 276,45 \ \text{Nm} \tag{2.40}$$

$$W_y \geq \frac{M_{y \ max}}{\sigma_{sd}} \geq 44,12 \ cm^3 \tag{2.41}$$

Choosing the C250 x 2,0 profile from (Figure 19), with properties $W_y = 56,49 \ cm^3$ and $W_z = 8,47 \ cm^3$. The moments of inertia $I_y = 7,06 \times 10^{-6} \ m^4$ and $I_z = 3,77 \times 10^{-7} \ m^4$. The profile has a total weight of 62,1 N/m.

2.5.3 Ultimate limit states (ULS)

$$Q_z = 4852,8 + 1,35 \cdot 62,1 \cdot \cos 2,3° = 4936,53 \ N/m \tag{2.42}$$

$$Q_y = 268 + 1,35 \cdot 62,1 \cdot \sin 2,3° = 110,6 \ N/m \tag{2.43}$$

Using **Equation** 2.39 and **Equation** 2.40 in order to calculate $M_{y \ max}$ and $M_{z \ max}$ .We have that:

$$\sigma_{sd} = \frac{M_{y \ max}}{W_y} + \frac{M_{z \ max}}{W_z} = \frac{12341}{56,49 \times 10^{-6}} + \frac{276,45}{8,47 \times 10^{-6}} = 251 \ MPa < 275 \ MPa \tag{2.44}$$

2.5.4   Serviceability limit states (SLS)

- q_{wind} (Load due to wind forces) = $1171 \cdot 1,5 \cdot 2 = 3513$ N/m^2;

- $q_{p,panels}$ (Load due to weight of panels) = $174 \cdot 2 = 348$ N/m^2;

- $q_{p,purlins}$ (Load due to weight of purlins) = $75,34$ N/m^2.

$$\delta_{max} = \frac{L}{200} = \frac{5}{200} = 0,025 \tag{2.45}$$

$$\delta_z = \frac{q_y \cdot L^4}{384 \cdot E \cdot I_z} = \frac{(110,60) \cdot 5^4}{384 \cdot 210 \cdot 10^9 \cdot 3,77 \text{ x } 10^{-7}} = 0,0023 \, m \tag{2.46}$$

$$\delta_y = \frac{q_z \cdot L^4}{384 \cdot E \cdot I_y} = \frac{(4936,53) \cdot 5^4}{384 \cdot 210 \cdot 10^9 \cdot 7,06 \text{ x } 10^{-6}} = 0,0055 \, m \tag{2.47}$$

Both the ULS and the SLS are verified; therefore, we can conclude that we can use the purlin C250 x 2,0 for our roof structure. In the next chapter we will apply loads to the overall structure, knowing already the purlins and panels used for it.

Chapter 3

Modern structural analysis software

The use of 3D modeling software in modern engineering has changed the design, development, and implementation process of a project. The capacity to digitally perceive and modify three-dimensional things has given engineers a valuable tool for increasing productivity and efficiency. This text will discuss the significance of 3D modeling software in modern engineering methods, emphasizing its role in optimizing designs and lowering costs. Cost considerations are pivotal in engineering projects, and 3D modeling software contributes significantly to this factor. Traditional prototyping and manufacturing methods often involve substantial expenses for materials, tooling, and production processes and by utilizing 3D modeling, engineers can detect design flaws early in the development stage, minimizing the need for costly rework and modifications. Moreover, 3D models serve as a valuable tool for pre-production visualization, anticipating potential challenges. These factors aid in optimizing manufacturing processes and ensuring efficient resource utilization.

3.1   Abilities of robot autodesk software

Robot Autodesk software, commonly known as Autodesk Robot Structural Analysis Professional, is a comprehensive Computer Aided Engineering (CAE) software program designed specifically for structural analysis and simulation of various building structures. Developed by Autodesk, a renowned leader in 3D design, engineering, and entertainment software, Robot Autodesk software offers advanced tools and capabilities to facilitate accurate and efficient structural analysis. Once the structural model is established, Robot Autodesk software provides an extensive library of analysis capabilities and tools. Engineers can apply different types of loads, including dead loads, live loads, wind loads, seismic loads, and temperature effects, to evaluate the response of the structure. Additionally, the software incorporates advanced analysis methods, such as linear and nonlinear static analysis, dynamic response analysis, and buckling analysis, enabling engineers to investigate complex structural behavior and assess design performance under various scenarios.

3.2   Structure modelling

With the previous introduction of the software used, we are now ready to explore the tool. The following chapter is going to demonstrate all the steps taken in order to fully dimension the structure and get the drawings and materials list to complete the project. It is also going to be applied to several different combinations of actions to see if the structure is well dimensioned, according to the Eurocode. The panels thickness, purlins sections and main dimensions are already chosen from the previous chapters, so the input of the data into the software is facilitated. The construction steel of the project is taken to be the S275 as it is one of the most used in the industrial pavilion sector. The **Figure** 2.2 shows the main view of the pavilion made in Robot Autodesk.

3.2.1   Structural axis

We first need to fully define the main axis of construction when using Robot Autodesk Software. These axes will serve as the main anchor points in 3D space to define the bars and connections of the structure. **Figure** 3.1 shows the cartesian coordinates of the xx axis used for our construction. Since we have a distance between purlins of 5 m, we are able to use this tool to define all the positions along the xx axis that will coincide with the main frameworks. The next step is to start building the bars and connections.
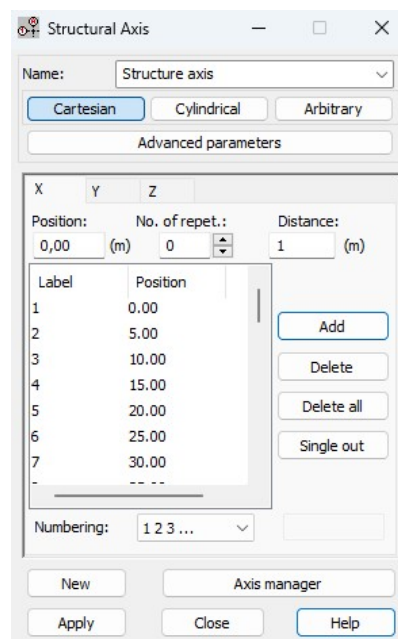
Figure 3.1: Structural axis command box from Robot Autodesk.

3.2.2   Section types and members

Using Robot Autodesk Section Command Box, we are able to choose from the European section database the materials that we want to build our structure. If it is needed, we can import, or

define our material properties and purlin geometric configuration to fit our needs. The following **Figure** 3.2 shows the customization window that pops up when we are defining a new section, in this case the side façade purlins (**Figure** 3.3). In our project we will define a different label for each one of the different members that are part of it.
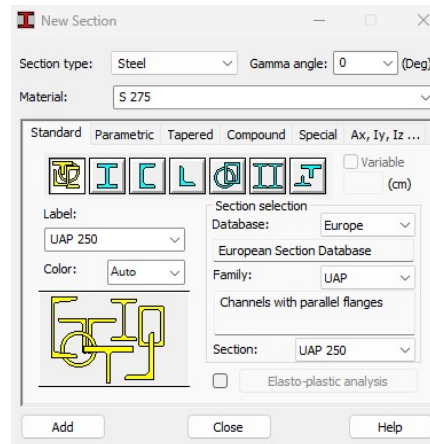
Figure 3.2: Side façade Purlins C Section definition window.
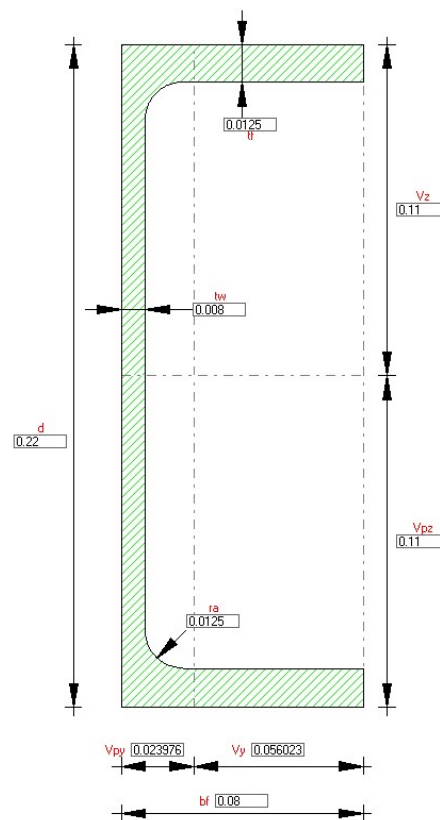
Figure 3.3: Defining the geometric parameters for C Section.

After defining a new section, we can then start to draw the desired structure that will be made from this section. **Figure** 3.4 shows us that we can define the node coordinates for the beginning and the end of our members and also its section. It is also possible to simply unite two points in our 3D space to fully define a beam.

Each one of the different beams that compose our structure can have distinct boundary conditions. To be able to fully analyze the beams behavior when subjected to different load conditions we need to check for each beam section the buckling for the purlin's axis and also the support (fixed, free, pinned, etc.).
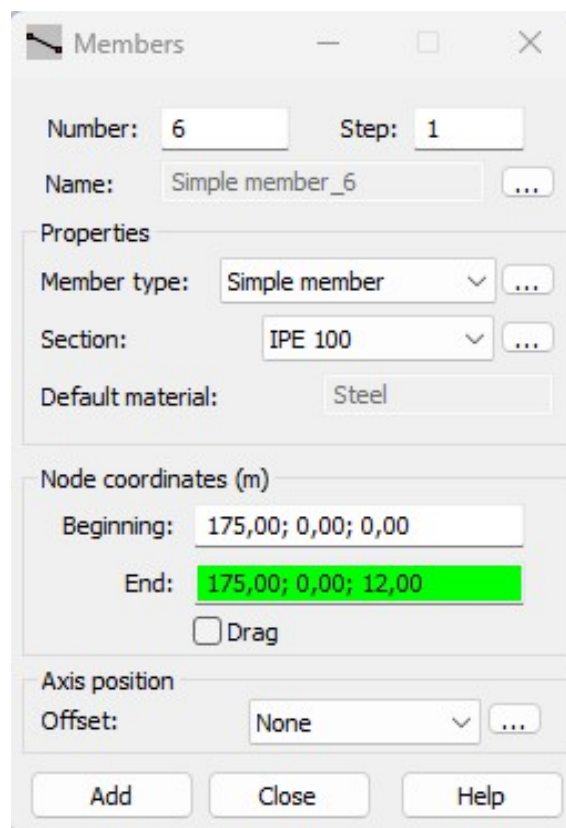
Figure 3.4: Member design window.

3.2.3   Main framework

Below in **Figure** 3.5 we can observe the main framework of the building, each one of the frameworks has two pillars to support it in its extremities and three intermediate pillars. The nodes that connect the pillars to the ground cannot be displaced in any direction and their rotation in the zz axis is blocked as well.
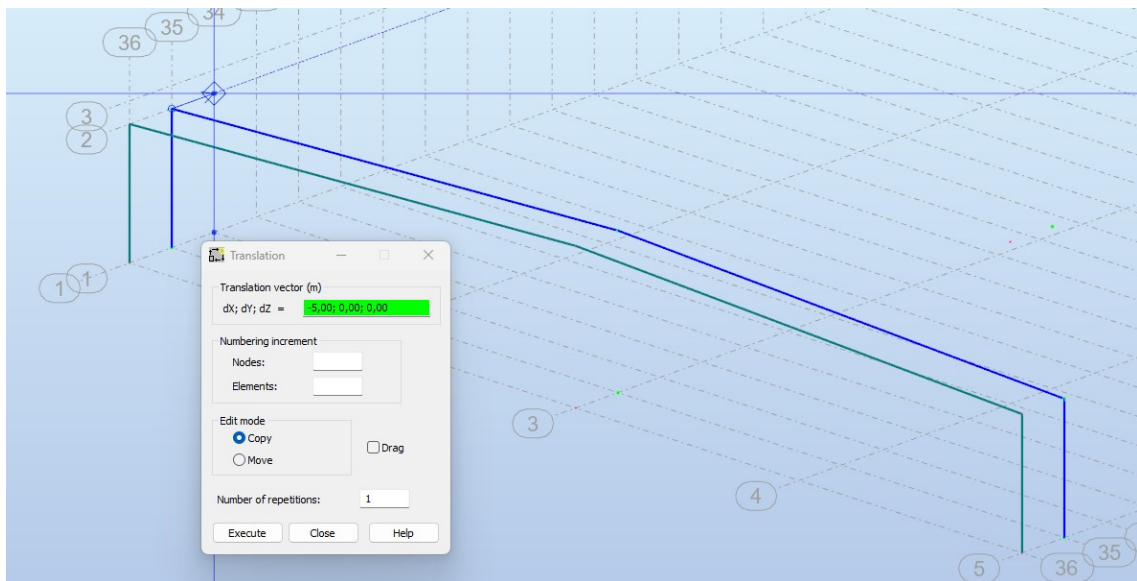
Figure 3.5: Support for the pillars and main framework.

3.2.3.1 Brackets reinforcement

In this project we will also consider brackets, they will be used to provide support and stability to the structure, by connecting and reinforcing different components of it. Brackets are commonly used in construction to join beams, columns, trusses, and other structural elements. They help distribute loads and forces, enhancing the overall strength and integrity of the structure. Brackets also facilitate the installation of various building systems, such as electrical wiring and plumbing. and their properties are listed below in **Figure** 3.6.
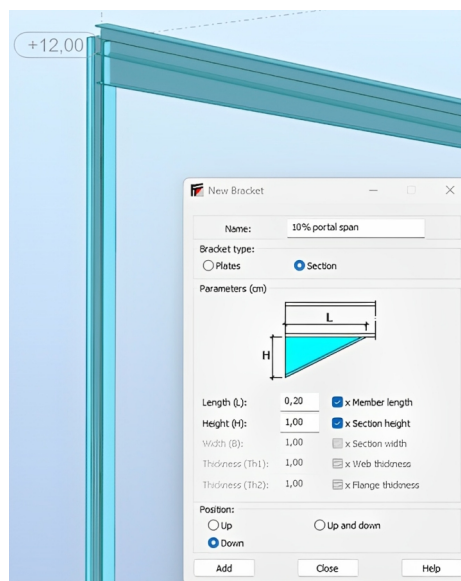
Figure 3.6: Brackets applied on the main purlins of the structure.

The length of the bracket will be 20% of the full length of the member and the height of the bracket is equal to 100% of the section height that the bracket is coupled to.

3.2.4   Bracings

A structure is said to be braced if a bracing system that is sufficiently rigid in respect to the horizontal components of the outside actions ensures lateral rigidity in its plane. In this instance, the horizontal actions, along the global xx axis, can be admitted being completely absorbed by the bracing system. The action of the wind on the front and back façades generates horizontal forces in the longitudinal direction of the building. These actions are applied to the columns of the front façade, so they are absorbed by the horizontal bracing on the roof between the first and second framework (**Figure** 3.7).
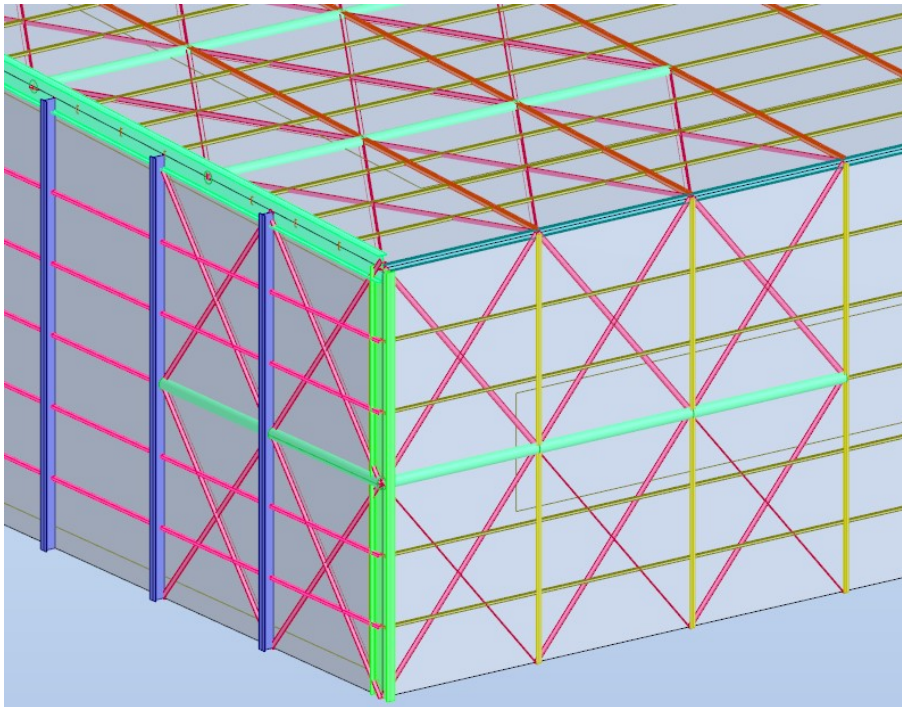
Figure 3.7: Roof and side façade bracings.

3.2.5   Longitudinal beams

The longitudinal beams are necessary to connect all the main frameworks of the building (**Figure** 3.8), they are connected to the extremities of the framework and also to the highest point of it. These members are simply supported.
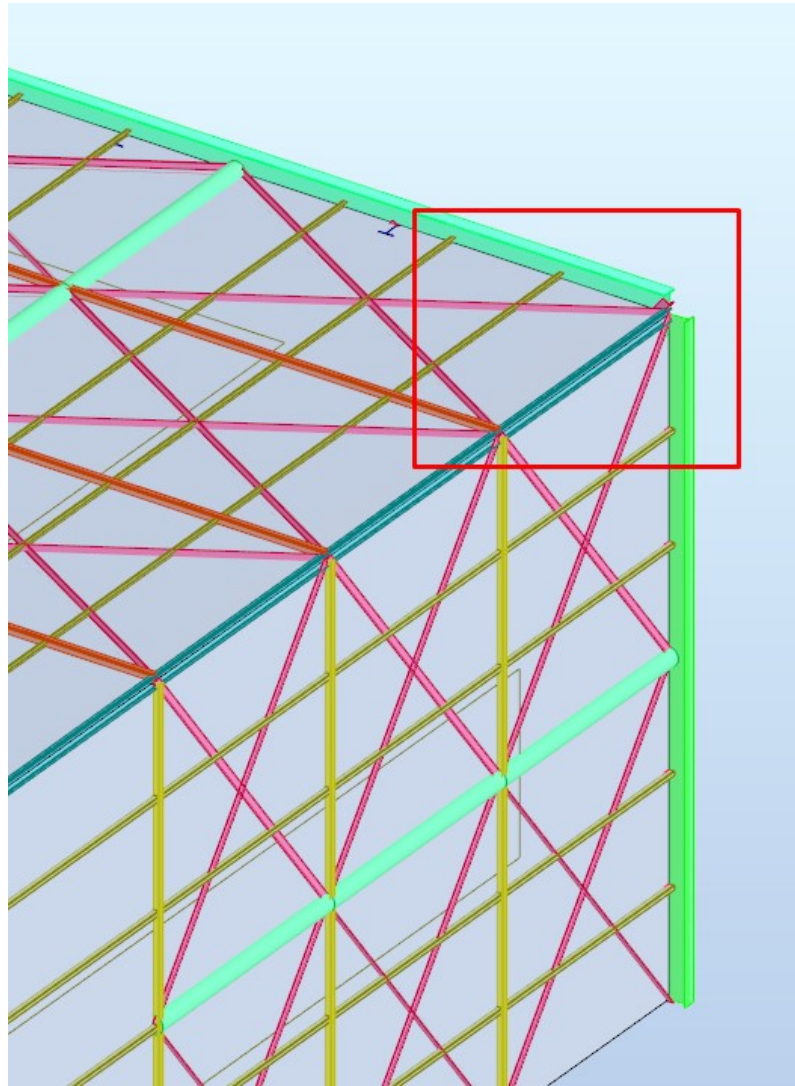
Figure 3.8: Longitudinal beams connecting the main frameworks.

3.2.6   Purlins

Purlins play a significant role in the structural integrity of industrial pavilions, particularly in large structures. These horizontal structural members are essential components that support the roof covering and transfer loads to the primary structural framework. These elements help to evenly distribute the load and minimize local stress concentrations. Purlins also serve as a platform for the roof covering materials. They provide a secure and stable surface for the roofing material to be fastened. In our project, purlins are a key element since they are the most numerous parts of our structure. It is of great importance to be cost effective when dimensioning these elements, because they can greatly reduce the labor and overall material costs. **Figure** 3.9 shows us that in just a small part of the structure we have many purlins.
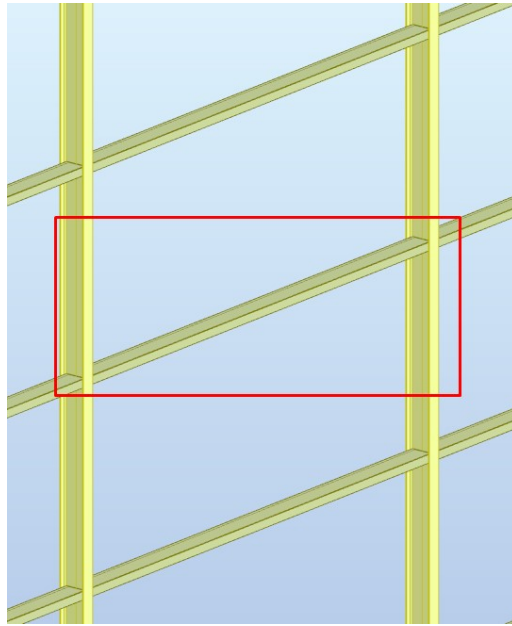
Figure 3.9: Lateral Purlins C-Section.

Having defined all the main elements for the structure, we are now ready to utilize Robot Autodesk abilities to simulate all the load cases and simulate what are the best possible scenarios for the beams design. **Figure** 3.10 illustrates an image that contains all the members of the structure.
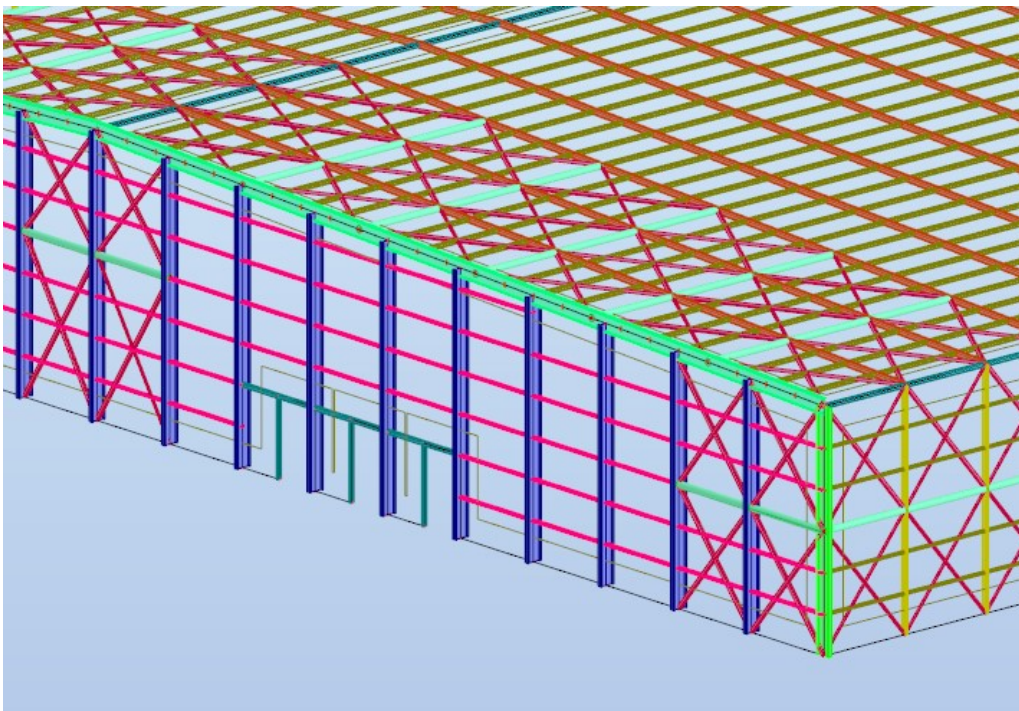
Figure 3.10: Main view of the pavilion structure members.

Chapter 4

SLS and ULS verification according to Eurocode

4.1 Load types on Robot Autodesk

In order to dimension all the beam types in Robot Autodesk we need to apply all the different combinations of loads to our structure. After defining all the boundary conditions and the releases, members that are connected by fixed connections in nodes, that is, rotation and displacement compatibility is ensured for all the members intersecting at a given node, they ensure equal displacements in nodes but allow rotation of element ends.

All the spoken above load types are going to be applied to the software. Therefore, a summary of all the load types is going to be presented below, with the codification used in Robot Autodesk:

- SN: Snow Load applied to the roof;

- OVR: Roof Overload;

- SW: Self Weight applied to the whole structure;

- TEMP: Temperature effects in metallic components of the building;

- WSX+ Automatic Wind Simulation, with magnitude of 27 m/s according to the global positive xx axis direction;

- WSX- Automatic Wind Simulation, with magnitude of 27 m/s according to the global negative xx axis direction;

- WSY+ Automatic Wind Simulation, with magnitude of 27 m/s according to the global positive yy axis direction;

- WSY- Automatic Wind Simulation, with magnitude of 27 m/s according to the global negative yy axis direction;

4.1.1 Surfaces and claddings

To correctly represent a surface in Robot Autodesk a Cladding is used, it is a surface that lets you distribute planar, linear, and concentrated loads on members [5]. Cladding can considerably help when generating loads as they allow you to define objects that do not participate in the load capacity of a structure, such as panel walls and roofing. In our structure we are able to use cladding along with the option of creating openings to dimension all the surfaces (**Figure** 4.1). With cladding elements, we are able to choose for each surface what type of forces and the total area that they are going to be applied.
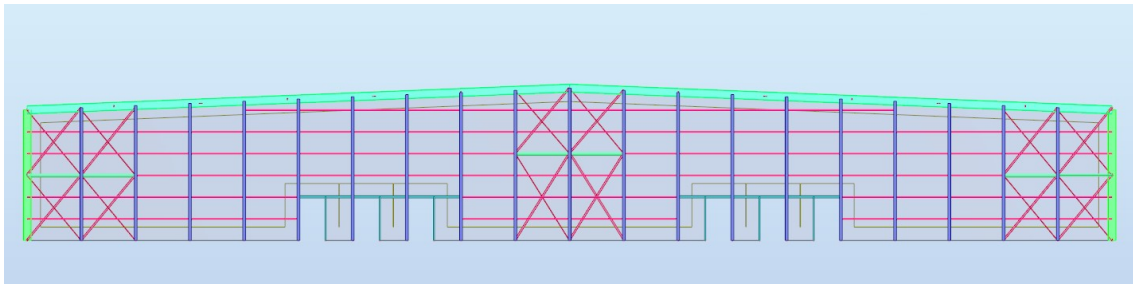
Figure 4.1: Visualization of the front façade cladding and dock openings.

Robot Autodesk offers us the option to choose if the properties of a cladding element. The load distribution can only be applied in one direction. In the front façade of the building the loads are distributed across the pillars and on the lateral façade of the building the loads are applied on the frameworks as the load distribution is on the xx axis, which has the same direction as the 175 m length façade.

4.1.2 Defining the loads

Having the surfaces and properties of it defined we are now ready to define all the main loads applied to the building. The input of the actions of a load in Robot Autodesk is going to be demonstrated in each one of the following points. Accurate load definition allows the structural software to optimize the design of the structure and by providing precise load information, the software can perform efficient calculations and generate optimized designs that meet the safety standards, while also minimizing material usage and costs.

4.1.2.1 Snow load

As it was calculated in **Chapter** 2, the snow load which has a magnitude of 195 N/m2 and acts on the roof surface is going to be added to the software (**Figure** 4.2). In order to do that we need to create a load type called Snow. The nature of this load is "dead" as it is a static action. This load is applied only on the roof claddings, and it has the direction from top to bottom of the global zz axis (**Figure** 4.3). It was also possible to choose an automatic load of snow from the software, because Robot Autodesk offers the option to choose a load type from Snow "nature" and

subnature : "Height under 1000 meters", however since the Portuguese National Annex [2] has small differences from the Eurocode, the "dead" nature load was used.
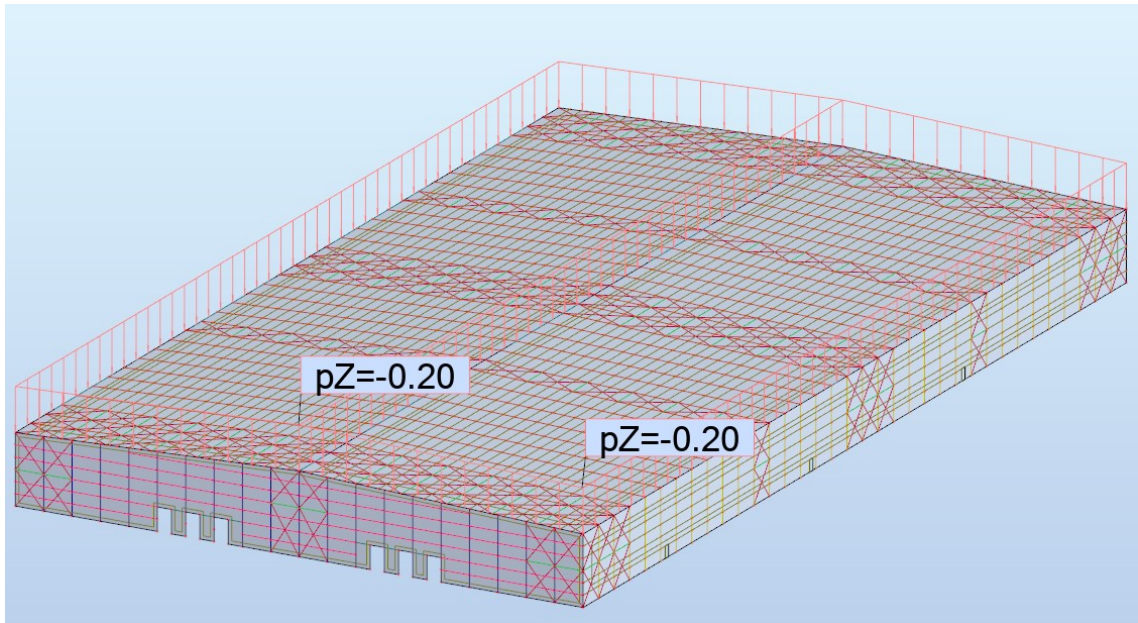
Figure 4.2: Snow Load being applied to the roof structure.
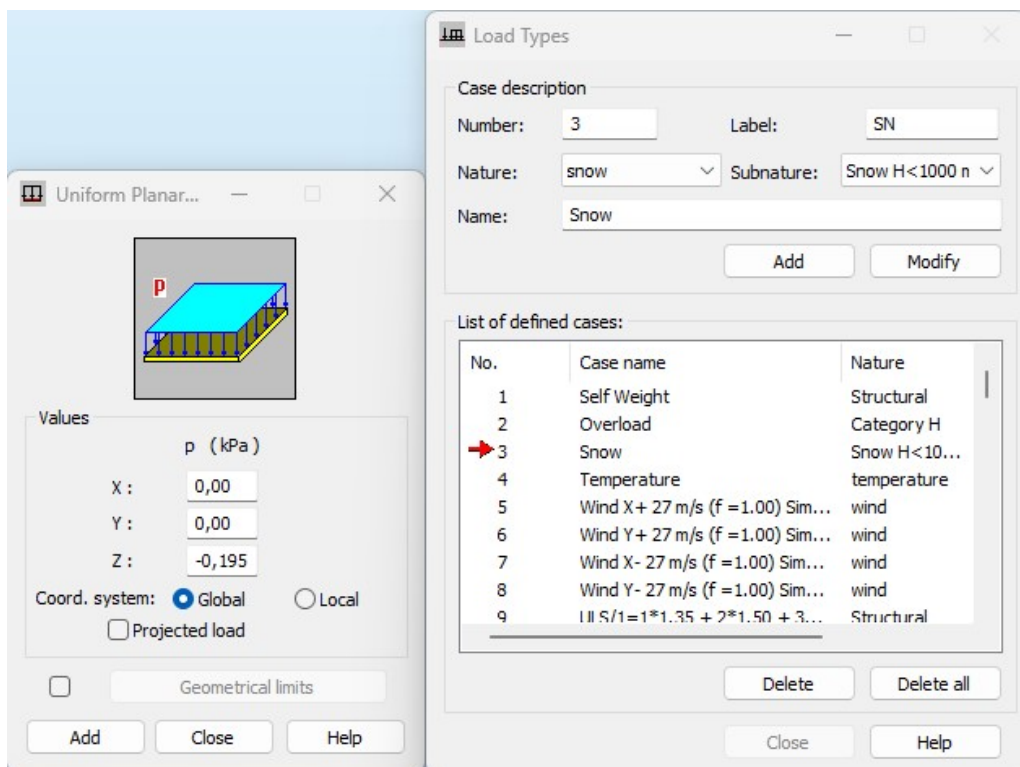
Figure 4.3: Snow Load Properties from Robot Autodesk.

4.1.2.2 Overload

From the Eurocode [4], it was possible to obtain the overload magnitude. Since our roof structure is from category H, which means that the roof should only be used for maintenance, then we know that the load is equal to 400 N/m2. This load is considered as nature "live" since it is a quasi-static and free action. Below, **Figure** 4.4 and **Figure** 4.5, we can see both the properties of the load and also the application of the same on the roof structure.
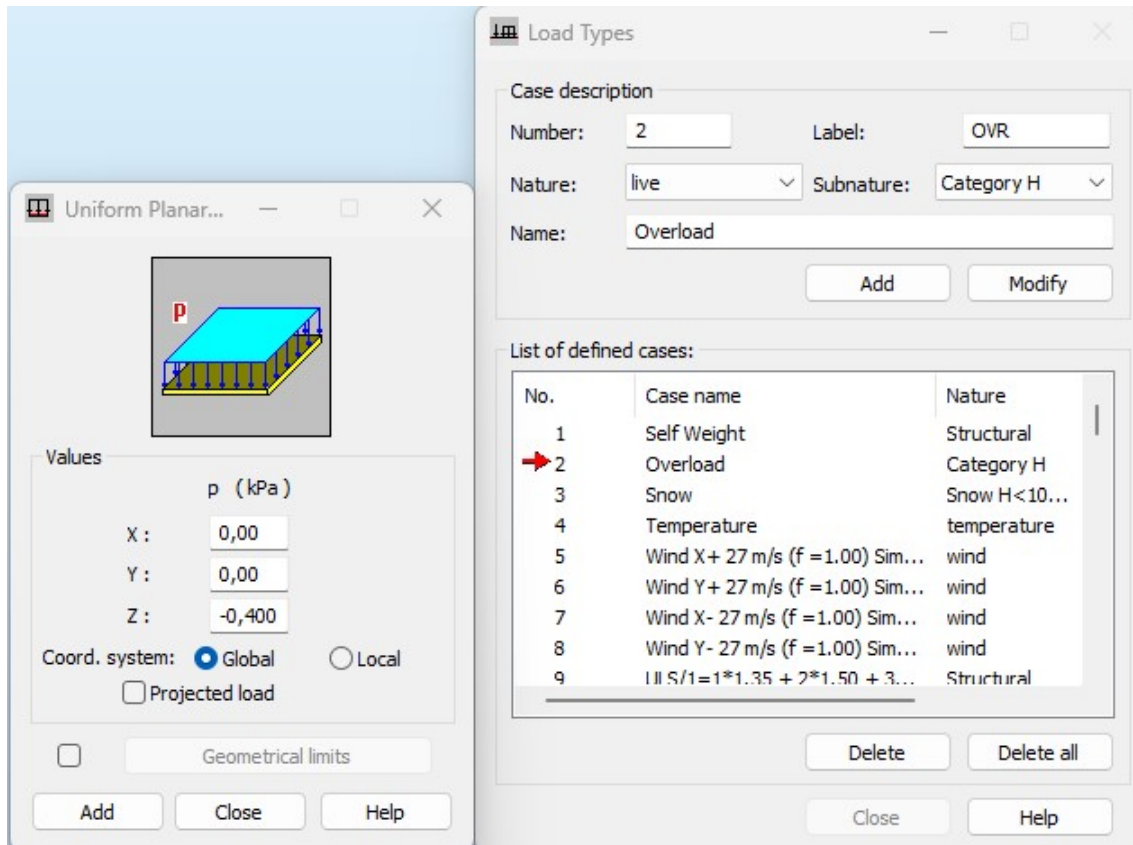
Figure 4.4: Overload Properties from Robot Autodesk.
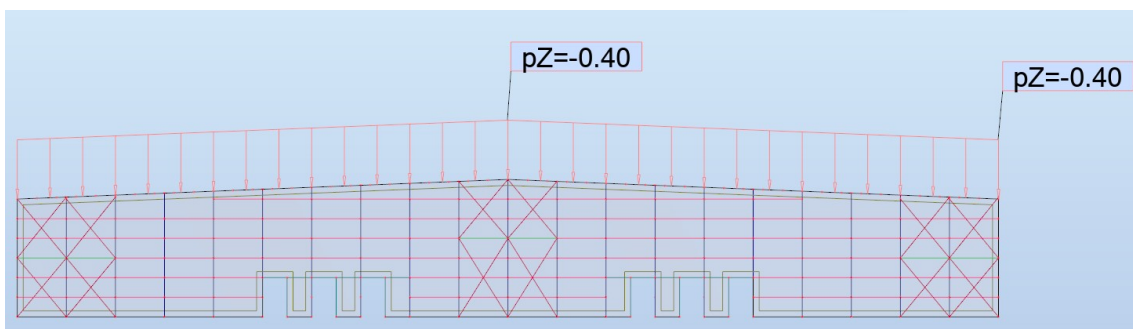
Figure 4.5: Overload 2D representation applied on the roof structure.

4.1.2.3 Self-weight

Robot Autodesk Software offers us the opportunity to automatically calculate the self-weight of all elements of the structure, however, since we are using cladding instead of panels for the dimensioning of the surfaces, we need to manually add a "dead" nature load with the self-weight of the panels. As calculated before in **Chapter** 2, the roof panels have a weight of about 210 N/m2 and the side façade 170 N/m2 (**Figure** 4.6).
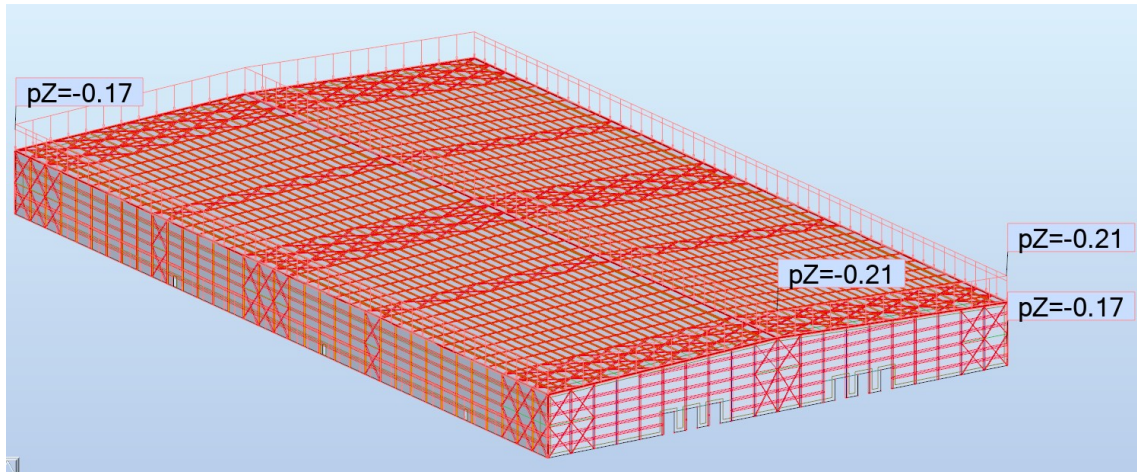
Figure 4.6: Self Weight of the whole structure along with the panels weight.

4.1.2.4 Thermal loads

The dilation of large metallic structures due to thermal effects refers to the change in dimensions, such as length, area, or volume, resulting from temperature fluctuations and also due to the inherent properties of metallic materials. In a metallic structure of this size, it is important to keep in mind that thermal expansion in the coldest or warmest months of the year takes a huge factor in the building behavior. According to the Eurocode [6], the thermal variation component, ΔT_u, is obtained from the following equation:

$$\Delta T_u = T - T_0 \tag{4.1}$$

Where:

- T- is the mean temperature calculated from the exterior temperature and interior temperature, from both winter and summer;

- T_0- Is the initial temperature of the studied element, given in the Portuguese National Annex [6].

The mean temperature can be calculated from the following expression:

$$T = \frac{T_{in} + T_{out}}{2} \tag{4.2}$$

Both components used in the calculation of the mean temperature have their reference values displayed in the Portuguese National Annex of the Eurocode [6]. The following **Figure** 4.7 shows the tables used to calculate the thermal variation component for the Winter and Summer.

Quadro NA–5.1 – Temperaturas indicativas T_{in} para ambientes interiores

Estação	Temperatura T_{in}
Verão	$T_1 = 25\,°C$
Inverno	$T_2 = 18\,°C$

Quadro NA–5.2 – Temperaturas indicativas T_{out} para zonas de edifícios acima do solo

Estação	Factor significativo		Temperatura T_{out} em °C
Verão	Absorvidade relativa dependente da cor da superfície	0,5 superficie clara brilhante	$T_{max} + T_3$
		0,7 superficie de cor clara	$T_{max} + T_4$
		0,9 superficie escura	$T_{max} + T_5$
Inverno			T_{min}

Devem utilizar-se os seguintes valores:

$$T_3 = 0\ °C;\ T_4 = 2\ °C;\ T_5 = 5\ °C$$

Os valores de T_{out} assim obtidos, são válidos para superficies horizontais ou viradas a Oeste. Para ter em conta outras orientações da superfície, o valor T_{out} pode ser multiplicado pelo coeficiente η obtido a partir da seguinte expressão empirica:

$$\eta = 0,9 + 0,1 \times sen[(\beta/360°)^{2,5} \times 360° - 90°]$$

onde β representa o ângulo, em graus, que a normal exterior do elemento estrutural faz com o Norte, medido no sentido horário (ex.: N → $\beta = 0°$; S → $\beta = 180°$; SO → $\beta = 225°$).

Figure 4.7: Tables from the EC1-5 [6] with the indicative temperatures for each season.

The Portuguese National Annex [6] also defines the T_{min} and T_{max} temperatures illustrated above, according to their building location and its zone. Our structure is located in zone B (**Figure** 4.8); therefore, we can assume $T_{min} = 0°C$ and $T_{max} = 40°C$.
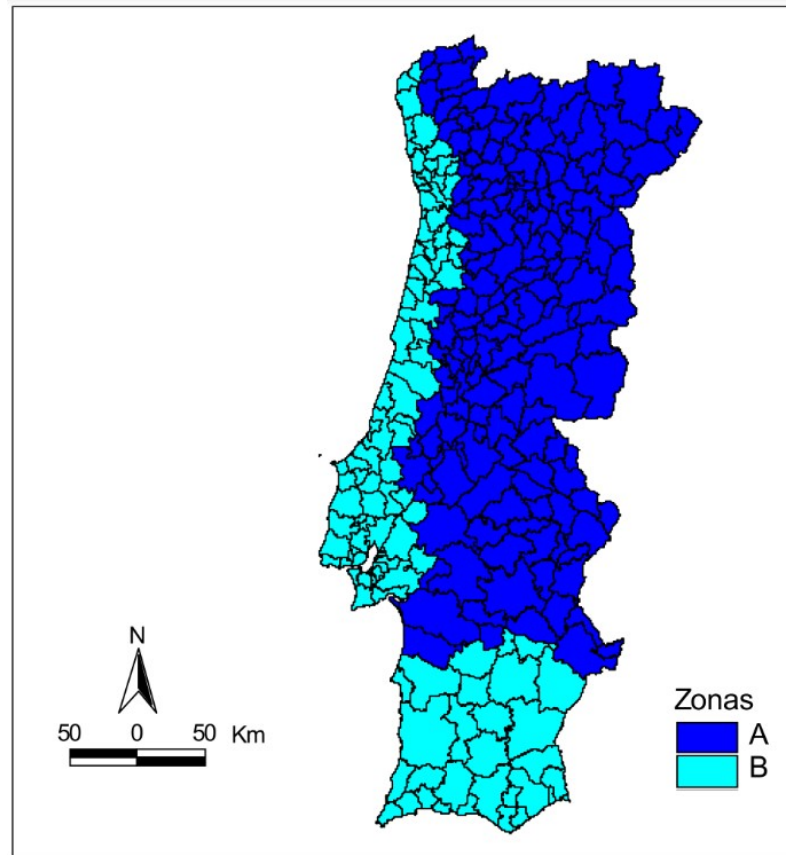
Figure 4.8: Different zones for Thermal Winter Conditions.

Assuming that the surface is made from a dark color, and that, according to the Portuguese National Annex [6], $T_0 = 15$°C we can also use the following **Table** 4.1 to calculate the thermal load variation component for both winter and summer seasons. The values given in the table were calculated using the Temperatures given in **Figure** 4.7.

Table 4.1: Inside and Outside Temperatures for Winter and Summer Seasons.

Temperature	Summer	Winter
T_{in}	25°C	18°C
T_{out}	45°C	0°C

With all this information it is now possible to calculate the thermal variation components, ΔT_S and ΔT_W for both summer and winter, respectively.

$$\Delta T_S = \frac{45°C + 25°C}{2} - 15°C = 20,0°C \tag{4.3}$$

$$\Delta T_W = \frac{18°C + 0°C}{2} - 15°C = -6°C \tag{4.4}$$

After obtaining the values for the thermal load variation component for both seasons, we can choose to see the local coordinate system and apply the thermal load to each one of the members and bars of the structure. With a simple filter of selection by similar materials we are able to choose all the metallic elements and apply the thermal loads. For each one of the beams, we are applying the temperature variation case for the winter (dTx=-6,0ºC) and summer (dTx=20,0ºC). We only apply this load to the xx local axis because the other directions thermal expansion/contraction is negligible (**Figure** 4.9).
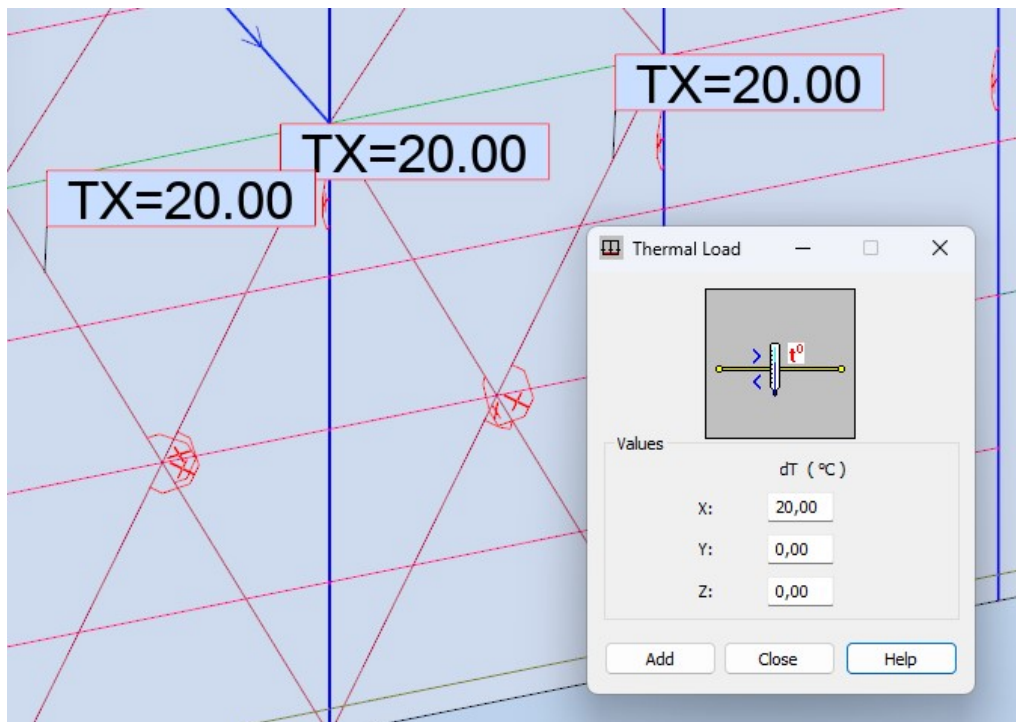
Figure 4.9: Application of thermal load to front façade pillars.

4.1.2.5   Wind loads

In the following subchapter we are going to take advantage of the abilities of Robot Autodesk software and calculate the wind loads applied to the structure automatically. Although we calculated the pressure coefficients in **Chapter** 2, it is important to check if there are any differences when using the analytical and the computational way. In **Figure** 4.10 it is possible to check all the parameters that are considered when using the automatic wind simulation resource. All wind directions in the perpendicular directions of the structure are considered. The serviceability wind speed is equal to 27 m/s, according to the Eurocode [3]. The wind exposed elements are only the claddings that simulate the outer surfaces of the structure, and it is considered that all openings in the claddings and panels are closed for the wind flow. The simulation also takes into account that the structure is at ground level, and that the loads generation has a limit of 0,5% for the deviation factor, as presented in **Equation** 2.10.
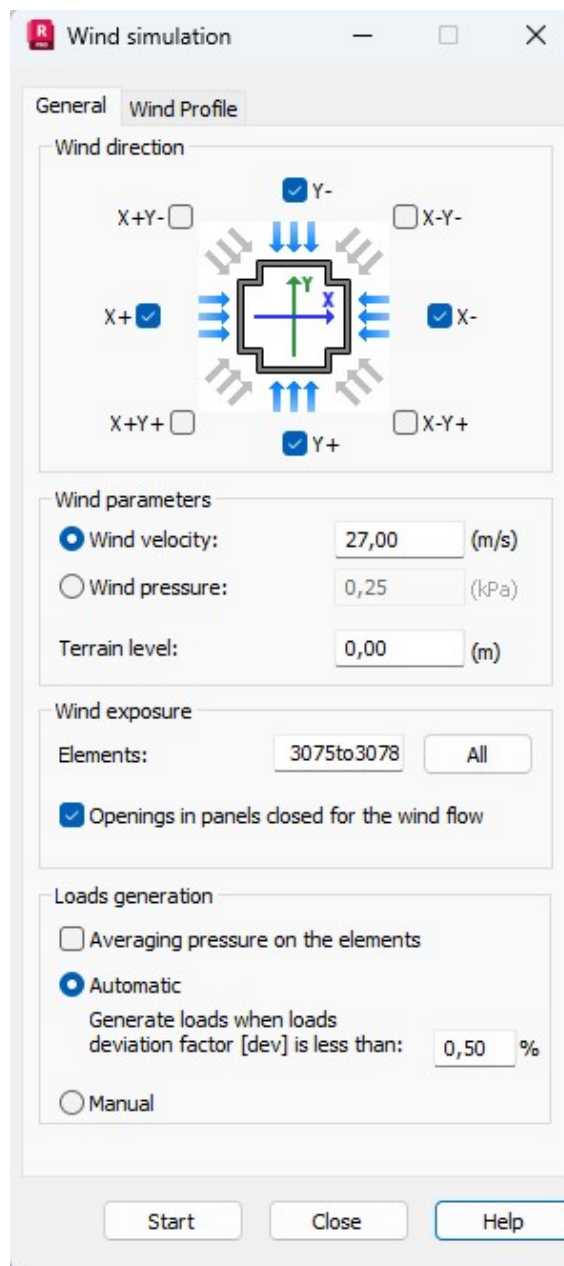
Figure 4.10: Wind simulation properties command window.

It is also possible to see the pressure on the elements of the structure for each of the calculated wind loads. In the following **Figure** 4.11, we are able to see the global axis on the lower left side and the pressure color scale in the upper side. The figure is a visual representation of the different areas of application for the wind loads. In this case, it is presented the pressure distribution in kPa, due to the wind loads in the positive yy axis.

From **Figure** 4.11, we are able to see that the Eurocode [3] offers a simple discretization of the real-life situation, so it is a great tool to dimension by rough estimates the wind load pressure coefficients.
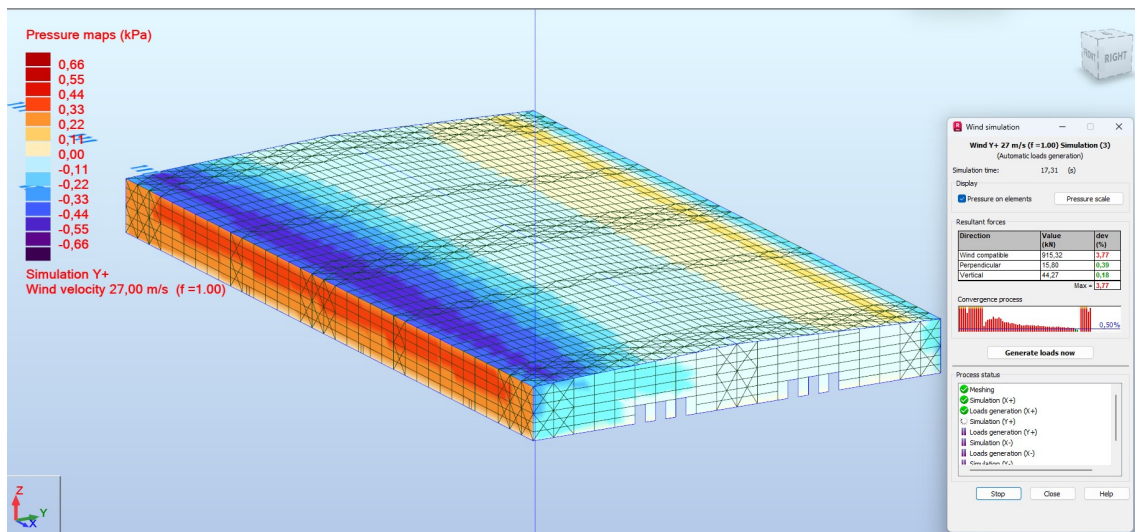
Figure 4.11: Pressure distribution caused by the wind loads in the positive yy axis.

Chapter 5

Results analysis

5.1 Combination of actions

Robot Autodesk allows us to automatically create the combination of actions. After defining the simple loads, meaning that all the loads such as the ones talked about in **Section** 4.1 are parametrized, we are able to use the software ability to create combination of actions. The software also allows us to input manually the loads that we want, which allows the user to choose all the coefficients and loads that they might want to study. Robot Autodesk also allows us to combine the actions according to a certain code. In our case, we are going to model our structure according to the Eurocode "NP EN 1990:2009" and use the generation of combinations by manual input. The following **Figure** 5.1 and **Figure** 5.2, shows the command boxes that appear when we are choosing the cases that we want to use and the calculation according to the Limit States, respectively.
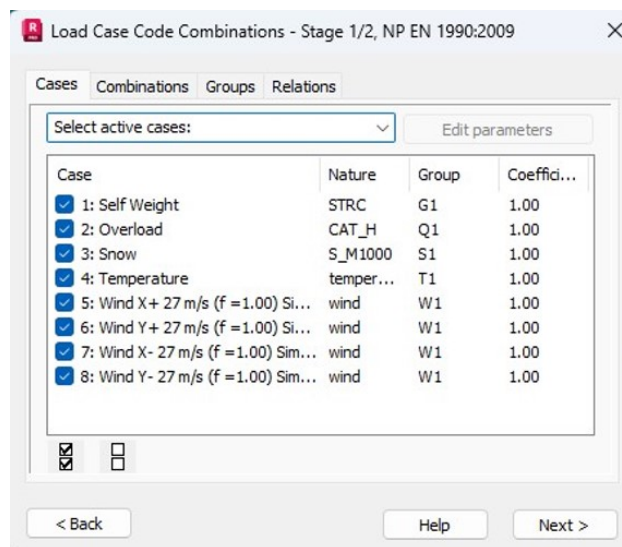
Figure 5.1: Load Case Combination Window.
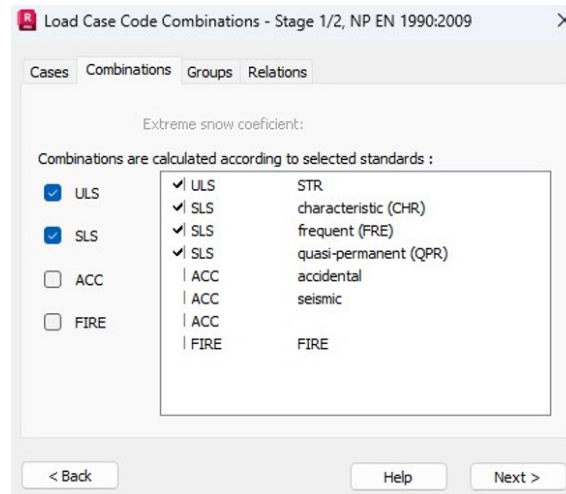
Figure 5.2: Standards used to calculate the combinations.

5.2   Members groups

After having all the combinations, we need to run a calculation analysis using Finite Element Method. It is then possible to obtain all the displacement, moments, forces diagrams of the structure. Having the maximum bending moments and normal forces for each one of the structure elements it is now possible to optimize the design of the building. For that we need to create groups that are made of the same material and have the same sections. The project has 10 different groups: Front Façade Columns,Pillars and Rafters, Framework Columns and Rafters, the Purlins for the front,side and roof, and also Longitudinal beams, each one of them has a section list assigned to them (**Figure** 5.3). For each one of mentioned groups above we are going to utilize the software's properties and abilities to find the most efficient section for our industrial pavilion.
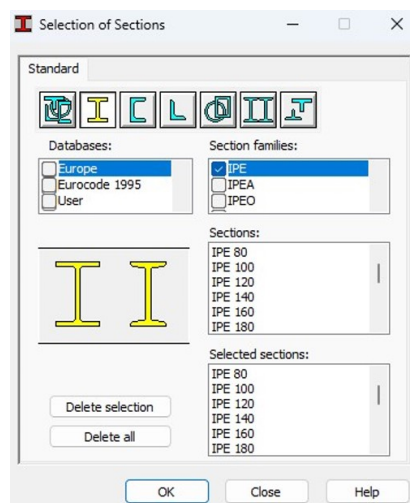
Figure 5.3: Selection of all the sections that could belong to a group design.

5.3   Dimensioning

Finally, with all the design groups defined (**Figure** 5.4) and the load combinations, it is time to choose the optimal section solution from the software that verifies the ULS and SLS conditions and also consider the weight optimization of the members. We will begin by optimizing the upper members of the structure in order to reduce the weight load to the lower members, due to the weight of the sections. In the calculation window it is needed to identify which members or design groups we are going to optimize. It is also possible to choose the loads and combinations that we want to take into account.
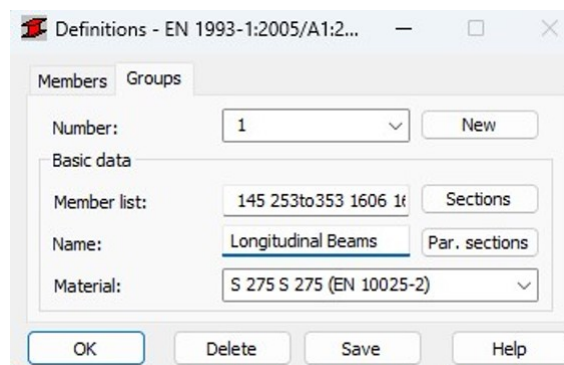
Figure 5.4: Definitions of the properties of a design group.

The software also allows an optimization mode that provides the section with constraints such as maximum section height, maximum flange width, minimum web thickness. We are going to tick the weight optimization option in order to reduce the overall costs of the structure. Each one of the design groups is going to be presented in the upcoming section and all the considerations done, therefore it is mandatory to present the color code used by the software to present the results. **Figure** 5.5 shows the results interpretation from Robot Autodesk.

Figure 5.5: Results Interpretation from Calculation Window.

5.3.1   Roof purlins

For the roof purlins design group, it was used the UAP 220 (S275) section. In **Figure** 5.6 we can observe that the UAP section is the optimal one. The ratio was exposed in the software is

0.35, so in order to understand why it has that value we can open the calculation notes to have a better understanding of the parameters that were taken into account when calculating the ratio. From **Figure** 5.7, it can be seen that the ratio from the Member stability check section, represents the formula that is applied to the members that are subjected to combined bending and axial compression, as taken from the Eurocode [7]. The software also retrieves the slenderness ratios of the structure, which are defined by the ratio of the length divided by the radius of gyration. When this ratio exceeds a value of 100 for a slim beam, failure by buckling can be expected.

Figure 5.6: Roof Purlins group design calculations.

Figure 5.7: Roof Purlins Section Results.

5.3.2 Framework and front façade rafters

The optimal section for the front façade rafters is the IPE 750 161 (S275) (**Figure** 5.8), the ratio is equal to 0,99, which is very close to the limit imposed by the Eurocode [7]. Despite being close to the limit the sections are still safe to use, since the Eurocode has a lot of safety factors take are considered. The optimal section for the rest of the framework rafters is the IPE 300 (S275) (**Figure** 5.9), with also a ratio of 0,99. As it is expected the front façade framework is more exposed to the loads, so it needs a bigger section to withstand the extra loads.
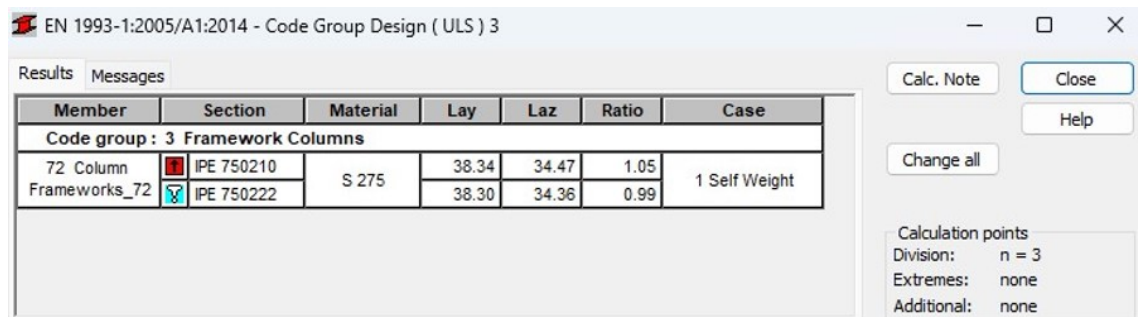
Figure 5.8: Front Façade Rafters group design calculations.

Figure 5.9: Framework Rafters group design calculations.

5.3.3 Longitudinal beams

The longitudinal beams are made from the IPE 220 (S275) (**Figure** 5.10), the optimal section has a factor of 0,83. It is important to remember that after all the calculations are made, we need to re-analyze the entire structure again to take into account the newer sections.

Figure 5.10: Longitudinal Beams group design calculations.

5.3.4   Bracing diagonals

For the bracing diagonals it is usual to use simple angle brackets with equal edges, subject to simple traction. The slenderness ratios L_{ay} and L_{az} are the same since this section is symmetrical. The bracings that were used are the CAE 150x18 (S275) section (**Figure** 5.11).

Figure 5.11: Bracings group design calculations.

5.3.5   Bracing uprights

The optimal section for this project bracing uprights is the TRON 355x8 (**Figure** 5.12), the material has a yield strength of 275 MPa and a ratio of 0,9. In the bracing uprights, it is usual to use round-section tubular profiles (ROR), as they have equal resistance to buckling in both axes of symmetry.

Figure 5.12: Bracing Uprights group design calculations.

5.3.6 Front façade columns and pillars

The front façade columns and front façade pillars are both made from the section IPE 750 (**Figure** 5.13 and **Figure** 5.14), however the strength of the materials is different. The front façade columns have a mass of 137 kg/m and a yield strength of 275 MPa. The front façade pillars have a mass of 196 kg/m and a yield strength of 355 MPa.

Figure 5.13: Front Façade Columns group design calculations.

Figure 5.14: Front Façade Pillars group design calculations.

5.3.7 Framework columns

The chosen section for the framework columns is the IPE 270 (S275) (**Figure** 5.15), the strength required by these elements is not as high as the front façade column, however an I-beam of these dimensions is still a big section and is normally only used for industrial applications.

Figure 5.15: Framework Columns group design calculations.

5.3.8 Side and front façade purlins

The front façade purlins section is the UAP 220 (**Figure** 5.16), and the front façade purlins section is the UAP 250, both element groups have a yield strength of 275 MPa. As it is expected the slenderness ratios vary according to the radius of gyration which is dependent on the moments of inertia of the section. These sections have different areas, therefore they have different slenderness ratios. If given more time, other sections would be explored to compare why the standard solutions of sections for each one of the elements of a structure are typically I, C and L sections.

Figure 5.16: Side and Front Façade Purlins groups design calculations.

5.3.9 Intermediate Pillars

For the intermediate pillars that are distributed along all the frameworks of the structure and provide support to the rafters of the roof, the IPE 750 (S355) was used. These members were manually

over-dimensioned since they might hold on extra weight in the future of the project, for instance, the fire extinguishers, electric elements or metallic signs. They are also prone to absorb impacts later on, so building them out of durable, high-resistance materials is recommended. **Figure** 5.17 shows us the intermediate pillars that are repeated every framework and separated by 25 m in width.
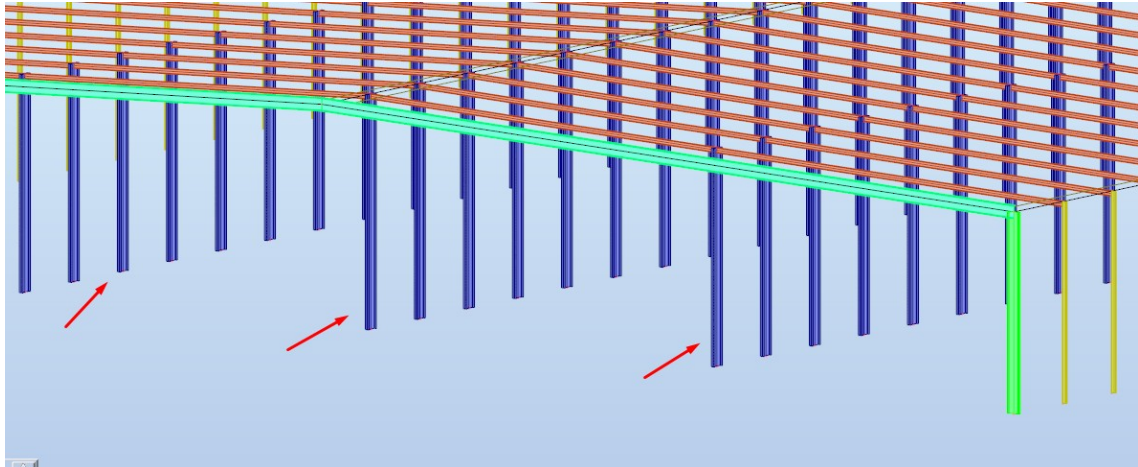

Figure 5.17: Intermediate pillars made from IPE 750.

Chapter 6

Conclusion

6.1 Proposed member elements and overall cost

In the following section a brief description of the proposed member elements for each one of the design groups is going to be presented as well as the total estimated overall cost for the execution of this project.

Table 6.1: Section types by groups and their number of elements, length, and total weight.

Group of Bars	Section Type	Yield Strength	Number of elements	Length (m)	Total Mass (kg)
Framework Rafters	IPE 300	(S275)	68	3402	143791
Front Façade Rafters	IPE 750	(S275)	4	200	44533
Longitudinal Beams	IPE 220	(S275)	105	525	13753
Diagonal Bracings	CAE 150x18	(S275)	400	3646	146081
Front Façade Column	IPE 750	(S275)	4	48	6578
Front Façade Pillars	IPE 750	(S355)	38	496	86209
Framework Columns	IPE 270	(S275)	68	816	29441
Side Purlins	UAP 220	(S275)	350	1750	49826
Front Façade Purlins	UAP 250	(S275)	224	1120	38511
Roof Purlins	UAP 220	(S275)	1680	8400	239168
Bracing Uprights	TRON 355x8	(S275)	152	760	52120
Intermediate Pillars	IPE 750	(S355)	99	1320	229427

The overall weight of the used 3050 bars equates to approximately 1000 tons and 21 kilometers of length (**Table** 6.1). The magnitude of the project is enormous, therefore the costs will also be large, the material costs are aproximatelly 2 euros per kilogram, therefore this places the raw materials costs at about 2 million. Accounting also for the logistical cost of transporting all the raw materials, the manual labor required to install these elements, the handling equipment used, the costs to pay to the engineers, the permits of construction to the city hall and a few more other costs, the total project costs is nearly 3 million euros. Despite all these costs, Company A is paying monthly instalments to rent out an external warehouse plus all the serviceability costs, therefore, there is an expected return of investment. Having all the company services and people in one place is a lot easier to control plus it reduces the time if takes for a product to arrive to a customer, since there is no intermediate warehouse in between.

6.2   Future work

Given the dissertation deadline, it was not possible to fully complete the entire project in order for it to go directly to the construction phase. The completion of this project is now going to be taken care of by the engineering department of Company A. The next step is to evaluate internally the assumptions made in this dissertation and perform the tweaks necessary to accommodate the newer constraints imposed by the plant. The Logistics Manager of the plant is pushing for this project to be concluded since it would bring greater benefits to the logistical internal flows, and also improve the complexity of receiving and shipping almost 100 trucks per day.

6.2.1   Connections

One of the final steps of this project will be to dimension the connections of the structure. Robot Autodesk offers tools to help dimensioning connections, such as beam to beam or beam to column. These connections provide an efficient load transfer between structural members and if given a bit more time would be taken into consideration. Another part that was left out of the project was the bolts dimensioning. Dimensioning bolts accurately in industrial pavilions is of utmost importance to ensure the structural integrity and reliability of the connections. They are essential components for connecting structural elements, such as beams, columns, purlins, and bracing members. The accurate dimensioning of bolts ensures proper load transfer between these components and also prevents corrosion between the elements if properly dimensioned.

6.2.2   Logistic oriented warehouse and sustainability

When dimensioning industrial pavilions, incorporating sustainability measures is essential to minimize the environmental impact and promote long-term sustainability. In future works, strategies such as optimizing insulation, using natural lighting, and considering using renewable energy should be taken into account. Using sustainable materials with low environmental impact, high recycling efficiency, and upgrading its cycle life should be a priority in the future. Furthermore, it

is also possible to implement natural ventilation and improve the surrounding landscape with more green emissions to neutralize the CO2 emissions. By incorporating these sustainability ideas, industrial pavilions can significantly reduce their environmental footprint, conserve resources, and create healthier and more sustainable working environments. In the near future, all the paperwork involved in this project should be stored digitally and all the in-house factory processes that use resources like paper or cardboard should be upgraded to a paper-free flow. Finally, to optimize the energy efficiency and consumption of the plant machines, such as forklifts and small trains, the layout of the new factory should be optimized to reduce the distance between inner flows transporting handling units. With newer digital tools it is possible to have a full control of the warehouse tasks and flows, and therefore, implement continuous improvement to these tasks. It is also possible to implement pathways for Autonomous Guided Vehicles (AGVs). These vehicles have revolutionized the logistics industry by increasing efficiency, reducing costs, and enhancing safety. They are equipped with safety features such as sensors and alarms, which prevent them from colliding with other vehicles or obstacles, ensuring a safe work environment for all employees. Furthermore, AGVs can be easily integrated into existing logistics systems, providing a seamless and efficient operation. This means that companies can move their products faster, resulting in increased productivity and reduced downtime.

6.3 Conclusion

In conclusion, this master thesis successfully achieved its main objective of dimensioning an industrial pavilion, and also highlights the role played by a structural design software (Robot Autodesk). Through the utilization of the software, the dimensioning was quick, concise, and efficient, paving the way to having a first draft of a structurally optimized industrial pavilion. This dissertation demonstrated that accurate load definition, along with the capabilities of Robot Autodesk and a good project definition ensured a good overview of the behavior of a huge pavilion structure. The software accurately calculated the internal forces and stresses within the structure and allowed for the design of appropriate structural elements, such as columns, beams, purlins and more; ensuring the pavilion's ability to withstand the imposed loads. Robot Autodesk advanced features and functionalities allowed the exploration of various design options, load combinations, and material selections, resulting in optimized designs that minimized material usage and had impact on cost, while also meeting the structural and performance requirements of the industrial pavilion. The software offers an accurate representation of the load definitions and the structural analysis, making it easier to keep the engineers, clients, contractors, and regulatory authorities clear communication throughout the project.

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